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COMPLETE STUDY MATERIAL

JUNIOR EXECUTIVE — TECHNICAL —

SUBJECT KNOWLEDGE for COMPETITIVE EXAMS

CWC JE (TECHNICAL) | FCI | SWC | IBPS AFO | NABARD

Basic Agriculture • Horticulture • Animal Husbandry • Plant Protection • Botany
Zoology • Storage Entomology • Microbiology • Chemistry & Biochemistry • Physics







UNDER THE GUIDANCE OF

G. V. SATISH

SBI PO – 2005 Batch

INTERVIEW PANEL MEMBER

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CWC JUNIOR EXECUTIVE

Subject Knowledge – Junior Executive (Technical)

Central Warehousing Corporation · Post Code 08 · Advt. No. CWC/I-Manpower/DR/Rectt/2026/01

Prepared by

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About the Exam & How to Use This Book

Online examination – Junior Executive (Technical)

#	Test (not by sequence)	Questions	Marks	Time
1	**Subject Knowledge (this book)**	65	65	55 min
2	Reasoning & Computer Aptitude	40	40	25 min
3	Data Analysis & Interpretation and Quantitative Aptitude	40	40	30 min
4	General Awareness	20	20	15 min
5	English Language	35	35	25 min
6	Language & Comprehension Abilities – Descriptive	2	30	30 min
	Total	**202**	**230**	**3 hours**

- **Negative marking**: ¼ of the marks of the question for each wrong answer; no penalty for a blank.
- **Qualifying marks** in Subject Knowledge: **40%** (UR), **35%** (OBC/EWS/SC/ST/PwBD/ExSM). Same for the Descriptive test.
- Selection: **Online test + Document Verification** (shortlisting up to **1:3**); no interview. Eligibility: **B.Sc (Agriculture / Botany / Zoology / Biotechnology / Microbiology / Biochemistry / Food Science / Chemistry)** with computer knowledge; age 18–28 years (as on 15.11.2026). Pay scale **₹29,000–93,000 (S-V, IDA)**; 78 posts.
- About **50 seconds per question**: these notes are built for recall. Each section ends with a **Previously Asked / Likely Questions** box; stars show weightage (★★★ = must-do).

Priority order of subjects (by usual weightage)

#	Subject	Syllabus part
1	Storage Pests, Rodents, Fumigation, Insecticides & Toxicology (CWC core)	C
2	Chemistry & Biochemistry	D
3	Crop Production, Plant Protection & Horticulture	A
4	Botany – Cell, Genetics, Diversity, Ecology, Physiology	B
5	Zoology – Insects, Organ Systems, Heredity	C
6	Microorganisms, Food Safety & Public Health	C
7	Physics	E
8	Extension, Economics, Marketing & Warehousing; Animal Husbandry	A
9	Last-Day Revision (value & fact sheet)	All
10	500 Most Expected Questions & Answers	All

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1. Crop Production (Agronomy & Soils)

> **NOTE**
> Crop production is the backbone of the CWC technical paper: what is stored in a warehouse is grown in the field first. Expect one-liners on botanical names, chromosome numbers, critical stages, fertiliser nutrient %, seed tag colours, herbicides, problem-soil reclamation and the latest production/MSP figures. Data in this chapter (production, MSP, leading states, varieties) are current to **October 2026**.

1.1 Agronomy Basics, Seasons & Cropping Systems ★★★

- **Agronomy** = Greek *agros* (field) + *nomos* (manage); the branch of agriculture dealing with principles and practices of **soil, water and crop management** for field crops.
- **Father of Agronomy**: **Pietro de Crescenzi** (Italy). **Jethro Tull** – seed drill (1701), book **"Horse Hoeing Husbandry"** (1731); called father of tillage.
- **Law of the Minimum** – **Justus von Liebig (1840)**: yield is governed by the nutrient present in the least relative amount (illustrated by Dobenek's **barrel** with staves of unequal length).
- **Law of Limiting Factors** – **F.F. Blackman (1905)**: when a process depends on several factors, its rate is limited by the slowest (one factor at a time).
- **Law of Diminishing Returns (yield law)** – **E.A. Mitscherlich (1909)**: each successive unit of input gives a smaller increase in yield; also called Mitscherlich–Spillman law. **Law of the Optimum** – Liebscher (1895).
- **Criteria of essentiality** of nutrients – **Arnon & Stout (1939)**. **Cardinal temperatures** (minimum, optimum, maximum) – **Sachs (1860)**.
- **Leaf Area Index (LAI)** = leaf area ÷ ground area (**Watson, 1947**). At **ceiling LAI** net photosynthesis becomes zero; optimum LAI gives maximum crop growth rate.
- **Harvest Index (HI)** = economic yield ÷ biological yield × 100 (**C.M. Donald, 1962**); Nichiporovich called it **coefficient of effectiveness**. Dwarf wheat/rice HYVs raised HI to ~45–50%.
- **Plant rectangularity** = row-to-row ÷ plant-to-plant spacing; **square planting (1:1)** gives the most even use of space.
- **Furrow slice** (0–15 cm, 1 ha) ≈ **2.24 million kg** soil – basis for converting ppm to kg/ha (1 ppm ≈ 2.24 kg/ha).
- **Tillage**: primary (mouldboard, disc plough – opens soil) vs secondary (harrow, cultivator, planker – fine tilth). **Zero tillage** – sowing directly into previous crop residue (e.g. wheat after rice with Happy Seeder / Super Seeder).
- **Conservation agriculture** – 3 principles: **minimum soil disturbance, permanent soil cover, crop rotation**.

Season	Sowing	Harvest	Typical crops
Kharif (monsoon)	June–July (with SW monsoon)	Sept–Oct	Rice, maize, jowar, bajra, ragi, tur, moong, urd, groundnut, soybean, cotton, jute, sesame
Rabi (winter)	Oct–Nov	Mar–Apr	Wheat, barley, gram, lentil, pea, mustard, linseed, safflower, potato
Zaid (summer)	Mar–Apr	June	Watermelon, muskmelon, cucumber, summer moong, fodder (cowpea, maize)

- Kharif crops are mostly **short-day** and warm-season; rabi crops mostly **long-day** and need cool growth + warm ripening. **Zaid-kharif** (sown Aug–Sept, e.g. **toria**) and **zaid-rabi** (sown Feb–Mar) are sub-types.
- Rice seasons in eastern India: **Aus** (autumn, sown Apr–May), **Aman** (winter, Jun–Jul – main crop), **Boro** (summer, sown Nov–Dec).

Cropping systems

- **Cropping pattern** = proportion of area under different crops at a time; **cropping system** = cropping pattern + its management (sequence, inputs, resources).
- **Monocropping** – same crop year after year (e.g. sugarcane belt). **Multiple cropping** = growing ≥ 2 crops on the same land in a year = **intercropping + mixed cropping + sequential cropping**.
- **Mixed cropping** – seeds of 2+ crops mixed and sown with **no row pattern** (insurance against failure; e.g. wheat + gram, "gochani"). **Intercropping** – crops in a **definite row ratio**, aim is yield advantage.
- Types of intercropping: **row**, **strip** (strips wide enough for separate cultivation), **relay** (2nd crop sown into a standing crop before its harvest), **parallel** (crops of similar duration but different habit, e.g. green gram + cotton) and **synergistic** (both gain, e.g. sugarcane + potato).
- **Relay cropping** example: **Paira / Utera** – lentil, lathyrus or linseed broadcast into standing rice ~2 weeks before harvest (eastern India) – uses residual moisture.
- **Sequential cropping** – crops one after another in a year: **double** (rice–wheat), **triple** (rice–wheat–moong), **quadruple**. **Ratoon cropping** – crop from stubble regrowth (sugarcane, sorghum, rice, banana).
- Largest cropping system of India: **rice–wheat (~10 Mha, Indo-Gangetic Plains)**, then rice–rice and cotton–wheat. **Sorghum sickness**: wide-C:N sorghum stubble immobilises N → give ~25% extra N to next crop.
- Recommended intercrop ratios: **wheat + mustard 9:1**; groundnut + pigeonpea 4:1 (or 6:1); sorghum + pigeonpea 2:1; chickpea + mustard 4:1; autumn sugarcane + potato/onion.
- **Integrated Farming System (IFS)** – crop + livestock + fish + poultry + horticulture; recycles residues, raises income per unit area.
- **SRI** (System of Rice Intensification) – **Fr. Henri de Laulanié, Madagascar (1983)**: 8–12-day seedlings, 1 seedling/hill, 25 × 25 cm, alternate wetting & drying, cono-weeder.

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KEY FORMULAE

- **Cropping intensity** = Gross cropped area ÷ Net sown area × 100 (India ≈ **155%**).
- **Land Equivalent Ratio (LER)** = (Y_a intercrop ÷ Y_a sole) + (Y_b intercrop ÷ Y_b sole); **LER > 1** → intercropping advantageous (Willey). LER 1.25 = 25% more land needed as sole crops.
- **Multiple Cropping Index** (Dalrymple) = Σ area of all crops in a year ÷ net cultivated area × 100.
- **Crop Rotation Intensity** = No. of crops ÷ duration of rotation (years) × 100 → rice–wheat in 1 yr = **200%**.
- **Crop Equivalent Yield** = yield of intercrop × its price ÷ price of base crop.
- **Growing Degree Days** (GDD) = Σ [(T_{max} + T_{min})/2 − T_{base}]; T_{base}: wheat ~4–5 °C, rice/sorghum ~10 °C.

Crop term	Meaning	Example
Catch crop	Short crop in a short gap or after main crop failure	Moong, urd, cowpea, toria
Cover crop	Covers soil, checks erosion	Cowpea, groundnut, sweet potato
Smother crop	Dense growth suppresses weeds	Cowpea, sorghum, barley, mustard
Trap crop	Attracts pest away from main crop	**Marigold** in tomato (fruit borer); **mustard** in cabbage (DBM)
Nurse crop	Shelters / supports young crop	Mustard with pea; cowpea in young plantations
Companion crop	Grown together without competition	Sugarcane + potato
Augmenting crop	Raises yield of main crop	Mustard (Japanese rape) with **berseem** – raises 1st cut
Restorative crop	Adds fertility	Legumes
Exhaustive crop	Heavy feeders	Sorghum, maize, sugarcane
Ley crop	Grass/legume in rotation for grazing	Lucerne, grasses
Alley cropping	Crops between hedgerows of N-fixing trees	Leucaena, Gliricidia
Contingent crop	Substitute crop when monsoon fails/late	Bajra, horse gram, castor

MEMORY TRICK

Laws in time order "**LBM**" → **L**iebig 1840 (minimum) → **B**lackman 1905 (limiting factors) → **M**itscherlich 1909 (diminishing returns).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Law of the Minimum was given by? → **Liebig (1840)**.
- LER > 1 indicates? → **Yield advantage of intercropping**.
- Harvest index concept? → **C.M. Donald (1962)**.
- Cropping intensity of a rice–wheat–moong system on the same land? → **300%**.
- Paira/utera cropping is associated with? → **Rice (relay of lentil/lathyrus)**.
- Recommended wheat + mustard intercrop ratio? → **9:1**.

1.2 Agro-climatic Zones, Weather & Dryland Farming ★★☆

- **Planning Commission (1988–89, 7th Plan)**: **15 agro-climatic regions** (14 on mainland + islands). Trans-Gangetic Plains (Punjab, Haryana) have the **highest irrigated area and cropping intensity**.
- **NARP (ICAR)**: **127 agro-climatic sub-zones**. **NBSS&LUP (Nagpur)**: **20 agro-ecological regions** and **60 sub-regions** (soil, physiography, bio-climate, length of growing period).
- 15 regions: W. Himalayan, E. Himalayan, Lower / Middle / Upper / **Trans-Gangetic** Plains, Eastern / Central / Western / Southern Plateau & Hills, East Coast Plains & Hills, West Coast Plains & Ghats, Gujarat Plains & Hills, **Western Dry Region**, Islands.
- **Weather** = day-to-day state of atmosphere; **climate** = long-term (≥ 30 yr) average. Troposphere – all weather; normal lapse rate **6.5 °C/km**.
- **SW monsoon** reaches Kerala ~**1 June**, gives ~**75%** of annual rain; All-India LPA (1971–2020) for June–Sept = **87 cm**. **NE monsoon** (Oct–Dec) benefits **Tamil Nadu** and coastal AP.
- **PAR** = **400–700 nm**. Air (by volume): N_2 78.08%, O_2 20.95%, Ar 0.93%, CO_2 ≈ 0.042% (~420 ppm).
- Forecasts: short range ≤ 3 days; medium range 3–10 days (**NCMRWF, Noida**); long range > 10 days. Agromet advisories (Gramin Krishi Mausam Sewa) by IMD.
- Iso-lines: **isohyet** – rainfall; isotherm – temperature; isobar – pressure; isohel – sunshine.

Instrument	Measures
Anemometer / wind vane	Wind speed / direction
Campbell–Stokes recorder	Sunshine duration
Pyranometer / pyrheliometer	Global / direct solar radiation
Psychrometer (wet & dry bulb), hygrometer	Relative humidity
Ordinary / self-recording (siphon) rain gauge	Rainfall
Class-A pan evaporimeter	Evaporation (121 cm dia, 25.5 cm deep)
Lysimeter	Evapotranspiration, leaching
Tensiometer	Soil moisture tension (up to ~0.85 bar)

Dryland farming

Type	Annual rainfall	Features
Dry farming	**< 750 mm**	Arid; growing season < 75 days; crop failure common; moisture conservation key
Dryland farming	**750–1150 mm**	Semi-arid; in-situ conservation; drainage needed in black soils
Rainfed farming	**> 1150 mm**	Humid/sub-humid; water erosion main problem

- Nearly **half of India's net sown area is rainfed** (net irrigated ≈ 55%); rainfed areas grow most pulses, millets, oilseeds and cotton.
- Drought types: **meteorological** (rain deficit), **hydrological** (surface/ground water), **agricultural** (soil moisture short of crop need). IMD: seasonal deficit **20–59% = deficient**, **≥ 60% = large deficient**.

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- **In-situ moisture conservation**: ridges & furrows, compartmental bunding, tied ridges, **Broad Bed & Furrow (BBF, ICRISAT, Vertisols)**, mulching, deep tillage, vertical mulching.
- **Ex-situ water harvesting**: farm ponds, **khadin** and **tanka** (Rajasthan), **jalkund** (NE hills), check dams, percolation tanks.
- **Mid-season corrections**: thinning, ratooning (sorghum), re-sowing; **contingency crop planning** for late monsoon (district plans by **CRIDA, Hyderabad**).
- **Seed hardening** – soak seed in water/salt solution (e.g. KH_2PO_4, $CaCl_2$) and re-dry → better drought tolerance at establishment.
- **Antitranspirants**: stomata-closing (**PMA**, low-dose atrazine); film-forming (mobileaf, hexadecanol, wax); reflecting (**kaolin 5%**); growth retardant (**cycocel/CCC**).
- **Windbreaks/shelterbelts** protect ~5–10 × tree height windward and up to ~30 × leeward. Best vegetative barrier: **vetiver (khus)**.
- Bench terracing – slopes **16–33%**; contour bunding – up to 6%, low rainfall; graded bunding – 2–10%, rainfall > 800 mm. Land capability classes: **8 (I–VIII)**; I–IV cultivable.

KEY FORMULAE

- **Moisture Availability Index (MAI)** = assured (dependable) rainfall at **75% probability** ÷ PET (Hargreaves).
- **Moisture Deficit Index (MDI)** = (P − PET)/PET × 100 → arid < −66.6; semi-arid −33.3 to −66.6; dry sub-humid 0 to −33.3.
- **Albedo** = reflected ÷ incident radiation.

CODE UPDATE

Key dryland institutes: **CRIDA – Hyderabad** (AICRP on Dryland Agriculture, 1970); **CAZRI – Jodhpur** (arid zone); **ICRISAT – Patancheru** (semi-arid tropics; mandate crops sorghum, pearl millet, chickpea, pigeonpea, groundnut, finger millet).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Number of agro-climatic regions (Planning Commission)? → **15**.
- Agro-ecological regions by NBSS&LUP? → **20**.
- Rainfall limit of dry farming? → **< 750 mm**.
- Kaolin is which type of antitranspirant? → **Reflecting**.
- Sunshine hours are measured by? → **Campbell–Stokes recorder**.

1.3 Soils & Soil Fertility ★★★

Formation, profile & Indian soils

- **Pedology** (origin, classification of soil) – father **V.V. Dokuchaev**; **Edaphology** – soil as medium for plants.
- **Jenny's (1941) factors**: S = f (**Cl, O, R, P, T**) – climate & organisms are **active**; relief, parent material, time are **passive**.
- Processes: **podzolisation** (cold humid; Fe/Al move down), **laterisation** (hot humid; silica leached, Fe/Al oxides stay), calcification (arid), salinisation, gleization (waterlogging).
- Profile: O – A (eluviation) – E – B (illuviation, accumulation) – C (parent material) – R (bedrock). **Solum = A + B**; regolith = A + B + C. **Pedon** = smallest 3-D soil unit (1–10 m^2).
- USDA Soil Taxonomy: **12 orders**; most extensive in India – **Inceptisols** (~40%); black soils = **Vertisols**; red = **Alfisols**; laterite = Ultisols/Oxisols; desert = Aridisols; peat = Histosols.
- Earth's crust: O (~47%) > Si (~28%) > Al (~8%) > Fe (~5%). Quartz – main mineral of sand (most resistant to weathering).

Indian soil	Area	Key features
Alluvial	~43% (largest)	Indo-Gangetic plains; Khadar (new) / Bhangar (old); rich in K, poor in N
Red & yellow	~18%	TN, Karnataka, Odisha; **kaolinite**; red due to iron oxide; poor in N, P
Black (regur)	~15%	Deccan trap (Maharashtra, MP, Gujarat); **montmorillonite**; high water holding; deep cracks, "self-ploughing"; rich in Ca, Mg; poor in N, P, OM – best for cotton
Laterite	~4%	High rainfall – Kerala, Karnataka, Odisha, NE; acidic; plantation crops, cashew
Others	–	Desert (Rajasthan), saline-alkaline (Punjab/Haryana/UP), peaty (Kerala **Kari** soils), forest/mountain

Physical properties

- Ideal loam (by volume): **mineral 45%, OM 5%, water 25%, air 25%.**
- Particle size (International/ISSS): sand 2–0.02 mm, silt 0.02–0.002 mm, **clay < 0.002 mm (< 2 µm)**. USDA: sand 2–0.05, silt 0.05–0.002 mm.
- **Texture** = relative proportion of sand, silt, clay – a **permanent property**; 12 classes on the USDA textural triangle; determined by hydrometer (**Bouyoucos**) or international pipette method. **Loam** is ideal.
- **Structure** = arrangement of particles into aggregates; **crumb/granular** best; platy in puddled soils; **columnar** in sodic B horizon.
- **Particle density ≈ 2.65 g/cc**; **bulk density ≈ 1.33 g/cc** (sand 1.6 > clay 1.1). Porosity (%) = (1 − BD/PD) × 100 ≈ 50%.
- Soil colour – **Munsell chart** (hue, value, chroma); red = haematite, yellow = limonite.

Chemical properties & pH

- Colloids < 1 µm, negatively charged. CEC order: **kaolinite (1:1, 3–15) < illite < montmorillonite (2:1, 80–120) < vermiculite (100–150) < humus (200–300 cmol/kg)**.
- **pH** = −log[H^+] (**Sørensen, 1909**); 1 unit change = **10-fold** change in H^+. Most nutrients available at **pH 6.5–7.5**; P most available at 6–7; Fe, Mn, Zn, Cu high in acid soils; **Mo** more available in alkaline soils.
- Organic matter = organic carbon × **1.724** (Van Bemmelen); OC by **Walkley & Black**. Indian soils mostly < 0.5% OC.
- C:N: soil ~10–12:1; FYM 20–30:1; straw 80:1. C:N > 30 → **immobilisation**; < 20 → mineralisation.
- Nitrification: NH_4^+ → NO_2^- (**Nitrosomonas**) → NO_3^- (**Nitrobacter**); denitrification (Pseudomonas, anaerobic); S oxidation – Thiobacillus.

Problem soils & reclamation

Parameter	Saline	Sodic (alkali)	Saline-sodic	Acid
pH	< 8.5	**> 8.5**	≤ 8.5	< 6.5
EC (dS/m)	**> 4**	< 4	> 4	Low
ESP	< 15	**> 15**	> 15	–
Local name	White alkali, solonchak, reh	Black alkali, solonetz, usar	–	Laterite, red, hill soils

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Reclamation	**Leaching** + drainage	**Gypsum**, pyrites, press mud, S, green manure (dhaincha)	Gypsum + leaching	**Lime** ($CaCO_3$), basic slag

- Gypsum requirement is calculated from **ESP**; gypsum is **not** needed for purely saline soils. Liming materials (neutralising value): $CaCO_3$ 100, **CaO 179**, $Ca(OH)_2$ 136, dolomite 109.
- Salt-tolerant crops: **barley**, sugar beet, cotton, dhaincha, date palm, Karnal grass; sensitive – beans, pea, gram, citrus. Varieties: rice **CSR** series, wheat **KRL-210, KRL-283** (**CSSRI, Karnal**).
- **Acid sulphate soils** (cat clays) – pH < 4 on drainage (pyrite oxidation) – Kuttanad (Kerala).

Essential nutrients (17)

- **Non-mineral**: C, H, O. **Primary**: N, P, K. **Secondary**: Ca, Mg, S. **Micronutrients (8)**: Fe, Mn, Zn, Cu, B, Mo, Cl, **Ni** (17th, 1987). Beneficial: Na, Si (rice), Co (N-fixation), V.
- **Mobile in plant** (N, P, K, Mg) → symptoms on **older leaves**; **immobile** (Ca, S, Fe, B, Zn, Cu, Mn) → symptoms on **young leaves / growing tips**.
- Uptake forms: N – NH_4^+, NO_3^-; P – $H_2PO_4^-$, HPO_4^{2-}; K – K^+; S – SO_4^{2-}; B – H_3BO_3; Mo – MoO_4^{2-}.
- Most deficient in Indian soils: **N > P > Zn > S > B**; **Zn** is the most deficient micronutrient (~36–40% of soils).

Nutrient	Key role	Deficiency symptom / disorder
N	Protein, chlorophyll	Yellowing of old leaves (V-shaped in maize); buttoning of cauliflower
P	ATP, nucleic acids	Purple leaves (maize), poor roots, late maturity
K	Stomata, enzymes, quality	Marginal scorching of old leaves; lodging
Ca	Cell wall (Ca pectate)	**Blossom-end rot** (tomato); tip burn (cabbage); **pops** in groundnut; bitter pit (apple)
Mg	**Central atom of chlorophyll**	Interveinal chlorosis of old leaves; sand drown (tobacco)
S	Cysteine, methionine, oil	Tea yellows; low oil in oilseeds
Fe	Cytochromes, ferredoxin	Interveinal chlorosis of young leaves; lime-induced chlorosis
Zn	Auxin (tryptophan), carbonic anhydrase	**Khaira** (rice); **white bud** (maize); little leaf; mottle leaf (citrus)
Mn	Photolysis of water	Grey speck (oats); marsh spot (pea)
Cu	Plastocyanin	**Reclamation disease** / white tip of cereals; exanthema (citrus)
B	Pollen germination, sugar transport	Browning/hollow stem (cauliflower); heart rot (sugar beet); hen & chicken (grape)
Mo	Nitrate reductase, nitrogenase	**Whiptail** of cauliflower
Ni	**Urease**	Mouse ear (pecan)

Fertilisers – nutrient content (most asked)

Fertiliser	N %	P_2O_5 %	K_2O %	Other / note
Urea	**46**	–	–	Amide-N; biuret ≤ 1.5% (≤ 0.25% for foliar); neem-coated mandatory (2015); 45-kg bag
Ammonium sulphate	20.6	–	–	S 24%; strongly acid-forming; good for rice, tea
CAN	25–26	–	–	Neutral ("Kisan Khad")
Ammonium chloride	25	–	–	Acidic
Anhydrous ammonia	**82**	–	–	Highest N
DAP	**18**	**46**	–	Complex fertiliser
MAP	11	52	–	Complex
SSP	–	**16**	–	S 12%, Ca ~19–21%
TSP	–	46	–	–
Rock phosphate	–	20–40	–	For acid soils
MOP (KCl)	–	–	**60**	Avoid for tobacco, potato (Cl)
SOP (K_2SO_4)	–	–	50	S 18%
NPK complexes	10:26:26; 12:32:16; 19:19:19 (water soluble); 20:20:0:13 (S 13%)			–
Nano Urea (IFFCO, 2021)	4	–	–	500 ml bottle, foliar
Nano DAP (IFFCO, 2023)	8	16	–	Liquid
Gypsum	–	–	–	Ca 23%, S 18% (pure)
Zinc sulphate	–	–	–	Zn 21% (heptahydrate) / 33% (monohydrate)
Borax	–	–	–	B 10.5–11%

KEY FORMULAE

- Fertiliser needed (kg) = nutrient required ÷ % nutrient × 100 → 100 kg N via urea = **217 kg urea**; 50 kg P_2O_5 via DAP = **109 kg DAP** (also supplies 19.6 kg N).
- P_2O_5 × **0.436** = P ($P \times 2.29 = P_2O_5$); K_2O × **0.83** = K ($K \times 1.2 = K_2O$).
- Base saturation % = exchangeable bases ÷ CEC × 100. **SAR** = $Na^+ / \sqrt{[(Ca^{2+} + Mg^{2+})/2]}$.

Manures & biofertilisers

Manure	N %	P_2O_5 %	K_2O %
FYM	**0.5**	0.2	0.5
Vermicompost	1.5–2.0	~1.0	1.0–1.5
Poultry manure	3.0	2.6	1.4
Neem cake	5.2	1.0	1.4
Groundnut cake	7.3	1.5	1.3

- Composting: **Indore method** (Howard & Wad); **Bangalore** (Acharya, anaerobic pit); **NADEP** (N.D. Pandharipande, brick tank). Vermicompost earthworm: **Eisenia fetida** (red wiggler).
- Green manures: **sunhemp** (*Crotalaria juncea*) – best, ~80–130 kg N/ha; **dhaincha** (*Sesbania aculeata*) – also for sodic soils; **Sesbania rostrata** – stem nodules. Incorporate at flowering (45–60 days).

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Biofertiliser	Type	Crops
Rhizobium	Symbiotic N-fixer (root nodules)	Legumes; **Bradyrhizobium japonicum** – soybean
Azotobacter	Free-living aerobic	Wheat, vegetables, cotton
Azospirillum	Associative	Sorghum, bajra, maize
Acetobacter (Gluconacetobacter) diazotrophicus	Endophytic	**Sugarcane**
BGA (Anabaena, Nostoc)	Free-living cyanobacteria	Rice; ~20–30 kg N/ha
Azolla–Anabaena azollae	Symbiotic water fern	Rice; ~40–60 kg N/ha
Frankia	Actinomycete (non-legume)	Casuarina, alder
PSB (Pseudomonas striata, Bacillus megaterium)	P-solubiliser	All crops
VAM (*Glomus*)	P mobiliser (mycorrhiza)	Absorbs P, Zn

- Leghaemoglobin (pink) in nodules protects **nitrogenase** (needs Mo, Fe) from O_2. Seed treatment order: **F-I-R** – Fungicide → Insecticide → Rhizobium.
- **Soil Health Card** – launched **19 Feb 2015, Suratgarh (Rajasthan)**; **12 parameters**: N, P, K, S (macro); Zn, Fe, Cu, Mn, B (micro); pH, EC, OC; issued every **2 years**; > 25 crore cards; now a component of **PM-RKVY**.
- Soil test methods: OC – Walkley & Black; available N – **alkaline $KMnO_4$ (Subbiah & Asija)**, low < 280 kg/ha; P – **Olsen** (alkaline/neutral) / Bray-1 (acid); K – neutral NH_4OAc (flame photometer); micronutrients – **DTPA**.

MEMORY TRICK

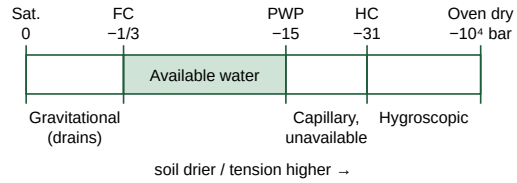
Big four "**46 – 18/46 – 16 – 60**": Urea 46 N, DAP 18-46, SSP 16 P_2O_5, MOP 60 K_2O. Saline = Salt = White = Wash; Sodic = Sodium = Black = Gypsum.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Amendment for sodic (alkali) soil? → **Gypsum**.
- N content of urea and of DAP? → **46% and 18%**.
- Khaira disease of rice is due to? → **Zn deficiency**.
- Number of parameters on a Soil Health Card? → **12**.
- Biofertiliser for sugarcane? → **Acetobacter diazotrophicus**.
- Dominant clay mineral of black soils? → **Montmorillonite**.

1.4 Irrigation & Water Management ★★★

Soil moisture constant	Tension (bar)	pF
Saturation	0	0
Field capacity (FC)	**−1/3** (−0.1 in sandy soils)	2.54
Permanent wilting point (PWP)	**−15**	4.18
Hygroscopic coefficient	−31	4.5
Oven dry	−10,000	7.0



Soil moisture constants: available water lies between FC and PWP.

- **Available water = FC − PWP** (Veihmeyer & Hendrickson). PWP concept – **Briggs & Shantz (1912)**, indicator plant **dwarf sunflower**. Available water is highest in **medium-textured soils (loam, silt loam)**, least in sand.
- **Irrigation scheduling**: critical growth stages; soil-moisture depletion (irrigate at 25–50% depletion of available soil moisture); **IW/CPE ratio** (Prihar et al., 1974; usual 0.6–1.0); plant indices (leaf water potential, canopy temperature).
- **Consumptive use** = ET + water used in metabolism (~1%). **Penman** – most accurate ET formula; FAO uses **Penman–Monteith**.
- **Delta** = total depth of water a crop needs; **Duty** = area irrigated per unit discharge (ha/cumec); **Base period** = days of supply.
- Irrigation projects by CCA: **major > 10,000 ha**; medium 2,000–10,000 ha; minor < 2,000 ha.
- Rice needs **3,000–5,000 L water per kg grain**; **AWD** (alternate wetting & drying) saves water and cuts methane. WUE lowest in rice.
- **Drainage**: surface drains, tile drains, **mole drains** (clay soils), vertical drainage (tube wells). Salt-affected soils in India ≈ **6.7 Mha**.
- Irrigation water quality: **RSC** = $(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ – safe < 1.25, unsafe > 2.5 meq/L.

Crop	Most critical stage(s) for irrigation
Rice	Panicle initiation, booting, flowering
Wheat	**CRI (21 DAS)** > jointing > flowering > milk
Maize	**Tasselling–silking**
Sorghum / bajra	Booting, flowering
Gram / pea	Pre-flowering, pod filling
Groundnut	**Pegging**, flowering, pod development
Soybean	Flowering, pod filling
Mustard	Flowering, siliqua formation
Sunflower	**Star bud**, flowering
Cotton	Flowering, boll formation
Sugarcane	**Formative (tillering) phase**, 60–130 days
Potato	Stolonisation, tuberisation

- Wheat with only **1 irrigation → at CRI**; with 2 → CRI + flowering/late jointing. Wheat stages (DAS): CRI 21, tillering 45, jointing 65, flowering 85, milk 105, dough 120.
- Seasonal water requirement (mm): **rice 900–2500**, wheat 450–650, maize 500–800, groundnut 500–700, cotton 700–1300, **sugarcane 1500–2500**.

Method	Key facts	Efficiency
Check basin / flooding	Most common; close-growing crops (wheat, groundnut); rice	~30–50%

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Border strip	Slope 0.5–1%; close-growing crops; not for sandy soils	~60–75%
Furrow	Row crops – cotton, sugarcane, potato, maize	~50–70%
Sprinkler	Undulating land, sandy soils; pressure ~2.5–4 kg/cm²; frost protection; **not for rice and jute**; saves 25–50% water	~70–80%
Drip (trickle)	Developed in **Israel**; emitter 1–4 L/h; **fertigation**; wide-spaced, high-value crops; saves 30–70% water	**~90–95%**
Surge	Intermittent flow; reduces deep percolation	–

KEY FORMULAE

- **1 ha-cm = 100 m³ = 1,00,000 L**; 1 ha-mm = 10,000 L; 1 ha = 2.47 acre.
- **1 cusec** (ft³/s) = **28.3 L/s**; **1 cumec** (m³/s) = 1000 L/s ≈ 35.3 cusec.
- **Δ (m) = 8.64 B ÷ D** (Δ = delta in m, B = base period in days, D = duty in ha/cumec).
- Depth of irrigation (cm) = (FC – present moisture %) × bulk density × root-zone depth (cm) ÷ 100.
- Water application efficiency = water stored in root zone ÷ water delivered to field × 100.

CODE UPDATE

PMKSY (1 Jul 2015, "Har Khet Ko Pani"); its **Per Drop More Crop** micro-irrigation component runs under **PM-RKVY** since 2022-23 – subsidy **55%** for small/marginal and 45% for other farmers; micro-irrigation coverage ≈ **115 lakh ha** (Jul 2026).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Most critical stage of wheat for irrigation? → **CRI, ~21 DAS**.
- Soil moisture tension at PWP? → **−15 bar**; at FC? → **−1/3 bar**.
- Most efficient irrigation method? → **Drip (~90–95%)**.
- Sprinkler is not suitable for? → **Rice and jute**.
- 1 hectare-cm of water equals? → **1 lakh litres**.

1.5 Weed Management & Seeds ★★☆

Weeds

- Weed = plant out of place. Weeds cause the **largest share of crop loss (~33%)** among pests (diseases ~26%, insects ~20%). **ICAR-DWR, Jabalpur**.
- **Cyperus rotundus** (nut sedge, motha) – "**world's worst weed**"; spreads by tubers. Main rice weed – **Echinochloa crus-galli**; mimic weeds of wheat – **Phalaris minor** (canary grass) and **Avena** (wild oat).
- **Critical period of crop-weed competition** ≈ first **1/4 to 1/3** of crop duration – keep weed-free then.
- **Allelopathy** (term by **Molisch**) – harmful chemical effect of one plant on another (e.g. Parthenium, sorghum).
- Parasitic weeds: **Cuscuta** (total stem; lucerne, niger), **Orobanche** (total root; mustard, tobacco, tomato), **Striga** (partial root; sorghum, sugarcane), **Loranthus** (partial stem; trees).
- Toxic weeds: **Argemone mexicana** seed in mustard oil → **epidemic dropsy** (sanguinarine); Parthenium → dermatitis.
- **Stale seedbed** – irrigate, let weeds germinate, kill them, then sow. Biocontrol: Parthenium – **Zygogramma bicolorata**; water hyacinth – **Neochetina** weevils; Lantana – Teleonemia; prickly pear – Dactylopius (cochineal).

Class	Meaning	Examples
Selective	Kills weeds, spares crop	2,4-D (broadleaf in cereals), atrazine, butachlor, pendimethalin, metsulfuron, clodinafop
Non-selective	Kills all green plants	**Glyphosate** (systemic), **paraquat** (contact)
Contact	Kills only tissue touched	Paraquat, diquat
Systemic (translocated)	Moves inside plant	Glyphosate, 2,4-D
Pre-plant incorporated (PPI)	Mixed into soil before sowing (volatile)	**Fluchloralin**
Pre-emergence	After sowing, before weed emergence	Pendimethalin, atrazine, butachlor, pretilachlor
Post-emergence	On emerged weeds	2,4-D, clodinafop, sulfosulfuron, bispyribac, imazethapyr

Herbicide (group)	Site of action	Main use
2,4-D (phenoxy) – first selective organic herbicide (1940s)	Synthetic auxin	Broadleaf weeds in wheat, rice, maize, sugarcane
Atrazine (triazine)	PS-II inhibitor	**Maize, sugarcane**
Isoproturon (substituted urea)	PS-II inhibitor	Wheat (Phalaris now resistant)
Paraquat (bipyridylium)	PS-I electron diverter	Non-selective, contact
Glyphosate	**EPSP synthase**	Non-selective, systemic
Clodinafop, fenoxaprop, pinoxaden ("fops/dens")	ACCase	Grassy weeds – **Phalaris** in wheat
Metsulfuron, sulfosulfuron, imazethapyr, bispyribac	ALS (AHAS)	Wheat; soybean (imazethapyr); DSR (bispyribac)
Butachlor, pretilachlor (chloroacetamide)	VLCFA synthesis	**Transplanted rice**
Pendimethalin, fluchloralin (dinitroaniline)	Microtubule assembly	Pulses, groundnut, soybean, cotton

CODE UPDATE

Glyphosate may be applied **only through Pest Control Operators** (GoI notification, Oct 2022); paraquat is also restricted. **Draft Seeds Bill, 2025** (12 Nov 2025) proposes to replace the Seeds Act 1966 and Seeds (Control) Order 1983 – National Register of varieties, QR-code traceability, penalty up to ₹30 lakh / 3 years for spurious seed; farmers may still save and exchange farm-saved seed (not branded sale).

Seeds

Seed class	Produced / certified by	Tag colour
Nucleus	Original breeder	No tag
Breeder	Breeder / ICAR / SAUs	**Golden yellow**
Foundation	NSC, State Seed Corporations; certified by SSCA	**White**
Certified	Seed agencies, seed growers; certified by SSCA	**Azure blue**

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Truthfully labelled (TL)	Private producers (not certified)	**Opal green**

- Seed laws: **NSC (1963)**; **Seeds Act 1966**; Seeds Rules 1968; **Seeds (Control) Order 1983** (under Essential Commodities Act); New Policy on Seed Development 1988; National Seed Policy 2002; **PPV&FR Act 2001**.
- Seed certification is **voluntary**; labelling of notified kinds is compulsory. Certification agency – **State Seed Certification Agency (SSCA)**.
- **Seed replacement rate**: self-pollinated varieties **33%** (every 3 yr); cross-pollinated **50%**; hybrids **100%** (every season) (some texts: 25% / 35% / 100%).
- Isolation distance (certified): wheat/rice ~3 m; maize ~200 m; hybrid sorghum ~200 m; cotton 30–50 m.
- Minimum germination (Indian Minimum Seed Certification Standards): **maize 90%**; wheat 85%; gram 85%; mustard 85%; **paddy 80%**; sorghum, bajra, tur, moong, urd 75%; groundnut, soybean 70%; **cotton 65%**. Physical purity usually **98%**.
- **Tetrazolium (TZ) test** – quick viability test; 2,3,5-triphenyl tetrazolium chloride is reduced by dehydrogenases of living tissue → viable embryo stains **red** (formazan).
- **Harrington's thumb rules** (storage): every **1% fall in seed moisture** (5–14%) or **5 °C fall in temperature** (0–50 °C) **doubles seed life**; RH (%) + temperature (°F) should not exceed **100**.
- **Orthodox** seeds tolerate drying to low moisture (cereals, pulses); **recalcitrant** seeds die on drying (mango, jackfruit, litchi, cocoa, coconut) – term by Roberts (1973).
- Seed treatment rate of Rhizobium ~200 g culture per 10 kg seed; order **F-I-R**. Seed priming / hardening improves vigour.

MEMORY TRICK

Tags "**Golden Boy, White Father, Blue Certificate, Green Truth**" → Breeder – golden yellow; Foundation – white; Certified – azure blue; TL – opal green. Phalaris killers "**C-S-P**" → Clodinafop, Sulfosulfuron, Pinoxaden.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Tag colour of certified seed? → **Azure blue**; breeder seed? → **Golden yellow**.
- Glyphosate inhibits which enzyme? → **EPSP synthase**.
- Seeds Act was enacted in? → **1966**.
- TZ test is used for? → **Seed viability**.
- Total root parasite of mustard? → **Orobanche**.
- Seed replacement rate for hybrids? → **100%**.

1.6 Cereals & Millets ★★★

Rice

- **Oryza sativa**, 2n = **24**, Poaceae; origin **Indo-Burma / SE Asia**; African rice = *O. glaberrima*. Ecotypes: indica, japonica, javanica. C3, **short-day**; fruit = caryopsis; test weight ~20–25 g; milling out-turn ~66–67%.
- Nursery: ~**1/10th area** of main field; seed rate ~30–40 kg/ha (transplanted); 21–25-day seedlings; spacing 20 × 10/15 cm, 2–3 seedlings/hill. **Dapog** nursery (Philippines) – seedlings ready in 11–14 days; mat nursery for mechanical transplanting.
- **Puddling** cuts percolation and weeds; place NH_4-N fertiliser in the **reduced zone**; avoid nitrate fertilisers (denitrification). Fertiliser (HYV) ~100–120 : 60 : 60 NPK + 25 kg $ZnSO_4$/ha.
- Disorders: **Khaira = Zn deficiency** (Y.L. Nene, Pantnagar, 1966); **Akiochi = H_2S toxicity**; bronzing = Fe toxicity. Paddy fields emit **methane**.
- **Parboiling** retains **vitamin B1 (thiamine)** and gives more head rice; polished rice → beriberi.
- Varieties: **TN-1** (Taiwan, first semi-dwarf to India); **IR-8** ("miracle rice", IRRI 1966; dwarf gene **sd1** from Dee-geo-woo-gen); **Jaya** – first Indian semi-dwarf HYV (1968); **Pusa Basmati 1121** (longest grain); PB 1509, 1692; **Swarna Sub-1** (submergence, *Sub1* gene); Improved Samba Mahsuri (bacterial blight).
- Hybrid rice – China (Yuan Longping, WA-CMS); India's first hybrids **1994** (APHR-1, APHR-2, MGR-1, KRH-1).
- **Genome-edited rice** (world's first, ICAR, **4 May 2025**): **DRR Dhan 100 (Kamala)** (from Samba Mahsuri; ~20 days earlier) and **Pusa DST Rice 1** (from MTU 1010; drought/salinity tolerant) – SDN-1, CRISPR-Cas.

Wheat, barley, triticale

- **Triticum aestivum** (bread wheat, **hexaploid 2n = 42**, ~87–90% area); **T. durum** (macaroni, 2n = 28); T. dicoccum (emmer, 2n = 28). Origin **SW Asia**; C3, **long-day**; inflorescence spike; test weight ~40 g.
- Dwarfing genes **Rht1, Rht2** from Japanese **Norin-10** (via Borlaug). Mexican **Lerma Rojo 64A, Sonora 64** started the Green Revolution; **Kalyan Sona**, **Sonalika** were selections.
- Timely sowing **1–15 Nov** (NW India); seed rate **100 kg/ha** (late 125 kg/ha); rows **22.5 cm**; fertiliser **120 : 60 : 40** NPK (½ N + full P, K basal; rest N at CRI).
- Gluten = **gliadin + glutenin**. Safe storage moisture **10–12%**.
- Recent varieties: HD 2967, HD 3086, **DBW 187 (Karan Vandana)**, **DBW 303 (Karan Vaishnavi)**, DBW 222, DBW 327 (Karan Shivani), HD 3385 (heat tolerant), PBW 826; biofortified **WB 2** (Zn), HPBW 01.
- **Barley** (*Hordeum vulgare*, 6-row; *H. distichum*, 2-row malting) – **most salt/alkali-tolerant cereal**. **Triticale** = wheat × rye – **first man-made cereal**.

Maize & millets (Shree Anna)

- **Zea mays**, 2n = **20**, C4, origin **Mexico/Central America**; **monoecious, protandrous**, cross-pollinated; "**Queen of cereals**" (highest genetic yield potential); day-neutral.
- Types: dent (most common, USA), **flint** (India), sweet (*saccharata*), pop (*everta*), waxy, flour, pod corn.
- Protein **zein** – low in **lysine & tryptophan** → **QPM** (opaque-2): Shaktiman-1, HQPM-1. Maize-only diets → **pellagra** (niacin).
- First double-cross hybrids (1961): Ganga-1, Ganga-101, Ranjit, Deccan; first AICRP was on **maize (1957)**. Now single-cross hybrids dominate.
- Seed rate 20–25 kg/ha; spacing 60–75 × 20 cm; ~67,000–83,000 plants/ha; very sensitive to **waterlogging**; white bud = Zn deficiency; herbicide atrazine.
- **Shree Anna** = millets brand; **International Year of Millets 2023** (India's proposal); **ICAR-IIMR Hyderabad** – Global Centre of Excellence on millets.

Millet	Botanical name	2n	Key facts

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Sorghum (jowar)	Sorghum bicolor	20	C4, origin Africa, "camel crop"; young plants have **HCN (dhurrin)** – feed after 50% flowering; Striga; first hybrid **CSH-1 (1964)**; rabi variety M 35-1; seed rate 10–12 kg/ha
Pearl millet (bajra)	Pennisetum glaucum	14	C4, **protogynous**, most drought-tolerant cereal; world's first hybrid **HB-1 (1965, Tift 23A CMS)**; Rajasthan largest; biofortified (Fe) Dhanshakti, HHB 299
Finger millet (ragi)	Eleusine coracana	36	Richest cereal in **calcium (~344 mg/100 g)**; Karnataka leads; very long storage life
Foxtail millet	Setaria italica	18	Short duration; AP, Karnataka
Kodo millet	Paspalum scrobiculatum	–	Hardy; MP; "kodo poisoning" from fungal-infected grain
Little, proso, barnyard millet	Panicum sumatrense, P. miliaceum, Echinochloa frumentacea	–	Minor millets; barnyard – quick-maturing, rich in fibre & iron

KEY FORMULAE

- **Seed rate (kg/ha)** = plant population/ha × test weight (g) ÷ (10^6 × germination fraction × purity fraction) → maize: 83,333 × 250 g ÷ (10^6 × 0.90 × 0.98) ≈ **24 kg/ha**.
- Plant population/ha = 10,000 m² ÷ (row spacing × plant spacing in m) → maize 60 × 20 cm = **83,333**.

MEMORY TRICK

Wheat recipe "**100 – 22.5 – 120**" → 100 kg seed, 22.5 cm rows, 120 kg N. Chromosomes: "**Rice 24 hours, Wheat 42, Maize 20, Bajra 14**".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Source of dwarfing genes in wheat? → **Norin-10**.
- Maize protein is deficient in? → **Lysine and tryptophan**.
- HCN poisoning in young sorghum is due to? → **Dhurrin**.
- Protogynous cereal? → **Pearl millet**.
- Richest cereal source of calcium? → **Finger millet**.
- First man-made cereal? → **Triticale**.

1.7 Pulses, Oilseeds & Commercial Crops ★★★

Pulses

- India is the **largest producer, consumer and importer** of pulses. **Gram** has the largest share (~45%), then tur. Protein ~20–25% (soybean ~40%); pulses low in **methionine**, cereals low in **lysine** – complementary.
- Pulses need **Rhizobium** inoculation, P, S and **Mo**. **ICAR-IIPR Kanpur**. World Pulses Day – 10 Feb.

Pulse	Botanical name	2n	Key facts
Chickpea (gram)	Cicer arietinum	16	Rabi; desi (brown) vs kabuli (white); **malic + oxalic acid** in leaf hairs; **nipping** at 30–40 DAS; seed rate 75–100 kg/ha; pod borer *Helicoverpa*; Fusarium wilt
Pigeonpea (tur)	Cajanus cajan	22	Often cross-pollinated (~20–30%); deep-rooted; seed rate 12–15 kg/ha; world's first pulse hybrid **ICPH-8 (ICRISAT, 1991)**; sterility mosaic (mite vector)
Green gram (moong)	Vigna radiata	22	Kharif and summer crop; **YMV** (whitefly); SML 668, IPM 02-3
Black gram (urd)	Vigna mungo	24	YMV-prone; T-9, PU-31
Lentil (masur)	Lens culinaris	14	Rabi; utera crop in rice fallows
Field pea	Pisum sativum	14	Powdery mildew; Mendel's plant
Lathyrus (khesari)	Lathyrus sativus	14	**BOAA/ODAP** → lathyrism; low-ODAP Ratan, Prateek
Cowpea	Vigna unguiculata	22	"**Vegetable meat**"; drought hardy

Oilseeds

- Edible oil is India's **largest agri import** (palm, soybean, sunflower oil). **ICAR-IIOR Hyderabad**; DRMR Bharatpur (mustard); DGR Junagadh (groundnut); IISR Indore (soybean).

Oilseed	Botanical name	Oil %	Key facts
Groundnut	Arachis hypogaea	45–50	Origin Brazil; **pegging**; **gypsum** at pegging (Ca prevents **pops**); aflatoxin (*Aspergillus flavus*); bunch (non-dormant) vs spreading (dormant); seed rate 100–120 kg/ha; 30 × 10 cm
Rapeseed–mustard	Brassica juncea etc.	38–42	Pungency = **allyl isothiocyanate**; "**double zero**" (canola) = low erucic acid + low glucosinolate; GM mustard **DMH-11** (2022); aphid *Lipaphis erysimi*; seed rate 4–5 kg/ha; Rajasthan ~45%
Soybean	Glycine max	~20 (protein ~40)	"Golden bean"; origin China; short-day; **Bradyrhizobium japonicum**; MP leads
Sunflower	Helianthus annuus	40–45	Photo-insensitive; **star bud** critical stage; Karnataka
Sesame (til)	Sesamum indicum	~50	"**Queen of oilseeds**"; highest oil among annual oilseeds; antioxidant sesamol
Safflower	Carthamus tinctorius	~30	Drought hardy; rich in linoleic acid
Castor	Ricinus communis	~50	Non-edible; **ricin**; Gujarat; India top exporter
Linseed	Linum usitatissimum	35–45	Omega-3 (α-linolenic acid); fibre = flax
Niger	Guizotia abyssinica	~38	Tribal areas; host of Cuscuta
Oil palm	Elaeis guineensis	Highest per ha	NMEO–Oil Palm (2021)

Commercial crops

- **Cotton** ("white gold"): *Gossypium hirsutum* (American upland, **2n = 52**), *G. barbadense* (Egyptian/Sea Island – **longest staple**, 2n = 52), *G. arboreum* and *G. herbaceum* (desi, 2n = 26). India grows all 4 species + hybrids. World's first cotton hybrid **H-4 (C.T. Patel,**

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Surat, 1970); first interspecific hybrid **Varalaxmi**. **Bt cotton** approved **2002** (Bollgard II = cry1Ac + cry2Ab). Bale = **170 kg** lint; ginning out-turn ~33–35%; seed contains **gossypol**; pink bollworm resistant to Bt. **CICR Nagpur**.

- **Sugarcane**: *Saccharum officinarum* ("noble cane", **2n = 80**, C4, origin **New Guinea**). **SBI Coimbatore (1912)** – nobilisation by **T.S. Venkatraman** (Co varieties); **IISR Lucknow**. Co 0238 (north), Co 86032 (south). 3-budded setts, ~35,000–40,000 setts/ha. Seasons: **Adsali** (Jul–Aug, ~18 months, Maharashtra), Eksali/spring (Jan–Mar, 12 months), autumn (Oct). Maturity: **Brix ≥ 18%** (hand refractometer). Ratoon 1–2 times. By-products: bagasse, molasses (ethanol), press mud (manure).
- **Jute**: *Corchorus olitorius* (tossa) and *C. capsularis* (white); Malvaceae (earlier Tiliaceae); **West Bengal ~80%**; **retting** (pectin breakdown by microbes); bale = **180 kg**; **CRIJAF Barrackpore**. Mesta = *Hibiscus cannabinus / H. sabdariffa*.
- **Tobacco**: *Nicotiana tabacum* (cigarette, bidi, cigar) and *N. rustica* (hookah, chewing; more nicotine); Solanaceae, 2n = 48. **FCV** (flue-cured Virginia) – AP, Karnataka. **Topping** and **de-suckering**; curing. Chloride harms burning quality. **CTRI Rajahmundry**.

Master crops table

Crop	Botanical name	Family	2n	Origin	C3/C4
Rice	Oryza sativa	Poaceae	24	SE Asia	C3
Wheat	Triticum aestivum	Poaceae	42	SW Asia	C3
Maize	Zea mays	Poaceae	20	Mexico	C4
Sorghum	Sorghum bicolor	Poaceae	20	Africa	C4
Pearl millet	Pennisetum glaucum	Poaceae	14	Africa	C4
Chickpea	Cicer arietinum	Fabaceae	16	SW Asia	C3
Pigeonpea	Cajanus cajan	Fabaceae	22	India/Africa	C3
Groundnut	Arachis hypogaea	Fabaceae	40	Brazil	C3
Soybean	Glycine max	Fabaceae	40	China	C3
Indian mustard	Brassica juncea	Brassicaceae	36	Asia	C3
Sunflower	Helianthus annuus	Asteraceae	34	N. America	C3
Sesame	Sesamum indicum	Pedaliaceae	26	India/Africa	C3
Castor	Ricinus communis	Euphorbiaceae	20	Africa	C3
Cotton	Gossypium hirsutum	Malvaceae	52	Central America	C3
Sugarcane	Saccharum officinarum	Poaceae	80	New Guinea	C4
Jute	Corchorus olitorius	Malvaceae	14	Africa/India	C3
Tobacco	Nicotiana tabacum	Solanaceae	48	S. America	C3
Potato	Solanum tuberosum	Solanaceae	48	Peru (Andes)	C3

- Practices: **topping** – cotton, tobacco; **de-suckering** – tobacco; **earthing up** – potato, sugarcane, maize; **nipping** – gram; **propping** – sugarcane, banana; **trashing** – sugarcane; **retting** – jute.
- **Sugarcane FRP 2026-27**: **₹365/q** (at 10.25% recovery). **E20** petrol blending target achieved in 2025.

CODE UPDATE

Mission for Aatmanirbharta in Pulses (Cabinet, 1 Oct 2025): ₹11,440 crore, 2025-26 to 2030-31; target **350 lakh t** pulses; 100% MSP procurement of tur, urad, masoor for 4 years. **NMEO-Oilseeds** (Oct 2024): ₹10,103 crore, target **69.7 Mt** primary oilseeds by 2030-31. NMEO–Oil Palm (2021): ₹11,040 crore, focus NE & A&N Islands.

MEMORY TRICK

C4 crops "**My Sugar Stays Bright Always**" → Maize, Sugarcane, Sorghum, Bajra, Amaranthus. Bales "**Cotton 170, Jute 180**" – jute is heavier by 10.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Pungency of mustard is due to? → **Allyl isothiocyanate**.
- Pops in groundnut are due to deficiency of? → **Calcium**.
- Queen of oilseeds? → **Sesame**.
- Chromosome number of sugarcane (*S. officinarum*)? → **2n = 80**.
- Weight of one bale of cotton? → **170 kg**; of jute? → **180 kg**.
- Lathyrism is caused by? → **BOAA/ODAP**.

1.8 Current Data & Institutes ★★★

CODE UPDATE

Crop production – **3rd Advance Estimates 2025-26** (released 27 May 2026) vs Final 2024-25. India overtook China as the **world's largest rice producer** (declared Jan 2026, 150.18 Mt) and is the largest rice exporter (~40% of world trade).

Crop	2024-25 (Final)	2025-26 (3rd AE)
Total foodgrains	357.73 Mt	**376.56 Mt** (record)
Rice	150.18 Mt	**154.02 Mt**
Wheat	117.95 Mt	**120.66 Mt**
Maize	43.41 Mt	**55.09 Mt** (record)
Nutri/coarse cereals	63.92 Mt	74.47 Mt
Total pulses	25.68 Mt	**27.41 Mt**
Gram / Tur	11.11 / 3.62 Mt	12.51 / 3.59 Mt
Total oilseeds	42.98 Mt	**43.06 Mt**
Groundnut / Rapeseed–mustard	11.94 / 12.67 Mt	13.07 / 13.77 Mt (both record)
Sugarcane	454.61 Mt	**500.06 Mt** (record)
Cotton (lakh bales of 170 kg)	297.2	290.2
Jute & mesta (lakh bales of 180 kg)	–	91.8

Crop (production, 2023-24)	1st	2nd	3rd
Total foodgrains	**Uttar Pradesh**	Madhya Pradesh	Punjab
Rice	**Telangana**	Uttar Pradesh	West Bengal

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Wheat	**Uttar Pradesh**	Madhya Pradesh	Punjab
Maize	**Karnataka**	Bihar	Madhya Pradesh
Nutri/coarse cereals	**Rajasthan**	Karnataka	Madhya Pradesh
Total pulses / gram	**Madhya Pradesh**	Maharashtra	Rajasthan
Tur	**Karnataka**	Maharashtra	Uttar Pradesh
Total oilseeds	**Rajasthan**	Madhya Pradesh	Gujarat
Groundnut	**Gujarat** (~45%)	Rajasthan	Madhya Pradesh
Rapeseed–mustard	**Rajasthan** (~45%)	Uttar Pradesh	Madhya Pradesh
Soybean	**Madhya Pradesh**	Maharashtra	Rajasthan
Sugarcane	**Uttar Pradesh** (~46%)	Maharashtra	Karnataka
Cotton	**Gujarat**	Maharashtra	Telangana
Jute & mesta	**West Bengal** (~81%)	Bihar	Assam

Minimum Support Price

- MSP is recommended by **CACP (1965)** and approved by **CCEA**; **22 mandated crops** (14 kharif + 6 rabi + 2 commercial – jute, copra) plus toria and de-husked coconut. Since 2018-19, MSP ≥ **1.5 × A2+FL** cost.
- Cost concepts: **A2** = paid-out costs; **A2+FL** = + imputed family labour (MSP benchmark); **C2** = comprehensive cost (+ rent and interest on owned capital) – Swaminathan Commission asked for C2 + 50%.

Kharif crop (KMS 2026-27; CCEA 13 May 2026)	MSP ₹/q	Increase ₹
Paddy (Common) / Grade A	**2,441** / 2,461	+72
Jowar (Hybrid)	4,023	+324
Bajra	2,900	+125
Ragi	5,205	+319
Maize	2,410	+10
Tur / Moong / Urad	8,450 / 8,780 / 8,200	+450 / +12 / +400
Groundnut	7,517	+254
Sunflower seed	8,343	**+622 (highest)**
Soybean (yellow)	5,708	+380
Sesamum	**10,346 (highest MSP)**	+500
Nigerseed	10,052	+515
Cotton (Medium / Long staple)	8,267 / 8,667	+557

- Kharif 2026-27 – highest margin over cost: **moong (61%)**, then bajra and maize (56%), tur (54%); others 50%.

Rabi crop (RMS 2027-28; CCEA 30 Sep 2026)	MSP ₹/q	Increase ₹	Margin over cost
Wheat	**2,610**	+25	**106% (highest)**
Barley	2,286	+136	58%
Gram	5,958	+83	59%
Lentil (masur)	7,390	+390	92%
Rapeseed & mustard	6,613	+413	96%
Safflower	7,215	**+675 (highest)**	50%

ICAR & crop institutes

- **ICAR** founded **16 July 1929** as Imperial Council of Agricultural Research (on Royal Commission on Agriculture, 1928); HQ New Delhi. **IARI** – est. 1905 at Pusa (Bihar), shifted to New Delhi 1936.

Institute	Location	Institute	Location
NRRI (rice)	**Cuttack**	IIRR (rice research)	Hyderabad
IIWBR (wheat & barley)	**Karnal**	IIMR (maize)	Ludhiana
IIMR (millets)	Hyderabad	IIPR (pulses)	**Kanpur**
IIOR (oilseeds)	Hyderabad	DRMR (rapeseed–mustard)	Bharatpur
DGR (groundnut)	Junagadh	IISR (soybean)	Indore
IISR (sugarcane)	Lucknow	SBI (sugarcane breeding)	**Coimbatore**
CICR (cotton)	**Nagpur**	CRIJAF (jute)	Barrackpore
CTRI (tobacco)	Rajahmundry	CPRI (potato)	Shimla
CRIDA (dryland)	Hyderabad	CAZRI (arid zone)	Jodhpur
CSSRI (salinity)	Karnal	IISS (soil science)	Bhopal
NBSS&LUP (soil survey)	Nagpur	DWR (weeds)	Jabalpur
NBPGR (plant genetic resources)	New Delhi	CIPHET (post-harvest engg.)	Ludhiana

Green Revolution & key scientists

- Green Revolution began with the **High Yielding Varieties Programme (kharif 1966)**; term coined by **William Gaud (USAID, 1968)**. Most successful in **wheat**, in Punjab, Haryana, western UP. Agriculture Minister: **C. Subramaniam**.
- Inputs: HYV seeds (dwarf wheat, rice), fertilisers, irrigation, pesticides, credit; also led to MSP (CACP) and FCI (both **1965**).
- **Norman Borlaug** – father of Green Revolution (world), Nobel Peace Prize **1970**. **M.S. Swaminathan** – father of Green Revolution in India; coined "**Evergreen Revolution**"; first World Food Prize (1987); Bharat Ratna (2024).

Scientist	Contribution
B.P. Pal	Wheat breeding; first DG of ICAR
D.S. Athwal	Pearl millet hybrid **HB-1**; wheat
T.S. Venkatraman	Sugarcane nobilisation (Co canes)
C.T. Patel	Cotton hybrid **H-4** (1970)
Pushkarnath	Seed plot technique (potato)
Gurdev S. Khush	IR36, IR64 (IRRI); World Food Prize 1996
S.K. Vasal & E. Villegas	QPM maize; World Food Prize 2000
Yuan Longping	Hybrid rice (China)
Verghese Kurien	White Revolution (milk)
Sam Pitroda	Yellow Revolution (oilseeds)

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CODE UPDATE

ICAR released **184 varieties of 25 crops** (60 rice, 50 maize, 13 oilseeds) on **4 Jan 2026**. At ICAR's **98th Foundation Day (16 Jul 2026)**, ICAR reported 386 varieties of 44 crops in the past year (94% climate-resilient, 29 biofortified). Earlier the PM released 109 varieties of 61 crops (11 Aug 2024).

MEMORY TRICK

"**376 – 154 – 120 – 27 – 43 – 500**" (2025-26 3rd AE, Mt): foodgrains – rice – wheat – pulses – oilseeds – sugarcane. MSP pair "**2441 paddy / 2610 wheat**".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Foodgrain production 2025-26 (3rd AE)? → **376.56 Mt**.
- MSP of paddy (common) for KMS 2026-27? → **₹2,441/q**.
- MSP of wheat for RMS 2027-28? → **₹2,610/q**.
- Largest producer of sugarcane? → **Uttar Pradesh**; of soybean? → **Madhya Pradesh**.
- MSP is recommended by? → **CACP**.
- Sugarcane Breeding Institute is at? → **Coimbatore**.

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2. Horticulture & Post-Harvest Technology

NOTE

For a warehousing corporation, horticulture matters mainly at the **post-harvest end**: maturity, ripening, cold storage temperature/RH, CA/MA storage, processing and the cold chain. Expect MCQs on climacteric fruits, storage conditions, preservation limits (sugar, salt, preservatives), irradiation, physiological disorders, PGRs, propagation methods, varieties/hybrids and the latest production data (2025-26).

2.1 Horticulture at a Glance ★★★

- **Horticulture** = Latin *hortus* (garden) + *cultura* (cultivation) – cultivation of garden crops.
- Branches: **Pomology** (fruits), **Olericulture** (vegetables), **Floriculture** (flowers & ornamentals), landscape gardening, plantation crops, spices, medicinal & aromatic plants, and **post-harvest technology** (handling, storage, processing).
- **Golden Revolution** = rapid growth of horticulture (≈ **1991–2003**); **Dr K.L. Chadha** – regarded as its father.
- Horticulture now contributes ≈ **33% of agricultural GVA** from a much smaller share (≈ 15–18%) of cropped area; its output has **exceeded foodgrains** (377.78 Mt vs 376.56 Mt in 2025-26 estimates).
- India = **2nd largest producer of fruits and of vegetables** (after **China**).
- India ranks **1st** in: **banana, mango, papaya, lime & lemon, okra**, ginger, dry onion (~25% of world), spices; coconut (per Coconut Development Board). **2nd** in potato, tomato, brinjal, cabbage, cauliflower, tea.
- Grapes = India's top **fresh-fruit export** by value; onion = top fresh-vegetable export. Fresh produce exports are promoted by **APEDA** (1985, New Delhi).

CODE UPDATE

Horticulture production – **2nd Advance Estimates 2025-26** (released 17 Jun 2026): total **377.78 Mt** (record) from **30.15 Mha**. 2013-14 output was 280.70 Mt – ≈ 35% rise in 12 years.

Item	2024-25 (Final)	2025-26 (2nd AE)
Total horticulture	370.74 Mt	**377.78 Mt** (record)
Area	30.14 Mha	**30.15 Mha**
Fruits	117.65 Mt	**121.48 Mt** (+3.25%)
Vegetables	217.80 Mt	**221.00 Mt**
Onion	30.77 Mt	**30.74 Mt**
Potato	–	**59.89 Mt**
Tomato	–	**21.46 Mt** (+4.2%)
Spices	–	**12.66 Mt**
Plantation crops	–	**16.93 Mt**
Flowers	–	**4.58 Mt** (+7.5%)

- Vegetables ≈ **59%** and fruits ≈ **32%** of total horticulture output; potato is the single largest vegetable, followed by onion and tomato.
- The Economic Survey quoted 2024-25 output as 367.72 Mt (earlier estimate); the final figure is 370.74 Mt – use the latest official figure in the exam.

Crop	Leading state	Crop	Leading state
Mango	**Uttar Pradesh**	Potato	**Uttar Pradesh**
Grapes	**Maharashtra** (Nashik)	Onion	**Maharashtra** (Lasalgaon market)
Apple	**J&K**, then HP	Tea	**Assam**
Litchi	**Bihar** (Muzaffarpur)	Coffee	**Karnataka** (~70%)
Pomegranate	**Maharashtra** (Solapur)	Rubber	**Kerala**
Banana, papaya	**Andhra Pradesh**	Saffron	**J&K** (Pampore)
Coconut	Kerala, Karnataka, TN	Cardamom	**Kerala** (Idukki)
Seed spices	Rajasthan & Gujarat	Chilli	Andhra Pradesh / Telangana

Schemes & boards

- **National Horticulture Board (NHB)** – set up **1984**, HQ **Gurugram**; commercial horticulture, cold storage subsidy, market information, **Cluster Development Programme** (2021, 55 clusters, 12 pilot – e.g. mango – Lucknow, Kutch, Mahbubnagar; banana – Anantapur, Theni; apple – Shopian, Kinnaur; grapes – Nashik; pomegranate – Solapur).
- **MIDH** (Mission for Integrated Development of Horticulture, **2014-15**) – centrally sponsored umbrella for **NHM, HMNEH, NHB, CDB** and **CIH** (Central Institute of Horticulture, Medziphema, Nagaland); now under **Krishonnati Yojana**. Funding **60:40** (Centre:State), **90:10** for NE & Himalayan states; 100% central for NHB, CDB, CIH.
- MIDH added ≈ **15.66 lakh ha** horticulture area; **58 Centres of Excellence** (mostly **Indo-Israel**; first for vegetables at **Gharaunda**, Karnal).
- **Clean Plant Programme** (Aug 2024) – ₹1,765.67 cr; **9 Clean Plant Centres** for virus-free planting material.
- Budget 2026-27 "high-value agriculture" – coconut promotion scheme, cashew & cocoa programme, sandalwood, nuts in hills.

Board / Institute	Location	Board / Institute	Location
NHB (1984)	**Gurugram**	IIHR ("Arka" varieties)	**Bengaluru**
Coconut Development Board	**Kochi**	CISH (subtropical)	**Lucknow**
Spices Board	**Kochi**	CITH (temperate)	**Srinagar**
Tea Board	**Kolkata**	CIAH (arid)	**Bikaner**
Coffee Board	**Bengaluru**	IIVR (vegetables)	**Varanasi**
Rubber Board	**Kottayam**	CPRI (potato)	**Shimla**
National Turmeric Board (2025)	**Nizamabad**	CPCRI (plantation crops)	**Kasaragod**
National Makhana Board (2025)	**Bihar**	IISR (spices)	**Kozhikode**

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NRC Banana	**Tiruchirappalli**	CTCRI (tuber crops)	**Thiruvananthapuram**
NRC Grapes	**Pune**	CCRI (citrus)	**Nagpur**
NRC Litchi	**Muzaffarpur**	DCR (cashew)	**Puttur**
NRC Pomegranate	**Solapur**	DOGR (onion & garlic)	**Rajgurunagar** (Pune)
DFR (floriculture)	**Pune**	DMAPR (medicinal plants)	**Anand** (Gujarat)
CIPHET (post-harvest engg.)	**Ludhiana**	CFTRI (CSIR, food tech)	**Mysuru**

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Horticulture production 2025-26 (2nd AE)? → **377.78 Mt**.
- India's rank in world fruit/vegetable production? → **2nd** (after China).
- India ranks first in? → **Banana, mango, papaya, okra, lime/lemon**.
- Father of the Golden Revolution? → **Dr K.L. Chadha**.
- Headquarters of NHB? → **Gurugram**.
- MIDH funding pattern for NE & Himalayan states? → **90:10**.

2.2 Propagation, Nursery & Orchard Management ★★★

Sexual vs asexual

- **Sexual (seed)** propagation: papaya, coconut, arecanut, most vegetables, rootstock raising; cheap, long-lived, but plants are **not true to type** and have a long juvenile phase.
- **Polyembryony** – more than one embryo per seed; **nucellar seedlings are true to type** (apomictic, virus-free): **mango** (west-coast types – Olour, Bappakai, Vellaikolamban), **citrus**, jamun. Monoembryonic mango = North Indian types (Dashehari, Langra).
- **Apomixis** (seed without fertilisation) – mangosteen (obligate), citrus.
- **Asexual (vegetative)** – true to type, early bearing, uniform; uses cuttings, layering, grafting, budding, specialised organs and tissue culture.
- **Stock** = lower part providing roots; **scion** = upper part (variety); union of **cambium** layers is essential.

Method	Type	Crop example
Cuttings	**Hardwood**	**Grape**, fig, pomegranate, rose, mulberry
	Semi-hardwood	Lemon, crotons, hibiscus
	Softwood / herbaceous	Chrysanthemum, carnation, coleus
	Leaf cutting	**Bryophyllum**, Sansevieria, Begonia
	Root cutting	Breadfruit, curry leaf
Layering	**Air layering** (gootee / marcottage / Chinese layering)	**Litchi**, pomegranate, guava
	Mound / stooling	**Guava**, apple clonal rootstocks (M, MM)
	Simple / ground	Jasmine, bougainvillea
	Compound / serpentine	Grapes, jasmine
	Tip layering / trench	Blackberry / apple
Grafting	**Softwood / veneer / epicotyl (stone)**	**Mango** (commercial); epicotyl also cashew
	Inarching (approach)	Mango (old method), sapota
	Whip & tongue	Apple, pear
	Cleft / wedge	Mango, grape top working
	Side grafting	Mango, cashew
	Bridge grafting	Repair of girdled trunk
	Top working	Converting old / inferior trees (mango, ber)
Budding	**T- (shield)**	**Rose**, citrus, peach, apple
	Patch	**Ber**, aonla, jamun (thick bark)
	Chip	Grapes, apple
	Ring / forkert (green & brown budding)	Ber / **rubber**
Specialised organs	Suckers (sword suckers best)	**Banana**; pineapple
	Slips, crown	Pineapple
	Runners	**Strawberry**, mint
	Offshoots / offsets	Date palm
Micropropagation	Tissue culture	**Banana (G-9)**, date palm, orchids, potato, strawberry

- **Budding** = grafting with a single bud – economical on scion wood. **Water-sucker** (broad leaves) of banana is inferior to the **sword sucker** (narrow leaves, large rhizome).
- Rooting hormone for cuttings = **IBA** (also NAA); air layers often treated with IBA in lanolin paste.
- Tissue culture (Skoog & Miller): **high auxin : cytokinin → roots**; **high cytokinin : auxin → shoots**; balanced → callus. **Meristem culture** gives virus-free plants (often with thermotherapy).
- Nursery: Nursery Act in several states; NHB/MIDH **nursery accreditation** (star rating) for quality planting material.

Rootstocks

Crop	Rootstock	Property
Apple	**M-9** (Malling)	**Dwarfing** – HDP
	M-27	Extremely dwarfing
	MM-106, MM-111 (Malling-Merton)	Semi-dwarf / vigorous; **woolly aphid resistant**

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Citrus	**Rangpur lime**	Drought tolerant, widely used
	Rough lemon (jatti khatti)	Vigorous, high yield
	Troyer / Carrizo citrange	Phytophthora & tristeza tolerant
	Trifoliate orange (*Poncirus*); Cleopatra mandarin	Dwarfing, cold hardy; salt tolerant
Mango	**Vellaikolamban**; Olour	Dwarfing; polyembryonic (uniform)
Grape	**Dogridge**	Salinity & drought tolerant
Pear	Quince	Dwarfing

Training, pruning & crop regulation

- **Training** = shaping the young plant (framework); **pruning** = removing parts of a bearing plant to regulate cropping. **Heading back** = cutting terminal part (makes bushy); **thinning out** = removing whole shoots.
- Systems: **open centre (vase)** – peach, plum; **central leader** – apple (HDP, spindle); **modified leader** – most fruit trees (apple, pear).
- Grapes: **bower / pandal** (S. India), kniffin, telephone / T-trellis, head system; **espalier** – trees trained flat against a wall/wire.
- Grapes in peninsular India: **back (foundation) pruning in April** + **forward (fruit) pruning in October** – two prunings, one crop. North India: single pruning in Jan.
- **Bahar treatment** (guava, pomegranate) – crop regulation by withholding water, root exposure, flower thinning: **Ambe bahar** (flowering Feb–Mar), **Mrig bahar** (Jun–Jul; winter crop – best quality in guava), **Hasta bahar** (Oct).
- **Alternate (biennial) bearing** – mango (Dashehari, Langra), apple; cure: **paclobutrazol**, regular-bearing hybrids (Amrapali).
- **Parthenocarpy** (fruit without fertilisation) – banana, pineapple, seedless grapes (also GA_3-induced; Thompson Seedless is strictly **stenospermocarpic** – seeds abort after fertilisation); **June drop** – citrus; **unfruitfulness** – self-incompatibility (apple – needs pollinisers like Golden Delicious).
- **Chilling requirement** – temperate fruits need hours below **7 °C** to break bud dormancy (apple ≈ 1,000–1,500 h).

Planting systems & HDP

- **Square** – most common, easy intercultivation; **rectangular**; **hexagonal (equilateral triangular)** – **≈ 15% more plants**; **quincunx** – square + one **filler** in centre (almost doubles plants; fillers removed later); **contour** – hills, along slopes.
- **High-density planting (HDP)**: more plants/ha, early returns, using dwarf varieties, dwarfing rootstocks, training/pruning and growth retardants. Mango **Amrapali 2.5 × 2.5 m = 1,600 plants/ha**; guava **meadow orchard** (CISH) 2 × 1 m = **5,000 plants/ha**; apple on **M-9**; banana paired rows; pineapple double rows.
- Normal spacing: mango 10 × 10 m (100 plants/ha); banana/papaya 1.8 × 1.8 m (≈ 3,086 plants/ha).

KEY FORMULAE

- Square/rectangular: N = Area ÷ (row spacing × plant spacing) → 10,000 m² ÷ (2.5 × 2.5) = **1,600**
- Hexagonal: N = Area ÷ (d^2 × 0.866) ≈ square number × **1.155** (15.5% more)
- Quincunx: ≈ 2 × square number (minus border)

MEMORY TRICK

"Mango-Graft, Litchi-Air, Guava-Stool, Ber-Patch, Rose-T, Grape-Cut, Banana-Sucker, Strawberry-Runner".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Commercial propagation of mango? → **Softwood / veneer / epicotyl grafting**.
- Litchi is propagated by? → **Air layering (gootee)**.
- Dwarfing rootstock of apple? → **M-9**.
- Nucellar seedlings are? → **True to type** (polyembryony – mango, citrus).
- Planting system with ~15% more plants than square? → **Hexagonal**.
- Bahar treatment is practised in? → **Guava** (and pomegranate).

2.3 Fruit Crops ★★★

Crop	Botanical name / family	Key varieties & facts
Mango ("king of fruits", national fruit)	*Mangifera indica* – Anacardiaceae	Origin Indo-Burma; Alphonso (Ratnagiri GI), Dashehari, Langra, Chausa, Banganapalli (AP GI), Totapuri, Kesar, Neelum; hybrids **Mallika** (Neelum × Dashehari), **Amrapali** (Dashehari × Neelum – dwarf, regular bearer, IARI), Ratna (Neelum × Alphonso), Sindhu (Ratna × Alphonso, very thin stone), Arka Puneet, Arka Anmol (IIHR), Pusa Arunima, Pusa Surya; fruit = **drupe**; edible part **mesocarp**; pests – hopper, fruit fly, stone weevil
Banana	*Musa* spp. (*M. acuminata* × *M. balbisiana*) – Musaceae	**Grand Naine (G-9)** – tissue culture, most popular (AAA); Dwarf Cavendish (Basrai), Robusta, Red Banana (AAA); Nendran (AAB, Kerala chips), Poovan, Rasthali (AAB); Monthan (ABB, cooking); **triploid, parthenocarpic**; true stem is underground rhizome, aerial "stem" = **pseudostem**; diseases – **Panama wilt** (*Fusarium oxysporum* f. sp. *cubense*, TR4), **bunchy top** (BBTV, aphid *Pentalonia nigronervosa*), Sigatoka leaf spot
Citrus	*Citrus* spp. – Rutaceae	Nagpur mandarin (santra), Coorg & Khasi mandarin; **Kinnow (King × Willow-leaf mandarin)** – Punjab; sweet orange – Mosambi, Sathgudi, Malta; acid lime – **Kagzi lime**, Vikram, PKM-1; fruit = **hesperidium**; edible part = juicy placental hairs; diseases – canker (*Xanthomonas citri*), tristeza (CTV, aphid), greening/HLB (psyllid *Diaphorina citri*), gummosis (*Phytophthora*); **citrus decline**
Grape	*Vitis vinifera* – Vitaceae	**Thompson Seedless** (most common; raisins), Sharad Seedless, Flame Seedless, Anab-e-Shahi, Bangalore Blue (juice/wine), Pusa Navrang (teinturier, IARI); fruit = **berry**; GA_3 – berry elongation/size; raisins dipped in **ethyl oleate + K_2CO_3** (dipping oil); downy mildew (*Plasmopara viticola*), powdery mildew

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Guava ("apple of the tropics", "poor man's apple")	*Psidium guajava* – Myrtaceae	Allahabad Safeda, **Sardar (L-49)**, Lalit (pink pulp), Arka Kiran, Shweta, Allahabad Surkha; rich in **vitamin C & pectin**; fruit = berry; wilt (*Fusarium*), fruit fly
Papaya	*Carica papaya* – Caricaceae	Pusa Delicious, Pusa Majesty, **Pusa Nanha** (dwarf, gamma-ray mutant), Red Lady (Taiwan hybrid), Surya, Arka Prabhat, **CO-2, CO-5** (papain); dioecious and gynodioecious types; **papain** from latex of raw fruit; **PRSV** (ringspot virus, aphid)
Apple	*Malus × domestica* – Rosaceae	Red Delicious, Royal Delicious, Golden Delicious (polliniser), **Ambri** (Kashmir), Gala, Fuji; low-chill Anna, Dorsett Golden; needs **1,000–1,500 chilling hours**; fruit = **pome** (edible thalamus); **scab** (*Venturia inaequalis*), San José scale, woolly aphid
Pomegranate	*Punica granatum* – Lythraceae	**Bhagwa** (most popular), Ganesh, Mridula, **Solapur Lal** (biofortified – Fe, Zn, vit C); fruit = **balausta**; edible part = juicy testa (aril); **bacterial blight** (*Xanthomonas axonopodis* pv. *punicae*, "telya"); anar butterfly
Litchi	*Litchi chinensis* – Sapindaceae	**Shahi** (Muzaffarpur GI), China; edible part = **aril**; fruit cracking; litchi mite
Pineapple	*Ananas comosus* – Bromeliaceae	**Kew** (canning), Queen, Mauritius; **CAM plant**; flowering induced by ethrel/NAA/calcium carbide; fruit = **sorosis**
Sapota	*Manilkara zapota* – Sapotaceae	Kalipatti, Cricket Ball, PKM-1; latex **chicle** (chewing gum)
Aonla	*Phyllanthus emblica* – Phyllanthaceae	NA-7, Krishna, Chakaiya, Banarasi; richest common source of **vitamin C** (≈ 600 mg/100 g; only Barbados cherry is richer); patch budding
Ber	*Ziziphus mauritiana* – Rhamnaceae	Gola, Umran, Seb, Kaithli; arid-zone fruit; **patch budding**
Jackfruit	*Artocarpus heterophyllus* – Moraceae	**Largest edible fruit**; fruit = sorosis; Kerala state fruit
Date palm	*Phoenix dactylifera* – Arecaceae	Dioecious; tissue-culture Barhee; Kutch (Gujarat)
Strawberry	*Fragaria × ananassa* – Rosaceae	Runners; edible part = thalamus; fruit = etaerio of achenes; Chandler, Sweet Charlie, Winter Dawn

Fruit type	Examples	Edible part
Drupe	Mango, ber, plum, peach	Mesocarp
Fibrous drupe	Coconut	**Endosperm** (water = liquid endosperm)
Berry	Grape, guava, papaya, tomato, banana, sapota	Whole pericarp + placenta (banana: meso- + endocarp)
Pome	Apple, pear	**Thalamus** (false fruit)
Hesperidium	Citrus	Juicy placental hairs
Balausta	Pomegranate	Juicy testa
Sorosis	Pineapple, jackfruit, mulberry	Whole inflorescence
Syconus	Fig	Fleshy receptacle
Nut	Litchi; cashew	Aril; cotyledons (cashew "apple" = swollen peduncle)
Pepo	Cucurbits	Mesocarp + endocarp

Physiological disorders

Disorder	Crop	Cause / management
Black tip	Mango	**Brick-kiln fumes** (SO_2, CO, ethylene); spray **borax 0.6%**
Spongy tissue	Mango (**Alphonso**)	Heat/convection near ripening; harvest at ¾ maturity, mulch
Mango malformation	Mango	*Fusarium mangiferae* + mite; **NAA 200 ppm** in October, prune affected panicles
Alternate bearing	Mango, apple	Variety/hormonal; **paclobutrazol** (Cultar) soil drench
Soft nose	Mango	Ca deficiency / excess N
Fruit cracking	Pomegranate, litchi	Moisture fluctuation, **boron** deficiency
Granulation	Citrus	Juice vesicles dry/hard; late harvest
Little leaf / mottle leaf	Citrus	**Zinc** deficiency
Bitter pit	Apple	**Calcium deficiency**; $CaCl_2$ sprays/dips
Internal cork / browning	Apple	**Boron** deficiency
Choke throat	Banana	**Low temperature** (winter) – bunch fails to emerge
Hen & chicken	Grapes	Zn/B deficiency – uneven berries
Blossom-end rot	Tomato	**Ca deficiency** (irregular watering)
Puffiness	Tomato	Poor pollination, low light, excess N
Buttoning	Cauliflower	**N deficiency**, over-aged seedlings
Whiptail	Cauliflower	**Molybdenum** deficiency
Browning / hollow stem	Cauliflower	**Boron** deficiency
Riceyness	Cauliflower	Hot weather – flower buds visible, curd granular
Bolting	Onion, cabbage, radish	Premature flowering (cold / long days)
Hollow heart / black heart	Potato	Fast growth / O_2 shortage in storage
Greening	Potato	Exposure to light → **solanine** (toxic)

Plant growth regulators (PGRs)

PGR	Major horticultural use
Auxins – IBA, NAA, IAA, 2,4-D	**IBA – rooting of cuttings**; NAA – prevents pre-harvest drop, pineapple flowering, fruit thinning, mango malformation; 2,4-D – fruit drop in citrus
Gibberellins – **GA_3**	**Seedless grapes – berry size/elongation**; parthenocarpy; breaks dormancy (potato); bolting; ↑ male flowers in cucurbits; malting

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Cytokinins – kinetin, BAP, CPPU	Cell division; shoot formation in tissue culture; delay senescence (leafy veg, cut flowers); CPPU – grape berry size
Ethylene – **ethrel / ethephon** (2-chloroethylphosphonic acid)	Fruit ripening, degreening of citrus, **pineapple flowering**, ↑ **female flowers in cucurbits**, latex flow in rubber
ABA	"Stress hormone" – stomatal closure, dormancy
Paclobutrazol (Cultar)	GA-biosynthesis inhibitor – **regular bearing in mango**, dwarfing
CCC (cycocel)	Growth retardant; dwarfing
Maleic hydrazide	**Sprout suppression** in onion (pre-harvest spray ≈ 2,500 ppm) & potato
1-MCP	Blocks ethylene receptors – **delays ripening** (apple, banana)
Calcium carbide	**Banned for ripening** (FSSAI) – releases acetylene

MEMORY TRICK

"**Black tip = Brick kiln, Bitter pit = Bad calcium, Buttoning = Bad nitrogen, Whiptail = Weak molybdenum**". Mango hybrids: **M-N-D** (Mallika = Neelum × Dashehari), **A-D-N** (Amrapali = Dashehari × Neelum).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Amrapali mango is a cross of? → **Dashehari × Neelum**.
- Most popular tissue-culture banana? → **Grand Naine (G-9)**.
- Kinnow is a cross of? → **King × Willow-leaf mandarin**.
- Edible part of litchi? → **Aril**. Of apple? → **Thalamus**.
- Black tip of mango is caused by? → **Brick-kiln fumes** (corrected with borax).
- Chemical for regular bearing in mango? → **Paclobutrazol**.

2.4 Vegetables, Spices & Plantation Crops ★★★

Vegetables

Family	Crops
Solanaceae	Tomato, brinjal, chilli, capsicum, potato
Cucurbitaceae	Cucumber, gourds, melons, pumpkin, squash
Brassicaceae (Cruciferae)	Cabbage, cauliflower, broccoli, knol-khol, radish, turnip ("cole crops")
Fabaceae	Pea, French bean, cowpea, cluster bean, dolichos
Amaryllidaceae (Alliaceae)	Onion, garlic, leek
Malvaceae	Okra (bhindi)
Apiaceae (Umbelliferae)	Carrot, coriander, cumin, fennel
Amaranthaceae (incl. Chenopodiaceae)	Beetroot, spinach, amaranth
Convolvulaceae / Euphorbiaceae / Araceae	Sweet potato / tapioca (cassava) / colocasia, elephant foot yam

Crop	Key facts & varieties
Tomato	*Solanum lycopersicum*; origin Peru; red colour **lycopene**; Pusa Ruby, Arka Vikas, **Arka Rakshak** (F_1, triple disease resistant – ToLCV, bacterial wilt, early blight), Pusa Hybrid-1; leaf curl (whitefly), *Tuta absoluta* (pinworm)
Brinjal	*S. melongena*; **origin India**; Pusa Purple Long, Arka Kusumakar; **Bt brinjal – moratorium in India (Feb 2010)**, grown in Bangladesh; shoot & fruit borer (*Leucinodes orbonalis*); little leaf (phytoplasma)
Chilli	*Capsicum annuum*; pungency **capsaicin**, red colour **capsanthin**; Pusa Jwala, G-4 (Guntur); Bhut Jolokia (NE) – among the hottest; leaf curl (thrips, mites)
Potato	*S. tuberosum*; origin Andes; tuber = **modified stem**; Kufri series (CPRI Shimla) – Kufri Jyoti, Bahar, Pukhraj, Khyati, **Kufri Chipsona-1/3** (chips); late blight (*Phytophthora infestans* – Irish famine 1845); seed-plot technique; **aeroponic minitubers**
Onion	*Allium cepa*; pungency **allyl propyl disulphide**; colour quercetin; bulb = fleshy scale leaves; kharif – N-53, Agrifound Dark Red, Bhima Super; rabi (good keepers) – **N-2-4-1**, Agrifound Light Red, Bhima Kiran, Bhima Shakti (DOGR); Maharashtra leads; Lasalgaon – largest onion market
Garlic	Smell **allicin** / diallyl disulphide; edible clove = axillary bud; G-41, Agrifound Parvati
Okra	Arka Anamika, **Parbhani Kranti** (YVMV-resistant – yellow vein mosaic, whitefly); India largest producer
Cole crops	Cauliflower – Pusa Katki (early), **Pusa Snowball-1** (late); cabbage – Golden Acre, Pride of India; cabbage head = **terminal bud**; cauliflower curd = **pre-floral fleshy apical meristem**; knol-khol = swollen stem; Brussels sprouts = axillary buds
Cucurbits	Mostly **monoecious**; ethrel ↑ female, GA_3/$AgNO_3$ ↑ male; bitter gourd – **momordicin**; cucumber bitterness – **cucurbitacin**; watermelon – Sugar Baby, Arka Manik, **Pusa Bedana** (seedless triploid); muskmelon – Pusa Madhuras, Hara Madhu; parthenocarpic cucumber for polyhouses – Pusa Seedless Cucumber-6
Root & tuber crops	Carrot (Pusa Kesar, Nantes – β-carotene); radish (Pusa Chetki, Japanese White); beetroot (**betanin**); tapioca – **HCN (linamarin)**, Sree Visakham; sweet potato = root tuber; colocasia = corm (CTCRI)
Peas / beans	Arkel (early, wrinkled seeded), Bonneville; French bean – Contender

- Seed rate (approx.): onion **8–10 kg/ha**; tomato/brinjal/chilli **400–500 g/ha** (hybrid 150–200 g); cabbage/cauliflower **500 g/ha**; okra 8–10 kg/ha; peas 80–100 kg/ha.
- Variety prefixes: **"Pusa"** – IARI; **"Arka"** – IIHR; **"Kashi"** – IIVR; **"Kufri"** – CPRI; **"Bhima"** – DOGR.

Spices

- India = "**Land of Spices**" – largest producer, consumer & exporter. Spices Board – **Kochi**; IISR – **Kozhikode**; NRCSS (seed spices) – **Ajmer**.

Spice	Botanical name	Economic part / key facts
Black pepper ("king of spices")	*Piper nigrum* – Piperaceae	Dried berry; pungency **piperine**; **Panniyur-1** – first hybrid; quick wilt (*Phytophthora*), slow wilt (nematodes); Kerala, Karnataka; white pepper = decorticated
Cardamom ("queen of spices")	*Elettaria cardamomum* – Zingiberaceae	Capsule; Kerala (Idukki); **katte** (mosaic virus), thrips; ICRI – Myladumpara
Saffron	*Crocus sativus* – Iridaceae	**Stigma**; propagated by **corms**; J&K (Pampore); ~1.5 lakh flowers per kg; colour crocin, aroma safranal; National Saffron Mission (2010)

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Turmeric	*Curcuma longa* – Zingiberaceae	Rhizome; colour **curcumin**; Telangana, Maharashtra; **Lakadong** (Meghalaya – high curcumin); National Turmeric Board – Nizamabad
Ginger	*Zingiber officinale* – Zingiberaceae	Rhizome; pungency **gingerol** (shogaol in dry ginger); India largest producer
Clove	*Syzygium aromaticum* – Myrtaceae	**Unopened flower bud**; eugenol
Nutmeg & mace	*Myristica fragrans*	Nutmeg = seed; **mace = aril** of the same fruit; dioecious
Cinnamon	*Cinnamomum verum* – Lauraceae	Bark
Vanilla	*Vanilla planifolia* – Orchidaceae	Cured pods; **hand pollination**; vanillin
Chilli	*Capsicum* spp.	India's **largest spice export** by value (with spice oils & oleoresins)
Seed spices	Cumin, coriander, fennel, fenugreek	Rajasthan & Gujarat; **Unjha** – largest cumin market
Asafoetida (hing)	*Ferula assa-foetida*	Oleo-gum resin from root; first cultivation in India – **Lahaul-Spiti** (2020, CSIR-IHBT)

Plantation crops

Crop	Key facts
Tea	*Camellia sinensis* – Theaceae; Assam largest; India 2nd producer (after China); plucking "**two leaves and a bud**"; CTC & orthodox; **Darjeeling tea – India's first GI** (2004-05); blister blight (*Exobasidium vexans*), tea mosquito bug (*Helopeltis*); caffeine (theine); Tea Board – Kolkata
Coffee	*Coffea arabica* (quality, high altitude) & *C. canephora* (robusta – larger share in India); grown **under shade**; Karnataka ~70%; leaf rust (*Hemileia vastatrix*), **white stem borer** (arabica), berry borer; Coffee Board – Bengaluru; CCRI – Balehonnur
Rubber	*Hevea brasiliensis* – Euphorbiaceae; latex by **tapping** (half-spiral, alternate day); propagated by green/brown **budding**; clone **RRII 105**; latex coagulated with **formic acid**; Kerala largest, Tripura 2nd; Rubber Board – Kottayam
Coconut	*Cocos nucifera* – Arecaceae ("Kalpavriksha"); West Coast Tall, Chowghat Orange Dwarf; hybrids Chandra Sankara, Kera Ganga (T × D / D × T); copra (dried kernel); root (wilt) disease (phytoplasma, Kerala), bud rot (*Phytophthora palmivora*), rhinoceros beetle, red palm weevil, eriophyid mite; CPCRI – Kasaragod; CDB – Kochi; **World Coconut Day – 2 Sep**
Arecanut	*Areca catechu*; Karnataka; yellow leaf disease, **Koleroga** (fruit rot, *Phytophthora*)
Cashew	*Anacardium occidentale* – Anacardiaceae; nut = true fruit, "apple" = **swollen peduncle** (false fruit); Vengurla, Ullal; tea mosquito bug; CNSL (shell liquid); DCR – Puttur
Cocoa	*Theobroma cacao* – Malvaceae; alkaloid theobromine; intercrop in coconut/areca; Kerala, Karnataka, AP
Oil palm	*Elaeis guineensis*; highest oil yield per ha; NMEO-Oil Palm (2021)

Floriculture & medicinal plants (brief)

- **Rose** ("queen of flowers") – T-budding; Pusa Sonia, Arjun, Raktagandha; rose oil/attar from *Rosa damascena* (Kannauj). National flower = **lotus**.
- **Marigold** (*Tagetes*) – pigment **lutein**; Pusa Narangi Gainda, Pusa Basanti Gainda. **Tuberose** (Rajanigandha) – Prajwal (single), Suvasini (double). Jasmine – Madurai malli (GI).
- **Orchids** – "queen of cut flowers" (Sikkim, NE; NRC Orchids – Pakyong). **Chrysanthemum** – short-day plant, "queen of the East". Gladiolus – **corms**. Gerbera, carnation – **protected cultivation**. Pinching & disbudding regulate bloom size.
- Medicinal: **Ashwagandha** (*Withania somnifera*, root – withanolides); **Sarpagandha** (*Rauvolfia serpentina* – **reserpine**, hypertension); **Isabgol** (*Plantago ovata* – seed husk; Gujarat/Rajasthan); **Senna** (sennosides, laxative); **Periwinkle** (*Catharanthus roseus* – vinblastine/vincristine, anticancer); **Opium poppy** (morphine; licensed cultivation); *Artemisia annua* – artemisinin (malaria); Stevia – steviosides (sweetener).
- Aromatic: **Menthol mint** (*Mentha arvensis*; India largest producer, UP); lemongrass – **citral**; palmarosa – geraniol; vetiver (khus) – root oil. CIMAP – Lucknow; National Medicinal Plants Board (2000, Ministry of AYUSH).

MEMORY TRICK

Compounds: "**Tomato-Lycopene, Chilli-Capsaicin (hot)/Capsanthin (red), Onion-Allyl propyl disulphide, Garlic-Allicin, Carrot-Carotene, Beet-Betanin, Bitter gourd-Momordicin, Cucumber-Cucurbitacin, Turmeric-Curcumin, Ginger-Gingerol, Pepper-Piperine**".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Pungency in chilli is due to? → **Capsaicin**.
- Edible part of cauliflower? → **Curd** (pre-floral apical meristem).
- King of spices? → **Black pepper**; queen? → **Cardamom**.
- Economic part of saffron? → **Stigma**.
- Cashew apple is? → **False fruit** (swollen peduncle).
- Rubber latex is coagulated with? → **Formic acid**.

2.5 Protected Cultivation ★★☆

- **Protected cultivation** = modifying the micro-climate (temperature, light, RH, CO_2) around the crop to obtain higher yield, quality and **off-season** produce; also called controlled-environment agriculture (CEA).
- **Greenhouse effect**: cover transmits short-wave solar radiation but traps long-wave (infrared) radiation from inside.
- **Naturally ventilated polyhouse (NVPH)** – most common in India (low cost); cover = **UV-stabilised 200 micron (800 gauge) LDPE film** (1 micron = 4 gauge); side/roof vents + insect-proof net (≈ 40 mesh).
- **Climate-controlled** polyhouse – **fan & pad** (evaporative cooling with cellulose pads), foggers, heaters, CO_2 enrichment; Venlo-type glasshouse (Netherlands).
- **Shade-net house** – HDPE nets giving **35–75% shade** (50% common) – nurseries, foliage plants, capsicum, anthurium, orchids.
- **Low tunnels / walk-in tunnels** – early cucurbits in N. India winter; **rain shelters** – protect from rain; **insect-proof net house** – virus-free seedlings.
- Crops: **coloured capsicum, parthenocarpic cucumber**, indeterminate tomato, gerbera, carnation, Dutch rose, strawberry; vegetable **nurseries in plug trays** (cocopeat).
- **Plastic mulch** (LLDPE 25–50 micron): **black** – weed control & moisture conservation; **silver/reflective** – repels aphids/thrips;

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transparent – soil solarisation.

- **NCPAH** (National Committee on Plasticulture Applications in Horticulture, MoA&FW) with **Precision Farming Development Centres (PFDCs)** promotes drip, fertigation, polyhouses.

System	Principle	Notes
Hydroponics	Soilless; roots in nutrient solution / inert medium	NFT (nutrient film technique – thin recirculating film), DWC/raft, ebb & flow, Kratky (passive); media – cocopeat, perlite, rockwool, vermiculite; pH ≈ **5.5–6.5**, EC ≈ 1.5–2.5 dS/m; Hoagland solution; leafy greens, tomato, fodder (maize sprouts in ≈ 7–8 days)
Aeroponics	Roots hang in air and are **misted** with nutrient solution	Best root aeration; **CPRI – seed-potato minitubers**
Aquaponics	Fish + hydroponics	Fish waste $NH_3 \rightarrow NO_2^-$ (*Nitrosomonas*) $\rightarrow NO_3^-$ (*Nitrobacter*) used by plants
Vertical farming	Crops in stacked layers indoors	LED lighting (red + blue within PAR **400–700 nm**), CEA, high yield/m^2; microgreens, lettuce, herbs

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Most common polyhouse in India? → **Naturally ventilated polyhouse**.
- Thickness of polyhouse cladding film? → **200 micron** (800 gauge), UV-stabilised.
- Mulch used for soil solarisation? → **Transparent polythene**.
- Growing plants with roots misted in air? → **Aeroponics**.
- Cooling system in climate-controlled greenhouses? → **Fan & pad** (evaporative).

2.6 Post-Harvest Management & Processing ★★★

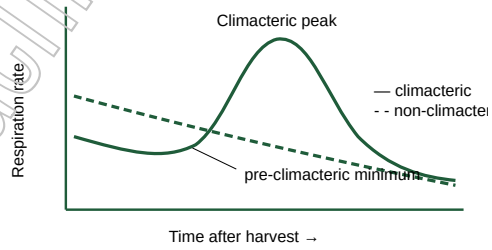
- Post-harvest losses of fruits ≈ **6–15%** and vegetables ≈ **5–12%** (CIPHET 2015; NABCONS 2022). India processes only ≈ **2–4%** of its fruits & vegetables.
- Harvested produce is **living** – it continues to **respire** and **transpire**; storage life is inversely related to respiration rate. Respiration roughly doubles–triples for every 10 °C rise (Q_{10} **≈ 2–3**).
- **Field heat** and **respiration heat** must be removed quickly – for highly perishable produce (e.g. strawberry) each hour of delay at ≈ 30 °C can cost about a day of shelf life.

Maturity indices

Index	Example
Visual – colour, size, shape	Mango shoulders rise above stem end; banana – **angularity of fingers disappears** (¾ full)
Physical – firmness, specific gravity, ease of separation	Penetrometer (apple, pear); mango sinks in water (**SG ≈ 1.01–1.02**); muskmelon "**full slip**" (abscission)
Chemical – TSS, acidity, TSS:acid, starch	**Hand refractometer** (°Brix) – grapes, citrus; **starch-iodine test** – apple; oil content – avocado
Computational – days from full bloom, heat units	Apple, mango
Physiological – respiration / ethylene	Climacteric fruits

Climacteric vs non-climacteric

Feature	Climacteric	Non-climacteric
Respiration at ripening	**Sharp rise** (climacteric peak) with **autocatalytic ethylene** burst	Gradual decline; no peak
Ripening after harvest	**Yes** – can be harvested mature-green and ripened	**No** – harvest only when fully ripe
Response to ethylene	Ripening triggered	Only degreening/senescence (e.g. citrus degreening)
Examples	**Mango, banana, apple, pear, papaya, guava, sapota, tomato, avocado**, peach, plum, kiwi, fig, muskmelon, jackfruit, custard apple	**Citrus, grape, pineapple, litchi, pomegranate, strawberry, cherry, watermelon**, cucumber, chilli/capsicum, brinjal, jamun



Respiration pattern of climacteric and non-climacteric fruits after harvest.

Ripening

- **Ethylene** (C_2H_4) = ripening hormone. Biosynthesis: methionine → SAM → **ACC** (ACC synthase) → ethylene (**ACC oxidase**) – Yang cycle.
- Ripening chamber: **ethylene gas ≈ 100 ppm** (FSSAI allows up to 100 ppm, depending on crop, variety, maturity) for ≈ 24 h at **18–20 °C**, RH 90–95%; ethylene may be generated from **ethephon** or ethylene sachets – as per FSSAI guidance ethephon is to be used only to generate ethylene gas, **not for direct dipping of fruits**.
- **Calcium carbide (CaC_2) – banned** for ripening under **Regulation 2.3.5 of FSS (Prohibition & Restrictions on Sales) Regulations, 2011**: $CaC_2 + 2H_2O \rightarrow C_2H_2$ (**acetylene**) + $Ca(OH)_2$; industrial grade carries traces of **arsenic & phosphorus hydride** – carcinogenic/neurotoxic.
- Ripening is delayed by **1-MCP** (blocks receptors, "SmartFresh"), **$KMnO_4$** (ethylene absorbent), AVG (inhibits ACC synthase), low temperature, low O_2/high CO_2; **silver thiosulphate (STS)** – cut flowers.
- **Degreening** of citrus – ethylene 1–5 ppm (chlorophyll breakdown, no real ripening).

MEMORY TRICK

Climacteric "**MAP-BAT-GS**" = Mango, Apple, Papaya, Banana, Avocado, Tomato, Guava, Sapota. Non-climacteric = "**no after-ripening**" – citrus, grape, pineapple, litchi, pomegranate, strawberry must be harvested ripe.

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Post-harvest handling & pack-house operations

- **Precooling** = rapid removal of field heat before storage/transport. Methods: **room cooling** (slowest), **forced-air (pressure) cooling** (most versatile – fruits, flowers), **hydrocooling** (chilled water – carrot, radish, sweet corn, mango), **vacuum cooling** (leafy vegetables – lettuce, spinach; water evaporates under low pressure), **package icing** (broccoli). Commercial target = "**7/8 cooling time**".
- **Curing** – potato, sweet potato (wound healing by **suberisation**/periderm), onion & garlic (drying of neck and outer scales).
- Sorting, **grading** (AGMARK – Agricultural Produce (Grading & Marking) Act **1937**; DMI, Faridabad; Central Agmark Lab – Nagpur), washing, disinfestation.
- **Hot-water treatment** of mango (≈ 48 °C for 60 min – fruit fly; brief dip ≈ 52 °C – anthracnose); **vapour heat treatment (VHT)** – mango export to Japan; **irradiation** – mango export to USA.
- **Waxing** – reduces moisture loss, adds shine (apple, citrus); FSSAI permits **beeswax, carnauba wax and shellac** with labelling.
- Grapes: **SO_2-generating pads** (sodium metabisulphite) in boxes against grey mould (*Botrytis*); litchi – **SO_2 fumigation** to retain red pericarp colour.
- **Packaging**: **CFB (corrugated fibre-board) boxes** replacing wooden crates; plastic crates for transport; leno/mesh bags (onion), jute bags (potato), punnets (strawberry, berries), cushioning (paper shreds, foam nets); 4–5% ventilation area on boxes.

Storage conditions

- **Chilling injury** – tropical/subtropical produce stored below **≈ 10–13 °C** (above freezing): pitting, browning, water-soaking, failure to ripen (banana – dull grey peel). **Freezing injury** – below the freezing point (ice in tissues).
- Most perishables need high RH (**85–95%**) to prevent shrivelling; **onion & garlic need low RH (65–70%)** to prevent rotting and sprouting.

Produce	Temperature	RH	Remarks
Apple	**0–1 °C** (−1 to 1)	90–95%	3–6 months; longer in CA
Grapes	**−1 to 0 °C**	90–95%	SO_2 pads
Litchi	1–2 °C	90–95%	SO_2 fumigation
Pomegranate	5–7 °C	90–95%	≈ 2 months
Kinnow / mandarin	4–7 °C	85–90%	Acid lime/lemon 9–12 °C (chill-sensitive)
Guava	8–10 °C	85–90%	2–3 weeks
Mango	**10–13 °C**	85–90%	Chilling injury below ≈ 10 °C
Papaya (mature-green)	10–13 °C	85–90%	Chill-sensitive
Banana (green)	**13–14 °C**	90–95%	Chilling injury below **≈ 12–13 °C**
Tomato	Mature-green **12–13 °C**; ripe 7–10 °C	85–90%	—
Cucumber, brinjal, okra	7–12 °C	90–95%	Chill-sensitive vegetables
Cabbage, cauliflower, carrot, leafy veg	**0 °C**	**95–98%**	Highest RH group
Potato (seed)	**2–4 °C**	90–95%	Sprouting checked
Potato (table/processing)	**10–12 °C** + CIPC	90–95%	Below ≈ 8–10 °C → **cold sweetening** (reducing sugars → dark chips, acrylamide)
Onion, garlic	**0–2 °C** (or ventilated ambient 25–30 °C)	**65–70%**	Bottom-ventilated onion stores; MH spray pre-harvest
Sweet potato (cured)	13–15 °C	85–90%	Chill-sensitive

Storage methods

- **Zero-energy cool chamber (ZECC)** – IARI (Pusa) design: double brick wall with the cavity filled with **wet sand**; works on **evaporative cooling**; keeps ≈ **10–15 °C below ambient** and RH ≈ **90–95%**; ≈ 100 kg capacity; no electricity.
- **Cold storage** – mechanical refrigeration (vapour-compression; ammonia common refrigerant in large stores). India has ≈ **40 Mt** cold-storage capacity, concentrated in **UP & West Bengal** and used mainly (≈ 70–75%) for **potato** (single-commodity stores).
- **Controlled atmosphere (CA)** – O_2 lowered and CO_2 raised and **continuously monitored/controlled** in gas-tight rooms; apple ≈ **2–3% O_2 + 1–5% CO_2** at 0–1 °C (normal air: 21% O_2, 0.04% CO_2). Low O_2 ↓ respiration; high CO_2 ↓ ethylene action. Excess CO_2/too-low O_2 → anaerobic off-flavours, brown heart.
- **Modified atmosphere (MA/MAP)** – atmosphere altered **once** (by produce respiration in a sealed film – **passive**, or gas flushing – **active**) and **not controlled** thereafter; films LDPE, PP; equilibrium MA.
- **Hypobaric (low-pressure) storage** – reduces O_2 and removes ethylene. **Freezing**: IQF (individual quick freezing), storage at **−18 °C**; vegetables blanched first.

Preservation & processing

Principle	Method / value
High osmotic pressure – **sugar**	**65–70%** sugar (jam, jelly, preserve, candy) – plasmolysis of microbes
High osmotic pressure – **salt**	**15–20%** salt (pickles, brine); 2.25–2.5% salt for **sauerkraut** (lactic fermentation – *Leuconostoc mesenteroides* → *Lactobacillus plantarum*)
Acid / fermentation	Vinegar (acetic acid ≈ 4–5%; *Acetobacter*); vinegar pickles ≥ 2% acetic acid
Pasteurisation (below 100 °C)	Kills pathogens/vegetative cells; milk: **LTLT 63 °C, 30 min**; **HTST 72 °C, 15 s**; UHT ≈ 135–150 °C, 2–4 s
Sterilisation / canning	Low-acid foods (pH > 4.6) at **121 °C** to destroy *Clostridium botulinum* spores (**12-D**); acid foods (pH < 4.6) in boiling water (100 °C)
Drying / dehydration	Lowers **water activity (a_w)**; sun, solar, cabinet/tray, tunnel, **spray drying** (juice powders, milk), **freeze drying** (sublimation – best quality), drum, osmotic dehydration

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Chemical preservatives	**KMS** (releases SO_2) – light-coloured products (bleaches anthocyanins); **sodium benzoate** – **coloured products** (best at low pH); squash: SO_2 **350 ppm** or benzoic acid **600 ppm**
Irradiation	Ionising radiation (γ-rays from **Cobalt-60**, Cs-137; electron beam; X-rays)
Hurdle technology	Several mild barriers combined (a_w, pH, preservative, heat) – Leistner

- **Nicolas Appert** (France, 1810) – "**father of canning**" (appertisation). Canning steps: selection → washing → peeling (lye peeling – hot NaOH) → **blanching** → filling → syruping/brining → **exhausting** (removes air, creates vacuum) → double-seam sealing → processing → cooling → labelling.
- **Blanching** inactivates enzymes; adequacy tested by **peroxidase** (most heat-stable enzyme).
- Can lacquers: **R-enamel** (acid-resistant) for **coloured fruits**; **C-enamel** for sulphur-rich foods (peas, corn – prevents black FeS). Spoilage: swells (hydrogen swell – chemical), **flat sour** (acid without gas – *Geobacillus stearothermophilus*).
- Minimum a_w for growth: bacteria ≈ **0.91**, yeasts ≈ **0.88**, moulds ≈ **0.80**; halophilic bacteria 0.75; osmophilic yeasts 0.60 – almost no growth below **0.60**. Pure water a_w = 1.0.
- Sulphuring (burning sulphur) of apricots, golden raisins before drying – prevents browning.

Product	Fruit / juice content	TSS (%)	Remarks
Jam	≥ 45% fruit	**68.5** (FPO textbook value)	Pulp + sugar + acid; end point ≈ **105.5 °C**
Jelly	Clear extract	**65**	**Pectin 0.5–1% + acid (pH ≈ 3.2) + sugar**; pectin best from guava, apple, citrus peel; tests – **alcohol test** (pectin), sheet/drop test (end point); fault – **syneresis** (weeping, excess acid)
Marmalade	Jelly with peel shreds	65	Citrus
Squash	≥ **25%** juice	**40–45**	Diluted before use; KMS/benzoate
Cordial	≥ 25% (clear)	≥ 30	Sparkling clear squash
Crush	≥ 25%	≥ 55	—
Syrup	≥ 25%	≥ 65	—
Nectar	≥ 20% pulp	≥ 15	Ready to drink
RTS beverage	≥ **10%** juice	≥ 10	Acidity ≈ 0.3%
Tomato ketchup	—	≥ 25	Puree ≥ 9%, paste ≥ 25% TSS

Food irradiation

- Unit: **Gray (Gy) = 1 J/kg**; 1 kGy = 1,000 Gy (old unit: 1 Gy = 100 rad). Symbol: **Radura** (green) + "Processed by irradiation" on label.
- **Low dose (< 1 kGy)**: **sprout inhibition** (onion, potato – ≈ 0.03–0.15 kGy), insect disinfestation / quarantine (mango to USA ≈ **0.4 kGy**), delay of ripening.
- **Medium dose (1–10 kGy)**: **radurisation** (shelf-life extension), **radicidation** (pathogen elimination). **High dose (> 10 kGy)**: **radappertisation** (sterilisation – spices, space food).
- India's first commercial facility for perishables – **KRUSHAK** (BARC), **Lasalgaon**, Nashik (2002, onion & mango). Regulated by Atomic Energy (Radiation Processing of Food & Allied Products) Rules, 2012 and FSSAI.

KEY FORMULAE

- TSS (°Brix) = g soluble solids per 100 g solution (hand refractometer)
- Brix : acid ratio = TSS ÷ titratable acidity (maturity & taste index)
- Water activity $a_w = p \div p_0 = ERH\ (\%) \div 100$
- Absorbed dose: 1 Gy = 1 J kg^{-1}; 1 kGy = 10^3 Gy
- Q_{10} = rate at (T + 10 °C) ÷ rate at T

FSSAI basics

- **Food Safety and Standards Act, 2006** → **FSSAI** (established **2008**, HQ New Delhi) under the **Ministry of Health & Family Welfare**; regulations in force from **5 Aug 2011**.
- FSS Act repealed/integrated **PFA Act 1954**, **Fruit Products Order (FPO) 1955**, Meat Food Products Order 1973, Milk & Milk Products Order 1992, Edible Oils Packaging Order 1998, etc.
- Licensing: **registration** for petty food businesses (turnover up to **₹12 lakh**), **State licence** (₹12 lakh – ₹20 crore), **Central licence** (above ₹20 crore, importers, exporters, multi-state). **14-digit** FSSAI licence number on labels.
- Logos/initiatives: **+F** (fortified foods), **Jaivik Bharat** (organic), green dot (veg), **Eat Right India** (2018), FoSTaC (training), hygiene rating; **World Food Safety Day – 7 June** (State Food Safety Index released).

Operation Greens, cold chain & warehousing link

- **Operation Greens** – Budget **2018-19**, ₹500 cr, **MoFPI**; for **TOP** (Tomato, Onion, Potato) price stabilisation; extended in June 2020 (Atmanirbhar Bharat) to **all fruits & vegetables** ("TOP to TOTAL"); Budget 2021-22 – **22 perishables**. Short-term: **50% subsidy on transport & storage** (also on **Kisan Rail**); long-term: integrated value-chain projects. Now a component of **PM Kisan SAMPADA Yojana** (PMKSY, 2017 – mega food parks, integrated cold chain, agro-processing clusters).
- **PMFME** (2020) – 35% credit-linked subsidy up to ₹10 lakh for micro food units; **ODOP**. **PLISFPI** (2021) – PLI for food processing.
- **NCCD** (National Centre for Cold-chain Development, 2011, New Delhi) – standards & planning for cold chain. **Agriculture Infrastructure Fund** (2020, ₹1 lakh cr; 3% interest subvention on loans up to ₹2 cr) funds cold stores, warehouses, pack-houses.
- Cold chain links: **pack-house & precooling** → cold storage / CA store → **reefer** trucks / reefer containers → **ripening chambers** → retail display. Weakest links in India: **pack-houses, reefer transport and ripening chambers** (storage capacity exists, mostly for potato). **Kisan Rail** (2020, first Devlali–Danapur) and **Krishi UDAN** (2020; 2.0 in 2021) move perishables.
- **CWC** (est. **1957**; Warehousing Corporations Act, 1962) provides scientific storage, including some temperature-controlled/cold-storage capacity; produce in **WDRA-registered** warehouses and cold storages can be pledged against (e-)NWRs.

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PREVIOUSLY ASKED / LIKELY QUESTIONS

- Which is non-climacteric – banana or grapes? → **Grapes**.
- Gas released by calcium carbide? → **Acetylene** (banned by FSSAI).
- Storage temperature for green banana? → **13–14 °C** (chilling injury below).
- Relative humidity for onion storage? → **65–70%**.
- Preservative for coloured fruit products? → **Sodium benzoate**.
- Logo of irradiated food? → **Radura**; low dose for sprout inhibition? → **< 1 kGy**.

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3. Animal Husbandry, Dairy & Fisheries

NOTE

Questions in this area come from five places: **breeds and their home tracts**, **gestation and oestrus figures**, **diseases (causal organism and vaccine)**, **milk composition, pasteurisation and adulteration tests**, and **production data and schemes** (Rashtriya Gokul Mission, NADCP, PMMSY, FIDF). For a warehousing body, milk powder, feed ingredients (aflatoxin in groundnut cake) and fish preservation also link back to storage questions. Learn the numbers in the tables.

3.1 Livestock Statistics & Census ★★★

CODE UPDATE

Basic Animal Husbandry Statistics 2025 (data for 2024-25): milk **247.87 million tonnes** (+3.58%), per-capita milk availability **485 g/day**, eggs **149.11 billion**, meat **10.50 million tonnes**, wool **34.57 million kg**. Fish production 2024-25 = **197.75 lakh tonnes** (≈ 19.8 million t).

Item (2024-25)	Value	World rank / remark
Milk	**247.87 Mt** (~248 Mt)	**1st** (~25% of world milk); was 146.3 Mt in 2014-15
Per-capita milk availability	**485 g/day**	World average ≈ 394 g/day; ICMR recommendation ≈ 300 g/day
Eggs	**149.11 billion**	**2nd** (after China); ~106 eggs/person/year; top state **Andhra Pradesh**
Meat	**10.50 Mt**	4th; poultry is the largest share of meat
Wool	34.57 million kg	Rajasthan ≈ 48% of output
Fish	**197.75 lakh t**	**2nd** (~8% of world); 2nd in aquaculture
Bovine productivity	2,251 kg/animal/yr	Indigenous cattle 1,343 kg; buffalo 2,365 kg

- **Top milk states: Uttar Pradesh** > Rajasthan > Madhya Pradesh > Gujarat > Maharashtra. Highest **per-capita availability**: **Punjab**, then Rajasthan and Haryana.
- **Milk by species:** buffalo and crossbred cattle ≈ **31–32% each**, indigenous/non-descript cattle ≈ 20%, goat ≈ 3%.
- Livestock sector grew at about **12.8% CAGR** (current prices) since 2014-15. It contributes about **31% of agricultural GVA** and ≈ 5.5% of total GVA, and gives ≈ 16% of farm household income.
- India has the **largest bovine population** and the **largest buffalo population** (~57% of the world's buffaloes); it is 2nd in goats.
- **Livestock Census** is taken every **5 years** by the Department of Animal Husbandry & Dairying (DAHD) with the states. The **first** was in **1919-20**.
- **21st Livestock Census** was taken from **Oct 2024 to Feb 2025**. It was the **first fully digital** census (mobile app) and covered **16 species** and **219 indigenous breeds** (as recognised by ICAR-NBAGR), plus poultry and pastoralists. Exam questions still quote the **20th Census (2019)** figures below.

20th Livestock Census (2019)	Number (million)	Change vs 2012 / top state
Total livestock	**535.78**	+4.6%; most livestock: **Uttar Pradesh**
Total bovines (cattle + buffalo + mithun + yak)	≈ 302.8	+1%
Cattle	**192.5**	+0.8%; most cattle: **West Bengal**; female cattle +18%; indigenous cattle −6%; exotic/crossbred +27%
Buffalo	**109.9**	+1%; top: **Uttar Pradesh**
Goat	**148.9**	+10.1%; top: **Rajasthan**
Sheep	**74.3**	+14.1%; top: **Telangana**
Pig	9.1	−12%; top: **Assam**
Poultry	**851.8**	+16.8%; backyard poultry +46%; top: **Tamil Nadu**
Camel / donkey	0.25 / 0.12	Sharpest falls (≈ −37% / −61%)

MEMORY TRICK

Top states in the 20th Census: "**U**ncle **W**ears **U**niform, **R**aja **T**akes **A**ll **T**ea". Livestock = **UP**, cattle = **WB**, buffalo = **UP**, goat = **Rajasthan**, sheep = **Telangana**, pig = **Assam**, poultry = **Tamil Nadu**.

- Important days: **World Milk Day – 1 June** (FAO); **National Milk Day – 26 Nov** (Kurien's birthday); World Egg Day – 2nd Friday of October; World Veterinary Day – last Saturday of April; World Zoonoses Day – 6 July; **National Fish Farmers Day – 10 July**; **World Fisheries Day – 21 Nov**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- India's milk production in 2024-25? → **247.87 million tonnes**.
- Per-capita milk availability (2024-25)? → **485 g/day**.
- India's world rank in egg production? → **2nd**.
- Total livestock population in the 20th Census? → **535.78 million**.
- State with the most sheep (20th Census)? → **Telangana**.
- The first Livestock Census in India was conducted in? → **1919-20**.

3.2 Cattle, Buffalo & Other Breeds ★★★

- Indian (humped) cattle = ***Bos indicus*** (zebu). They have a **hump and dewlap** and are heat-tolerant and tick-resistant. Exotic (humpless) cattle = ***Bos taurus***. Buffalo = ***Bubalus bubalis***.
- ICAR-**NBAGR, Karnal** registers breeds. India has **219+ registered indigenous breeds** across species, including about cattle 53, buffalo 20, goat 39 and sheep 46. The count rises every year as new breeds are registered.
- Breeds are classified by use: **milch** (cows give high milk; bullocks are poor workers), **draught** (good bullocks; cows give little milk) and **dual-purpose** (cows give fair milk and bullocks are good workers).

Type	Cattle breed	Home tract	Key feature
Milch	**Sahiwal**	Punjab (Montgomery, now Pakistan)	**Best indigenous dairy breed**; also called Lola, Lambi Bar
Milch	**Gir**	Gujarat (Gir forest, Kathiawar)	Domed forehead, long pendulous ears; exported to Brazil

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Milch	**Red Sindhi**	Sindh (Karachi, Pakistan)	Red colour; tick and heat resistant
Milch	Rathi	Rajasthan (Bikaner)	Milch breed of the arid tract
Dual	**Tharparkar**	Rajasthan (Thar desert)	White/grey; drought hardy (also counted as milch)
Dual	**Hariana**	Haryana (Rohtak, Hisar)	White/grey; most widespread dual breed of the north
Dual	**Ongole**	Andhra Pradesh (Nellore, Prakasam)	Large and heavy; called "Nelore" in Brazil
Dual	**Kankrej**	Gujarat (Rann of Kutch) / Rajasthan	One of the heaviest Indian breeds; fastest draught ("**sawai chal**")
Dual	Deoni, Gaolao, Krishna Valley, Mewati	Maharashtra/Karnataka; Maharashtra/MP; Karnataka; Rajasthan/Haryana	–
Draught	**Amritmahal**, **Hallikar**	Karnataka (Mysore)	Amritmahal = "army (transport) breed"; Hallikar is its parent
Draught	**Khillar**	Maharashtra (Satara, Sangli)	Fast trotting bullocks
Draught	**Kangayam**, Bargur	Tamil Nadu (Coimbatore; Erode)	Hardy; Kangayam linked to jallikattu
Draught	**Nagori**, Malvi	Rajasthan (Nagaur); MP (Malwa)	Nagori = fast-trotting bullocks
Draught	Siri, Ponwar, Kenkatha, Bachaur	Sikkim/Darjeeling; UP; UP/MP; Bihar	Siri = hill breed
Miniature	**Vechur**; **Punganur**	Kerala; Andhra Pradesh (Chittoor)	Vechur = **smallest cattle**; Punganur = dwarf

Exotic cattle	Origin	Milk fat %	Key fact
Holstein-Friesian (HF)	Netherlands (Holland)	**≈ 3.5** (lowest)	**Highest milk yield**; largest dairy breed; black-and-white
Jersey	Jersey Island (UK)	**≈ 5** (highest)	**Smallest** exotic dairy breed; tolerates heat best; widely used in Indian crossbreeding
Brown Swiss	Switzerland	≈ 4	Hardy; parent of Karan Swiss
Guernsey	Guernsey Island (UK)	≈ 4.5–5	"Golden milk" (high carotene)
Ayrshire	Scotland	≈ 4	Hardy dairy breed

- Crossbreds bred in India: **Karan Swiss** = Brown Swiss × Sahiwal and **Karan Fries** = **HF × Tharparkar** (both from **NDRI, Karnal**); **Frieswal** = HF × Sahiwal (Military Dairy Farms and ICAR); **Sunandini** (Kerala).
- National breeding policy: in crossbreds, **exotic inheritance is normally kept at about 50%**, because higher levels lose heat tolerance and disease resistance.

Buffalo breed	Home tract	Identification
Murrah	Haryana (Rohtak, Jind, Hisar)	**Best dairy buffalo**; jet black; **tightly curled** horns; "black gold"
Nili-Ravi	Punjab (Sutlej–Ravi)	**Wall eyes** (white in the eyes); white markings
Jaffarabadi	Gujarat (Saurashtra, Gir)	**Heaviest** buffalo; heavy **drooping** horns
Surti	Gujarat (Kaira, Vadodara)	**Sickle-shaped** horns; two white collars (chevrons)
Mehsana	Gujarat	Probably Murrah × Surti
Bhadawari	UP/MP (Agra, Etawah, Bhind)	Copper-coloured; **highest milk fat** (≈ 8–13%)
Nagpuri, Pandharpuri	Maharashtra	Long sword-shaped / very long horns
Toda; Chilika; Banni	Nilgiris (TN); Odisha; Kutch (Gujarat)	Tribal buffalo; brackish-water buffalo; hardy Kutchi buffalo

- **River buffalo** (India) have **2n = 50** chromosomes and are bred for milk. **Swamp buffalo** (NE, SE Asia) have **2n = 48** and are used for draught.
- Chromosome numbers (2n): cattle **60**, goat **60**, sheep **54**, pig **38**, horse **64**, donkey **62**, mule **63** (sterile), chicken **78**.
- **Mule** = male donkey (jack) × female horse (mare). **Hinny** = stallion × female donkey (jenny).

Species (scientific name)	Important breeds (home tract)	Key facts
Goat (*Capra hircus*) – "poor man's cow"	**Jamunapari** (Etawah, UP – tallest, Roman nose, milch); **Beetal** (Punjab); **Barbari** (UP – stall-fed, twins); **Black Bengal** (WB – meat, prolific, **best skin**); Sirohi (Rajasthan); Osmanabadi (Maharashtra); Malabari (Kerala); **Changthangi** (Ladakh – **pashmina**)	Exotic: **Saanen** (Switzerland – highest milk), Alpine, Anglo-Nubian, **Boer** (S. Africa – meat), **Angora** (Turkey – **mohair**). CIRG – **Makhdoom** (Mathura)
Sheep (*Ovis aries*)	**Chokla** (Rajasthan – finest carpet wool, "**Merino of India**"); Marwari, Magra, Nali (carpet wool); **Nellore** (AP – tallest, hairy, meat); Deccani, Bellary, Mandya (meat); Gaddi, Rampur Bushair (hill wool); **Garole** (Sundarbans, WB – **FecB gene**, twins)	Exotic: **Merino** (Spain – fine wool), Rambouillet (France), Corriedale (NZ). CSWRI breeds: Avikalin, **Bharat Merino**. CSWRI – **Avikanagar** (Rajasthan)

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Pig (*Sus scrofa domesticus*)	Exotic: **Large White Yorkshire** (England – most common), **Landrace** (Denmark – long body, bacon), Hampshire (USA – white belt), Duroc (red). Indigenous: **Ghungroo** (WB), **Niang Megha** (Meghalaya), Doom (Assam)	Most prolific meat animal (8–12 piglets/litter); NRC Pig – **Rani**, Guwahati
Poultry (*Gallus gallus domesticus*)	**Aseel** (AP/Odisha – fighter, best meat); **Kadaknath** (Jhabua, MP – **black meat**, GI tag); Chittagong; **Naked Neck** (heat tolerant); Nicobari	Improved rural birds: Vanaraja, Gramapriya (ICAR-DPR, Hyderabad), Giriraja (Karnataka), Kalinga Brown (Odisha). CARI – **Izatnagar**
Camel (*Camelus dromedarius* – one hump)	Bikaneri, Jaisalmeri, Kachchhi, **Kharai** (Gujarat – **swimming camel**)	Bactrian (two humps) – Nubra valley, Ladakh. NRC Camel – **Bikaner**; state animal of Rajasthan
Mithun (*Bos frontalis*); Yak (*Bos grunniens*)	Arunachal, Nagaland, Mizoram, Manipur; Ladakh, Sikkim, Arunachal	NRC Mithun – Medziphema (Nagaland); NRC Yak – Dirang (Arunachal)
Horse (*Equus caballus*)	**Marwari**, **Kathiawari** (inward-curving ears), Zanskari, Manipuri pony; Halari donkey	NRC Equines – **Hisar**

Institute	Location	Institute	Location
NDRI (dairy; deemed university)	**Karnal**	**IVRI** (veterinary)	**Izatnagar** (Bareilly)
NBAGR (animal genetic resources)	Karnal	CIRB (buffalo)	Hisar
CIRC (cattle)	Meerut	NRCE (equines)	Hisar
NIHSAD (high-security animal diseases)	Bhopal	NIANP (nutrition & physiology)	Bengaluru
IGFRI (grassland & fodder)	**Jhansi**	**NDDB**	**Anand** (Gujarat)

MEMORY TRICK

"**S-G-S-T**" (Sahiwal, Gir, Sindhi, Tharparkar) are the top four milch breeds. **M**urrah = "**M**ost milk"; **B**hadawari = "**B**utterfat buffalo"; Jaffarabadi = "**J**umbo" (heaviest); **S**urti = **S**ickle horns.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Best indigenous dairy cattle breed? → **Sahiwal**.
- Karan Fries is a cross of? → **Holstein-Friesian × Tharparkar**.
- Buffalo breed with "wall eyes"? → **Nili-Ravi**.
- Buffalo breed with the highest milk fat? → **Bhadawari**.
- Pashmina comes from which goat? → **Changthangi**.
- Sheep breed carrying the FecB (prolificacy) gene? → **Garole**.

3.3 Animal Nutrition & Feeding ★★☆

Feed class	Definition	Examples
Roughage – dry	Bulky; **crude fibre > 18%**, TDN < 60%; moisture 10–15%	Wheat/paddy straw (bhusa), stover (kadbi), hay
Roughage – succulent	Moisture 60–90%	Green fodder, silage, roots and tubers
Concentrate – energy-rich	**CF < 18%**, TDN > 60%, **CP < 20%**	Maize, barley, oats, wheat bran, rice bran, molasses
Concentrate – protein-rich	**CP > 20%**	Oil cakes: groundnut cake (~45% CP), soybean meal (~44–48%), mustard cake, cottonseed cake; fish meal
Supplements / additives	Small quantities	Mineral mixture, vitamins, urea (NPN), probiotics, sodium bicarbonate buffer, bypass protein/fat

KEY FORMULAE

- **TDN** (Total Digestible Nutrients) = DCP + DCF + DNFE + (**2.25** × digestible ether extract). Fat is multiplied by 2.25 because it gives ~2.25 times the energy of carbohydrate.
- 1 kg TDN ≈ **4.4 Mcal** digestible energy.
- **DCP** (Digestible Crude Protein) = CP × digestibility coefficient; CP = N × **6.25** (protein contains ~16% N).
- **Nutritive ratio (NR)** = (TDN – DCP) ÷ DCP. A **narrow** NR (≈ 1:3–1:4) suits young, growing and milking animals; a **wide** NR (≈ 1:8 or more) suits maintenance.
- Energy flow: Gross energy → **DE** (minus faecal) → **ME** (minus urine and methane; ME ≈ 82% of DE) → **NE** (minus heat increment).
- Starch equivalent (SE) – **Kellner**; proximate (Weende) analysis – Henneberg & Stohmann.

- **Dry matter intake** = about **2.5–3% of body weight** per day. About two-thirds should be roughage, and of that roughage about one-third should be green fodder.
- **Thumb rule for concentrate:** 1–1.5 kg/day for maintenance (cow), plus **1 kg for every 2.5 kg milk (cow)** or **1 kg for every 2 kg milk (buffalo)**. Pregnant animals get an extra 1–1.5 kg in the last 2–3 months.
- **Hay** = green fodder dried to **15–20% moisture** so it does not mould. Legume hay (lucerne, berseem) is richer in protein and calcium. **Haylage** ≈ 40–50% moisture.
- **Silage** = green fodder preserved by **anaerobic fermentation**. Lactic acid bacteria produce **lactic acid** and drop the pH to about **3.8–4.2**. Crops are chopped at about **30–35% dry matter** (65–70% moisture), and **maize** (best), sorghum and oats are used. Silos may be pit, trench, bunker or tower. Adding **molasses** (~2–3%) helps poor-sugar crops. A **butyric** (rancid) smell means poor silage. Good silage is greenish-yellow with a pleasant acidic smell.
- **Straw treatment: 4% urea** solution treatment (ammoniation) raises the CP and digestibility of straw. **UMMB** = urea-molasses mineral block (a lick).
- **Urea** (NPN, ~46% N, equivalent to ~287% CP) can be fed only to ruminants with a functional rumen, at no more than about **1% of the ration DM** (≈ 2–3% of concentrate). Excess causes **ammonia toxicity**.
- India's **fodder deficit** (IGFRI) is about **11–12% green** and about **23% dry** fodder.

Ruminant stomach part	Common name / feature
Rumen	Largest (~80% of stomach capacity in adults); fermentation vat holding bacteria, protozoa and fungi
Reticulum	"**Honeycomb**"; foreign bodies lodge here causing **hardware disease** (traumatic reticulo-peritonitis)

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Omasum	"**Manyplies / book stomach**"; absorbs water
Abomasum	"**True stomach**"; HCl and pepsin (rennin in calves)

- In calves, milk bypasses the rumen through the **oesophageal (reticular) groove**. The camel is a pseudo-ruminant with 3 compartments. The horse is a monogastric **hind-gut fermenter** (caecum).
- The rumen produces **volatile fatty acids**: acetic > propionic > butyric (≈ 65:20:15 on roughage). **Acetate** is the precursor of **milk fat**, and **propionate** is **glucogenic**. Low-fibre rations reduce acetate and cause **milk-fat depression**.
- Rumen microbes make **B-complex vitamins and vitamin K** and convert NPN to **microbial protein**. **Methane** is a by-product (an energy loss and a greenhouse gas).
- Rumen disorders: **bloat** (frothy bloat from lush legumes, treated with an antifoaming oil or a trocar-cannula in the **left flank**) and **acidosis** (grain overload, lactic acid).

Mineral / vitamin	Deficiency disease
Calcium	**Milk fever** (parturient paresis), rickets
Phosphorus	**Pica** (depraved appetite), osteomalacia, infertility
Magnesium	**Grass tetany** (hypomagnesaemia)
Iron	**Piglet anaemia** (give iron injection on day 3)
Copper	Anaemia, depigmented hair, **sway-back** in lambs
Cobalt	Vitamin B_{12} deficiency ("pine", wasting)
Iodine	**Goitre**, hairless newborns
Selenium + vitamin E	**White muscle disease**
Zinc	**Parakeratosis** (pigs)
Vitamin A	Night blindness, poor fertility

- **Mineral mixture** is added at about **2% of the concentrate** (≈ 50–60 g/day for an adult cow), plus **1% common salt**. Ideal **Ca:P ratio is 1:1 to 2:1**. **Area-specific mineral mixture (ASMM)** is formulated from local soil and feed deficiencies.

Fodder crop	Scientific name	Note
Berseem (Egyptian clover)	*Trifolium alexandrinum*	"**King of fodders**"; rabi legume; 4–6 cuts; var. Wardan, Mescavi
Lucerne (alfalfa)	*Medicago sativa*	"**Queen of fodders**"; perennial legume; ~20% CP
Cowpea	*Vigna unguiculata*	Kharif legume; mixed with maize/sorghum
Fodder maize, sorghum	*Zea mays*, *Sorghum bicolor*	Best silage crops; young sorghum contains **HCN (dhurrin)**, so do not feed it before 50% flowering
Oats	*Avena sativa*	Rabi cereal fodder; can accumulate nitrate
Hybrid Napier (Bajra-Napier)	*Pennisetum purpureum* × *P. glaucum*	Perennial; var. **CO-4, CO-5**; high yield; contains oxalate
Guinea grass; Para grass	*Megathyrsus* (*Panicum*) *maximus*; *Brachiaria mutica*	Shade-tolerant; para grass suits **waterlogged** land
Subabul	*Leucaena leucocephala*	Tree fodder; **mimosine** toxicity
Azolla	*Azolla pinnata* (with *Anabaena azollae*)	Aquatic fern; ~25% CP supplement

- Toxic factors in feed: **aflatoxin** (*Aspergillus flavus*) in damp-stored groundnut cake and maize, a **storage** link; **gossypol** in cottonseed cake (toxic to pigs and poultry); **glucosinolates** in mustard cake; **ODAP/BOAA** in *Lathyrus* (khesari); **mimosine** in subabul; **HCN** in young sorghum.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- The "king of fodders" is? → **Berseem**.
- Factor by which digestible fat is multiplied in TDN? → **2.25**.
- The true stomach of ruminants is? → **Abomasum**.
- Acid that predominates in good silage? → **Lactic acid** (pH ≈ 4).
- Toxic principle of cottonseed cake? → **Gossypol**.
- Precursor of milk fat produced in the rumen? → **Acetic acid** (acetate).

3.4 Breeding, Reproduction & Health ★★★

Species	Oestrous cycle	Duration of heat	Gestation
Cow	**21 days**	**18–24 h**	**≈ 280 days** (~9 months 10 days)
Buffalo	21 days	≈ 24 h; **silent heat** common	**≈ 310 days** (305–315)
Sheep (ewe)	**17 days**	24–36 h	**≈ 150 days**
Goat (doe)	21 days	24–48 h	**≈ 150 days**
Pig (sow)	21 days	2–3 days	**114 days** (3 months 3 weeks 3 days)
Horse (mare)	21–22 days	**5–7 days** (longest heat)	**≈ 340 days**
Donkey; camel	–	–	≈ 365 days; **≈ 390 days** (longest among livestock)
Rabbit; dog/cat	– (rabbit and cat are induced ovulators; dog is not)	–	**31 days**; ≈ 63 days

MEMORY TRICK

Gestation ladder "**114 – 150 – 280 – 310 – 340**" = **P**ig, **G**oat/sheep, **C**ow, **B**uffalo, **M**are → "**P**igs **G**et **C**ows **B**usy **M**ating". Sow = "3-3-3".

- **Signs of heat:** bellowing, restlessness, clear stringy **mucus** discharge, swollen vulva, drop in milk. The surest sign is **standing to be mounted** ("standing heat").
- The cow ovulates spontaneously about **10–14 h after the end of heat**. **Camel, rabbit and cat** are **induced ovulators**.
- **Buffalo** is a **seasonal (short-day) breeder** that mostly breeds in autumn and winter and often shows **silent heat** in summer. Sheep and goats are also short-day breeders, and the horse is a **long-day breeder**.
- **Best time to inseminate** is mid to late heat. Under the **a.m.–p.m. rule**, a cow seen in heat in the morning is inseminated the same evening, and one seen in the evening is inseminated the next morning.
- Hormones: **FSH** causes follicle growth; **LH** causes ovulation; the corpus luteum secretes **progesterone** (maintains pregnancy);

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$PGF_{2\alpha}$ lyses the corpus luteum and is used for **oestrus synchronisation**; **oxytocin** causes milk let-down; **prolactin** starts lactation. **Ovsynch** (GnRH–$PGF_{2\alpha}$–GnRH) is a protocol for fixed-time AI.

- Pregnancy is diagnosed by **per-rectal examination** at 45–60 days (ultrasonography earlier). **Retained placenta** = placenta not expelled within **12 h**. **Freemartin** = a female born twin to a male, which is usually **sterile** (> 90%).
- Herd management norms: standard lactation is **305 days**, the dry period about **60 days**, and the ideal calving interval **12–13 months** (cow) or 13–14 months (buffalo). Age at first calving is about **30–36 months** for indigenous cattle and earlier for crossbreds.

Technology	Key facts
Artificial insemination (AI)	First scientific AI was by **Spallanzani (1780, dog)**. In India, the first AI was in **1939** at the Palace Dairy Farm, Mysore (Dr Sampath Kumaran). Semen is collected with an **artificial vagina** and deposited in the **cervix/uterine body** (recto-vaginal method). One ejaculate can serve hundreds of cows, and AI prevents venereal diseases.
Frozen semen	**Glycerol** is the cryoprotectant (Polge, Smith & Parkes, 1949). Extenders are egg-yolk citrate or Tris. Semen is stored in French straws (**0.25 mL** mini, 0.5 mL medium) in **liquid nitrogen at −196 °C** and thawed at **37 °C for ~30 s**. The standard is ≥ **50% post-thaw motility** and ~20 million sperm per dose.
Sex-sorted semen	**Flow cytometry** separates sperm because X-bearing sperm carry ~4% more DNA than Y. It gives **≈ 90% female calves** and is promoted under the Rashtriya Gokul Mission (more than 1 crore doses produced).
MOET / ETT	The donor is **superovulated** with FSH or eCG (PMSG). Embryos are flushed on **day 7** and transferred non-surgically to synchronised recipients (surrogates). This multiplies elite females.
OPU–IVF	Oocytes are collected by ovum pick-up (ultrasound-guided) and matured and fertilised in vitro; the embryo is then transferred. There are 22 IVF labs under RGM.
Cloning	**Samrupa** (2009, NDRI Karnal) was the world's first cloned buffalo calf, made by the hand-guided cloning technique.
Selection	**Progeny testing** judges a bull by the yield of its daughters and is the most accurate method. Heritability of milk yield is about 0.25–0.3.
Breeding systems	**Inbreeding** (mating relatives; increases homozygosity) versus **outbreeding**, which includes **crossbreeding**, **grading up** (non-descript females are repeatedly mated to pure-breed bulls, and after 5–6 generations the offspring are ~97–98% pure) and outcrossing.

Disease	Causal organism (type)	Key features	Vaccine / control
Foot-and-mouth disease (FMD)	**Virus** – Aphthovirus (Picornaviridae); 7 serotypes; in India **O, A, Asia-1**	Vesicles in the mouth and feet, drooling, drop in milk; affects cloven-footed animals; very high economic loss	Inactivated **trivalent** vaccine every **6 months** (NADCP)
Haemorrhagic septicaemia (HS)	**Bacterium** – *Pasteurella multocida* (B:2)	"**Galghotu**"; throat swelling; monsoon; buffaloes most affected; high fatality	Alum-precipitated or oil-adjuvant vaccine **before monsoon**, yearly
Black quarter (BQ)	**Bacterium** – *Clostridium chauvoei* (anaerobe, spore-former)	Young cattle 6 months–2 years; **crepitating** (gas) swelling of the hind quarter	Formalin-killed BQ vaccine before monsoon, yearly
Anthrax	**Bacterium** – *Bacillus anthracis* (spore-former)	Sudden death; **tarry, unclotted blood** from natural openings; **zoonotic**; **never open the carcass** (spores form on air contact)	Live spore vaccine (**Sterne strain**), yearly in endemic areas; burn or deep-bury carcass
Brucellosis	**Bacterium** – *Brucella abortus*	**Abortion in the last trimester**, retained placenta; zoonotic (**undulant fever** in humans)	**Strain-19 (S-19)** vaccine, **female calves 4–8 months**, once in a lifetime
Mastitis	Mainly **bacteria** – *Staphylococcus aureus*, *Streptococcus agalactiae* (contagious), *E. coli* (environmental)	Inflammation of the udder; the **costliest dairy disease**; subclinical form most common; detected by **CMT** (California Mastitis Test) and somatic cell count	No routine vaccine; teat dipping, **dry-cow therapy**, clean milking
Lumpy skin disease (LSD)	**Virus** – Capripoxvirus (Poxviridae)	Skin nodules, fever, drop in milk; spread by **vectors** (flies, mosquitoes, ticks); major outbreak in **2022**	**Lumpi-ProVacInd** (live attenuated, ICAR-NRCE Hisar & IVRI); goat-pox vaccine also used
Bird flu (HPAI)	**Virus** – Influenza A **H5N1** (Orthomyxoviridae)	Sudden high mortality in poultry; zoonotic	No routine vaccination in India; **stamping out** (culling within **1 km**, surveillance zone 10 km)

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Newcastle / Ranikhet disease (ND)	**Virus** – avian paramyxovirus-1	Respiratory and nervous signs (twisted neck), greenish diarrhoea; first reported at Ranikhet (Uttarakhand) in India and Newcastle (England)	**F1 / LaSota** (chicks, eye/nasal drop, week 1) and **R2B** (Mukteswar strain, booster at ~8 weeks, injection)
African swine fever (ASF)	**Virus** – Asfivirus (Asfarviridae, DNA)	Pigs only; mortality up to **100%**; first in India **2020** (Assam, Arunachal)	India's first indigenous live-attenuated vaccine from ICAR-NIHSAD, Bhopal (Aug 2026); otherwise culling and biosecurity

- Other diseases: **PPR** ("goat plague", **Morbillivirus**; vaccine with lifelong immunity; eradication target **2030**). **Theileriosis** (*Theileria annulata*, protozoan, spread by the *Hyalomma* tick). **Babesiosis** (protozoan, spread by the *Boophilus* tick; **red urine**). **Tuberculosis** (*Mycobacterium bovis*). **Rabies** (Lyssavirus).
- **Metabolic diseases: milk fever** (hypocalcaemia within ~72 h of calving; treated with **calcium borogluconate IV**); **ketosis** (low blood glucose in high yielders; **sweet/acetone breath**); grass tetany (hypomagnesaemia).
- **Rinderpest** (cattle plague, Morbillivirus) was **eradicated**: India was declared free in **2006** and the world in **2011**, the second disease ever eradicated after smallpox. India is also free of CBPP and African horse sickness.
- Bacterial diseases worth recalling together: HS, BQ, anthrax, brucellosis, TB, mastitis. Viral diseases: FMD, LSD, PPR, ND, rabies, bird flu, ASF.
- The law for notifiable animal diseases is the **Prevention and Control of Infectious and Contagious Diseases in Animals Act, 2009**. The Mobile Veterinary Units helpline number is **1962**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Gestation period of a buffalo? → **≈ 310 days**.
- Temperature at which frozen semen is stored? → **−196 °C** (liquid nitrogen).
- Causal organism of black quarter? → ***Clostridium chauvoei***.
- Vaccine strain against brucellosis and the age it is given? → **S-19, female calves 4–8 months**.
- Disease in which the carcass must not be opened? → **Anthrax**.
- Milk fever is caused by deficiency of? → **Calcium** (hypocalcaemia).

3.5 Milk & Dairy Technology ★★★

- **Milk** (FSSAI) = the normal mammary secretion from healthy milch animals, free of colostrum. **Colostrum** is the first milk after calving. It is rich in **immunoglobulins** and **vitamin A** and is laxative. Feed it within **1 hour of birth** at about 10% of body weight per day.

Constituent (%)	Cow	Buffalo	Goat	Human
Water	≈ 87	≈ 83–84	≈ 87	≈ 87.5
Fat	**≈ 4–4.5**	**≈ 6.5–7.5**	≈ 4–4.5	≈ 3.8
Protein	≈ 3.3	≈ 3.8–4.0	≈ 3.4	≈ 1.1 (lowest)
Lactose	≈ 4.8	≈ 5.0	≈ 4.3	**≈ 7.0** (highest)
Ash	≈ 0.7	≈ 0.8	≈ 0.8	≈ 0.2
SNF	**≈ 8.5–9.0**	**≈ 9.5–10**	≈ 8.6	≈ 8.5

- **SNF** (solids-not-fat) = total solids − fat (protein + lactose + minerals). **Lactose** is "milk sugar" (glucose + galactose).
- **Casein** makes up about **80% of milk protein** and precipitates at its **isoelectric pH 4.6**. **Whey proteins** are β-lactoglobulin (the major one) and α-lactalbumin. **A1/A2 milk** differ in their β-casein variant; indigenous cattle and buffalo give **A2** milk.
- Colour: cow milk is **yellowish** because of **β-carotene**. Buffalo milk is **white** because buffalo convert carotene to vitamin A. **Whey** is greenish-yellow because of **riboflavin**.
- Milk is a poor source of **iron and vitamin C**. Its fat globules are about 2–5 µm, and buffalo milk has larger fat globules than cow milk.
- Physical constants: pH **6.6–6.8**; **specific gravity** 1.028–1.030 (cow) and 1.030–1.032 (buffalo), measured with a **lactometer**. Skimming raises specific gravity and adding water lowers it. **Freezing point** is about **−0.525 to −0.55 °C** and is the most reliable check for added water. Natural (apparent) acidity is **0.13–0.14% lactic acid** and comes from casein, phosphates, citrates and CO_2.
- **Milk let-down** is caused by **oxytocin** and lasts about 5–7 minutes; fear (adrenaline) stops it. **Full-hand milking** is the recommended method. Cooling: a **bulk milk cooler (BMC)** chills milk to **4 °C** within about 2 hours of milking.

FSSAI minimum standards (pasteurised milk)	Fat %	SNF %
Cow milk	3.0–4.0 (varies by state)	8.5
Buffalo milk	5.0–6.0	9.0
Full-cream milk	**6.0**	9.0
Standardised milk	**4.5**	8.5
Toned milk	**3.0**	**8.5**
Double-toned milk	**1.5**	**9.0**
Skimmed milk	≤ 0.5	8.7

- **Toned milk** is buffalo milk diluted with **skim milk powder plus water**. Standardisation means adjusting the fat level.

Heat treatment	Temperature / time	Note
LTLT (holder / batch)	**63 °C for 30 min**	Small plants
HTST (flash / continuous)	**72 °C for 15 s**	Most common; plate heat exchanger with regeneration; then cooled to ≤ 4–5 °C
Thermisation	63–65 °C for ~15 s	Mild; extends raw-milk storage
UHT	**135–150 °C for 2–4 s**	**Aseptic packaging** (Tetra Pak); shelf-stable for months without refrigeration
Sterilisation (in-container)	≈ 115–121 °C for 15–20 min	In sealed bottles/cans; cooked flavour and browning

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- Pasteurisation (named after **Louis Pasteur**) kills all **pathogens** but not all microbes. The index organism is ***Coxiella burnetii*** (Q fever), which replaced *Mycobacterium tuberculosis*. Efficiency is checked by the **alkaline phosphatase test**: the enzyme is destroyed by correct pasteurisation, so a negative test means the milk was properly pasteurised.
- **Homogenisation** pushes milk through a fine valve at about 2,000–2,500 psi (~60 °C), breaking fat globules to < 2 µm. This **prevents cream-line formation**.
- Milk powder is made mainly by **spray drying** (the best method; also roller/drum drying). Skim milk powder (SMP) has ≤ 1.5% fat and must be stored dry and cool in moisture-proof packs (a storage link).

Product	Key composition / standard	Note
Ghee	≥ 99.5% fat; moisture ≤ 0.5%	Made by the desi (makkhan), direct-cream or **creamery-butter** method; **RM value** (Reichert-Meissl, volatile soluble fatty acids) is the main purity index; **Baudouin test** detects vanaspati (which contains sesame oil)
Butter	≥ **80% fat**; moisture ≤ 16%	Made by churning cream (phase inversion)
Cream	≥ 25% fat	Separated by a centrifugal cream separator
Khoa	Milk heat-desiccated in an open pan; ~65–70% total solids	Types: **pindi** (burfi, peda), **dhap** (gulab jamun), **danedar** (kalakand); buffalo milk yields more
Paneer	Moisture ≤ 70%; fat ≥ 50% of dry matter	**Acid–heat coagulation** (citric acid at ~70 °C) of buffalo or mixed milk
Chhana	Acid-coagulated cow milk	Base for rasogolla and sandesh
Cheese	Rennet coagulation	**Rennet** enzyme = **chymosin (rennin)**, from calf abomasum or microbial/recombinant sources
Dahi / yoghurt	Lactic fermentation	Yoghurt = *Lactobacillus delbrueckii* subsp. *bulgaricus* + *Streptococcus thermophilus*; dahi = mixed mesophilic lactic cultures (*Lactococcus lactis*)
Shrikhand	Chakka (strained dahi) + sugar	Western India
Ice cream	≥ 10% fat	**Overrun** (air incorporated) ≈ 80–100%
Sweetened condensed milk	~40% sugar	Sugar acts as the preservative

Test / adulterant	Reagent / principle	Positive result
Added water	Lactometer reading; **freezing point** (cryoscope)	Low specific gravity; freezing point closer to 0 °C
Starch	**Iodine** solution	**Blue** colour
Urea	**DMAB** (p-dimethylaminobenzaldehyde)	Distinct **yellow** colour
Neutralisers (soda)	**Rosolic acid**	Rose-red colour
Formalin	Conc. H_2SO_4 + $FeCl_3$ (**Hehner's test**)	**Violet/purple ring**
Detergent	Bromocresol purple	Violet colour
Cane sugar	Resorcinol + HCl (Seliwanoff)	Red colour
Hydrogen peroxide	p-Phenylenediamine	Blue colour
Vanaspati in ghee	**Baudouin test** (furfural + HCl)	Crimson/red colour
Fat %	**Gerber test** (H_2SO_4 ~90% + amyl alcohol, butyrometer)	Direct fat reading
Bacterial quality	**MBRT** (methylene blue reduction time); resazurin test	Faster decolourisation means poorer milk (MBRT ≥ 5 h = very good)
Heat stability	**COB** (clot-on-boiling); **alcohol test** (68% alcohol)	Clotting means developed acidity
Pasteurisation efficiency	**Alkaline phosphatase test**	Positive = under-pasteurised
Sterilised milk	Turbidity test	No turbidity = properly sterilised
Mastitis milk	**CMT** (detergent + bromocresol purple); SCC	Gel formation; SCC > ~2 lakh/mL = subclinical mastitis

MEMORY TRICK

Pasteurisation "**63-30, 72-15**" → LTLT 63 °C/30 min; HTST 72 °C/15 s. UHT "135 for 2". Adulteration colours: "**S**tarch **B**lue, **U**rea **Y**ellow, **F**ormalin **V**iolet ring".

- **Operation Flood** (**1970–96**) was the world's largest dairy development programme and made India the largest milk producer (the **White Revolution**). It ran in three phases: **I 1970–80**, **II 1981–85**, **III 1985–96**. It was financed by selling milk powder and butter oil gifted by the **EEC** (World Food Programme), and later by World Bank loans. It linked rural milksheds to metro markets through the **National Milk Grid**.
- Dr **Verghese Kurien** is the "**Father of the White Revolution**" and "Milkman of India". He was the first Chairman of **NDDB** and of **GCMMF**; his autobiography is "*I Too Had a Dream*". **National Milk Day – 26 November** is his birthday.
- **NDDB** was set up in **1965** at **Anand** (Gujarat) at the instance of PM Lal Bahadur Shastri. It became a statutory body under the **NDDB Act, 1987**.
- **AMUL** (Anand Milk Union Ltd) = the Kaira District Co-operative Milk Producers' Union, founded in **1946** by **Tribhuvandas Patel** under the guidance of **Sardar Patel**. **GCMMF** (1973) markets the Amul brand. Amul is ranked the **No. 1 cooperative in the world** (ICA World Cooperative Monitor) and has about 36 lakh farmer members.
- The **Anand pattern** has **3 tiers**: village Dairy Cooperative Society (DCS) → district milk union → state federation. The network has about 22 federations and 241 district unions covering about 1.72 crore farmers. Women make up about 70% of the dairy workforce.

Scheme	Year	Key features

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Rashtriya Gokul Mission (RGM)	Dec **2014**; revised Mar 2025	Conserves and develops **indigenous breeds**. Outlay **₹3,400 cr (2021-26)** after an extra ₹1,000 cr. Includes the National AI Programme (free doorstep AI; 14 crore+ inseminations), sex-sorted semen, 22 IVF labs, **MAITRIs** (multipurpose AI technicians), Gokul Grams, **Gopal Ratna Award**, 35% one-time aid for heifer-rearing centres, and 3% interest subvention for IVF heifers
NPDD – National Programme for Dairy Development	2014-15; restructured 2021	Component A – milk chilling and testing infrastructure; Component B – "Dairying through Cooperatives" (JICA-assisted)
NADCP – National Animal Disease Control Programme	Sep **2019** (launched at Mathura)	100% centrally funded vaccination against **FMD and brucellosis**; aims to control FMD by 2025 and **eradicate it by 2030**; now part of LHDCP
LHDCP – Livestock Health & Disease Control Programme	Revised Mar 2025 (₹3,880 cr, 2024-26)	Covers NADCP, **Mobile Veterinary Units (helpline 1962)** and **Pashu Aushadhi** (generic veterinary medicines)
NLM – National Livestock Mission	2014-15; revised 2021	Entrepreneurship with **50% capital subsidy** (poultry up to ₹25 lakh; sheep/goat ₹50 lakh; pig ₹30 lakh; fodder/silage ₹50 lakh); breed improvement; livestock insurance
AHIDF	2020	₹15,000 cr infrastructure fund (DIDF merged, total ₹29,110 cr to 2025-26); **3% interest subvention** for dairy, meat, feed and vaccine plants
White Revolution 2.0	Launched **25 Dec 2024** (2024-25 to 2028-29)	Ministry of Cooperation with DAHD: **75,000 new dairy cooperatives** and 46,422 existing ones strengthened; procurement target 1,007 lakh kg/day by 2028-29; 3 multi-state societies (cattle feed, organic manure/biogas, hides)
Bharat Pashudhan (NDLM) / INAPH	2023-24	Digital livestock database; **12-digit ear tag** ("Pashu Aadhaar"); **e-GOPALA** app for farmers

CODE UPDATE

The **Budget 2026-27** provides a loan-linked capital subsidy to add **20,000+ veterinary professionals**, and credit-linked support for **Livestock FPOs**. India's first indigenous **ASF vaccine** (ICAR-NIHSAD, Aug 2026) and **Lumpi-ProVacInd** are recent disease-control milestones.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- HTST pasteurisation temperature and time? → **72 °C for 15 seconds**.
- Test for the efficiency of pasteurisation? → **Alkaline phosphatase test**.
- Minimum fat and SNF in toned milk? → **3.0% fat, 8.5% SNF**.
- Yellow colour of cow milk is due to? → **β-carotene**.
- Reagent used to detect urea in milk? → **DMAB** (p-dimethylaminobenzaldehyde).
- Target of White Revolution 2.0? → **75,000 new dairy cooperatives** (by 2028-29).

3.6 Poultry & Fisheries ★★☆

Class of fowl	Breeds	Egg shell / use
Mediterranean	**White Leghorn** (Italy), Minorca, Ancona	**White** eggs; light layers; White Leghorn = **best egg-layer**
American	**Rhode Island Red**, **Plymouth Rock**, New Hampshire, Wyandotte	Brown eggs; dual purpose; Plymouth Rock = female line of broilers
English	**Cornish**, Australorp, Orpington, Sussex	Brown eggs; **Cornish** = male line of commercial broilers
Asiatic	Brahma, Cochin, Langshan	Heavy, meat; brown eggs

- **Layers** start laying at about **18–20 weeks**, peak at 26–30 weeks, and lay about **300+ eggs/year**. They need **16 h of light/day** and **3.5–4% calcium** in the ration for shell formation.
- **Broilers** reach market weight of about **2 kg in 5–6 weeks**, with an **FCR ≈ 1.6–1.8** (feed conversion ratio = feed consumed ÷ weight gained).
- **Brooding**: about **35 °C (95 °F)** in week 1, reduced by ~3 °C (5 °F) each week down to about 21 °C. Other practices: **beak trimming** (debeaking) to prevent cannibalism, and **forced moulting** to start a second laying cycle.

Bird	Incubation period (days)
Chicken	**21**
Japanese quail	**17–18** (shortest)
Guinea fowl	26–28
Duck, turkey	**28**
Goose	≈ 30 (28–33)
Muscovy duck	35
Ostrich; emu	≈ 42; ≈ 48–52

- **Incubator conditions:** temperature **37.5 °C (99.5 °F)**; relative humidity about 55–60% in the setter and 65–75% in the hatcher; eggs are **turned** several times a day up to day 18, then moved to the hatcher. **Candling** (on about days 7 and 18) removes infertile eggs and dead embryos.
- **Egg facts:** an egg weighs about **55–60 g**, made up of shell ≈ 10–12%, albumen (white) ≈ **56–60%** and yolk ≈ **30–32%**. The shell is about **94% $CaCO_3$** and has thousands of pores. The **air cell** is at the **broad end**. The major white protein is **ovalbumin**; **avidin** binds biotin. Yolk colour comes from **xanthophylls**. Albumen quality is measured as the **Haugh unit**. Shell colour depends on the **breed**, not on nutritive value.
- **Poultry diseases:** Ranikhet/ND (virus); **Marek's disease** (herpesvirus; **HVT vaccine** at **day 1**); **Gumboro / IBD** (Birnavirus, bursa damage); fowl pox (wing-web vaccination); **coccidiosis** (*Eimeria tenella*, **bloody droppings**; coccidiostats); CRD (*Mycoplasma gallisepticum*); pullorum (*Salmonella*, white diarrhoea); bird flu (H5N1).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Incubation period of a chicken egg? → **21 days**.
- Incubation period of duck and turkey eggs? → **28 days**.
- Best egg-laying breed of fowl? → **White Leghorn**.
- Black-meat indigenous chicken breed? → **Kadaknath** (MP).
- The air cell of an egg lies at the? → **Broad end**.

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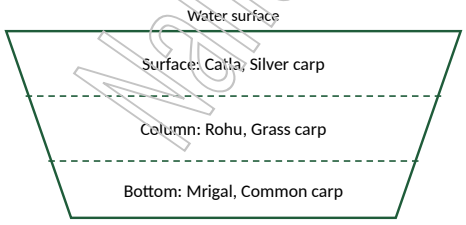
Fisheries

CODE UPDATE

Fish production in 2024-25 was **197.75 lakh tonnes**, making India the **2nd largest** producer in the world (~8%). It has risen 106% from 95.79 lakh t in 2013-14. **Inland fisheries** (mainly aquaculture) give about **75%** of production and marine about 25%. Fisheries is the **fastest-growing agri sub-sector** (~8.8%/yr, FY16–FY25) and supports about 3 crore fishers and fish farmers. Seafood exports in 2024-25 were ₹62,408 cr, and **frozen shrimp** is the top export item.

- **Top fish-producing state** is **Andhra Pradesh** (inland and shrimp). **West Bengal** is 2nd and is the largest **fish seed** producer. Coastline ≈ **11,099 km** (revised); EEZ ≈ **2.02 million km²**.
- A separate **Department of Fisheries** has existed since **2019**, under the Ministry of Fisheries, Animal Husbandry & Dairying.
- **Induced breeding** (hypophysation) of carps was first achieved by **Dr Hiralal Chaudhuri** and **Dr K.H. Alikunhi** on **10 July 1957**, which is why 10 July is National Fish Farmers Day. Early work used **pituitary extract**; synthetic preparations are now used, such as **Ovaprim** / Ovatide (GnRH analogue + domperidone). Breeding is done in a **Chinese (circular) hatchery**.
- **Seed stages:** egg → **spawn** (hatchling, 3–4 days) → **fry** (~1 inch, 15–20 days) → **fingerling** (~3–4 inches, 2–3 months) → yearling / table fish.

Carp	Scientific name	Feeding zone	Food
Catla (IMC)	*Catla catla*	**Surface**	Zooplankton; fastest-growing IMC
Rohu (IMC)	*Labeo rohita*	**Column** (mid-water)	Plankton and decaying vegetation; most popular
Mrigal (IMC)	*Cirrhinus mrigala*	**Bottom**	Detritus
Calbasu (minor IMC)	*Labeo calbasu*	Bottom	Detritus, insect larvae
Silver carp (exotic)	*Hypophthalmichthys molitrix*	Surface	**Phytoplankton**
Grass carp (exotic)	*Ctenopharyngodon idella*	Column / all zones	**Aquatic weeds** (macrophytes); used for weed control
Common carp (exotic)	*Cyprinus carpio*	Bottom	Omnivore, detritus; breeds in ponds



Feeding zones exploited in six-species composite fish culture

- **Composite fish culture** stocks fast-growing, compatible species that feed in different zones so that **all natural food niches** of the pond are used without competition. It uses 3 IMC + 3 exotic carps (6 species), with surface, column and bottom feeders each making up roughly one-third of the stock. Stocking is about **5,000–8,000 fingerlings/ha**, and yield is about **4–6 t/ha/yr** (10+ t with intensive feeding). The technology was developed by ICAR-CIFRI/CIFA in the 1970s.
- **Pond preparation:** drying and ploughing; **liming** ($CaCO_3$ 200–500 kg/ha); killing predatory and weed fish with **mahua oil cake** (**250 ppm**; its active principle is **saponin**, and it later acts as manure), bleaching powder or tea-seed cake; then manuring (cow dung) and fertilising. Ideal water: pH **7.5–8.5**, dissolved oxygen > **5 mg/L**, transparency 30–40 cm.
- **Integrated farming:** fish-cum-paddy, fish-cum-duck, fish-cum-poultry, fish-cum-pig and fish-cum-cattle systems. **Sewage-fed fisheries** are practised in the **East Kolkata Wetlands** (bheries; a Ramsar site).
- **Modern systems: RAS** (recirculatory aquaculture system); **biofloc** (C:N > 15:1, in which microbes convert waste to protein); cage culture in reservoirs; pen culture; aquaponics; seaweed farming (*Kappaphycus*, Tamil Nadu).
- Other species: **catfish** – magur (*Clarias batrachus*), singhi (*Heteropneustes fossilis*), pangasius; **African catfish** (*Clarias gariepinus*) is **banned**. **Tilapia** (*Oreochromis niloticus*; GIFT strain). Coldwater fish: rainbow trout and **mahseer** (*Tor* spp., "tiger of water"). Brackish-water fish: milkfish (*Chanos chanos*), seabass/bhetki (*Lates calcarifer*), and **pearl spot** (*Etroplus suratensis*, Kerala's state fish "karimeen").
- **Shrimp: Pacific white shrimp** (*Litopenaeus vannamei*, introduced 2009) is the **most farmed** shrimp. Others are tiger shrimp (*Penaeus monodon*) and the giant freshwater prawn (*Macrobrachium rosenbergii*, "scampi"). Main shrimp diseases are **WSSV** (white spot) and EHP.
- **Marine catch:** the **oil sardine** (*Sardinella longiceps*) is the top marine catch; others are the Indian mackerel (*Rastrelliger kanagurta*) and Bombay duck (*Harpadon nehereus*). **Hilsa** (*Tenualosa ilisha*) is **anadromous** (migrates from the sea to rivers to breed).
- The uniform **monsoon fishing ban** lasts **61 days**: east coast 15 Apr–14 Jun, west coast 1 Jun–31 Jul. Potential Fishing Zone (PFZ) advisories come from **INCOIS, Hyderabad**.
- **Preservation:** icing (fish:ice 1:1), freezing (−18 to −40 °C; IQF), canning, salting, drying and smoking. Products include **surimi** and fish meal. Spoilage indicators are **TMA** (trimethylamine, the **fishy odour**), TVB-N and histamine (scombroid poisoning). Fish is rich in **omega-3 fatty acids** (EPA, DHA).
- The most important fish disease in carps is **EUS** (epizootic ulcerative syndrome, caused by the oomycete *Aphanomyces invadans*).

Scheme / fund	Year / outlay	Key features
Blue Revolution ("Neel Kranti") scheme	2015-16 to 2019-20; ₹3,000 cr	Integrated development and management of fisheries; merged into PMMSY. Dr Hiralal Chaudhuri is called the father of the Blue Revolution (induced breeding)
PMMSY – Pradhan Mantri Matsya Sampada Yojana	Launched **10 Sep 2020**; **₹20,050 cr** (2020-21 to 2024-25, extended to 2025-26)	Flagship fisheries scheme with production, infrastructure and post-harvest components. Assistance is **60% for women/SC/ST** and **40% for others**. Supports RAS, biofloc, cage culture, fishers' insurance and livelihood support during the ban. Production target was 220 lakh t. Budget 2026-27: ₹2,500 cr

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PM-MKSSY (Matsya Kisan Samridhi Sah-Yojana)	Feb 2024; ₹6,000 cr (to 2026-27)	Central sub-scheme of PMMSY: **National Fisheries Digital Platform (NFDP)**, aquaculture insurance, performance grants, traceability
FIDF – Fisheries & Aquaculture Infrastructure Development Fund	**2018-19**; **₹7,522 cr**; extended to Mar 2026	**3% interest subvention**; loans at not less than **5%** through **NABARD, NCDC** and scheduled banks; for fishing harbours, landing centres and cold chains

- Institutes: **CIFA – Bhubaneswar** (freshwater aquaculture); **CIFRI – Barrackpore** (inland fisheries); **CMFRI** and **CIFT – Kochi**; **CIBA – Chennai** (brackish water); **CIFE – Mumbai** (deemed university); NBFGR – Lucknow; DCFR – Bhimtal; **NFDB – Hyderabad** (2006); **MPEDA – Kochi** (1972, seafood exports); Coastal Aquaculture Authority – Chennai (CAA Act 2005).

MEMORY TRICK

IMC zones "**C-R-M = Top-Middle-Bottom**" (Catla, Rohu, Mrigal). Exotic partners: **S**ilver with Catla on the **S**urface, **G**rass in the column eating **G**reens, **C**ommon with Mrigal on the bottom (**C**ommon = **C**rawler).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Surface feeder among the Indian major carps? → **Catla**.
- Exotic carp used to control aquatic weeds? → **Grass carp** (*Ctenopharyngodon idella*).
- Fish production of India in 2024-25? → **197.75 lakh tonnes**.
- Total outlay of PMMSY? → **₹20,050 crore**.
- Interest subvention under FIDF? → **3%**.
- Piscicide used in pond preparation, with its active principle? → **Mahua oil cake – saponin**.

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4. Plant Protection – Diseases, Pests & IPM

> **NOTE**
> Most questions are straight matches: disease → pathogen, pest → scientific name/order, virus → vector, bio-agent → target, label colour → toxicity. Learn the crop-wise tables first, then the history "firsts", IPM terms (ETL/EIL) and the regulatory bodies (PPQS, CIB&RC, DIP Act 1914). This chapter covers **field** crop protection only; storage insects, rodents, fumigation (phosphine, methyl bromide) and insecticide toxicology/antidotes are in **Chapter 10**.

4.1 Plant Pathology Basics & History ★★☆

- **Plant pathology (phytopathology)** = study of plant diseases – causes, mechanism, losses and management. **Disease** = continuous malfunction caused by a persistent agent; **injury** = momentary damage (e.g. insect bite, hail).
- **Disease triangle** = **susceptible host + virulent pathogen + favourable environment**; all three must coincide. Adding **time** gives the **disease tetrahedron/pyramid** (some add **man** as the fifth factor).
- **Pathogenicity** = ability to cause disease (qualitative); **virulence** = degree of pathogenicity (quantitative); **aggressiveness** = speed/amount of disease.
- **Obligate parasites** (biotrophs) grow only on living hosts – **rusts, powdery mildews, downy mildews, viruses, phytoplasma**; cannot be cultured on artificial media. **Facultative** parasites/saprophytes (Pythium, Fusarium, Rhizoctonia) can.
- **Incubation period** = inoculation → first symptom; **latent period** = infection → new inoculum produced.
- **Primary inoculum** starts disease in a season (seed, soil, alternate/collateral host); **secondary inoculum** spreads it within the season.
- **Monocyclic** ("simple interest") – one cycle/season (loose smut, wilts); **polycyclic** ("compound interest") – many cycles (rusts, late blight, blast). Terms by **J.E. Van der Plank** (*Plant Diseases: Epidemics and Control*, 1963) – father of epidemiology.
- Occurrence: **endemic** (constantly present in an area), **epidemic/epiphytotic** (sudden widespread outbreak), **sporadic** (irregular), **pandemic** (continent-wide).
- Spread: **seed-borne** (loose smut, bakanae, Karnal bunt), **soil-borne** (wilts, root rots, damping-off), **air-borne** (rusts, blast, powdery mildew).

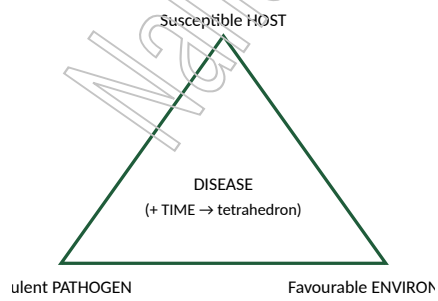

Fig 4.1 Disease triangle – remove any one side and disease does not develop.

Koch's postulates (Robert Koch, 1876–1882 – anthrax/TB)
1. The suspected pathogen must be **constantly associated** with the disease.
2. It must be **isolated and grown in pure culture** (studied on artificial medium).
3. Pure culture **inoculated** on a healthy host must reproduce the **same symptoms**.
4. The same organism must be **re-isolated** from the inoculated plant.

- Purpose: to **prove that a given organism causes a disease (pathogenicity)**. For obligate parasites (rusts, viruses) step 2 is modified – inoculum is maintained on living plants.

Year	Milestone	Person
c. 300 BC	First described plant diseases; **father of botany**	**Theophrastus**
1729	**Father of mycology**; first observed fungal spores	**P.A. Micheli**
1755	Wheat bunt is contagious (via spore dust)	M. Tillet
1807	First proof that a microorganism (bunt fungus) causes disease; copper sulphate inhibits spores	**B. Prevost**
1858	First textbook of plant pathology	Julius Kühn
1861–65	Proved *Phytophthora infestans* causes late blight; heteroecism of wheat stem rust (barberry)	**Anton de Bary – father of (modern) plant pathology**
1878	First bacterial plant disease – **fire blight of pear/apple** (*Erwinia amylovora*)	**T.J. Burrill**
1882–85	**Bordeaux mixture** (downy mildew of grapes)	**P.M.A. Millardet**
1892 / 1898	Tobacco mosaic agent passes bacterial filters / "contagium vivum fluidum"	**D. Ivanowski / M.W. Beijerinck**
1935	**TMV crystallised** (Nobel 1946)	**W.M. Stanley**
c. 1900s	**Father of phytobacteriology**	**E.F. Smith**
—	**Father of nematology**	**N.A. Cobb**
1942–56	**Gene-for-gene hypothesis** (flax rust)	**H.H. Flor**
1967	**Phytoplasma (MLO)** discovered (Japan)	**Doi et al.**
1971	First **viroid** – Potato spindle tuber viroid (PSTVd)	**T.O. Diener**

- **India: E.J. Butler – father of Indian plant pathology and Indian mycology**; first Imperial Mycologist (Pusa, 1905); book **"Fungi and Disease in Plants" (1918)**; later first director of the Imperial Mycological Institute, Kew.
- **K.C. Mehta** – wheat rust epidemiology in India: rust survives the hot summer as uredospores in the **Nilgiri & Palni hills (south) and the Himalaya (north)** and re-infects the plains each year; barberry plays no role in India.
- **B.B. Mundkur** – founded the **Indian Phytopathological Society (1947)**.
- **Karnal bunt** first reported by M. Mitra at **Karnal (Haryana), 1931**.

Famous epidemic	Disease – pathogen
Irish famine (1845–47) – ~1 million deaths, mass emigration	**Late blight of potato – *Phytophthora infestans***

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Bengal famine (1942–43)	**Brown spot of rice – *Helminthosporium oryzae* (= *Bipolaris oryzae*; sexual stage *Cochliobolus miyabeanus*)**
Coffee rust, Ceylon (Sri Lanka), 1870s	*Hemileia vastatrix* – Ceylon shifted from coffee to **tea**
Southern corn leaf blight, USA, 1970	*Bipolaris (Helminthosporium) maydis* race T – maize with **Texas male-sterile (T) cytoplasm**
Wheat stem rust race **Ug99**	*Puccinia graminis tritici* – Uganda, 1999
Wheat blast, Bangladesh, 2016	*Magnaporthe oryzae* pathotype *Triticum* – first in Asia

Pathogen group	Key features	Examples
Fungi	Eukaryotic, chitin cell wall, spores; cause **most (~70–80%)** plant diseases	Rusts, smuts, blast, wilts
Oomycetes ("water moulds")	Now kingdom Chromista/Stramenopila; **cellulose** wall, **oospores**, biflagellate zoospores	Pythium, Phytophthora, downy mildews, *Albugo*
Bacteria	Prokaryotic, mostly **Gram-negative rods**; enter via wounds/stomata/hydathodes	Xanthomonas, Ralstonia, Pectobacterium
Viruses	Nucleoprotein; obligate; mostly **(+)ssRNA**; spread by vectors	TMV, YMV, PLRV
Viroids	**Naked, circular ssRNA** (~250–400 nt), no protein coat	PSTVd, coconut cadang-cadang, citrus exocortis
Phytoplasma	Class Mollicutes – **no cell wall**, pleomorphic, phloem-limited; **tetracycline-sensitive**, penicillin-resistant	Little leaf, grassy shoot, phyllody
Nematodes	Round worms with a **stylet**	Root-knot, cyst nematodes
Algae	—	***Cephaleuros virescens* – red rust of tea**
Parasitic flowering plants	See below	Cuscuta, Striga, Orobanche, Loranthus

Fungal class	Sexual spore	Examples
Oomycetes	**Oospore**	Pythium, Phytophthora, Sclerospora, Albugo, Plasmopara
Zygomycetes	**Zygospore**	Rhizopus (soft rot)
Ascomycetes (sac fungi)	**Ascospore** (in ascus)	Powdery mildews (Erysiphe), Claviceps, Venturia
Basidiomycetes (club fungi)	**Basidiospore**	**Rusts, smuts**, Rhizoctonia (sexual stage Thanatephorus)
Deuteromycetes ("fungi imperfecti")	None known – only **conidia**	Alternaria, Fusarium, Colletotrichum, Cercospora, Pyricularia

- **Rust spore stages**: **0** – pycnia (spermogonia), **I** – aecia, **II** – uredia (**repeating**, red/brown), **III** – telia (black, overwintering), **IV** – basidia. Stem rust of wheat is **macrocyclic** (all 5 stages) and **heteroecious** (two hosts) – alternate host **barberry (*Berberis*)**.
- Fungal structures: **haustoria** (absorb food – obligate parasites), **appressoria** (attachment – blast), **sclerotia** (resting bodies – Rhizoctonia, Sclerotinia, ergot), **chlamydospores** (thick-walled – Fusarium, smuts).
- Symptoms: **hypertrophy** (cell enlargement – club root of crucifers, *Plasmodiophora brassicae*), **hyperplasia** (cell multiplication – crown gall), **necrosis**, **chlorosis**, **damping-off** (Pythium – nursery), wilting, mummification.
- **Non-parasitic (abiotic) disorders**: **khaira of rice – zinc deficiency**; **black heart of potato – O_2 deficiency** in storage; **black tip of mango – brick-kiln fumes**; whiptail of cauliflower – Mo deficiency.

Parasitic plant	Type	Hosts
Cuscuta (dodder, amarbel)	**Total stem** parasite (no chlorophyll)	Lucerne, berseem, niger, linseed; also transmits viruses
Loranthus (Dendrophthoe)	**Partial stem** parasite	Mango, fruit trees
Orobanche (broomrape)	**Total root** parasite	Tobacco, mustard, tomato, brinjal
Striga (witchweed)	**Partial root** parasite	Sorghum, maize, sugarcane, bajra

MEMORY TRICK

Famines: "**Irish Potato – Phytophthora; Bengal Rice – Brown spot**" (I-P-P, B-R-B). Parasites: "**CuS-ToS / LoS-PaS, ORo-ToR / STri-PaR**" – Cuscuta total stem, Loranthus partial stem, Orobanche total root, Striga partial root.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- irish famine (1845) was caused by? → **Late blight of potato (*Phytophthora infestans*)**.
- Bengal famine 1943 was due to? → **Brown spot of rice (*Helminthosporium oryzae*)**.
- Father of Indian plant pathology? → **E.J. Butler**.
- First viroid discovered? → **PSTVd, by T.O. Diener (1971)**.
- Gene-for-gene concept was given by? → **H.H. Flor**.
- Alternate host of black stem rust of wheat? → **Barberry**.

4.2 Fungal, Bacterial, Viral & Other Diseases ★★★

(F) fungus/oomycete, (B) bacterium, (V) virus, (P) phytoplasma, (N) nematode.

Crop	Disease	Pathogen	Key symptom / fact
Rice	**Blast**	***Pyricularia oryzae*** (*Magnaporthe oryzae*) (F)	**Spindle/eye-shaped** lesions with grey centre; node & **neck blast** (panicle breaks); most destructive rice disease
Rice	**Brown spot**	*Bipolaris (Helminthosporium) oryzae* (F)	Oval brown "sesame-seed" spots; worse on **nutrient-poor soils**; Bengal famine
Rice	**Bacterial leaf blight (BLB)**	***Xanthomonas oryzae* pv. *oryzae*** (B)	Yellow wavy-margined leaf-tip drying; seedling wilt phase = **"kresek"**

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Rice	**Sheath blight**	***Rhizoctonia solani*** (F)	Oval greenish-grey lesions on sheath – "snake-skin"; sclerotia
Rice	**False smut**	*Ustilaginoidea virens* (F)	Individual grains become **orange → greenish-black velvety balls**
Rice	**Bakanae / foot rot**	***Fusarium fujikuroi*** (F)	**Abnormally tall, thin, pale seedlings** – excess **gibberellin** (GA first isolated from this fungus)
Rice	**Tungro**	RTBV + RTSV (V)	Yellow-orange leaves, stunting; vector **green leafhopper *Nephotettix virescens***
Rice	Grassy stunt, ragged stunt	Viruses (V)	Vector **brown planthopper**
Wheat	**Black/stem rust**	***Puccinia graminis* f. sp. *tritici*** (F)	Elongated reddish-brown pustules on stem; black telia; needs high temp (~20–30 °C) – central & peninsular India
Wheat	**Brown/leaf rust**	*Puccinia triticina* (*P. recondita*) (F)	Small round orange-brown pustules scattered on leaf; most widespread rust
Wheat	**Yellow/stripe rust**	***Puccinia striiformis*** (F)	Lemon-yellow pustules in stripes; cool climate – **north-western plains & hills**
Wheat	**Loose smut**	***Ustilago segetum tritici*** (*U. tritici*) (F)	Ear replaced by black spore mass; **internally seed-borne** (embryo) – **monocyclic**
Wheat	**Karnal bunt (partial bunt)**	***Tilletia indica*** (*Neovossia indica*) (F)	Few grains partly converted to black powder; **fishy smell (trimethylamine)**; **quarantine** importance
Wheat	Flag smut	*Urocystis agropyri* (F)	Black stripes on leaves; soil & seed-borne
Wheat	Powdery mildew	*Blumeria graminis* f. sp. *tritici* (F)	White powdery growth on leaves
Wheat	**Ear cockle + tundu**	***Anguina tritici*** (N) + *Rathayibacter tritici* (B)	Grains replaced by hard dark **nematode galls**; tundu = yellow slime on ear
Maize, sorghum	Downy mildew	*Peronosclerospora sorghi* (F)	Chlorotic streaks, white downy growth
Sorghum	**Grain smut** (covered/kernel smut)	*Sporisorium sorghi* (*Sphacelotheca sorghi*) (F)	Grains replaced by smut sori – controlled by sulphur/fungicide seed treatment
Sorghum	Ergot / **sugary disease**	*Claviceps sorghi* (*Sphacelia sorghi*) (F)	Sticky honeydew from florets
Bajra	**Green ear (downy mildew)**	***Sclerospora graminicola*** (F)	Ear converted into **leafy green structures** (phyllody)
Bajra	**Ergot**	***Claviceps fusiformis*** (F)	Honeydew, then **sclerotia** with toxic alkaloids (ergotism); rye ergot = *C. purpurea*
Bajra	Smut	*Moesziomyces* (*Tolyposporium*) *penicillariae* (F)	Green → black sori in place of grains

Crop	Disease	Pathogen	Key symptom / fact
Gram	**Wilt**	***Fusarium oxysporum* f. sp. *ciceri*** (F)	Drooping, brown vascular tissue; soil-borne
Gram	**Ascochyta blight**	*Ascochyta rabiei* (F)	Concentric lesions on pods/stem; cool wet weather
Pigeonpea	**Wilt**	***Fusarium udum*** (F)	Purple band on stem base
Pigeonpea	**Sterility mosaic** ("green plague")	PPSMV (V)	Bushy, pale, **no flowers/pods**; vector **eriophyid mite *Aceria cajani***
Moong, urd, soybean	**Yellow mosaic**	MYMV (begomovirus) (V)	Bright yellow patches; vector **whitefly *Bemisia tabaci***
Groundnut	**Tikka (early leaf spot)**	***Cercospora arachidicola*** (F)	Reddish-brown spots with **yellow halo**, upper surface
Groundnut	**Tikka (late leaf spot)**	*Phaeoisariopsis personata* (*Nothopassalora personata*) (F)	Darker spots, **no halo**, lower surface
Groundnut	Rust; collar rot	*Puccinia arachidis*; *Aspergillus niger* (F)	Orange pustules on lower leaf; seedling collar rot
Groundnut	**Bud necrosis (PBND)**	GBNV (tospovirus) (V)	Terminal bud necrosis; vector **thrips (*Thrips palmi*)**
Groundnut	Aflatoxin contamination	***Aspergillus flavus*** (F)	Carcinogenic aflatoxin B_1 (see ch10)
Mustard	**White rust**	***Albugo candida*** (F – oomycete)	White blisters under leaf; **"stag-head"** deformed inflorescence
Mustard	**Alternaria blight**	*Alternaria brassicae* (F)	Concentric dark spots on leaves & pods
Mustard	Sclerotinia stem rot	*Sclerotinia sclerotiorum* (F)	White cottony growth, black sclerotia in stem
Sesame	**Phyllody**	Phytoplasma (P)	Flowers → leafy structures; vector **leafhopper *Orosius albicinctus***

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Cotton	**Bacterial blight** (black arm, angular leaf spot)	***Xanthomonas citri* pv. *malvacearum*** (B)	Angular water-soaked spots; black lesions on stem ("black arm")
Cotton	**Leaf curl**	CLCuV (begomovirus) (V)	Upward/downward curling, **leaf enations**; vector **whitefly**; N-India problem
Cotton	Wilt; root rot	*F. oxysporum* f. sp. *vasinfectum*; *Rhizoctonia bataticola* (*Macrophomina phaseolina*) (F)	Vascular browning; dry root rot
Sugarcane	**Red rot** ("cancer of sugarcane")	***Colletotrichum falcatum*** (F)	Internal tissue **red with white cross-bands**; **sour/alcoholic smell**; sett-borne
Sugarcane	**Whip smut**	*Sporisorium (Ustilago) scitamineum* (F)	Long **black whip** from growing point
Sugarcane	**Grassy shoot (GSD)**	Phytoplasma (P)	Numerous thin grassy tillers; spread mainly by infected setts
Sugarcane	**Ratoon stunting (RSD)**	*Leifsonia xyli* subsp. *xyli* (B, Gram +)	Stunted ratoons; no external symptom; hot-water sett treatment

Crop	Disease	Pathogen	Key symptom / fact
Potato	**Late blight**	***Phytophthora infestans*** (F – oomycete)	Water-soaked dark lesions, white growth below; **cool humid** weather; forecasting model **JHULSACAST** (ICAR-CPRI, Shimla)
Potato	**Early blight**	***Alternaria solani*** (F)	**Concentric rings – "target board"** spots
Potato	Black scurf	*Rhizoctonia solani* (F)	Black sclerotia on tuber skin
Potato	**Common scab**	***Streptomyces scabies*** (actinomycete, B)	Corky scabby lesions; favoured by **alkaline** soil
Potato	**Wart**	***Synchytrium endobioticum*** (F)	Cauliflower-like warts; **Darjeeling – domestic quarantine**
Potato	Brown rot / bacterial wilt	*Ralstonia solanacearum* (B)	Bacterial ooze from cut stem
Potato	**Leaf roll**; mosaic	PLRV; PVY, PVX (V)	PLRV – aphid ***Myzus persicae*** (persistent); PVX – contact/sap (no vector)
Tomato	**Leaf curl**; spotted wilt	ToLCV (whitefly); TSWV (thrips) (V)	Curling, stunting / bronzing, ring spots
Tomato, brinjal, chilli	**Bacterial wilt**	***Ralstonia solanacearum*** (B)	Sudden wilting of green plant; **ooze test** in water
Brinjal	**Little leaf**	Phytoplasma (P)	Tiny leaves, bushy plant, no fruit; vector **leafhopper *Hishimonus phycitis***
Chilli	Die-back / anthracnose	*Colletotrichum capsici* (F)	Twigs die from tip; fruit rot
Bhindi	**Yellow vein mosaic**	YVMV (V)	Vein yellowing; vector **whitefly**; tolerant var. **Parbhani Kranti**
Crucifers	Club root; black rot	*Plasmodiophora brassicae*; *Xanthomonas campestris* pv. *campestris* (B)	Swollen roots / **V-shaped** yellow lesions, black veins
Cucurbits	Downy mildew; powdery mildew	*Pseudoperonospora cubensis*; *Erysiphe cichoracearum* (F)	Angular yellow spots / white powder (cucurbits are sulphur-shy)
Banana	**Panama wilt**	***Fusarium oxysporum* f. sp. *cubense*** (F)	Yellowing, splitting pseudostem; TR4 race is a global threat
Banana	**Bunchy top**	BBTV (V)	Leaves bunched at top, "Morse code" streaks; vector **banana aphid *Pentalonia nigronervosa***
Banana	Sigatoka leaf spot; Moko	*Mycosphaerella musicola* (F); *Ralstonia solanacearum* (B)	Spindle leaf spots / wilt
Mango	Powdery mildew; anthracnose; **malformation**	*Oidium mangiferae*; *Colletotrichum gloeosporioides*; ***Fusarium mangiferae*** (F)	Malformation = bunchy vegetative shoots / panicles (mite also implicated)
Citrus	**Canker**	***Xanthomonas citri* subsp. *citri*** (B)	Raised corky lesions with yellow halo (acid lime most susceptible)
Citrus	**Greening (Huanglongbing, HLB)**	*Candidatus* Liberibacter asiaticus (B, phloem-limited)	Blotchy mottle, lopsided fruit; vector **psyllid *Diaphorina citri***
Citrus	**Tristeza** (quick decline)	CTV (V)	Vector **brown citrus aphid *Toxoptera citricida***

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Grapes	**Downy mildew**; powdery mildew; anthracnose	***Plasmopara viticola***; *Erysiphe (Uncinula) necator*; *Elsinoe ampelina* (F)	Bordeaux mixture was invented for downy mildew; anthracnose = "bird's-eye spot"
Apple	**Scab**	***Venturia inaequalis*** (F)	Olive-black scabby spots (J&K, HP)
Papaya	**Ring spot**	PRSV (V)	Rings on fruit; vector **aphid** (non-persistent)
Coffee	**Leaf rust**	***Hemileia vastatrix*** (F)	Orange powdery spots under leaf
Tea	**Blister blight**; red rust	***Exobasidium vexans*** (F); *Cephaleuros virescens* (alga)	Blisters on young leaves / rusty patches on stem
Coconut	Bud rot; **root (wilt)**; Thanjavur wilt	*Phytophthora palmivora*; phytoplasma (Kerala); *Ganoderma lucidum*	Root wilt vector – lace bug *Stephanitis typica*; Thanjavur wilt = basal stem rot

Bacterial diseases – quick facts

- Most phytopathogenic bacteria are **Gram-negative, rod-shaped, non-spore-forming**; exceptions (Gram +): **Clavibacter, Leifsonia, Streptomyces**.
- ***Xanthomonas*** – yellow pigment **xanthomonadin**; causes BLB of rice, citrus canker, black arm of cotton, black rot of crucifers.
- ***Ralstonia solanacearum*** – wilts of solanaceous crops, banana moko; **bacterial ooze test**.
- ***Pectobacterium (Erwinia) carotovorum*** – **soft rot** (pectolytic enzymes) of potato, vegetables in transit/storage.
- ***Agrobacterium tumefaciens*** – **crown gall**; **Ti plasmid** – natural genetic engineer, used to make transgenic plants. *A. rhizogenes* – hairy root (Ri plasmid).
- Control: **streptocycline** (streptomycin sulphate + tetracycline HCl, 9 : 1), **copper oxychloride**, hot-water treatment, resistant varieties.

Viruses, viroids & phytoplasma

- Most plant viruses are **(+) ssRNA** (TMV – rod-shaped). **Geminiviruses** (twin particles) = **ssDNA** – begomoviruses: YMV, leaf curl, YVMV, all **whitefly-borne**. **Caulimoviruses** (CaMV) = **dsDNA** – source of the **CaMV 35S promoter**. Tospoviruses (TSWV, GBNV) – **thrips**.
- Transmission: insect vectors (aphids ≈ largest group of vectors), mites, nematodes (*Xiphinema*, *Longidorus*), fungi (*Olpidium*, *Polymyxa*), sap/contact (TMV, PVX), seed, grafting, **dodder**.
- Aphid–virus relationships: **non-persistent/stylet-borne** (PVY, CMV, PRSV – acquired in seconds, lost quickly) · **semi-persistent** (CTV) · **persistent/circulative** (PLRV; begomoviruses in whitefly) · **propagative** (multiplies in vector – TSWV in thrips).
- Symptoms: mosaic, mottling, vein clearing, leaf curl, ring spot, stunting, yellowing. Control: vector control, roguing, **virus-free seed/planting material (meristem-tip culture, thermotherapy)**, resistant varieties, **cross-protection** (mild strain – CTV, PRSV).
- **Viroids** – PSTVd (potato), coconut cadang-cadang (Philippines), citrus exocortis, chrysanthemum stunt.
- **Phytoplasma diseases** (vector mostly **leafhoppers**): brinjal little leaf, sugarcane grassy shoot, sesame phyllody, coconut root (wilt), sandal spike, rice yellow dwarf; respond to **tetracycline**.

Vector	Diseases transmitted
Whitefly (*Bemisia tabaci*)	Yellow mosaic (moong, urd, soybean), cotton leaf curl, tomato leaf curl, bhindi YVMV, chilli leaf curl
Aphids	Potato leaf roll & PVY (*Myzus persicae*), banana bunchy top, citrus tristeza, papaya ring spot, groundnut rosette, CMV
Thrips	Tomato spotted wilt, groundnut bud necrosis, sunflower necrosis
Leafhoppers	Rice tungro (*Nephotettix*), brinjal little leaf (*Hishimonus*), sesame phyllody (*Orosius*)
Planthopper (BPH)	Rice grassy stunt, ragged stunt
Psyllid (*Diaphorina citri*)	Citrus greening
Eriophyid mite (*Aceria cajani*)	Pigeonpea sterility mosaic

Plant-parasitic nematodes

Nematode	Disease / crop
***Meloidogyne* spp.** (*M. incognita*)	**Root-knot** – galls on roots of vegetables, pulses, banana; sedentary endoparasite; female pear-shaped; induces **giant cells**
Heterodera avenae	**Molya disease** of wheat & barley (cereal cyst nematode) – Rajasthan, Haryana
Anguina tritici	**Ear cockle** of wheat (seed galls); with bacterium → tundu
Ditylenchus angustus	**Ufra** of deep-water rice (Assam, WB, Bangladesh)
Aphelenchoides besseyi	**White tip** of rice (seed-borne)
Globodera rostochiensis	**Golden cyst nematode** of potato – **Nilgiris (1961)**; domestic quarantine
Radopholus similis	**Burrowing nematode** – banana toppling, black pepper slow decline
Tylenchulus semipenetrans	**Citrus slow decline**
Rotylenchulus reniformis	**Reniform nematode** – cotton, vegetables

- Nematode management: **summer ploughing**, crop rotation, **soil solarisation**, trap/antagonistic crop **marigold (*Tagetes*)**, neem cake, bio-agents ***Purpureocillium (Paecilomyces) lilacinum*** and ***Pochonia chlamydosporia***, nematicides (carbofuran – now restricted).

MEMORY TRICK

Vectors "**W-A-T-L-M**": **W**hitefly → yellow mosaic & leaf curls · **A**phid → leaf roll, bunchy top, tristeza, ring spot · **T**hrips → spotted wilt, bud necrosis · **L**eafhopper → tungro, little leaf, phyllody · **M**ite → sterility mosaic. Rusts of wheat: "**Black-Stem, Brown-Leaf, Yellow-Stripe**".

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PREVIOUSLY ASKED / LIKELY QUESTIONS

- Pathogen of rice blast? → ***Pyricularia oryzae* (*Magnaporthe oryzae*)**.
- "Kresek" is a phase of? → **Bacterial leaf blight of rice**.
- Karnal bunt of wheat is caused by? → ***Tilletia indica***.
- Vector of yellow mosaic of moong? → **Whitefly (*Bemisia tabaci*)**.
- "Cancer of sugarcane"? → **Red rot (*Colletotrichum falcatum*)**.
- Molya disease of wheat is caused by? → ***Heterodera avenae***.

4.3 Disease Management & Fungicides ★★☆

Principle (Whetzel, extended)	Meaning	Examples
Exclusion	Keep pathogen out of an area	**Plant quarantine**, certified seed, seed treatment
Eradication	Remove pathogen already present	Roguing, crop rotation, destroying **alternate/collateral hosts**, soil solarisation
Protection	Barrier between host and pathogen	Protectant sprays – **mancozeb, Bordeaux**
Immunisation / resistance	Use resistant varieties	Rust-resistant wheat, BLB-resistant rice (Improved Samba Mahsuri)
Therapy	Cure infected plant	Hot-water treatment, systemic fungicides, antibiotics
Avoidance	Escape by timing/site	Adjusting sowing date, disease-free area

Cultural & physical methods

- **Hot-water treatment for loose smut** of wheat (**Jensen**): pre-soak seed in water ~4 h, then dip at **52 °C for 10 min**; kills internally seed-borne mycelium without killing embryo.
- **Solar heat treatment** for loose smut (**Luthra**): soak seed 4 h in the morning in summer, then dry in hot sun.
- Sugarcane setts: **hot water ~50 °C for 2 h** (ratoon stunting); moist hot air / aerated steam therapy against grassy shoot.
- **Soil solarisation** – cover moist soil with **transparent polythene** (25–50 µm) for 4–6 weeks in summer; controls soil-borne fungi, nematodes, weeds.
- Crop rotation, deep summer ploughing, clean cultivation, balanced fertilisation (excess N favours blast, BLB, sheath blight), proper spacing, drainage, roguing (virus/phytoplasma plants), destruction of crop residue.
- **Resistance**: **vertical** (race-specific, monogenic/oligogenic, breaks down easily) vs **horizontal** (race-non-specific, polygenic, durable) – **Van der Plank (1963)**.
- **Systemic acquired resistance (SAR)** – signalled by **salicylic acid**; **induced systemic resistance (ISR)** – by rhizobacteria, **jasmonic acid/ethylene** signalling.

Chemical control – fungicides

- **Bordeaux mixture** – discovered by **Millardet (France, 1882; published 1885)** against **downy mildew of grapes**; **1 : 1 : 100 = 1 kg $CuSO_4 \cdot 5H_2O$ + 1 kg quick lime (CaO) + 100 L water** (= 1%). Active compound – basic copper sulphate.
- Preparation: dissolve copper sulphate and lime separately in 50 L each, pour **copper sulphate solution into lime**, use **earthen/wooden/plastic** vessels (not iron). **Neutrality test** – dip a **polished iron knife/blade**: a reddish copper deposit = acidic (add more lime). Use the same day.
- **Bordeaux paste** = **1 : 1 : 10** – wound/stump dressing (e.g. gummosis). **Burgundy mixture** = $CuSO_4$ + **sodium carbonate**. **Cheshunt compound** = $CuSO_4$ + ammonium carbonate (damping-off). **Chaubattia paste** = copper carbonate + red lead + lanolin/linseed oil – pruning-wound dressing in apple.
- **Sulphur** (wettable sulphur, dusting sulphur, **lime sulphur** = calcium polysulphide) – **powdery mildews** and mites; **cucurbits are "sulphur-shy"** (phytotoxic). Oldest fungicide (Homer).
- **Protectant (contact)** fungicides act on the surface before infection; **systemic** fungicides are absorbed and translocated (mostly **acropetally in xylem**) and can cure early infection. **Fosetyl-Al** is **ambimobile** (moves both up and down).
- **Carboxin** (Vitavax) – **first systemic fungicide** (von Schmeling & Kulka, **1966**).
- **Dithiocarbamates** – first organic fungicides (Tisdale & Williams, 1934).

Group	Examples (trade name)	Main use
Inorganic copper	Bordeaux mixture, **copper oxychloride (Blitox)**, copper hydroxide	Downy mildews, blights, bacterial diseases
Inorganic sulphur	Wettable sulphur, lime sulphur	**Powdery mildews**, mites
Dithiocarbamates	**Mancozeb (Dithane M-45 – Mn + Zn)**, zineb, ziram, **thiram**	Broad-spectrum protectants; thiram – **seed treatment**
Phthalimides / others	**Captan**, chlorothalonil	Seed treatment, foliar protectant
Benzimidazoles	**Carbendazim (Bavistin)**, thiophanate-methyl (benomyl – banned 2018)	Systemic – wilts, seed/soil-borne, powdery mildew
Oxathiins (carboxamides)	**Carboxin (Vitavax)**	**Loose smut** (systemic seed dressing)
Phenylamides	**Metalaxyl (Ridomil)**	**Oomycetes only** – late blight, downy mildews, damping-off, white rust
Triazoles (sterol/ergosterol biosynthesis inhibitors)	**Propiconazole (Tilt)**, hexaconazole, tebuconazole	**Rusts**, sheath blight, smuts
Strobilurins (QoI – from mushroom *Strobilurus tenacellus*)	Azoxystrobin, trifloxystrobin	Broad-spectrum systemic
Melanin biosynthesis inhibitor	**Tricyclazole (Beam)**	**Rice blast**
Antibiotics	**Validamycin** (sheath blight), kasugamycin & blasticidin-S (blast), **streptocycline** (bacteria), aureofungin	—
Organomercurials	Ceresan, Agallol (methoxy ethyl mercury chloride)	**Banned** (mercury toxicity)

Seed treatment

- Cheapest, most effective protection against seed- and soil-borne pathogens. Equipment: **seed-treating drum** (rotary seed dresser).

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- Typical doses: **thiram / captan 2–3 g/kg**, **carbendazim 2 g/kg**, **carboxin 2 g/kg** (loose smut), **metalaxyl 6 g/kg** (downy mildew of bajra/maize, white rust), ***Trichoderma* 4–10 g/kg**, ***Pseudomonas fluorescens* 10 g/kg**.
- Sequence: **F-I-R = Fungicide → Insecticide → Rhizobium/biofertiliser** (biofertiliser last, just before sowing). Chemical fungicides and biofertilisers/bio-agents are generally not mixed together.

Biological control of diseases

Bio-agent	Type	Mechanism / target
Trichoderma viride*, *T. harzianum	Fungus	**Mycoparasitism**, antibiosis (gliotoxin, viridin), competition; wilts, root rots, damping-off; seed (4–10 g/kg) & soil application with FYM
Pseudomonas fluorescens	Bacterium (PGPR)	**Siderophores** (pyoverdine – iron competition), antibiotics (2,4-DAPG), ISR; rice blast, sheath blight, wilts
Bacillus subtilis	Bacterium	Antibiosis; seed/soil-borne diseases
Ampelomyces quisqualis	Fungus	**Hyperparasite of powdery mildews**
Purpureocillium lilacinum, *Pochonia chlamydosporia*	Fungi	**Nematode** egg parasites
Mild virus strain	—	**Cross-protection** (CTV, PRSV)

MEMORY TRICK

Bordeaux "**1-1-100 = 1%**" (paste 1-1-10 = 10%). "**Copper for Downy, Sulphur for Powdery, Metalaxyl for Oomycetes, Carboxin for Loose smut, Tricyclazole for Blast, Validamycin for Sheath**".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Bordeaux mixture was discovered by? → **Millardet**.
- Ratio of Bordeaux mixture? → **1 : 1 : 100 ($CuSO_4$: lime : water)**.
- Systemic fungicide for loose smut of wheat? → **Carboxin (Vitavax)**.
- Fungicide specific to Oomycetes (late blight, downy mildew)? → **Metalaxyl**.
- Hot-water treatment of wheat seed for loose smut? → **52 °C for 10 min**.
- Main mechanism of *Trichoderma*? → **Mycoparasitism (+ antibiosis, competition)**.

4.4 Field Insect Pests ★★★

- Insects – class **Insecta**, phylum **Arthropoda**; body = head + thorax + abdomen; **3 pairs of legs**; usually 2 pairs of wings. **Mites** (4 pairs of legs, class Arachnida) are controlled by **acaricides**.
- Father of entomology – **Aristotle**; modern – William Kirby; Indian economic entomology – **T.V. Ramakrishna Ayyar**.
- Metamorphosis: **complete (holometabolous)** egg → larva → pupa → adult (beetles, moths, flies, bees); **incomplete (hemimetabolous)** egg → nymph → adult (bugs, grasshoppers, termites). Moulting hormone – **ecdysone** (prothoracic gland); **juvenile hormone** – corpora allata.

Mouthpart type	Insects	Damage / control implication
Chewing (biting)	Grasshoppers, locusts, beetles, caterpillars, termites	Holes, defoliation, borers – **stomach/contact poisons**
Piercing–sucking	Aphids, jassids, whitefly, planthoppers, bugs, mealybugs	Yellowing, curling, honeydew → **sooty mould**, virus transmission – **systemic insecticides**
Rasping–sucking	**Thrips**	Silvery streaks, curling
Siphoning	Adult moths/butterflies	Non-damaging
Chewing–lapping	**Honey bee**	—
Sponging	House fly	—

Order	Key feature	Important pest families
Lepidoptera	Scaly wings; larva = caterpillar – **most crop pests**	Noctuidae (*Helicoverpa*, *Spodoptera*), Crambidae (*Scirpophaga*, *Chilo*, *Leucinodes*), Gelechiidae (*Pectinophora*), Plutellidae
Coleoptera	Hard forewings (**elytra**); **largest insect order**	Curculionidae (weevils), Scarabaeidae (white grub, rhinoceros beetle), Chrysomelidae (hispa, pumpkin beetle), Coccinellidae
Hemiptera	Piercing–sucking; **main virus vectors**	Delphacidae (BPH), Cicadellidae (leafhoppers, jassid), Aleyrodidae (whitefly), Aphididae, Pseudococcidae (mealybugs), Psyllidae, Pentatomidae
Diptera	One pair of wings + **halteres**	Cecidomyiidae (gall midge), Tephritidae (fruit flies), Muscidae (shoot fly), Agromyzidae (pod fly, leaf miner)
Orthoptera	Jumping hind legs, stridulation	Acrididae (locusts, grasshoppers)
Thysanoptera	**Fringed wings**	Thripidae
Isoptera (now in Blattodea)	Social, caste system	Termitidae (*Odontotermes*, *Microtermes*)
Hymenoptera	Membranous wings; **most beneficial order**	Bees, parasitoid wasps (*Trichogramma*); pests – sawfly

Crop-wise major field pests

Crop	Pest	Scientific name	Order	Dama sympt
Rice	**Yellow stem borer**	***Scirpophaga incertulas***	Lepidoptera	**Dead** (veget **white** (repro
Rice	**Brown planthopper (BPH)**	***Nilaparvata lugens***	Hemiptera	Circul patch **"hopp burn"** of gra ragge classic **resurg** pest
Rice	**Green leafhopper**	*Nephotettix virescens*	Hemiptera	Vecto **tungr**

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Rice	**Gall midge**	***Orseolia oryzae***	Diptera	**"Silver shoot" / "onion leaf"** – tubular gall
Rice	Leaf folder	*Cnaphalocrocis medinalis*	Lepidoptera	Folds leaf, scrapes green tissue
Rice	**Gundhi / ear-head bug**	*Leptocorisa acuta*	Hemiptera	Sucks **milky grains** → chaffy; foul smell
Rice	Hispa	*Dicladispa armigera*	Coleoptera	White parallel streaks (scraping), leaf mining
Wheat	Termites; aphids	*Odontotermes obesus*, *Microtermes*; *Rhopalosiphum maidis*, *Sitobion avenae*	Isoptera; Hemiptera	Plants dry, easily pulled / honeydew
Wheat, maize	Pink stem borer	*Sesamia inferens*	Lepidoptera	Dead heart
Maize, sorghum	**Spotted stem borer**	***Chilo partellus***	Lepidoptera	"Shot holes" in leaves, dead heart
Maize	**Fall armyworm**	***Spodoptera frugiperda***	Lepidoptera	Whorl feeding, ragged holes, sawdust-like frass
Sorghum	**Shoot fly**	***Atherigona soccata***	Diptera	**Dead heart** in seedlings (late sowing ↑ attack)
Sugarcane	**Early shoot borer**	***Chilo infuscatellus***	Lepidoptera	Dead heart (easily pulled, **foul smell**) in young crop
Sugarcane	**Top borer**	*Scirpophaga excerptalis*	Lepidoptera	Dead heart (not easily pulled), **bunchy top**, red tunnel in midrib
Sugarcane	**Pyrilla (leafhopper)**	***Pyrilla perpusilla***	Hemiptera	Sucks sap, honeydew → sooty mould; bio-agent ***Epiricania melanoleuca***
Sugarcane	**Woolly aphid**	*Ceratovacuna lanigera*	Hemiptera	White woolly colonies under leaves; predator *Dipha aphidivora*
Cotton	**American bollworm**	***Helicoverpa armigera***	Lepidoptera	Bores bolls; **highly polyphagous**, resistant to many insecticides
Cotton	**Pink bollworm**	***Pectinophora gossypiella***	Lepidoptera	**"Rosette" flowers**, double seed, stained lint
Cotton, bhindi	**Spotted / spiny bollworm**	*Earias vittella* / *E. insulana*	Lepidoptera	Shoot droop bored bolls/
Cotton	**Whitefly**	***Bemisia tabaci***	Hemiptera	Honey sooty **leaf cu vecto**
Cotton	**Jassid (leafhopper)**	***Amrasca biguttula biguttula***	Hemiptera	Leaf e yellow cuppi **hoppe** hairy resist
Cotton	Mealybug	*Phenacoccus solenopsis*	Hemiptera	White coloni stunti (outbr 2006–
Cotton	Red cotton bug; dusky cotton bug	*Dysdercus cingulatus*; *Oxycarenus* spp.	Hemiptera	**Staine** poor s
Chickpea, pigeonpea, tomato	**Pod borer / fruit borer**	***Helicoverpa armigera***	Lepidoptera	Larva pods inside outsid
Pigeonpea	Pod fly; spotted pod borer	*Melanagromyza obtusa*; ***Maruca vitrata***	Diptera; Lepidoptera	Magg seed (extern webb flower
Mustard	**Mustard aphid**	***Lipaphis erysimi***	Hemiptera	Colon inflore most s musta cloudy weath favour
Mustard	Painted bug; sawfly	*Bagrada hilaris*; *Athalia lugens proxima*	Hemiptera; Hymenoptera	Seedli loss / defoli
Groundnut	**White grub**	***Holotrichia consanguinea***	Coleoptera	Grubs roots; emerg **first m showe** traps)
Groundnut	Leaf miner; red hairy caterpillar	*Aproaerema modicella*; *Amsacta albistriga*	Lepidoptera	Mines / defo
Polyphagous	**Tobacco caterpillar**	***Spodoptera litura***	Lepidoptera	Grega defoli castor crop
Brinjal	**Shoot & fruit borer**	***Leucinodes orbonalis***	Lepidoptera	Wiltin bored
Brinjal, potato	Hadda (Epilachna) beetle	*Henosepilachna vigintioctopunctata*	Coleoptera	Skelet leaves (phyto ladybi

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Cabbage, cauliflower	**Diamondback moth (DBM)**	***Plutella xylostella***	Lepidoptera	"Window" holes; **first insect to develop field resistance to Bt (sprays)**
Tomato	**Pinworm / leaf miner**	*Tuta absoluta* (*Phthorimaea absoluta*)	Lepidoptera	Mines in leaves & fruits; invasive (India 2014)
Cucurbits	**Melon fruit fly**; red pumpkin beetle	***Zeugodacus (Bactrocera) cucurbitae***; *Aulacophora (Raphidopalpa) foveicollis*	Diptera; Coleoptera	Maggots rot fruit (**cue-lure** trap) / seedling leaves eaten
Mango	**Mango hopper**; mealybug	*Idioscopus* spp.; *Drosicha mangiferae*	Hemiptera	Flower drying, sooty mould / **banding of trunk** with polythene
Mango	Stone weevil; fruit fly	*Sternochetus mangiferae*; ***Bactrocera dorsalis***	Coleoptera; Diptera	Quarantine pest / **methyl eugenol** trap
Coconut	**Rhinoceros beetle**	***Oryctes rhinoceros***	Coleoptera	Adult bores crown → **V-shaped cuts** in fronds; *Metarhizium*, Oryctes virus
Coconut	**Red palm weevil**	*Rhynchophorus ferrugineus*	Coleoptera	**Grubs** tunnel trunk; oozing brown fluid; crown topples
Coconut	Black-headed caterpillar	*Opisina arenosella*	Lepidoptera	Galleries under leaflets; parasitoid *Goniozus nephantidis*
Coconut	Eriophyid mite; rugose spiralling whitefly	*Aceria guerreronis*; *Aleurodicus rugioperculatus*	Acari Hemiptera	Nut scarring / spiral wax (invasive, 2016)
Citrus	Lemon butterfly; leaf miner; psylla	*Papilio demoleus*; *Phyllocnistis citrella*; ***Diaphorina citri***	Lepidoptera; Hemiptera	Defoliation / serpentine mines / **greening vector**
Tea	**Tea mosquito bug**	***Helopeltis theivora***	Hemiptera	Necrotic spots on buds; also cashew
Apple	San José scale; woolly apple aphid	*Quadraspidiotus perniciosus*; *Eriosoma lanigerum*	Hemiptera	Encrusted bark (domestic quarantine) / root & stem galls

Locusts

- **Desert locust – *Schistocerca gregaria*** (Orthoptera: Acrididae) – most dangerous migratory pest; others in India: migratory locust (*Locusta migratoria*), Bombay locust (*Nomadacris succincta*).
- **Phase theory – B.P. Uvarov (1921)**: **solitarious** (green, harmless) ⇄ **gregarious** (yellow/pink-black, swarming) phase; crowding triggers gregarisation (serotonin).
- **Locust Warning Organisation (LWO)** – set up **1939**, field HQ **Jodhpur** (central HQ with PPQS, Faridabad; circle offices incl. Bikaner), under **Directorate of PPQS**; monitors the **Scheduled Desert Area ≈ 2 lakh km²** in **Rajasthan and Gujarat** (some texts add parts of Haryana).
- Breeding seasons: spring breeding in Iran–Pakistan (Baluchistan); **summer (monsoon) breeding in the Indo-Pak Thar desert**. Global forecasting – **FAO Desert Locust Information Service, Rome**.
- 2019–20 outbreak – worst in ~26 years; control by **malathion 96% ULV** sprays, vehicle-mounted sprayers, and for the first time **drones** and helicopter.

Fall armyworm (FAW)

- ***Spodoptera frugiperda*** (Noctuidae) – native of tropical **Americas**; Africa 2016; **first in India May 2018 – Shivamogga, Karnataka**; now in all maize-growing states.
- Prefers **maize** but polyphagous (sorghum, sugarcane, rice); adults fly long distances.
- Identification: larva with **inverted "Y" mark on head** and **four dark spots forming a square on the 8th abdominal segment**.
- Management: pheromone traps, whorl application of **sand + lime**, egg parasitoid ***Telenomus remus***, *Trichogramma*, fungus ***Metarhizium (Nomuraea) rileyi***, *Bt*, NPV; chemicals – emamectin benzoate, chlorantraniliprole, spinetoram (as per CIB&RC label claim).

Pink bollworm (PBW)

- ***Pectinophora gossypiella*** (Gelechiidae) – larva pinkish in later instars; feeds **inside bolls**, causing rosette flowers, **double seed**, poor lint & oil.
- **Bt cotton** approved in India **2002** (Bollgard I – *Cry1Ac*); Bollgard II (*Cry1Ac + Cry2Ab*) – 2006. PBW developed resistance to **BG-I (~2009, Gujarat)** and to **BG-II (by 2014–15)**; now the main pest of Bt cotton.
- Management: **refuge crop** (non-Bt border rows), short-duration varieties, **terminate crop by December**, destroy stalks/ginnery waste (carry-over in seeds), **pheromone *gossyplure*** traps and **mating disruption** (PB-Rope L).

MEMORY TRICK

Symptom → pest: "**DEAD heart / WHITE ear** = stem borer · **SILVER shoot** = gall midge · **HOPPER BURN** = BPH (rice) / jassid (cotton) · **ROSETTE flower** = pink bollworm · **V-cut fronds** = rhinoceros beetle · **Y on head** = fall armyworm".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Hopper burn in rice is caused by? → **Brown planthopper (*Nilaparvata lugens*)**.
- Scientific name of brinjal shoot & fruit borer? → ***Leucinodes orbonalis***.
- Fall armyworm was first reported in India in? → **2018, Karnataka**.
- Pink bollworm scientific name? → ***Pectinophora gossypiella***.
- Locust Warning Organisation is located at? → **Jodhpur**.
- Thrips have which type of mouthparts? → **Rasping–sucking**.

4.5 IPM & Biological Control ★★★

- **IPM (Integrated Pest Management)** = use of all compatible methods – **cultural, mechanical, biological, host-plant resistance and need-based chemical** – to keep pests **below the economic**

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threshold level with least harm to people and environment. Chemicals = **last resort**.

- Concept of **integrated control, EIL and ET** – **Stern, Smith, van den Bosch & Hagen (1959)**. **Rachel Carson's "Silent Spring" (1962)** exposed DDT hazards.
- Problems of chemical-only control = "**3 R**": **Resistance, Resurgence, Residues** (+ secondary pest outbreak, destruction of natural enemies).
- **Resurgence** = pest returns in larger numbers after insecticide use (e.g. **BPH after synthetic pyrethroids**); **secondary pest outbreak** = a minor pest becomes major (e.g. whitefly, mites).
- India adopted IPM as the **main plank of plant protection in 1985**; implemented through **Central IPM Centres (CIPMCs)** of PPQS and **Farmers' Field Schools (FFS)**.
- **AESA (Agro-Ecosystem Analysis)** – decision based on field observation of pests, natural enemies (**P : D = pest : defender ratio**), weather, crop health – promoted by PPQS/NIPHM over fixed ETLs.

Term	Meaning
EIL (Economic Injury Level)	**Lowest pest density that causes economic damage** – cost of control = value of crop loss prevented
ETL / ET (Economic Threshold Level)	Pest density at which **control must be started** to prevent it reaching EIL (action threshold); **ETL < EIL**
GEP (General Equilibrium Position)	Average long-term pest density around which population fluctuates

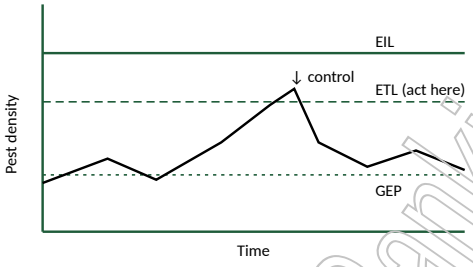

Fig 4.2 ETL lies below EIL; control applied at ETL keeps the pest from reaching EIL.

KEY FORMULAE

- **EIL = C ÷ (V × I × D × K)** (Pedigo) – C = cost of control per ha; V = market value per unit produce; I = injury per insect; D = damage (yield loss) per unit injury; K = proportion of injury prevented by control.
- Higher control cost → higher EIL; higher crop price → lower EIL.

Pest	Commonly cited ETL (values vary between sources/states)
Rice yellow stem borer	**5% dead hearts** (some use 10%) or 1 egg mass/m²; 2% white ears
Rice BPH	≈ **10 hoppers/hill** (5–10)
Rice gall midge	5% silver shoots
Rice leaf folder	10% damaged leaves
Cotton bollworms (incl. PBW)	**8 moths/pheromone trap/night for 3 consecutive nights**, or 5–10% damaged fruiting bodies
Cotton jassid	2 nymphs/leaf
Chickpea pod borer	1 larva per metre row (or 1–2 larvae/10 plants)

IPM tools

- **Cultural**: summer ploughing (exposes pupae), resistant varieties, **synchronous sowing**, crop rotation, intercropping, clean cultivation, balanced N (excess N ↑ BPH, leaf folder), alleyways of 30 cm every 2–3 m in rice (BPH), destruction of stubble.
- **Trap crops**: **marigold in tomato** (Helicoverpa, nematodes); **mustard in cabbage** (DBM); **castor** (Spodoptera litura); maize/sorghum border rows. **Push–pull**: Desmodium (push) + Napier grass (pull) for stem borers.
- **Mechanical/physical**: hand-picking, egg-mass collection, **light traps** (white grub, stem borer moths), **yellow sticky traps** (whitefly, aphids, leaf miner), **blue sticky traps** (thrips), **T-shaped bird perches**, **trunk banding** (mango mealybug).
- **Semiochemicals**: **pheromones** act within a species (sex, aggregation, alarm, trail); **allelochemicals** act between species – **kairomone** (benefits receiver), **allomone** (benefits emitter), **synomone** (both).
- First sex pheromone identified – **bombykol** (silkworm, **Butenandt, 1959**). Uses: **monitoring** (decide spray timing), **mass trapping**, **mating disruption**.

Lure / pheromone	Target pest
Gossyplure	**Pink bollworm**
Helilure	*Helicoverpa armigera*
Spodolure (Litlure)	*Spodoptera litura*
Scirpolure	Rice yellow stem borer
Methyl eugenol (para-pheromone, attracts males)	**Oriental fruit fly *Bactrocera dorsalis*** (mango, guava)
Cue-lure	**Melon fly *Zeugodacus cucurbitae***

Biological control

- **Classical** (import of exotic natural enemy), **augmentative/inundative** (mass release – Tricho-cards), **conservation** (protect existing enemies).
- World landmark: **vedalia beetle *Rodolia cardinalis*** controlled **cottony cushion scale (*Icerya purchasi*)** on citrus, California, **1888–89**.
- India's first: cochineal insect ***Dactylopius ceylonicus*** against **prickly pear (*Opuntia*)** (late 18th–19th century) – also first successful biological weed control.
- **Parasitoid** – develops on/in a single host and kills it (Trichogramma, Bracon); **predator** – eats many prey (ladybird, lacewing, spiders); **pathogen** – bacteria, fungi, viruses, nematodes.
- Nodal institute: **ICAR-NBAIR, Bengaluru** (National Bureau of Agricultural Insect Resources). PPQS runs Central Biological Control Stations and CIPMC bio-agent labs.
- ***Trichogramma*** is mass-reared on eggs of the **rice moth *Corcyra cephalonica*** (a storage pest – see ch10); parasitised eggs glued on cards = **Tricho-cards**, released at **~50,000–1,50,000 adults/ha** per release.

Bio-agent	Type	Target pests
Trichogramma chilonis (*T. japonicum* for rice)	**Egg parasitoid** (tiny wasp, Hymenoptera)	Borers, bollworms, sugarcane borers
Telenomus remus	Egg parasitoid	Fall armyworm, *Spodoptera*

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Encarsia formosa	Nymphal parasitoid	Greenhouse whitefly
Acerophagus papayae; *Anagyrus lopezi*	Parasitoids (classical)	Papaya mealybug; cassava mealybug
Epiricania melanoleuca	Ecto-parasitoid moth	Sugarcane pyrilla
***Chrysoperla zastrowi sillemi* (*C. carnea*)**	**Predator – green lacewing ("aphid lion" larva)**	Aphids, whitefly, mealybugs, eggs of moths
Cryptolaemus montrouzieri	Predator – ladybird, **"mealybug destroyer"** (from Australia)	Mealybugs, scales
Coccinella septempunctata, *Cheilomenes sexmaculata*	Predators – **ladybird beetles** (Coccinellidae)	Aphids
***Bacillus thuringiensis* (Bt)**	Bacterium – **Cry (δ-endotoxin) crystal** proteins, act in **alkaline midgut**	Caterpillars (var. *kurstaki*); mosquito larvae (var. *israelensis*); beetles (var. *tenebrionis*)
NPV (HaNPV, SlNPV – baculovirus)	Virus; polyhedral occlusion bodies	*Helicoverpa*, *Spodoptera*; dose **250 LE/ha** (1 LE ≈ 6×10^9 POB); dead larvae hang **upside down from plant tops** ("tree-top disease")
Beauveria bassiana	Fungus – **white muscardine**	Borers, beetles, hairy caterpillars
Metarhizium anisopliae	Fungus – **green muscardine**	White grub, rhinoceros beetle, termites
Lecanicillium (Verticillium) lecanii	Fungus	Sucking pests (aphids, whitefly, scales)
Hirsutella thompsonii	Fungus	Coconut eriophyid mite
Steinernema, *Heterorhabditis* (EPN)	Entomopathogenic nematodes (symbiotic bacteria *Xenorhabdus*, *Photorhabdus*)	Soil insects – white grub, root weevils
Zygogramma bicolorata	Mexican beetle – weed bio-agent	***Parthenium*** (congress grass)
Neochetina eichhorniae*, *N. bruchi	Weevils – weed bio-agents	**Water hyacinth**

Botanical pesticides

Botanical	Source plant (part)	Active principle / note
Neem	***Azadirachta indica*** (Meliaceae) – seed kernel, oil	**Azadirachtin** (tetranortriterpenoid/limonoid) – **antifeedant**, repellent, oviposition deterrent, **insect growth regulator**; NSKE **5%**, neem oil 2–3%; safe to natural enemies; neem cake for nematodes
Pyrethrum	***Chrysanthemum (Tanacetum) cinerariifolium*** – flowers	**Pyrethrins** – quick **knock-down**, photolabile; synergist **piperonyl butoxide**; model for synthetic pyrethroids
Tobacco	*Nicotiana tabacum* – leaves	**Nicotine** (nicotine sulphate) – sucking pests; model for neonicotinoids
Derris	*Derris elliptica*, *Lonchocarpus* – roots	**Rotenone** – also a fish poison

Beneficial insects

Honey bee	Common name	Notes
Apis mellifera	Italian / European bee (exotic)	**Highest yield in hives (~25–40 kg/hive/yr)**; gentle; Langstroth hive; most kept in India
Apis cerana indica	Indian / Asiatic hive bee	~10–15 kg/hive/yr; Newton hive
Apis dorsata	**Rock / giant bee**	Wild, **most aggressive**, single comb; highest honey per wild colony
Apis florea	Little / dwarf bee	Least honey; single small comb
Tetragonula / Trigona	Stingless (dammer) bee	Small yield; medicinal honey; pollinator

- Castes: **queen** (fertile female, fed **royal jelly**, 1,500–2,000 eggs/day), **workers** (sterile females), **drones** (males from **unfertilised eggs – haploid, parthenogenesis**). Development time: **queen 16, worker 21, drone 24 days**.
- **Royal jelly** – hypopharyngeal (and mandibular) glands of nurse workers; **beeswax** – wax glands on ventral abdomen of workers; **propolis** – "bee glue" from plant resins; bee venom (apitoxin – **melittin**).
- **Bee dance – Karl von Frisch** (Nobel 1973): **round dance** (food near) and **waggle dance** (food far, gives direction & distance).
- **L.L. Langstroth** – father of modern beekeeping; movable-frame hive and **bee space (6–9 mm)**. Bees are the chief **pollinators** – gains in yield often exceed honey value. **World Bee Day – 20 May**; **National Beekeeping & Honey Mission (NBHM, 2020)** – "Sweet Revolution".
- Honeybee hazards: **neonicotinoids** and spraying during flowering – spray in the evening.

Silk type	Silkworm	Food plant / region
Mulberry (bulk of India's raw silk)	***Bombyx mori*** (Bombycidae) – fully domesticated, monophagous	Mulberry (*Morus alba*); **Karnataka** leads
Tasar (tropical)	***Antheraea mylitta***	Arjun, asan – Jharkhand, Chhattisgarh
Muga – golden silk (GI)	***Antheraea assamensis***	Som & soalu – **only Assam**
Eri – "ahimsa" silk	***Samia ricini*** (*Philosamia*)	**Castor** – NE India; open-ended cocoon, silk is spun not reeled

- Silk = **fibroin** (core protein) + **sericin** (gum); secreted by **silk glands = modified labial (salivary) glands**. Killing pupae inside cocoons = **stifling**; unwinding = **reeling**.
- India – **2nd largest silk producer** (after China) and the **only country producing all four commercial silks**. **Central Silk Board – Bengaluru** (under CSB Act 1948; Ministry of Textiles).
- Silkworm diseases: **pebrine – *Nosema bombycis*** (microsporidian; Pasteur's mother-moth examination), **grasserie** (BmNPV), **flacherie** (bacterial/viral), **white muscardine** (*Beauveria bassiana*); parasitoid **uzi fly** (*Exorista bombycis*).

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- **Lac insect – *Kerria lacca*** (Hemiptera: Coccoidea, Kerriidae); resin secreted by **females**. Hosts: **kusum (*Schleichera oleosa*), palas (*Butea monosperma*), ber (*Ziziphus*)**, bush host *Flemingia semialata*. Strains: **Rangeeni** (palas, ber – crops Katki & Baisakhi) and **Kusmi** (kusum – better quality; Aghani & Jethwi).
- Lac products: **shellac**, lac dye, lac wax – varnish, sealing wax, fruit coating, bangles. **India is the largest producer**; **Jharkhand** leads. Institute: **ICAR-IINRG (Indian Institute of Natural Resins & Gums), Ranchi** (est. 1925 as Indian Lac Research Institute).

MEMORY TRICK

"**Tricho on eggs, Chryso eats aphids, Crypto eats mealybugs**". Muscardines: "**Beauveria = White, Metarhizium = Green**" (B-W, M-G). Silks "**M-T-M-E**": Mulberry–Bombyx, Tasar–mylitta, Muga–assamensis (Assam gold), Eri–ricini (castor).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- ETL is always ___ than EIL? → **Lower**.
- Egg parasitoid released as Tricho-cards? → ***Trichogramma***.
- Active principle of neem? → **Azadirachtin**.
- Green muscardine fungus? → ***Metarhizium anisopliae***.
- Golden silk is produced by? → **Muga silkworm (*Antheraea assamensis*)**.
- Scientific name of lac insect? → ***Kerria lacca***.

4.6 Pesticide Basics & Plant Protection Organisation ★★☆

Pesticide (by target)	Target	Example
Insecticide	Insects	Malathion, imidacloprid, chlorantraniliprole
Acaricide / miticide	Mites	Sulphur, propargite, fenazaquin
Fungicide	Fungi	Mancozeb, carbendazim
Bactericide	Bacteria	Streptocycline, copper oxychloride
Nematicide	Nematodes	Carbofuran (restricted)
Herbicide / weedicide	Weeds	2,4-D, atrazine, glyphosate
Rodenticide	Rats	Zinc phosphide, bromadiolone (ch10)
Molluscicide	Snails, slugs	**Metaldehyde**
Avicide / piscicide / algicide	Birds / fish / algae	— / rotenone / copper sulphate
Fumigant	Pests in enclosed space (gas)	Aluminium phosphide (ch10)

- By mode of entry: **stomach poison** (chewing insects), **contact poison**, **systemic** (absorbed & translocated in sap – best for **sucking pests**, e.g. imidacloprid, dimethoate), **fumigant**. Other terms: **repellent, antifeedant, attractant, chemosterilant, IGR** (insect growth regulator – buprofezin, diflubenzuron).
- Chemical classes (organochlorines, organophosphates, carbamates, pyrethroids, neonicotinoids, diamides), mode of action, toxicity symptoms and antidotes – see **Chapter 10**.
- **MRL** – maximum residue limit (FSSAI); **PHI / waiting period** – minimum days between last spray and harvest.

Formulation (code)	Nature	Use / note
EC – emulsifiable concentrate	a.i. + **organic solvent + emulsifier**	Forms **milky emulsion** in water; most common spray formulation
WP – wettable powder	a.i. + inert carrier + **wetting agent**	Forms **suspension** – needs agitation
DP / D – dustable powder (dust)	Low a.i. (≈ 2–10%) + talc/clay	**Ready to use**, dry (no water); drift-prone
G / GR – granules	a.i. (≈ 3–10%) on coarse carrier	**Ready to use** – soil, whorl or paddy water; least drift, safer to handle
SC – suspension concentrate (flowable)	Solid a.i. finely dispersed in water	Diluted in water; no dust
SL / SP	Soluble liquid / soluble powder	True solution in water
FS / DS / WS	Flowable / dry / water-slurry for **seed treatment**	Seed dressing
ULV	Ultra-low-volume liquid	Applied undiluted (locust control)

- **Adjuvants**: wetting agents/spreaders (surfactants), **stickers** (improve rain-fastness), emulsifiers, **synergists** (**piperonyl butoxide** with pyrethrins).
- Numbers in names = % a.i.: e.g. **"Chlorpyrifos 20 EC" = 20% a.i.**, **"Carbofuran 3 G" = 3% a.i.** granules.

KEY FORMULAE

- **Quantity of formulation = (Recommended dose of a.i. × Area) ÷ (% a.i. in formulation ÷ 100)**. E.g. 0.5 kg a.i./ha of a 50 EC → 0.5 ÷ 0.5 = **1 L/ha**.
- **Dilution: $C_1V_1 = C_2V_2$** (concentration × volume of stock = concentration × volume of spray).
- **LD_{50}** = dose (**mg a.i. per kg body weight**) killing 50% of test animals; **lower LD_{50} = more toxic**. LC_{50} – concentration (mg/L) for 50% kill. (Details – ch10.)

Label colour (lower triangle of a diamond)	Category	Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)	Symbol / word
Bright red	**Extremely toxic**	**1–50**	1–200	Skull & crossbones, "POISON"
Bright yellow	**Highly toxic**	**51–500**	201–2,000	"POISON"
Bright blue	**Moderately toxic**	**501–5,000**	2,001–20,000	"DANGER"
Bright green	**Slightly toxic**	**> 5,000**	> 20,000	"CAUTION"

- The label symbol (Insecticides Rules 1971) is a **square set at 45° (diamond)** divided into two triangles; the **lower triangle carries the colour**, the upper the warning.

Application equipment

Equipment	Features / use
Knapsack sprayer (lever-operated, hydraulic)	Most common manual sprayer; ~15–16 L tank; field crops
Foot sprayer / rocker sprayer	Pump operated by foot/rocking lever; orchards, tall crops

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Power sprayer	Engine-driven pump; orchards, large areas
Knapsack mist blower	Engine fan – air-assisted fine spray; **low volume**
ULV sprayer (spinning disc / CDA)	Controlled droplet application; **< 5 L/ha**; locusts, cotton
Dusters (plunger, bellows, rotary, power)	Apply dusts (DP)
Aircraft / **drones (Kisan drones)**	Large areas; drone spraying allowed under Agriculture Ministry SOPs and CIB&RC approvals

- Spray volume: **high volume ≈ 400–1,000 L/ha** (knapsack, field crops ~500 L/ha); **low volume** (mist blower) much less; **ULV < 5 L/ha** (classes vary slightly between sources).
- Nozzles: **hollow-cone** – insecticides & fungicides (fine droplets, good coverage); **flat-fan / flood-jet** – **herbicides** (uniform band, coarse droplets, less drift).

Plant protection organisation & law

Body / law	Key facts
Directorate of Plant Protection, Quarantine & Storage (PPQS)	Under Dept of Agriculture & Farmers Welfare; HQ **Faridabad (Haryana)**; set up **1946**; functions – plant quarantine, IPM (CIPMCs), locust control (LWO Jodhpur), regulation of pesticides (Insecticides Act), human resource development
CIB&RC – Central Insecticides Board & Registration Committee	Constituted under **Insecticides Act 1968**; **Faridabad**. **CIB** = advisory (technical advice, safety, shelf-life); **RC** = **registers pesticides** (Sec. 9(3) – new/regular; Sec. 9(4) – "me-too" of already registered)
Central Insecticides Laboratory (CIL)	Faridabad – referee analysis of pesticide samples
NIPHM (National Institute of Plant Health Management)	**Hyderabad** – training in plant health, IPM, pesticide management
Locust Warning Organisation	**Jodhpur** (field HQ; 1939)
Insecticides Act, 1968 & Insecticides Rules, 1971	Regulates **import, manufacture, sale, transport, distribution and use** of insecticides (= all pesticides) to prevent risk to humans & animals; Act came into force **1971**; enforced by Insecticide Inspectors & Analysts
Destructive Insects & Pests (DIP) Act, 1914	Prevents **introduction (import) of pests** into India and their **inter-state spread** (domestic quarantine)
Plant Quarantine (Regulation of Import into India) Order, 2003	Issued under DIP Act; in force from **1 Jan 2004**; import permit + **phytosanitary certificate** from exporting country; **Pest Risk Analysis**; replaced PFS (Plants, Fruits & Seeds) Order 1989
International	**IPPC** (International Plant Protection Convention, FAO, 1951); WTO **SPS Agreement** (1995)

- **Domestic quarantine** examples: **potato wart** (Darjeeling, WB), **golden cyst nematode** (Nilgiris, TN), **banana bunchy top** & banana mosaic, **San José scale** (apple areas) – movement of planting material out of notified areas is restricted.
- Quarantine pests of seed/grain trade: **Karnal bunt**, **khapra beetle** (ch10), mango stone weevil.

Banned / restricted (selected, India)	Status
DDT	Banned for **agriculture (1989)**; restricted use only for **public-health vector control**
BHC (HCH); aldrin, chlordane, heptachlor, endrin	Banned (BHC – **1997**)
Endosulfan	Banned by **Supreme Court order, 2011** (Stockholm Convention listing)
12 pesticides (order of **Aug 2018**)	Benomyl, carbaryl, diazinon, fenarimol, fenthion, linuron, methoxy ethyl mercury chloride, methyl parathion, sodium cyanide, thiometon, tridemorph, trifluralin
6 more from **31 Dec 2020**	Alachlor, dichlorvos, **phorate**, phosphamidon, triazophos, trichlorfon
2023 order	Dicofol, dinocap, methomyl banned
Monocrotophos	Not permitted on vegetables
Glyphosate	Use only through **Pest Control Operators (2022)**
Aluminium phosphide, methyl bromide	Restricted – trained PCOs / quarantine (ch10)

CODE UPDATE

- **Pesticide Management Bill, 2020** (introduced in Rajya Sabha, March 2020) to replace the Insecticides Act 1968 **did not become law**. A fresh **draft Pesticides Management Bill, 2025** was placed in the public domain on **7 January 2026** (comments till 4 February 2026); it would set up a **Central Pesticides Board** + Registration Committee. As of **October 2026** it remains a **draft – not introduced in Parliament** (not taken up in the Monsoon Session, July–August 2026). Until it is enacted the **Insecticides Act 1968 and Rules 1971 remain in force**.
- Draft orders (2026) propose banning **paraquat dichloride** (13 July 2026) and **carbosulfan** (August 2026) – treat as proposals until final notification.

MEMORY TRICK

Label colours "**R-Y-B-G**" = most → least toxic; oral LD_{50} cut-offs "**50 – 500 – 5000**" (just add a zero). Acts: "**DIP 1914 = pests at the border; Insecticides 1968 = poisons in the shop**".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Red triangle on a pesticide label indicates? → **Extremely toxic (oral LD_{50} 1–50 mg/kg)**.
- Headquarters of Directorate of PPQS and CIB&RC? → **Faridabad**.
- Plant quarantine in India is governed by? → **DIP Act 1914 & PQ Order 2003**.
- Pesticides are registered in India by? → **Registration Committee (CIB&RC) under Insecticides Act 1968**.
- Formulation that forms a milky emulsion in water? → **EC (emulsifiable concentrate)**.
- Nozzle preferred for herbicide spraying? → **Flat-fan / flood-jet**.

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5. Agricultural Extension, Economics, Marketing & Warehousing

> **NOTE**
> This chapter is the "home ground" of CWC. Expect direct questions on CWC itself (year, Act, ministry, status, services), WDRA and e-NWR, FCI/CAP/silo storage, buffer norms, NFSA and the cooperative grain-storage plan. From the "Basic Agriculture" syllabus, extension (adopter %, programme timeline, demonstrations) and economics (cost concepts A1–C3, MSP formula, stages of production) are fixed-answer areas. Scheme figures are as on **Oct 2026**.

5.1 Extension Education ★★★

- **Extension** – Latin *ex* (out) + *tensio* (stretching) = "stretching out" knowledge from research institutions to farmers; **education for rural people outside the classroom** (non-formal, voluntary, problem-solving).
- Term "university extension" first used in **England (Cambridge University, 1873)**. **Father of agricultural extension – Seaman A. Knapp** (USA; introduced the **result demonstration**). **Smith–Lever Act 1914** (USA) created the Cooperative Extension Service.
- **Kelsey & Hearne**: extension is an out-of-school educational system in which adults and young people learn by doing; its basic philosophy is **"to help people to help themselves"**.
- **J.P. Leagans**: extension education is an **applied behavioural science**, bringing desirable changes in **knowledge, skills and attitudes** (KSA) of people. Leagans also gave the communication model (communicator–message–channel–treatment–audience–response).
- **Objective of extension** = desirable **behavioural change**: change in knowledge (know), skill (do), attitude (feel); ultimate aim – better standard of living.
- **Principles of extension**: interests & needs of people; **grass-roots** organisation; cultural difference; **participation**; **learning by doing**; adaptability (of methods); trained specialists; whole-family approach; leadership (use local leaders); satisfaction; **evaluation**; cooperation.
- **Extension programme planning** cycle: situation analysis → objectives → plan of work → execution → **evaluation** → reconsideration. Plan of work = who, what, when, where, how.
- **Learning experience** – Dale's **Cone of Experience** (Edgar Dale): base = **direct purposeful experience** (most concrete) → contrived experience → dramatised → demonstrations → field trips → exhibits → TV/motion pictures → radio/recordings/pictures → visual symbols → **verbal symbols** (top, most abstract).
- **Audio-visual aids**: audio (radio, recordings), visual (charts, posters, flash cards, flannel graph, slides), audio-visual (TV, film, video). Projected aids – slides, film strips, OHP; non-projected – charts, posters, models, specimens.

Approach / method	Examples	Merits / limits
Individual contact	Farm & home visits, office calls, telephone calls, personal letters, **result demonstration**	**Most effective**, builds confidence; covers few people, **highest cost** per farmer
Group contact	**Method demonstration**, group meetings/discussions, field days, **Kisan Goshthi**, study tours, training camps, **Farmer Field School (FFS)**	Medium reach; peer learning; method demonstration teaches skill
Mass contact	Radio, TV (**DD Kisan, 26 May 2015**), newspapers, posters, exhibitions, **Kisan Mela**, campaigns, **Kisan Call Centre (1800-180-1551**, 2004), mKisan SMS, mobile apps	**Widest reach, lowest cost per person**; least personal; creates awareness

- **Method demonstration** – shows **"how to do"** a practice (skill), e.g. seed treatment, budding, grafting, use of sprayer. Short duration.
- **Result demonstration** – shows **"what can be done"** – proves the worth of a practice by comparing results (e.g. HYV vs local). Long duration (whole season). Introduced by **Seaman Knapp** (1903–04, Porter farm, Texas).
- **Front-Line Demonstration (FLD)** – by KVK/ICAR scientists on farmers' fields to show newly released technology; **On-Farm Testing (OFT)** – to test/refine a technology under local conditions (location specificity).
- **Farmer Field School** – season-long, **FAO**-promoted (Indonesia, 1989, rice IPM); "discovery learning" through agro-ecosystem analysis (AESA).
- **Communication models**: **Aristotle** – speaker–speech–audience; **Shannon & Weaver (1949)** – mathematical model with **noise**; **Berlo (1960) – SMCR** (Source–Message–Channel–Receiver); **Schramm** – field of experience (overlap needed); **Leagans (1961)** – 6 elements; **Lasswell (1948)** – "Who says what, in which channel, to whom, with what effect".
- **Fidelity** = accuracy of communication; **noise** = any interference; **feedback** = receiver's response to the source.
- **Diffusion** = spread of an innovation **through a social system** over time; **adoption** = **individual's** decision to make full use of an innovation. Cumulative adoption follows an **S-shaped curve**; number of adopters per period – **bell-shaped (normal) curve**.
- **Everett M. Rogers** – *Diffusion of Innovations* (**1962**). Adopter categories based on mean ($\bar{x}$) and standard deviation (sd) of adoption time:

Adopter category	% of people	Position on curve	Trait
Innovators	**2.5%**	before $\bar{x}$ – 2sd	**Venturesome**, cosmopolite, high risk-takers
Early adopters	**13.5%**	$\bar{x}$ – 2sd to $\bar{x}$ – sd	**Respectable**; highest **opinion leadership**; "localite"
Early majority	**34%**	$\bar{x}$ – sd to $\bar{x}$	**Deliberate**
Late majority	**34%**	$\bar{x}$ to $\bar{x}$ + sd	**Sceptical**; adopt under economic/social pressure
Laggards	**16%**	beyond $\bar{x}$ + sd	**Traditional**; last to adopt; point of reference is the past

- **Adoption process – 5 stages** (North Central Rural Sociology Sub-committee, USA, **1955**; popularised by Beal & Bohlen): **Awareness → Interest → Evaluation → Trial → Adoption**. Mass media most useful at **awareness**; personal contacts/neighbours at **evaluation**.
- **Innovation–decision process** (Rogers, revised 1983): **Knowledge → Persuasion → Decision → Implementation → Confirmation**. Rejection after adoption = **discontinuance**.

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- **Attributes of innovations** (Rogers) that speed adoption: **relative advantage, compatibility, (low) complexity, trialability, observability**.
- **Opinion leaders** – informal leaders who influence others' attitudes; identified by **sociometry** (**J.L. Moreno**). Two-step flow of communication: media → opinion leader → followers (Lazarsfeld).
- **PRA** (Participatory Rural Appraisal) – **Robert Chambers**; tools: social & resource maps, **transect walk**, seasonal calendar, Venn (chapati) diagram, matrix ranking, time line. RRA (Rapid Rural Appraisal) came before PRA.

Year	Programme	Person / place / key fact
1920	**Gurgaon Experiment**	**F.L. Brayne** (Deputy Commissioner, Gurgaon); village guides
1921	**Sriniketan** (Bengal)	**Rabindranath Tagore** (Visva-Bharati; with L.K. Elmhirst) – Institute of Rural Reconstruction
1921	**Marthandam** (Travancore; now Kanyakumari dist., TN)	**Spencer Hatch** (YMCA); "**beehive**" symbol; 5-fold development
1932	Baroda Rural Reconstruction	**V.T. Krishnamachari**
1943	Grow More Food Campaign	After the Bengal famine; enquiry committee (V.T. Krishnamachari, 1952) led to CDP
1946	**Firka Development** (Madras)	**T. Prakasam**; Gandhian, firka = group of villages
1948	**Etawah Pilot Project** (UP)	**Albert Mayer** (US town planner), Mahewa; forerunner of CDP
1948	**Nilokheri** (Haryana)	**S.K. Dey**; resettlement of refugees; "**Mazdoor Manzil**"
2 Oct 1952	**Community Development Programme (CDP)**	55 projects; **block** = unit; Ford Foundation support; VLW (Gram Sevak)
2 Oct 1953	**National Extension Service (NES)**	Less intensive version of CDP to cover the whole country
1957 / 1959	Balwant Rai Mehta Committee → Panchayati Raj	3-tier PRI; first at **Nagaur, Rajasthan (2 Oct 1959)**
1960–61	**IADP** (Package Programme)	**7 districts** (first **West Godavari**, Shahabad, Raipur, Aligarh, Tanjore, Ludhiana, Pali); Ford Foundation
1964–65	IAAP	Intensive Agricultural Area Programme
1966–67	**HYVP**	High-Yielding Varieties Programme – Green Revolution
1971 / 1973	SFDA / MFAL, DPAP	Target-group (small farmers) and area (drought-prone) programmes
1974	**First KVK – Puducherry**	Under **TNAU**; concept: **Mohan Singh Mehta Committee (1973)**; motto "learning by doing", "Lab to Land"
1974–77	**T&V (Training & Visit)**	**Daniel Benor**, **World Bank**; fortnightly visits by VEW; monthly workshops; single-line command
1978–80	IRDP	Integrated Rural Development Programme
1979	**Lab to Land Programme**	ICAR **Golden Jubilee**
1998	NATP	National Agricultural Technology Project (World Bank) – ATMA piloted
2005	**ATMA**	Agricultural Technology Management Agency – **district-level** registered society; **bottom-up** planning; **SREP** (Strategic Research & Extension Plan); Farmer Friend (1 per 2 villages)
2006	**NAIP**	National Agricultural Innovation Project (ICAR + World Bank; 2006–2014); value chains
2015–16	ARYA, Mera Gaon Mera Gaurav, Farmer FIRST, Student READY	Youth retention; scientists adopt villages; farm-innovation partnerships
2023–26	Kisan e-Mitra, NPSS, Krishi Sakhi, **Viksit Krishi Sankalp Abhiyan** (2025), **Bharat-VISTAAR** (2026)	Digital / AI and campaign-mode extension

- **KVK** (Krishi Vigyan Kendra) – **731 KVKs** (2026) under **ICAR**, coordinated through **11 ATARIs**. Mandate: **OFT, FLD**, capacity development (training), seed/planting material, knowledge resource centre.
- **ATMA** now under **SMAE** (Sub-Mission on Agricultural Extension) of NMAET; Farmer Interest Groups (FIGs), Block Technology Team.
- **MANAGE** – National Institute of Agricultural Extension Management, **Hyderabad** (1987); runs **ACABC** (Agri-Clinics & Agri-Business Centres, 2002, with NABARD) and DAESI (diploma for input dealers).
- Krishi Sakhi Convergence Programme (MoA&FW + MoRD) – para-extension women workers; **Kisan e-Mitra** – AI chatbot for PM-KISAN queries.

MEMORY TRICK

Adopters "**2.5 – 13.5 – 34 – 34 – 16**" = "I-E-E-L-L" (Innovators, Early adopters, Early majority, Late majority, Laggards). Stages "**AIETA**" – "All Indian Extension Teams Adopt". Pre-independence "**G-S-M-B**": Gurgaon (Brayne 1920) – Sriniketan (Tagore 1921) – Marthandam (Hatch 1921) – Baroda (1932).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Percentage of laggards in Rogers' classification? → **16%**.
- Demonstration that teaches "how to do"? → **Method demonstration**.
- Etawah Pilot Project was started by? → **Albert Mayer (1948)**.
- First KVK was set up at? → **Puducherry (1974, under TNAU)**.
- T&V system was developed by? → **Daniel Benor (World Bank)**.
- SMCR model of communication? → **Berlo (1960)**.

5.2 Agricultural Economics & Farm Management ★★☆

- **Economics** – "science of choice"/allocation of **scarce resources** among competing ends (**Lionel Robbins**). Agricultural economics = application of economic principles to agriculture.
- **Farm management** – how a farmer organises **land, labour, capital and management** to get **maximum net return** on a continuing basis. Tools: farm records & accounts, **farm budgeting** (complete / partial), farm planning, **linear programming** (G.B. Dantzig, 1947).
- **Factors of production** and their rewards: land → **rent**; labour → **wages**; capital → **interest**; organisation/management → **profit**.

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- **Production function** – $Y = f(X_1, X_2 \ldots X_n)$: technical relation between inputs and output. **Cobb–Douglas**: $Y = aX^b$ (b = elasticity of production).
- **Law of Diminishing (Marginal) Returns** / Law of variable proportions: when more units of a **variable input** are added to **fixed inputs**, each additional unit eventually adds **less and less** to total output. Most common relationship in agriculture (e.g. fertiliser response). Associated with **Turgot** and classical economists (Ricardo, Malthus) for land.
- Three types of returns: **increasing** (MP rising), **constant** (MP constant), **diminishing** (MP falling).

KEY FORMULAE

- Average product **AP = TP ÷ X**; Marginal product **MP = ΔTP ÷ ΔX**.
- Elasticity of production **E_p = MP ÷ AP** = (% change in output ÷ % change in input).
- Optimum input use (profit maximum): **MVP = P_x**, i.e. **MPP = P_x ÷ P_y** (marginal revenue = marginal cost).
- Least-cost combination: **MRTS (X_1 for X_2) = P_{X1} ÷ P_{X2}** (slope of isoquant = slope of isocost).
- Optimum product combination: **MRPS = P_{Y1} ÷ P_{Y2}** (production possibility curve tangent to iso-revenue line).
- Total cost **TC = TFC + TVC**; AC = TC ÷ Q; MC = ΔTC ÷ ΔQ. Break-even output = TFC ÷ (price – AVC).
- Straight-line depreciation = **(Cost – Salvage value) ÷ Useful life**.
- Benefit–Cost Ratio (B:C) = gross returns ÷ total cost; project acceptable if **B:C > 1**, NPV > 0, IRR > discount rate.

Stage of production	Range	E_p	Rationality
Stage I	Origin to **AP maximum** (MP = AP)	**> 1**	Irrational – fixed factor under-used; MP > AP
Stage II	AP max to **MP = 0** (TP max)	**0 to 1**	**Rational zone** – optimum lies here
Stage III	Beyond TP max	**< 0**	Irrational – **MP negative**, TP falls

- When **MP = AP**, AP is **maximum**; when **MP = 0**, TP is **maximum**.
- **Three basic relationships**: factor–product (**how much to produce**), factor–factor (**how to produce** – least-cost input mix; isoquant–isocost), product–product (**what to produce** – enterprise mix; PPC).
- **Product relationships**: **competitive** (wheat vs mustard on the same land); **complementary** (legume increases cereal yield); **supplementary** (poultry using spare family labour); **joint products** (wheat grain & straw; cotton lint & seed; mutton & wool).
- **Returns to scale** – long-run, **all** inputs changed in the same proportion: increasing / constant / decreasing.
- **Fixed costs** (do not vary with output – land revenue, rent, depreciation, interest on fixed capital) vs **variable costs** (seed, fertiliser, labour, irrigation). In the **short run** a farmer continues production as long as price ≥ **AVC** (shut-down point).

Principle of farm management	Meaning
Law of diminishing returns	Basis of deciding **how much** input to use
Cost principle	Produce as long as price covers variable cost (short run)
Opportunity cost	Return from the **next best alternative** foregone
Equi-marginal returns	Allocate limited capital so that the **last rupee gives equal return** in every use
Substitution	Substitute an input/enterprise if cost saved > cost added
Combining enterprises	Choose mix where MRPS = price ratio
Comparative advantage	Region grows crops for which it has the **greatest relative advantage**
Time comparison	Discounting (NPV) and compounding of future returns

- **Cost concepts (CACP)** – used in the **Comprehensive Scheme for Cost of Cultivation** (DES, MoA&FW):

Cost	Includes
A1	All **actual paid-out costs** in cash & kind: hired human labour, bullock/machine labour (hired/owned), seed, insecticides, manure, fertiliser, irrigation, land revenue, **depreciation**, interest on working capital, misc.
A2	A1 + **rent paid for leased-in land**
A2 + FL	A2 + **imputed value of family labour** → **MSP benchmark**
B1	A1 + interest on value of **owned fixed capital** (excluding land)
B2	B1 + **rental value of owned land** + rent paid for leased-in land
C1	B1 + imputed family labour
C2	B2 + imputed family labour = **comprehensive cost**
C2*	C2 with family labour valued at statutory/market wage (whichever higher)
C3	C2* + **10%** of C2* as **managerial cost** of the farmer

- **MSP rule** (Union Budget 2018-19, applied from Kharif 2018-19): MSP ≥ **1.5 × A2 + FL** (i.e. ≥ 50% margin over A2+FL). **Swaminathan Commission** (National Commission on Farmers, 2004–06) recommended MSP = **C2 + 50%**.
- MSP is recommended by **CACP** (Commission for Agricultural Costs & Prices; set up **1965** as Agricultural Prices Commission, renamed **1985**; attached office of MoA&FW) and approved by **CCEA** (chaired by the PM).
- **Cost of cultivation** = cost per **hectare**; **cost of production** = cost per **quintal** of output.
- **Farm income measures**: gross income; **farm business income** = gross income – Cost A1 (A2 for tenants); **family labour income** = gross income – Cost B2; **net income** = gross income – Cost C2 (C3).
- **Land holdings** (Agriculture Census 2015-16): **146.45 million** holdings, average **1.08 ha**; marginal (< 1 ha) **68.5%**, small (1–2 ha) 17.6% → small + marginal ≈ **86%** of holdings. Census every **5 years** (first 1970-71); 11th (2021-22) results awaited.
- Land use: geographical area **328.7 Mha**; net sown area ≈ **141 Mha**; gross cropped area ≈ 219 Mha; cropping intensity ≈ **155%** (= GCA ÷ NSA × 100).
- **Agricultural statistics basics**: mean, median (middle value), mode (most frequent); for moderately skewed data **Mode = 3 Median – 2 Mean**. **CV = (SD ÷ Mean) × 100** (compares variability; CV < 20% acceptable in field trials). Correlation **r** lies between **–1 and +1**; r^2 = coefficient of determination.
- **R.A. Fisher** – principles of experimental design: **replication, randomisation, local control**. **CRD** – homogeneous material

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(lab/pot); **RBD** – heterogeneity in **one direction** (most common field design); **LSD** – heterogeneity in **two directions** (rows = columns = treatments). ANOVA uses the **F-test**; t-test compares two means; χ^2 – goodness of fit/independence.

- **Crop Cutting Experiments (CCE)** – yield estimation (basis of PMFBY claims along with YES-TECH); General Crop Estimation Surveys.
- **Engel's law** – share of income spent on food **falls** as income rises. **Cobweb theorem** – cyclical price–output swings in crops with a production lag (onion, potato, tomato). **Terms of trade** = prices received by farmers ÷ prices paid.

MEMORY TRICK

Cost ladder: "**A1 → A2 (+rent) → A2+FL (+family labour = MSP base) → B (+own capital & land) → C2 (Swaminathan) → C3 (+10% management)**". Stages: "**I – Increase it, II – Ideal, III – Idiotic**".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Rational stage of production? → **Stage II** (AP maximum to MP = 0).
- Cost concept used for MSP under the 1.5× formula? → **A2 + FL**.
- Swaminathan Commission formula for MSP? → **C2 + 50%**.
- Cost C3 adds what to C2*? → **10% managerial cost**.
- Wheat grain and straw are examples of? → **Joint products**.
- Design for field with fertility gradient in one direction? → **RBD**.

5.3 Agricultural Marketing & Price Policy ★★★

- **Agricultural marketing** – all activities in the movement of produce from **farm gate to consumer** (assembling, grading, processing, storage, transport, distribution).
- **Marketable surplus** = total production – farm family requirement (seed, feed, consumption, wages in kind) – i.e. the **theoretical** surplus. **Marketed surplus** = quantity **actually sold**. Marketed > marketable = **distress sale** (small farmers, for cash needs).
- **Price spread** = consumer price – farmer price (= marketing costs + margins). **Producer's share in consumer's rupee = $(P_f \div P_r) \times 100$**.
- **Marketing efficiency – Shepherd's formula: ME = (V ÷ I) – 1**, where V = value of goods sold (consumer price), I = total marketing cost. (Acharya's modified measure adds margins and farmer's price.)

Marketing function	Includes
Exchange functions	**Buying** (assembling) and **selling**
Physical functions	**Storage** (creates **time utility**), **transport** (place utility), **processing** (form utility), packaging
Facilitating functions	**Standardisation & grading**, **financing**, **risk-bearing**, market information / intelligence

- **Utilities**: storage – **time**; transport – **place**; processing – **form**; selling/exchange – **possession**.
- **Marketing channels** (typical, food grains): Producer → village trader → **commission agent (arhatiya)** → wholesaler → retailer → consumer. Shorter channel = higher producer's share. Others: producer → consumer (direct marketing – **Apni Mandi** (Punjab), **Rythu Bazars** (AP, 1999), **Uzhavar Sandhai** (TN, 1999)); producer → FPO/cooperative → processor; contract farming.
- **Types of markets**: **primary/rural** (haats, shandies – weekly/biweekly); **secondary/wholesale** (mandis, at district/taluka); **terminal** (export/large consuming centres); regulated; cooperative; **spot vs forward/futures**.
- **Regulated market** – market whose business is governed by rules under a state **APMC Act**; run by a Market Committee; fixes market charges, licenses traders, supervises open auction, correct weights, prompt payment. First regulated market: **Karanja (Berar), 1886** (cotton) under Hyderabad Residency Order. **Royal Commission on Agriculture (1928)** recommended regulated markets.
- **Model APMC Act 2003** – private markets, direct marketing, contract farming, farmer–consumer markets. **Model APLM Act 2017** (Agricultural Produce & Livestock Marketing) – **whole state = one market**, warehouses/cold stores as deemed markets. **Model Contract Farming Act 2018**. Three farm laws of 2020 were **repealed in Nov–Dec 2021**.
- **e-NAM** (National Agriculture Market) – launched **14 Apr 2016** (21 mandis, 8 states); lead agency **SFAC** (Small Farmers' Agri-Business Consortium, 1994). Now **1,656 mandis** in 23 states + 4 UTs; > 1.80 crore farmers, **4,724 FPOs**; **247 commodities** (9 added 9 Oct 2025); cumulative trade ≈ ₹4.84 lakh cr (Mar 2026). Features: e-auction, assaying, **Platform of Platforms (PoP)**, inter-mandi/inter-state trade, **warehouse-based sale (e-NWR)**.
- **FPO** – legal entity of primary producers, registered as a **Producer Company** (Companies Act) or a **cooperative society**. **Formation & Promotion of 10,000 FPOs** scheme – launched **29 Feb 2020, Chitrakoot**; outlay **₹6,865 cr**; **₹18 lakh per FPO over 3 years**; equity grant ₹2,000/member (max **₹15 lakh**/FPO); credit guarantee up to **₹2 cr**; minimum members **300 (plains), 100 (NE/hills)**; agencies SFAC, NABARD, NCDC (+ CBBOs). **Target of 10,000 achieved (31 Dec 2025)**.

Institution / Act	Year	Key fact
Agricultural Produce (Grading & Marking) Act – AGMARK	**1937**	Grading & quality certification of agri produce; administered by **DMI**
DMI – Directorate of Marketing & Inspection	1935	Head office **Faridabad** (branch HQ Nagpur); MoA&FW; runs AGMARK, ISAM/AMI
NAFED	**2 Oct 1958**	Apex cooperative marketing body; **PSS procurement of pulses, oilseeds, copra**; Bharat brand sales
NCDC	1963	Finance for cooperatives (now under Ministry of Cooperation)
FCI	**14 Jan 1965** (Food Corporations Act **1964**)	Procurement, storage, movement, PDS distribution, buffer; first district office **Thanjavur**; HQ New Delhi
CACP	**1965**	MSP for **22 mandated crops** + FRP for sugarcane
NCCF	1965	Consumer cooperative; price stabilisation sales
SFAC	1994	e-NAM lead; FPO promotion
NCDEX	**2003** (Mumbai)	Largest **agri-commodity derivatives** exchange; promoted NERL (e-NWR repository)

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Forward Markets Commission	1953 → merged with **SEBI, 28 Sep 2015**	Forward Contracts (Regulation) Act 1952 repealed; commodities now under SEBI
Operation Greens	2018	**TOP** (tomato, onion, potato) → TOTAL (22 perishables) – under PM Kisan Sampada

- **Grading** = sorting produce into lots of uniform quality by **grade standards**; **standardisation** = fixing the standards. AGMARK standards exist for **~220+ commodities**; AGMARK is **voluntary** for domestic trade, **compulsory** for some exports and for certain items (e.g. blended edible oils, under FSSAI rules). AGMARK labs: Central Agmark Laboratory, **Nagpur**.
- **Grading at farm/mandi level** – assaying labs under e-NAM; **Grade Specifications** for procurement (FAQ – Fair Average Quality) fixed by the **Department of Food & PD**.
- **Futures contract** – standardised, exchange-traded agreement to buy/sell at a future date; used for **price discovery and hedging**. **Forward contract** – private, non-standard. **Hedging** = taking an opposite position in futures to protect against price risk.
- **Minimum Support Price (MSP)** – announced **before sowing**; **22 mandated crops** (**14 kharif + 6 rabi + 2 commercial: jute, copra**) plus toria and de-husked coconut; **FRP** for sugarcane (**₹365/q for 2026-27**, at 10.25% recovery). CACP considers cost (A2+FL, C2), demand–supply, inter-crop parity, terms of trade, world prices, cost of living.
- MSP 2026-27 (Kharif): **paddy (common) ₹2,441/q**; highest MSP – **sesamum ₹10,346**. MSP Rabi Marketing Season 2027-28: **wheat ₹2,610/q** (+₹25); highest increase – **safflower (+₹675)**.
- **Procurement**: wheat & rice by **FCI** and state agencies; **Decentralised Procurement (DCP, 1997-98)** – states procure, store and distribute; pulses/oilseeds by **NAFED/NCCF** under **PSS** (PM-AASHA); cotton by **CCI**; jute by **JCI**.
- **PM-AASHA** (Sep 2018) components: **PSS** (physical procurement at MSP; cap 25% of state production; **tur, urad, masur 100%**), **PDPS** (pays MSP–market price gap; oilseeds), **MIS** (perishables), **PSF** (Price Stabilisation Fund, 2015 – buffer of pulses/onion) merged in.
- **Market Intervention Scheme (MIS)** – for perishables not under MSP, on state request (loss shared 50:50, NE 75:25).
- **WTO Agreement on Agriculture (1995)**: **Amber box** – trade-distorting (MSP, input subsidies; de minimis **10%** of value of production for developing countries); **Blue box** – production-limiting; **Green box** – minimal distortion (research, extension, PDS stocks, decoupled income support). **Peace clause (Bali, 2013)** protects India's public stockholding.

KEY FORMULAE

- Marketable surplus **MS = P − C** (P = production, C = total farm requirement).
- Price spread = $P_r - P_f$; Producer's share = $(P_f \div P_r) \times 100$.
- Shepherd's marketing efficiency **ME = V/I − 1**.
- MSP ≥ **1.5 × (A2 + FL)**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- AGMARK is issued under which Act? → **Agricultural Produce (Grading & Marking) Act, 1937**.
- Storage creates which utility? → **Time utility**.
- Lead agency for e-NAM? → **SFAC**.
- Number of crops for which MSP is announced? → **22** (+ FRP for sugarcane).
- Financial support per FPO under the 10,000 FPO scheme? → **₹18 lakh over 3 years**.
- Commodity market regulator in India now? → **SEBI** (FMC merged 2015).

5.4 Warehousing in India & CWC ★★★

- **Warehouse** – a building/structure for **scientific storage** of goods with facilities for protection against **moisture, insects, rodents, birds, fire and theft**, and which issues a **warehouse receipt**. Warehousing creates **time utility**.
- **Functions of warehousing**: scientific storage & preservation; **price stabilisation** (release in lean season); **financing** (loans against warehouse receipts – **pledge financing**); risk-bearing (insurance of stocks); grading, packing, processing; transport/logistics; market information; reduces **distress sale**.

Type of warehouse	Key feature
Private	Owned by an individual/firm for **own goods** (manufacturers, traders)
Public	Open to all on payment of rent; licensed/regulated (CWC, SWCs, WDRA-registered); issue receipts
Government	Owned and run by Central/State Govts, PSUs (FCI, CWC, SWCs)
Cooperative	Owned by cooperatives/PACS for members; low charges (e.g. grain-storage plan godowns)
Bonded	Stores **imported goods before payment of customs duty**; licensed under **Customs Act 1962** (Sec 57 public, Sec 58 private, Sec 58A special)
Cold storage	Perishables (fruits, vegetables, potato, meat, dairy) at low temperature; UP has the most capacity; ≈ 3/4 of capacity used for **potato**
Controlled-atmosphere (CA)	Low O_2, high CO_2, low temperature – apples, pears
Field / rural godowns	Near production area; farmer storage (Grameen Bhandaran)
CFS / ICD	Customs-notified **dry ports** for import–export cargo (containers) in the hinterland
Special commodity	Silos (bulk grain), tank farms (liquids), cotton/tobacco/wool warehouses

- **History**: **All India Rural Credit Survey Committee (A.D. Gorwala, 1951–54)** recommended a network of warehouses for credit-linked marketing → **Agricultural Produce (Development & Warehousing) Corporations Act, 1956** (also created the National Cooperative Development & Warehousing Board).
- **CWC established 2 March 1957** under the 1956 Act. The 1956 Act was **repealed and replaced by the Warehousing Corporations Act, 1962** – CWC is now a **statutory body under the 1962 Act**, which also governs SWCs.
- CWC is a **Navratna CPSE** (as CWC styles itself in its notices and website since 2024; earlier Schedule 'A' **Miniratna Category-I**)

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under the **Ministry of Consumer Affairs, Food & Public Distribution** (Department of Food & PD). Corporate office: **Warehousing Bhawan, 4/1 Siri Institutional Area, August Kranti Marg, Hauz Khas, New Delhi**. **18 Regional Offices** + 4 satellite offices (31 Mar 2026).

- Capital: authorised **₹100 cr**, paid-up **₹68.02 cr** (Govt of India). CWC holds **50% equity in 19 SWCs** (other 50% by state govts) – **"50:50" CWC–State** rule of the 1962 Act.
- **Capacity**: CWC is India's **largest public warehouse operator** – CWC's own "At a Glance" (31 Mar 2026) lists **986 warehouses** with total storage capacity ≈ **164 lakh MT** (≈ 424 warehouses, 102.34 lakh MT on 31 Mar 2023; figures change yearly as capacity is hired/de-hired). FY 2025-26 (64th AGM, Sep 2026): record turnover **₹3,636 cr**, net profit **≈ ₹695 cr** (₹694.94 cr, +30%); 19 CFS/ICDs, 18 bonded and 25 rail-side warehouses.
- **CRWC** (Central Railside Warehouse Co., 2007, a CWC subsidiary) – merger approved by Cabinet (Jun 2021); business taken over by CWC on **31 Oct 2022**.
- **Functions of CWC (Sec 11, 1962 Act)**: acquire/build warehouses in India or abroad; run warehouses for **agricultural produce, seeds, manures, fertilisers, agricultural implements and notified commodities**; arrange transport to/from warehouses; subscribe to SWC share capital; act as **agent of Govt** for purchase, sale, storage, distribution; form joint ventures / subsidiaries.
- **CWC services**: food-grain storage (largely for **FCI**, central pool), storage of notified commodities, industrial warehousing & **3PL logistics**, **CFS/ICDs**, **bonded warehouses**, Land Customs Stations, air cargo complexes, rail-side warehouses, **Pest Control Services (PCS)**, consultancy and training.
- **Pest Control Services** of CWC: **disinfestation** of stocks (prophylactic sprays, fumigation under gas-proof covers with **aluminium phosphide**), **methyl bromide fumigation** of import/export cargo and containers (accredited by the Directorate of PPQ&S under the **Plant Quarantine Order 2003**), **anti-termite** (pre- and post-construction) treatment, rodent control, household pest control, ship fumigation.
- CWC warehouse receipt is a **negotiable** document → pledge loans from banks. **Farmers get 30% rebate** on CWC storage charges (cooperatives and agri start-ups 10%).
- **Farmers' Extension Service** (CWC, **1978-79**) – CWC staff teach scientific storage and post-harvest loss reduction in villages near its rural warehouses.
- **SWCs** – set up by state govts under the 1962 Act; operate at district/centre level; can act as agents of CWC/state; build warehouses after **consulting CWC**.

Body	Year / Act	Parent / role
CWC	**1957**; 1956 Act → **Warehousing Corporations Act 1962**	Ministry of Consumer Affairs, Food & PD; public warehousing, logistics
SWCs	1962 Act	State govt + CWC (50:50); 19 SWCs
FCI	1965; Food Corporations Act 1964	Central pool storage – owned + hired (CWC, SWC, private PEG)
WDRA	**Warehousing (Development & Regulation) Act 2007**; Authority set up **26 Oct 2010**	Regulates warehouses, NWR/e-NWR; Dept of Food & PD; HQ New Delhi
NCDC / PACS	Ministry of Cooperation (2021)	Cooperative godowns; grain storage plan

- **FCI storage**: as on 1 Jan 2024 total covered capacity with FCI + state agencies ≈ **762 lakh MT**; FCI ≈ **362 LMT** (owned ≈ **147**, hired ≈ **215**); state agencies ≈ 401 LMT. FCI hires from CWC, SWCs and private parties.
- **PEG scheme** (Private Entrepreneurs Guarantee, **2008**) – private parties/CWC/SWCs build godowns which FCI hires with a **guaranteed hiring period (10 years for private investors)**; created over 1 crore t capacity in consuming and procuring states.
- **Covered godown** – conventional warehouse (brick/RCC walls, ventilators, raised plinth, damp-proof floor), stacks on **dunnage** (wooden crates/polythene) with aisles; for all grains. Standard practice: **first in–first out (FIFO)**, periodic inspection, prophylactic & curative treatment.
- **CAP storage** (**Cover And Plinth**) – **outdoor** storage on a **raised pucca plinth** with wooden crates/dunnage; stacks covered with **black LDPE (polythene) covers** and tied with nylon ropes/nets. **Temporary**, cheap, quick to create; mainly for **wheat** (and paddy) in procuring states (Punjab, Haryana, MP); higher risk of damage – **govt policy is to phase out CAP**.
- **Silos** – vertical **steel/concrete bins** for **bulk** (unbagged) grain with mechanised handling, aeration, temperature monitoring and fumigation; losses much lower than bag storage. First modern private silos for FCI – **Adani Agri Logistics, Moga (Punjab) and Kaithal (Haryana), 2007** (BOO). Govt roadmap (2016) for **~100 LMT silos** in **PPP** mode (DBFOO / DBFO, hub-and-spoke); e.g. 0.5 LMT each at Ahmedabad & Amreli (Gujarat).

Feature	Covered godown	CAP	Steel silo
Form	Bagged, under roof	Bagged, open plinth + covers	**Bulk** grain in bins
Cost / speed	Medium	**Cheapest, fastest**	High capital, low running cost
Losses	Low (if scientific)	**Highest** (rain, birds, rodents)	**Lowest**
Duration	Long-term	**Short-term** (wheat)	Long-term
Mechanisation	Manual (labour)	Manual	Fully mechanised

- **WDRA** – **Warehousing (Development & Regulation) Act 2007** (in force **25 Oct 2010**); **Warehousing Development & Regulatory Authority** set up **26 Oct 2010**, HQ **New Delhi**, under Dept of Food & PD. Chairperson (2026): **Anita Praveen**.
- WDRA functions: **registration** of warehouses (voluntary, except where notified), accreditation of assaying labs, regulation of **NWRs**, warehousing standards, training of warehousemen, farmer awareness. About **7,500+** active registered warehouses (7,512 on 31 Mar 2026).
- **Negotiable Warehouse Receipt (NWR)** – receipt issued by a **WDRA-registered** warehouse; transferable by endorsement and delivery; can be **pledged** to banks or traded. Non-registered warehouses issue ordinary (non-negotiable) receipts.
- **e-NWR** – launched **26 Sep 2017**; from **1 June 2019** registered warehouses issue **only electronic** NWRs. Held through two repositories: **NERL** (National E-Repository Ltd, promoted by NCDEX) and **CCRL** (CDSL Commodity Repository Ltd). Can be split, transferred, sold on e-NAM, used for exchange delivery.
- **e-Kisan Upaj Nidhi (e-KUN)** – WDRA's digital gateway (2024) for farmers to store in registered warehouses and get e-NWR loans

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online; **mWDRA** mobile app.

- **Credit Guarantee Scheme for e-NWR-based Pledge Financing (CGS-NPF)** – launched **16 Dec 2024**; corpus **₹1,000 cr**; agri loans up to **₹75 lakh** (non-agri up to ₹2 cr); guarantee **85%** (loans ≤ ₹3 lakh for small/marginal, women, SC/ST, PwD), 80% (₹3–75 lakh), 75% others.
- **PSL** (RBI 2025): pledge loans against **e-NWR/NWR up to ₹90 lakh per farmer** (₹60 lakh against other warehouse receipts) count as agriculture.
- **Agricultural Marketing Infrastructure (AMI)** – sub-scheme of **ISAM** (Integrated Scheme for Agricultural Marketing, 2014), DMI. Subsumed **Grameen Bhandaran Yojana** (Rural Godown Scheme, **2001-02**, NABARD-linked; credit-linked back-ended subsidy for rural godowns) and the scheme for marketing infrastructure. Storage subsidy **25%** (general) and **33.33%** (NE, hilly, SC/ST, women, FPOs/cooperatives). Oct 2024 amendment for PACS godowns: subsidy **33.33%**, margin money **20% → 10%**.
- **World's Largest Grain Storage Plan in the Cooperative Sector** – Cabinet approval **31 May 2023**; Ministry of **Cooperation**; builds godowns, custom hiring centres and processing units at the **PACS** level by **convergence** of existing schemes – **AIF, AMI, SMAM, PMFME** (+ PDS/OMSS hiring). Pilot: godowns in **11 PACS of 11 states** (inaugurated 24 Feb 2024); extended pilot with 500+ PACS. Originally projected to add **~700 LMT** in 5 years. FCI gives a **9-year hiring assurance** for eligible godowns (subject to minimum-size and other conditions); FCI mapped ≈ 26 LMT need at 216 locations in 18 States/UTs.
- **Agriculture Infrastructure Fund (AIF, Jul 2020)** – ₹1 lakh cr; **3% interest subvention** on loans up to **₹2 cr** for 7 years; credit guarantee via CGTMSE; eligible: warehouses, cold stores, silos, pack houses, assaying units, primary processing.
- **PM Kisan SAMPADA Yojana (PMKSY, MoFPI)** – approved **May 2017** as SAMPADA (Scheme for Agro-Marine Processing & Development of Agro-Processing Clusters), renamed 2017; components: **Mega Food Parks**, **Integrated Cold Chain & Value Addition Infrastructure** (grant **35%** general / **50%** NE, hilly, SC/ST areas; max ₹10 cr), Agro-Processing Clusters, food safety & QA infrastructure, backward–forward linkages, **Operation Greens**. Continued to 2025-26.
- Also **NHB** capital-investment subsidy for cold storages; **MIDH** post-harvest management (pack houses, ripening chambers, reefer vans).

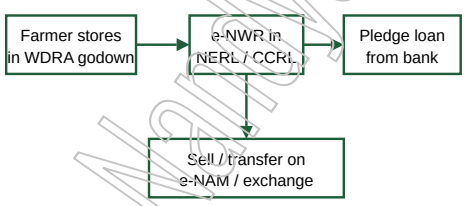

Fig 5.1 – How an e-NWR helps a farmer avoid distress sale

CODE UPDATE

2026 status: CWC FY 2025-26 record turnover ≈ ₹3,636 cr and profit ≈ ₹695 cr; WDRA – ≈ 7,500+ active registered warehouses (7,512 on 31 Mar 2026); cooperative grain-storage plan being scaled from the pilot with FCI hiring assurance (9 years). Policy direction: phase out CAP, add silos (PPP) and PACS godowns.

MEMORY TRICK

"**56-57-62**": Act **1956** → CWC born **1957** → new Act **1962**. WDRA "**07-10-17-19**": Act 2007 → Authority 2010 → e-NWR 2017 → only e-NWR from 2019.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- CWC was established in? → **1957** (under the Agricultural Produce (Development & Warehousing) Corporations Act, 1956).
- CWC now functions under which Act? → **Warehousing Corporations Act, 1962**.
- Administrative ministry of CWC? → **Ministry of Consumer Affairs, Food & Public Distribution**.
- WDRA was established under? → **Warehousing (Development & Regulation) Act, 2007** (Authority 2010).
- "CAP" storage stands for? → **Cover And Plinth**.
- Rebate on CWC storage charges for farmers? → **30%**.

5.5 Government Schemes & Agri-Finance ★★★

NOTE

Data as on Oct 2026. Most schemes ran in the 15th Finance Commission cycle (to 2025-26). Only PM-KISAN has a confirmed Cabinet renewal (2026-27 to 2030-31); for others answer with the last approved period.

Scheme	Launch	Core feature (exam value)
PM-KISAN	**24 Feb 2019**, Gorakhpur (effective 1 Dec 2018)	**₹6,000/yr in 3 × ₹2,000** by DBT; Central Sector (100% central); continued to **2030-31** (₹3.15 lakh cr); BE 2026-27 **₹63,500 cr**
PMFBY	Kharif **2016**	Farmer premium **2% kharif, 1.5% rabi, 5% commercial/horticulture**; voluntary since Kharif 2020; NE share 90:10
KCC	**1998** (R.V. Gupta Committee; NABARD)	Crop loan at **7%**, effective **4%** with 3% prompt-repayment incentive (MISS limit ₹3 lakh)
PMKSY	**1 Jul 2015**	"**Har Khet Ko Pani**", "**Per Drop More Crop**"; PDMC subsidy 55% (SMF) / 45% others
Soil Health Card	**19 Feb 2015**, Suratgarh (Rajasthan)	**12 parameters**; card every **2 years**; > 25 crore cards
PKVY	2015	Organic farming in **20-ha clusters**; **₹31,500/ha over 3 years**; PGS-India certification
RKVY → PM-RKVY	**2007**; revamped 2024	State "**cafeteria**" umbrella; RKVY-RAFTAAR (2017) for agri start-ups
NFSM → NFSNM	Rabi **2007-08**	Rice, wheat, pulses (later coarse cereals, nutri-cereals); now **National Food Security & Nutrition Mission** under **Krishonnati Yojana**
AIF	Jul 2020	₹1 lakh cr; **3% subvention** up to ₹2 cr, 7 years; scheme period to 2032-33
e-NAM	14 Apr 2016	Online mandi; SFAC
10,000 FPOs	29 Feb 2020	₹6,865 cr; ₹18 lakh/FPO

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NMEO-Oil Palm	Aug 2021	₹11,040 cr; focus NE and A&N Islands; viability price for FFBs
NMEO-Oilseeds	**3 Oct 2024**	₹10,103 cr (2024-25 to 2030-31); raise primary oilseeds ≈ 39 → **69.7 Mt**; SATHI seed portal
Digital Agriculture Mission	**2 Sep 2024**	₹2,817 cr; **AgriStack** (Farmer ID, geo-referenced maps, Digital Crop Survey), **Krishi DSS**
NMNF (Natural Farming)	25 Nov 2024	₹2,481 cr; 1 crore farmers; 7.5 lakh ha; 10,000 Bio-input Resource Centres
PM Dhan-Dhaanya Krishi Yojana	Approved 16 Jul 2025; launched 11 Oct 2025	**100 districts**; 36 schemes of 11 depts; ₹24,000 cr/yr × 6 yrs
Pulses Mission (Aatmanirbharta)	1 Oct 2025	₹11,440 cr to 2030-31; **100% MSP procurement of tur, urad, masoor** for 4 years
PM-KMY (Kisan Maan-Dhan)	12 Sep 2019	Pension **₹3,000/month at 60**; entry age 18–40; LIC fund manager
PM-KUSUM	2019 (MNRE)	Solar pumps & plants; Comp. B – 30% CFA + 30% state + 40% farmer

- **Umbrella rationalisation (Cabinet, 3 Oct 2024)**: all CSSs of the Agriculture Ministry merged into **PM-RKVY** (₹57,074.72 cr; includes Soil Health & Fertility, PDMC, PKVY, mechanisation, RKVY-RAFTAAR, rainfed area development) and **Krishonnati Yojana** (₹44,246.89 cr; includes NFSNM, **MIDH**, seeds, MOVCDNER, NMEO-Oil Palm). Total ₹1,01,321.61 cr.
- **PMFBY risks**: prevented sowing; standing crop (drought, flood, pests, disease); **post-harvest losses up to 14 days** (cyclone, unseasonal rain, hailstorm) for crops kept in "cut and spread" condition; localised calamities. From Kharif 2026 – **wild animal attack** add-on cover. Technology: **YES-TECH** (remote-sensing yields), **WINDS** (weather stations), **CROPIC** (crop photos). Helpline **14447**.
- **RWBCIS** (Restructured Weather-Based Crop Insurance, 2016) – weather-index based; same premium as PMFBY.
- **Soil Health Card parameters (12)**: N, P, K, S (macro); Zn, Fe, Cu, Mn, B (micro); pH, EC, OC.
- **KCC limit** (1st year) = (scale of finance × area) + **10%** post-harvest/household + **20%** repairs/maintenance + crop insurance; then **+10% a year**. Scale of finance fixed by **DLTC**. RBI revised KCC Directions (final 19 Jun 2026; effective **1 Jan 2027**): validity **6 years** (was 5); crop season 12 / 18 months. Extended to **animal husbandry & fisheries in 2018-19**. Collateral-free agri loans up to **₹2 lakh** (from 1 Jan 2025). ≈ 7.7 crore operative KCCs.
- **MISS** (Modified Interest Subvention Scheme): banks get **1.5%** subvention; farmer pays 7%, gets 3% PRI → **4%**; BE 2026-27 ₹22,600 cr. Budget 2025-26 announced raising the limit to ₹5 lakh (Cabinet approval of May 2025 still used ₹3 lakh).
- **NABARD** – **12 Jul 1982** under NABARD Act 1981, on **CRAFICARD (B. Sivaraman)** recommendation; HQ **Mumbai**; 100% GoI owned; Chairman **Shaji K.V.** Roles: refinance, development (SHG-BLP 1992, FPOs, watersheds), supervision of **RRBs, StCBs, DCCBs**. Funds: **RIDF (1995-96**, from PSL shortfall), **WIF – Warehouse Infrastructure Fund (2013-14)**, LTIF (2016-17), MIF (₹5,000 cr), FIDF, NIDA. Subsidiaries: NABKISAN, NABFINS, NABCONS, NABSanrakshan (FPO credit-guarantee trustee).
- **Priority Sector Lending** (RBI Directions 2025, from 1 Apr 2025): total PSL **40%** of ANBC/CEOBE (RRBs **75%**, SFBs 60%); **agriculture 18%**; within it non-corporate farmers 14% and **small & marginal farmers 10%**; micro-enterprises 7.5%; weaker sections 12%. FPO loans up to ₹4 cr (₹10 cr with assured marketing). Shortfall → deposit in **RIDF** (NABARD).
- **Small farmer** 1–2 ha; **marginal** < 1 ha. RRBs: shareholding **Centre 50 : Sponsor bank 35 : State 15**; **28 RRBs** after One State One RRB (1 May 2025).
- Ground-level agricultural credit target **2025-26: ₹32.5 lakh cr**.

MEMORY TRICK

PMFBY premium "**K2 – R1.5 – C5**". PSL "**40-18-14-10-7.5-12**". Scheme years "**07-15-16-19-20-24-25**": RKVY/NFSM (07) → SHC, PKVY, PMKSY (15) → PMFBY, e-NAM (16) → PM-KISAN, KUSUM (19) → FPO, AIF (20) → DAM, NMEO-OS, NMNF (24) → PMDDKY, Pulses (25).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Farmer's premium share for rabi crops under PMFBY? → **1.5%**.
- Number of parameters on a Soil Health Card? → **12**.
- Assistance under PKVY? → **₹31,500/ha over 3 years**.
- AgriStack is part of which mission? → **Digital Agriculture Mission**.
- NABARD was set up on whose recommendation? → **CRAFICARD (B. Sivaraman)**.
- PSL target for agriculture (domestic banks)? → **18%** of ANBC/CEOBE.

5.6 Food Security & Public Distribution ★★☆

- **Food security** (FAO, 1996 World Food Summit): all people at all times have physical and economic access to sufficient, safe, nutritious food. Pillars: **availability, access, utilisation, stability**.
- **PDS evolution**: rationing in the **1940s** (WW-II, Bengal famine) → PDS (1960s; FCI 1965) → **RPDS** (Revamped PDS, **1992**, hilly/tribal blocks) → **TPDS** (Targeted PDS, **June 1997**; APL/BPL) → **Antyodaya Anna Yojana (AAY, 25 Dec 2000)** – poorest of poor → **NFSA 2013**.
- **National Food Security Act (NFSA), 2013** (notified 10 Sep 2013) – rights-based; covers up to **75% of rural and 50% of urban population** (≈ two-thirds; **~81.35 crore** people).

NFSA provision	Entitlement
Priority Households (PHH)	**5 kg** foodgrains **per person per month**
AAY households	**35 kg per household per month**
Issue price (original)	Rice ₹3, wheat ₹2, coarse grains ₹1 per kg – now **free** (from 1 Jan 2023)
Pregnant women & lactating mothers	Free meal + maternity benefit ≥ **₹6,000**
Children 6 months–14 years	Nutritious meals (ICDS/Anganwadi, PM POSHAN mid-day meal)
Women empowerment	**Eldest woman (≥ 18 yrs)** = head of household for ration card
Non-supply of grain	**Food security allowance**
Grievance redressal	District Grievance Redressal Officer (DGRO), **State Food Commission**

- **PMGKAY** (Pradhan Mantri Garib Kalyan Anna Yojana) – started **April 2020** (COVID) as **additional** 5 kg free grain; from **1 Jan 2023** NFSA grain itself made **free** under the PMGKAY name; extended for **5 years from 1 Jan 2024** (to Dec 2028) for ~81 crore

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beneficiaries; outlay ≈ **₹11.80 lakh cr**. **Fortified rice** supplied under PMGKAY and other welfare schemes (continued to Dec 2028).

- **One Nation One Ration Card (ONORC)** – started **Aug 2019** (inter-state pilot); **national portability** of NFSA entitlements via Aadhaar-seeded ration cards and **ePoS** devices at Fair Price Shops; all **36 States/UTs** covered by **2022** (Assam last). **Mera Ration** app.
- **Fair Price Shops (FPS)** – ≈ 5.4 lakh; end-to-end computerisation, ePoS, Aadhaar authentication.
- **Central pool** – stocks of **wheat and rice** procured by FCI/DCP states. **Buffer norms** (fixed by Govt; revised **Jan 2015**) include **operational stock** (4 months' TPDS/OWS need) + **strategic reserve** (wheat **30 LMT**, rice **20 LMT**):

As on	Rice (LMT)	Wheat (LMT)	Total (LMT)
1 April	135.80	74.60	**210.40**
1 July	135.40	275.80	**411.20** (highest – after wheat procurement)
1 October	102.50	205.20	**307.70**
1 January	76.10	138.00	**214.10**

- Actual stocks are usually far above norms: on **1 Apr 2026** central pool ≈ **604 LMT** (rice ≈ 386, wheat ≈ 218) – nearly **3×** the 210.40 LMT norm.
- **OMSS(D)** – Open Market Sale Scheme (Domestic): FCI sells surplus **wheat/rice** in the open market by **e-auction** (to flour mills, processors, traders) and to agencies (e.g. **Bharat Atta, Bharat Rice** via NAFED/NCCF/Kendriya Bhandar) – to **cool prices** and liquidate excess stocks. Also used for ethanol (rice) and state sales.
- **Other Welfare Schemes (OWS)** – PM POSHAN, ICDS, welfare institutions, SC/ST hostels draw grain from the central pool.
- **Economic cost** of FCI = MSP + procurement incidentals + distribution cost (freight, handling, **storage**, interest, transit & storage losses). **Food subsidy** = economic cost − central issue price; with free grain (CIP nil) the Centre bears the full economic cost.
- **Storage gap**: foodgrain production ≈ **376.56 Mt** (2025-26, 3rd AE) vs total storage capacity of only about **47% of production** (commonly cited 2023 estimate) – the basis for the cooperative grain-storage plan, silos and PEG. Covered capacity with FCI + states ≈ **762 LMT** (Jan 2024).
- **Post-harvest losses** (NABCONS study, 2022, for MoFPI): cereals ≈ **3.9–5.9%** (paddy 4.77%, wheat 4.17%), pulses ≈ 5.7–6.7%, oilseeds ≈ 2.9–7.5%, fruits ≈ 6–15% (**guava highest, 15.05%**), vegetables ≈ 4.9–11.6%; total value ≈ **₹1.53 lakh cr** a year. Earlier CIPHET study (2015) put it at ≈ ₹92,651 cr.
- **Causes of storage losses**: **insects** (Khapra beetle, rice weevil, lesser grain borer, red flour beetle, pulse beetle, Angoumois grain moth), **rodents**, birds, **moulds** (high moisture > 14%, aflatoxin), moisture migration, poor CAP covers, spillage and handling. Safe grain moisture for storage ≈ **10–12%** (cereals, long-term); paddy ≈ 12–14%.
- **Storage/transit losses** in FCI are measured against norms; reduced through **scientific storage** – CAP phase-out, silos, **FIFO**, regular prophylactic (malathion/deltamethrin sprays) and curative (**aluminium phosphide** fumigation) treatment, rodent control, depot online system (DOS) monitoring.

MEMORY TRICK

NFSA "**75-50-5-35**": 75% rural, 50% urban, 5 kg/person, 35 kg/AAY household. Buffer totals "**210 – 411 – 308 – 214**" (April – July – October – January): July peak = fresh wheat.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- NFSA coverage of rural population? → **Up to 75%** (urban 50%).
- Monthly entitlement of an AAY household? → **35 kg**.
- Buffer norm for 1 April (rice + wheat)? → **210.40 lakh tonnes**.
- Strategic reserve of wheat in the buffer? → **30 lakh tonnes** (rice 20 LMT).
- PMGKAY extended for how long from 1 Jan 2024? → **5 years**.
- OMSS is used to? → **Sell excess FCI grain in the open market to control prices**.

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6. Botany I – Cell Biology, Tissues & Genetics

> **NOTE**
> For B.Sc (Botany/Agriculture/Biotech) candidates this is a scoring chapter: questions are NCERT 11–12 one-liners – who discovered what, organelle functions, ribosome types, stages of meiosis, plant tissues, monocot vs dicot anatomy, Mendelian and epistatic ratios, DNA structure numbers, genetic code, lac operon, restriction enzymes, PCR and GM-crop regulation (Bt cotton, GEAC). Detailed biochemistry (metabolism, vitamins, enzymes kinetics in depth) is in Chapter 11.

6.1 Cell – Structure & Organelles ★★★

- **Robert Hooke (1665)** – first saw (dead) cells in a thin slice of **cork**; coined the word **"cell"**; book *Micrographia*.
- **Antonie van Leeuwenhoek** – first to see and describe a **live cell** (bacteria, protozoa, sperm) with his own simple microscope; "Father of microbiology".
- **Robert Brown (1831)** – discovered the **nucleus** (in orchid cells). Purkinje coined **protoplasm** (1839).
- **Cell theory**: **Matthias Schleiden (1838, botanist – plants)** + **Theodor Schwann (1839, zoologist – animals)**; Schwann also noted the plasma membrane and that cell wall is unique to plants.
- **Rudolf Virchow (1855)** – modified cell theory: **"Omnis cellula-e cellula"** (all cells arise from pre-existing cells).
- Smallest cells: **Mycoplasma (PPLO) ≈ 0.3 µm**; bacteria 3–5 µm. Largest single cell: **egg of ostrich**. Longest cell in human body: **nerve cell**. Human RBC ≈ 7.0 µm.
- Viruses are **not cells** (acellular, obligate parasites).

Feature	Prokaryotic cell	Eukaryotic cell
Examples	Bacteria, **cyanobacteria** (blue-green algae), mycoplasma, PPLO	Protists, fungi, plants, animals
Nucleus	No nuclear membrane – **nucleoid** (naked circular DNA)	True nucleus with double nuclear envelope, nucleolus
DNA	Circular, no histones (single chromosome) + **plasmids**	Linear, with **histones** (chromatin)
Ribosomes	**70S** (50S + 30S)	**80S** in cytoplasm (60S + 40S); 70S in mitochondria & chloroplasts
Membrane-bound organelles	Absent; **mesosome** (infolding of plasma membrane – respiration, DNA replication, cell wall formation)	Present (mitochondria, ER, Golgi, plastids etc.)
Cell wall	**Peptidoglycan (murein)**	Cellulose (plants), **chitin** (fungi), absent in animals
Flagellum	Simple, single fibril (flagellin)	**9 + 2** microtubule arrangement
Cell division	Binary fission (amitosis)	Mitosis & meiosis

- Bacterial cell envelope: **glycocalyx** (slime layer – loose; capsule – thick, tough) → cell wall → plasma membrane. **Gram +ve** retain crystal violet (thick peptidoglycan); **Gram –ve** do not.
- **Pili** = attachment/conjugation; **fimbriae** = attachment to surfaces; **polysome** = several ribosomes on one mRNA.
- Inclusion bodies in prokaryotes: phosphate granules, **cyanophycean granules**, glycogen granules; **gas vacuoles** in blue-green, purple and green photosynthetic bacteria.

Feature	Plant cell	Animal cell
Cell wall	Present (cellulose)	Absent
Plastids	Present	Absent
Vacuole	**Large central vacuole** (up to 90% of volume)	Small, temporary or absent
Centrioles	**Absent in higher plants**	Present
Reserve food	Starch	Glycogen
Cytokinesis	**Cell plate** (centre → periphery)	Cleavage furrow (periphery → centre)
Glyoxysomes	Present (fatty seeds)	Absent

Organelle	Structure / key facts	Function
Mitochondria (Altmann – "bioblasts"; Benda named 1898)	Double membrane; inner folded into **cristae** bearing **F_0-F_1 particles (oxysomes)**; matrix has **circular DNA, 70S ribosomes, RNA** → **semi-autonomous**; divide by fission; ~0.2–1.0 µm wide, 1.0–4.1 µm long	**"Powerhouse of the cell"** – aerobic respiration, Krebs cycle (matrix), ETS & ATP synthesis (inner membrane)
Chloroplast (term – Schimper)	Double membrane; **thylakoids → grana** (stacks), stroma lamellae; **stroma** has circular DNA, **70S ribosomes**, RuBisCO; semi-autonomous; 1 per cell in *Chlamydomonas*, 20–40 per mesophyll cell	Photosynthesis: light reaction in **thylakoid/grana**, dark reaction (Calvin cycle) in **stroma**
Other plastids	**Chromoplasts** (carotene, xanthophyll – yellow/orange/red); **leucoplasts**: **amyloplast** (starch, e.g. potato), **elaioplast** (oils, fats), **aleuroplast** (proteins)	Colour, storage
Ribosomes (George **Palade 1953** – "Palade particles")	Non-membranous; RNA + protein; **70S = 50S + 30S**; **80S = 60S + 40S**; S = **Svedberg unit** (sedimentation coefficient, indirectly size/density); Mg^{2+} needed for association	**Protein synthesis**
Endoplasmic reticulum (Porter, Claude & Fullam 1945)	**RER** – ribosomes attached; **SER** – smooth	RER: protein synthesis & secretion; SER: **lipid/steroid synthesis**, detoxification; in muscle = sarcoplasmic reticulum
Golgi apparatus (Camillo **Golgi 1898**)	Stacked flat cisternae; **cis (forming) face** toward ER, **trans (maturing) face**; in plants scattered units = **dictyosomes**	Packaging, modification & secretion; **glycoproteins & glycolipids formed here**; forms acrosome of sperm, cell plate in plants, lysosomes

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Lysosome (Christian **de Duve 1955**)	Single membrane vesicles formed by Golgi; acid hydrolases (lipases, proteases, carbohydrases) active at **acidic pH (~5)**	Intracellular digestion; **"suicide bags"** (autolysis)
Vacuole	Bounded by single membrane – **tonoplast**; cell sap (water, sap, excretory products); tonoplast pumps ions **into** vacuole against gradient	Turgidity, storage; **contractile vacuole** (Amoeba – osmoregulation), food vacuole (protists)
Peroxisome (microbody; de Duve)	Single membrane; enzymes **catalase** & oxidases	Breaks H_2O_2; in plants takes part in **photorespiration (C_2 cycle)** with chloroplast & mitochondria
Glyoxysome (Beevers)	Microbody in **germinating fatty (oil) seeds** e.g. castor	**Glyoxylate cycle** – converts fats → carbohydrates (enzymes isocitrate lyase, malate synthase)
Centrosome	Two **centrioles** perpendicular; each with **9 peripheral triplet** microtubules (cartwheel, 9 + 0)	Basal bodies of cilia/flagella; spindle formation in animal cells
Cilia/flagella	Axoneme **9 + 2** (9 doublets + 2 central singlets); dynein arms	Movement
Cytoskeleton	Microtubules (tubulin), microfilaments (actin), intermediate filaments	Support, motility, shape
Nucleus	Double envelope with **nuclear pores**; perinuclear space 10–50 nm; **nucleolus** (not membrane-bound); chromatin (DNA + histones + non-histone proteins + RNA)	Control centre; **nucleolus = site of rRNA synthesis**

- **Endomembrane system** = ER + Golgi + lysosomes + vacuoles (functions coordinated). **Mitochondria, chloroplasts and peroxisomes are NOT** part of it.
- Mature mammalian **RBC** and plant **sieve tube** cells **lack a nucleus**.
- Chromosome types by centromere: **metacentric** (middle, two equal arms), **sub-metacentric**, **acrocentric** (near end, very short arm), **telocentric** (terminal). **Satellite** = small fragment beyond a **secondary constriction** (SAT chromosome; nucleolar organiser). **Kinetochore** = disc on centromere where spindle fibres attach.
- Human somatic cell: **46 chromosomes (23 pairs)**; DNA ~2 m long in each diploid cell.

Cell wall & plasma membrane

- Algal wall: cellulose, galactans, mannans, $CaCO_3$. Plant wall: **cellulose, hemicellulose, pectins, proteins**.
- **Middle lamella** = mainly **calcium pectate**; glues neighbouring cells. Order (outside in): middle lamella → **primary wall** (young, growing, capable of growth) → **secondary wall** (inner side, after growth ceases; **lignin**, suberin, cutin deposits).
- **Plasmodesmata** = cytoplasmic strands through walls connecting adjacent cells (symplast). **Pits** = unthickened areas of secondary wall.
- Plasma membrane composition (human RBC): **~52% protein, ~40% lipids** (mainly phospholipids in a bilayer, polar heads outward, hydrophobic tails inward), plus carbohydrates.
- **Fluid mosaic model – Singer & Nicolson (1972)**: quasi-fluid lipid bilayer with **integral** (embedded/transmembrane) and **peripheral** (surface) proteins that move laterally. Earlier: Danielli & Davson sandwich model (1935); Robertson unit membrane (1959).
- Transport: passive (diffusion, osmosis, facilitated via carriers) – along gradient, no energy; **active transport** against gradient uses ATP – e.g. **Na^+/K^+ pump**. Water moves by osmosis (aquaporins).

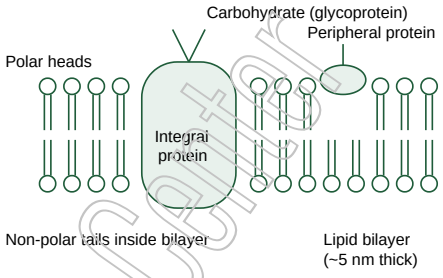

Fig 6.1 Fluid mosaic model of plasma membrane (Singer & Nicolson, 1972)

MEMORY TRICK

"**M**itochondria & **C**hloroplast = **MC** with their own **DNA + 70S**" – they are semi-autonomous, supporting the **endosymbiotic theory** (Lynn Margulis). Lysosome = **L**ethal (suicide bag); Glyoxysome = **G**erminating oil seed.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- "Omnis cellula-e cellula" was proposed by? → **Rudolf Virchow**.
- Fluid mosaic model was given by? → **Singer & Nicolson (1972)**.
- Ribosomes of prokaryotes are? → **70S (50S + 30S)**.
- Membrane surrounding the plant vacuole? → **Tonoplast**.
- Organelle that converts fats into sugars in germinating castor seeds? → **Glyoxysome**.
- Middle lamella is mainly made of? → **Calcium pectate**.

6.2 Cell Division ★★★

- **Cell cycle** = Interphase (G_1 → S → G_2) + M phase (karyokinesis + cytokinesis). Typical human cell in culture divides once in **~24 h**; **yeast ~90 min**.
- M phase lasts only **~1 h** of 24 h; **interphase occupies > 95%** of the cycle ("resting phase" – metabolically most active, preparation phase).
- **G_1** – cell grows, metabolically active, no DNA replication. **S phase – DNA replication**: DNA content doubles (**2C → 4C**) but **chromosome number stays the same (2n)**; in animal cells **centriole duplicates in the cytoplasm**. **G_2** – proteins (tubulin) synthesised, growth continues.
- **G_0 (quiescent stage)** – cells exit G_1 and stop dividing but remain metabolically active (e.g. heart cells, neurons).
- In animals mitosis occurs in diploid somatic cells; in **plants** both **haploid and diploid** cells divide by mitosis. Meristems are the sites of mitosis in plants.
- Term **mitosis – Walther Flemming (1882)**; **meiosis – Farmer & Moore (1905)**.

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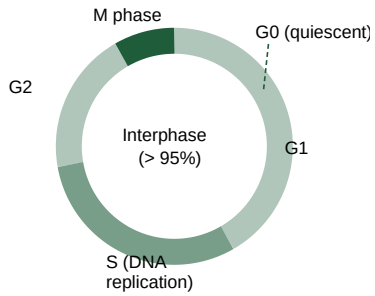

Fig 6.2 Cell cycle (clockwise $G_1 \rightarrow S \rightarrow G_2 \rightarrow M$); G_0 exits from G_1

Mitosis stage	Key events
Prophase	Chromatin condenses into chromosomes (each with 2 chromatids joined at centromere); centrioles move to poles; spindle starts; **nucleolus and nuclear envelope disappear** at end; Golgi, ER not seen
Metaphase	Chromosomes align at **equatorial (metaphase) plate**; spindle fibres attach to **kinetochores**; **best stage to study chromosome morphology/count** (karyotype)
Anaphase	**Centromeres split**; sister chromatids (now daughter chromosomes) move to opposite poles, centromere leading, arms trailing
Telophase	Chromosomes decondense at poles; **nuclear envelope & nucleolus reappear**; Golgi, ER re-form
Cytokinesis	Animal – **cleavage furrow**; plant – **cell plate** (middle lamella) from centre outward, formed by Golgi vesicles (phragmoplast). Karyokinesis without cytokinesis → **syncytium** (e.g. **liquid endosperm of coconut**)

- **Colchicine** (from *Colchicum autumnale*) inhibits spindle formation → arrests cells at **metaphase**; used to induce **polyploidy**.
- Onion root tip is the classic material for mitosis; anther (pollen mother cells) / flower buds for meiosis.

Meiosis

- Occurs in diploid **meiocytes** (spore/gamete mother cells) → **4 haploid** cells. Only **one DNA replication** (before meiosis I) but **two divisions**.
- **Meiosis I = reductional** (homologous chromosomes separate; 2n → n). **Meiosis II = equational** (like mitosis; sister chromatids separate).
- **Interkinesis** = short stage between meiosis I and II; **no DNA replication**.

Sub-stage of Prophase I	Event
Leptotene	Chromosomes become gradually visible (condensation begins)
Zygotene	**Synapsis** – pairing of homologues, forming **synaptonemal complex**; paired pair = **bivalent / tetrad**
Pachytene	Tetrads clear; **recombination nodules**; **crossing over** between non-sister chromatids (enzyme **recombinase**); longer than leptotene & zygotene (some texts: diplotene longest)
Diplotene	Synaptonemal complex dissolves; homologues separate except at X-shaped **chiasmata** (visible). Can last months/years in oocytes of some vertebrates (**dictyotene**)
Diakinesis	**Terminalisation of chiasmata**; spindle assembles; nucleolus & nuclear envelope disappear → transition to metaphase I

- **Metaphase I** – bivalents on equatorial plate. **Anaphase I** – **homologues separate**, sister chromatids remain together at centromere. **Anaphase II** – centromeres split, sister chromatids separate.
- Significance of meiosis: **maintains chromosome number** across generations in sexually reproducing organisms; produces **genetic variation** (crossing over + independent assortment) → raw material for evolution.
- Significance of mitosis: growth, repair, regeneration, maintains nucleo-cytoplasmic ratio, asexual/vegetative reproduction; produces genetically identical cells.

Point	Mitosis	Meiosis
Occurs in	Somatic cells	Reproductive (germ) cells / meiocytes
Divisions	One	Two (I & II)
Daughter cells	2, diploid, identical	4, haploid, genetically different
Synapsis / crossing over	Absent	Present (zygotene / pachytene)
Nature	**Equational**	I – **reductional**; II – equational
Prophase	Short, simple	Long, 5 sub-stages
Anaphase	Sister chromatids separate	Anaphase I – homologues separate

KEY FORMULAE

- Number of cells after *n* mitotic generations = 2^n; number of mitotic divisions to form *N* cells = **N – 1**.
- Meiosis: 1 meiocyte → 4 gametes/spores; to get *N* seeds need **N/4 + N** meiotic divisions (N/4 for pollen + N for megaspores) in angiosperms.
- DNA content: G_1 = 2C → after S = 4C → after mitosis = 2C each; after meiosis I = 2C (n chromosomes, 2 chromatids) → after meiosis II = **1C**.

MEMORY TRICK

Prophase I sub-stages: "**L**ady **Z**ebra **P**lays **D**uring **D**ays" – Leptotene, Zygotene (Zip = synapsis), Pachytene (Pass genes = crossing over), Diplotene (Double, chiasmata seen), Diakinesis (terminalisation).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Crossing over takes place in? → **Pachytene**.
- Chiasmata first become visible in? → **Diplotene**.
- Synaptonemal complex forms during? → **Zygotene**.
- Best stage to count chromosomes? → **Metaphase**.
- DNA replication occurs in which phase? → **S phase**.
- Free nuclear division without cytokinesis is seen in? → **Coconut liquid endosperm**.

6.3 Biomolecules ★★☆

- Living tissue is ~70–90% **water**. Biomolecules of MW < 1000 Da = micromolecules (acid-soluble pool); > 1000 Da = **macromolecules** (proteins, nucleic acids, polysaccharides). Lipids are in acid-

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insoluble fraction though MW < 800 (they form membrane vesicles).

- Most abundant protein in the biosphere: **RuBisCO**; in the animal world: **collagen**. Most abundant organic compound on earth: **cellulose**.

Class	Building unit / bond	Examples & facts
Carbohydrates	Monosaccharides; **glycosidic bond**	Glucose, fructose, ribose (5C); sucrose = glucose + fructose; maltose = glucose + glucose; lactose = glucose + galactose. **Starch** (amylose α-1,4; amylopectin α-1,4 + α-1,6 branches), **glycogen** (animal starch), **cellulose** (β-1,4 glucose – no helix, gives no blue colour with I_2), **inulin** (fructose polymer), **chitin** (N-acetyl glucosamine – exoskeleton of arthropods, fungal wall)
Proteins	20 amino acids; **peptide bond** (–CO–NH–)	Structure: primary (sequence), secondary (α-helix, β-sheet; H-bonds), tertiary (3-D fold), quaternary (subunits, e.g. **haemoglobin – 2α + 2β**). Left end = N-terminal, right end = C-terminal
Lipids	Fatty acids + glycerol; **ester bond**	Saturated (no double bond, e.g. palmitic 16C) & unsaturated (oleic, linoleic); **phospholipids** (lecithin) in membranes; oils = liquid at room temp. Steroids (cholesterol)
Nucleic acids	Nucleotide = sugar + base + phosphate; **phosphodiester bond**	Nucleoside = sugar + base. Purines: **adenine, guanine**; pyrimidines: **cytosine, thymine (DNA), uracil (RNA)**

- Amino acids: **acidic** (glutamic, aspartic), **basic** (lysine, arginine), neutral (valine); aromatic (tyrosine, phenylalanine, tryptophan). Simplest: **glycine** (R = H, not optically active). Exist as **zwitterion** in solution.
- Essential amino acids must come from diet (e.g. lysine, tryptophan, methionine); cereals deficient in **lysine**, pulses in **methionine**.

Enzymes

- Almost all enzymes are **proteins**; exceptions = **ribozymes** (catalytic RNA, e.g. peptidyl transferase – 23S rRNA). Term "enzyme" – **Kühne (1878)**; first crystallised enzyme – **urease (Sumner, 1926)**.
- Enzymes lower **activation energy**, do not change equilibrium. Models: **lock & key – Emil Fischer**; **induced fit – Koshland**.
- Holoenzyme = **apoenzyme** (protein) + **cofactor**. Cofactors: **prosthetic group** (tightly bound – **haem in peroxidase & catalase**), **coenzyme** (loosely bound, often vitamin-derived – NAD, NADP contain **niacin**), **metal ions** (Zn^{2+} for carboxypeptidase).
- Activity rises with temperature up to an **optimum**, then denatures; low temperature inactivates (reversibly). Each enzyme has an optimum pH (pepsin ~2, trypsin ~8).
- **Michaelis constant (K_m)** = substrate concentration at which velocity = ½ V_{max}; low K_m = high affinity.

KEY FORMULAE

- Michaelis–Menten: $v = V_{max}[S] \div (K_m + [S])$; when [S] = K_m, v = $V_{max}/2$.
- Lineweaver–Burk (double reciprocal): $1/v = (K_m/V_{max})(1/[S]) + 1/V_{max}$; y-intercept = $1/V_{max}$, x-intercept = $-1/K_m$.

Inhibition	Binds	K_m	V_{max}	Example / note
Competitive	Active site (substrate analogue)	**Increases**	**Unchanged**	**Malonate** inhibits **succinate dehydrogenase**; overcome by more substrate
Non-competitive	Other site (enzyme or ES)	Unchanged	**Decreases**	Heavy metals (Hg, Pb), cyanide on cytochrome oxidase
Uncompetitive	ES complex only	Decreases	Decreases	Parallel lines in L-B plot
Feedback (allosteric)	Allosteric site	Sigmoid kinetics		End product inhibits first enzyme of pathway

EC class (IUBMB)	Reaction
1 Oxidoreductases	Oxidation–reduction (dehydrogenases)
2 Transferases	Transfer of groups other than H
3 Hydrolases	Hydrolysis of ester, ether, peptide, glycosidic bonds
4 Lyases	Removal of groups forming double bonds (non-hydrolytic)
5 Isomerases	Inter-conversion of isomers
6 Ligases	Joining two compounds using ATP
7 Translocases	Movement of ions/molecules across membranes (added **2018**)

PREVIOUSLY ASKED / LIKELY QUESTIONS

- K_m is the substrate concentration at which reaction velocity is? → **Half of V_{max}**.
- In competitive inhibition K_m and V_{max}? → **K_m increases, V_{max} unchanged**.
- Malonate inhibits? → **Succinate dehydrogenase** (competitive).
- Cellulose is a polymer of? → **β-D-glucose (β-1,4 linkage)**.
- Most abundant protein on earth? → **RuBisCO**.

6.4 Plant Tissues & Anatomy ★★★

- **Tissue** = group of cells of common origin performing a common function. Two types: **meristematic** (dividing) and **permanent** (differentiated, no division).
- Meristem cells: small, thin cellulose walls, dense cytoplasm, large nucleus, **no/small vacuoles**, no intercellular spaces.

Meristem	Location	Role
Apical	Tips of root & shoot	**Primary growth – increase in length**; root apex covered by root cap

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Intercalary	Between mature tissues – base of internodes/leaves of **grasses**	Regenerates parts removed by grazing; elongation of internodes
Lateral	Along sides – **vascular cambium, cork cambium (phellogen)**	**Secondary growth – increase in girth**

- Apical and intercalary meristems = **primary meristems**. **Interfascicular cambium** and cork cambium arise from permanent tissues → **secondary meristems**. Axillary buds arise from left-over shoot apical meristem cells.

Simple tissue	Living/dead	Wall	Features / function
Parenchyma	Living	Thin, cellulose	Major component; isodiametric; photosynthesis (**chlorenchyma**), storage, secretion, buoyancy (**aerenchyma** – hydrophytes)
Collenchyma	Living	Thickened at **corners** with cellulose, hemicellulose, **pectin**	Mechanical support to **young stems & petioles**; layers below epidermis (hypodermis) of **dicot stem**; **absent in monocots and roots**; may have chloroplasts
Sclerenchyma	**Dead**	Thick, **lignified**, with pits	**Fibres** (long, pointed – jute, flax, hemp) and **sclereids/stone cells** (short – pulp of **guava, pear, sapota**, nut shells, legume seed coats, tea leaves)

Complex tissue	Elements	Living element(s)	Key points
Xylem (water & minerals; support)	**Tracheids, vessels, xylem fibres, xylem parenchyma**	Only **xylem parenchyma**	Tracheids & vessels = main water-conducting, dead, lignified. **Vessels** characteristic of **angiosperms**; **gymnosperms lack vessels** (except Gnetales). Protoxylem first-formed; metaxylem later
Phloem (food conduction)	**Sieve tube elements, companion cells, phloem parenchyma, phloem fibres (bast)**	All except **phloem fibres** (only dead element)	Sieve tubes with **sieve plates**; mature sieve tube **lacks nucleus**, controlled by companion cell (pit connections). Gymnosperms have **albuminous cells & sieve cells** instead of companion cells & sieve tubes. **Phloem parenchyma absent in most monocots**

- **Endarch** xylem (protoxylem towards centre/pith) – **stems**. **Exarch** (protoxylem towards periphery) – **roots**.
- Vascular bundles: **radial** (xylem & phloem on different radii – **roots**); **conjoint collateral** (same radius – stems, leaves); **open** (cambium present – dicot stem) vs **closed** (no cambium – monocot); **bicollateral** (phloem on both sides – *Cucurbita*); concentric: **amphicribral** (phloem surrounds xylem – ferns) & **amphivasal** (xylem surrounds phloem – *Dracaena*).

Tissue system (Sachs)	Components
Epidermal	Epidermis, **cuticle** (absent in roots), **stomata** (guard cells – **bean-shaped** in dicots, **dumb-bell shaped** in grasses; subsidiary cells), hairs: **root hairs** (unicellular) & **trichomes** (shoot, usually multicellular)
Ground	All tissues except epidermis & vascular bundles – cortex, pericycle, pith, medullary rays; in leaves = **mesophyll**
Vascular	Xylem, phloem (± cambium)

Character	Dicot root	Monocot root
Xylem bundles	**2–4** (diarch–tetrarch)	**More than 6 (polyarch)**
Pith	Small or absent	**Large, well developed**
Secondary growth	Present (cambium from conjunctive tissue + pericycle)	**Absent**
Common to both	Epiblema with root hairs; parenchymatous cortex; **endodermis** with **Casparian strips** (suberin – blocks apoplast water flow); **pericycle** → lateral roots & vascular cambium; radial, exarch bundles	

Character	Dicot stem	Monocot stem
Hypodermis	**Collenchymatous**	**Sclerenchymatous**
Ground tissue	Differentiated into cortex, endodermis (**starch sheath**), pericycle, pith	**Undifferentiated**, parenchymatous
Vascular bundles	**Arranged in a ring**; conjoint, collateral, **open**, endarch	**Scattered**; conjoint, collateral, **closed**; surrounded by **sclerenchymatous bundle sheath**
Other	Medullary rays present	**Water-containing cavities** (protoxylem lacunae); phloem parenchyma absent; bundles near periphery smaller

Character	Dicot leaf (dorsiventral)	Monocot leaf (isobilateral)
Stomata	More on **abaxial (lower)** surface; may be absent on upper	**Equal on both** surfaces
Mesophyll	Differentiated: **palisade** (adaxial, elongated) + **spongy** (abaxial, loose)	**Not differentiated**
Venation	Reticulate; vein size varies	Parallel; veins of similar size
Special	Bundle sheath around veins	**Bulliform cells** (large, empty, colourless adaxial cells) – **leaf rolling** to reduce water loss in grasses

- **Kranz anatomy** (C_4 plants – maize, sugarcane, sorghum): large **bundle sheath cells** with many chloroplasts, thick walls, no intercellular spaces, arranged as a wreath.

Secondary growth

- In dicot stem: **intrafascicular cambium** (inside bundles) + **interfascicular cambium** (from medullary ray cells) → continuous **cambial ring**.

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- Cambium is **more active on the inner side** → produces more **secondary xylem** than secondary phloem; primary & secondary phloem get crushed. Secondary medullary rays pass through xylem & phloem.
- **Spring wood / early wood** – cambium very active; more xylem elements with **wide vessels**, lighter colour, lower density. **Autumn wood / late wood** – less active; narrow vessels, darker, higher density.
- **Annual ring** (growth ring) = one spring + one autumn wood band. Counting rings to estimate tree age = **dendrochronology**. Distinct rings in temperate trees; indistinct in tropical evergreen trees (uniform climate).

Point	Heartwood (duramen)	Sapwood (alburnum)
Position	Central/inner, older secondary xylem	Peripheral, younger
Colour	**Dark brown** – tannins, resins, oils, gums, aromatic substances	Light
Function	**Does not conduct water**; mechanical support	**Conducts water & minerals**
Features	Tracheary elements plugged by **tyloses**; hard, durable, resistant to microbes & insects	Less durable

- **Cork cambium (phellogen)** develops usually in the cortex; produces **phellem (cork)** on the **outer side** and **phelloderm (secondary cortex)** on the **inner side**.
- **Periderm = phellem + phellogen + phelloderm**. Cork cells are dead, **suberised** (impervious to water). Commercial cork: ***Quercus suber*** (cork oak).
- **Bark** (non-technical) = all tissues **outside the vascular cambium** (secondary phloem + periderm). Early/soft bark formed early in season; late/hard bark late.
- **Lenticels** – lens-shaped openings in bark formed by phellogen (complementary cells) for **gaseous exchange**; present in most woody trees.
- Secondary growth in dicot root: vascular cambium is **secondary in origin** (from conjunctive tissue + pericycle), initially **wavy**, later circular.
- Secondary growth is normally absent in monocots; anomalous secondary growth in *Dracaena*, *Yucca*, palms (increase in girth by other means).

MEMORY TRICK

Phellogen gives **"Phellem Out, Phelloderm In"** – **P**OD: **P**hellem **O**utside, phello**D**erm inside. Heartwood = "Heart is dead but strong (tyloses)"; Sapwood = "Sap flows".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Only dead element of phloem? → **Phloem fibres (bast)**.
- Meristem responsible for regrowth of grass after grazing? → **Intercalary meristem**.
- Bulliform cells are found in? → **Monocot (grass) leaves** – leaf rolling.
- Scattered vascular bundles with bundle sheath are a feature of? → **Monocot stem**.
- Age of a tree is estimated by counting? → **Annual rings – dendrochronology**.
- Casparian strips in endodermis are made of? → **Suberin**.

6.5 Plant Morphology & Organ Systems ★★☆

- **Tap root** – from **radicle** (dicots, e.g. mustard). **Fibrous root** – primary root short-lived, replaced by many roots from stem base (monocots, e.g. wheat). **Adventitious** – from parts other than radicle (grass, *Monstera*, banyan).
- Root regions from tip: **root cap → meristematic zone → elongation zone → maturation zone (root hairs)**.

Modification	Examples
ROOT	
Storage (tap root)	**Carrot** (conical), **radish** (fusiform), **turnip, beetroot** (napiform)
Storage (adventitious, tuberous)	**Sweet potato**, *Asparagus*, dahlia
Prop roots (from branches)	**Banyan**
Stilt roots (lower nodes)	**Maize, sugarcane**, *Pandanus*
Pneumatophores (respiratory, negatively geotropic)	***Rhizophora*** (mangroves – swampy areas)
Epiphytic roots with **velamen**	Orchids (*Vanda*)
Nodules (N-fixation, *Rhizobium*)	Legumes
STEM	
Underground food storage	**Potato – tuber** (eyes = nodes); **ginger, turmeric – rhizome**; **Colocasia, Amorphophallus – corm**; **onion, garlic – bulb**
Stem tendrils (from axillary bud)	**Cucumber, pumpkin, watermelon, grapevine**
Thorns (axillary bud)	**Citrus, *Bougainvillea***
Phylloclade (flattened green stem)	***Opuntia***, *Euphorbia*; cladode (one internode) – *Asparagus*
Sub-aerial: runner / stolon / offset / sucker	Runner – **grass, strawberry**; stolon – **mint, jasmine**; offset – ***Pistia***, ***Eichhornia*** (water hyacinth); sucker – **banana, pineapple, *Chrysanthemum***
LEAF	
Leaf tendrils	**Pea** (leaflets modified)
Spines	**Cacti, *Opuntia*** (leaves reduced to spines)
Phyllode (petiole flattened, green)	**Australian *Acacia***
Fleshy storage leaves	Onion, garlic
Insectivorous	**Pitcher plant (*Nepenthes*)**, **bladderwort (*Utricularia*)**, Venus fly-trap (*Dionaea*), sundew (*Drosera*)

- **Phyllotaxy**: **alternate** – China rose, mustard, sunflower; **opposite** – *Calotropis*, guava; **whorled** (> 2 per node) – *Alstonia*.
- Compound leaves: **pinnate** – neem; **palmate** – silk cotton (*Bombax*). Leaf base swollen = **pulvinus** (legumes); sheathing leaf base in monocots. Leaf with stipules = stipulate.
- Venation: **reticulate** – dicots; **parallel** – monocots.

Inflorescence & flower

Type	Feature	Examples

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Racemose	Main axis grows indefinitely; flowers in **acropetal** order (older at base)	Raceme (mustard), spike (*Achyranthes*), catkin (mulberry), spadix (banana, *Colocasia*), umbel (coriander), corymb
Cymose	Main axis ends in a flower – limited growth; **basipetal** order	*Jasminum*, *Solanum* (cymes)
Capitulum / head	Flattened receptacle with ray & disc florets	**Sunflower**, marigold (Asteraceae)
Cyathium	Cup-like involucre, one female + many male flowers	***Euphorbia*** (poinsettia)
Hypanthodium	Flask-shaped hollow receptacle	***Ficus*** (fig, banyan)
Verticillaster	Cymes in axils of opposite leaves	*Ocimum* (tulsi) – Lamiaceae

- Flower = modified shoot. Whorls: **calyx** (sepals), **corolla** (petals), **androecium** (stamens), **gynoecium** (carpels/pistil). Undifferentiated calyx & corolla = **perianth** (tepals) – lily.
- Symmetry: **actinomorphic** (radial, ⊕) – mustard, datura, chilli; **zygomorphic** (bilateral, %) – pea, gulmohur, bean, *Cassia*; asymmetric – *Canna*.
- Position of ovary: **hypogynous** (ovary superior) – mustard, China rose, brinjal; **perigynous** (half-inferior) – plum, rose, peach; **epigynous** (ovary inferior) – guava, cucumber, ray florets of sunflower.
- Stamens: **epipetalous** (attached to petals) – brinjal; **epiphyllous** (to perianth) – lily. **Monoadelphous** (one bundle) – **China rose**; **diadelphous** (two bundles) – **pea**; **polyadelphous** – **citrus**; **syngenesious** (anthers fused, filaments free) – **Asteraceae**. **Tetradynamous** (4 long + 2 short) – Brassicaceae.
- Gynoecium: **apocarpous** (free carpels) – lotus, rose; **syncarpous** (fused) – mustard, tomato.

Aestivation (arrangement of petals in bud)	Examples
Valvate – margins just touch	***Calotropis***
Twisted – one margin overlaps next regularly	**China rose, lady's finger (okra), cotton**
Imbricate – overlapping irregular	***Cassia*, gulmohur**
Vexillary (papilionaceous) – standard (vexillum) + 2 wings + keel (2 fused)	**Pea, bean**

Placentation	Description	Examples
Marginal	Ridge along ventral suture, monocarpellary	**Pea**
Axile	Placenta on central axis, multilocular ovary	**China rose, tomato, lemon**
Parietal	On inner wall; unilocular becomes bilocular by **false septum (replum)**	**Mustard,** ***Argemone***
Free central	Ovules on central axis, no septa	***Dianthus*, *Primrose***
Basal	Placenta at base, single ovule	**Sunflower, marigold**

Fruits & seeds

- **True fruit** – develops from ovary only. **False fruit** – other floral parts contribute (thalamus etc.): **apple, pear (pome), strawberry, cashew**.
- **Parthenocarpic fruit** – develops **without fertilisation** → seedless (e.g. **banana**); can be induced by **auxins/gibberellins**.
- Fruit wall = **pericarp** → epicarp, mesocarp, endocarp. **Drupe** (one-seeded, stony endocarp, from monocarpellary superior ovary): **mango** (edible fleshy mesocarp), **coconut** (fibrous mesocarp).

Fruit type	Examples	Edible part
Caryopsis (pericarp fused with seed coat)	Rice, wheat, maize	Endosperm (+ embryo)
Legume / pod	Pea, bean, gram	Seeds
Siliqua	Mustard	Seeds
Berry	Tomato, grape, brinjal, guava	Pericarp & placenta (whole fruit)
Hesperidium	Citrus	**Juicy hairs** (from endocarp)
Pepo	Cucurbits (cucumber, melon)	Mesocarp/endocarp
Pome (false)	Apple, pear	**Fleshy thalamus**
Cypsela	Sunflower, marigold	Seed
Drupe	Mango / coconut	**Mesocarp / endosperm**
Aggregate (etaerio)	Strawberry (achenes on fleshy thalamus), custard apple	Thalamus / fleshy fruitlets
Multiple (composite) – **sorosis**	**Pineapple, jackfruit, mulberry**	Whole inflorescence (bracts, perianth, rachis)
Multiple – **syconus**	Fig (*Ficus*)	Fleshy receptacle
Other edible parts	**Litchi – aril**; **pomegranate – juicy testa**; cashew – peduncle/thalamus (false fruit)	—

Part	Dicot seed (pea, gram, bean)	Monocot seed (maize)
Cotyledons	**Two**, often fleshy (food storage)	**One** – shield-shaped **scutellum**
Endosperm	Mostly **non-endospermic (exalbuminous)**; **castor** is endospermic	Usually **endospermic** (bulky, stores food); orchids non-endospermic
Seed coat	**Testa** (outer) & **tegmen** (inner); **hilum** (scar of attachment), **micropyle** (small pore)	Seed coat fused with fruit wall (caryopsis)
Embryo sheaths	Plumule & radicle naked	Plumule in **coleoptile**, radicle in **coleorhiza**
Special	—	Proteinaceous **aleurone layer** = outermost layer of the endosperm, just inside the seed coat (NCERT wording: "separates the embryo") (site of α-amylase induction by GA)

Floral formula & important families

- Symbols: **Br** bracteate, **K** calyx, **C** corolla, **P** perianth, **A** androecium, **G** gynoecium; ⊕ actinomorphic, **%** zygomorphic, ⚥ bisexual, ♂ male, ♀ female. **( )** = fusion (cohesion); line over

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symbols = adhesion. $\underline{G}$ (line below G) = **superior ovary**; $\bar{G}$ (line above G) = **inferior ovary**; ∞ = numerous.

Family	Key characters	Floral formula (NCERT style)	Economic examples
Fabaceae (Papilionoideae of Leguminosae)	Root nodules; pinnate leaves, pulvinus; **vexillary aestivation**; **diadelphous (9)+1**; monocarpellary, **marginal placentation**; legume pod	% ♀♂ $K_{(5)}$ $C_{1+2+(2)}$ $A_{(9)+1}$ $\underline{G}_{1}$	Pulses – **gram, arhar, soybean, pea, moong**; groundnut; *Indigofera* (dye); *Crotalaria juncea* (sunn hemp fibre); *Sesbania*, *Trifolium* (fodder); lupin, sweet pea (ornamental); *Glycyrrhiza* (muliathi, medicine)
Solanaceae (potato family)	**Epipetalous** stamens; bicarpellary, **oblique** ovary, **swollen axile placenta**; berry/capsule; persistent calyx	⊕ ♀♂ $K_{(5)}$ $C_{(5)}$ A_5 $\underline{G}_{(2)}$ (A epipetalous)	**Potato, tomato, brinjal, chilli**; **tobacco**; ashwagandha (*Withania*), belladonna (*Atropa*); petunia (ornamental)
Liliaceae (lily family) – monocot	Perianth of 6 tepals (3 + 3); **epiphyllous** stamens; tricarpellary syncarpous, superior, **axile**	⊕ ♀♂ $P_{(3+3)}$ A_{3+3} $\underline{G}_{(3)}$	Tulip, *Gloriosa* (ornamental); ***Aloe***; *Asparagus*; **colchicine** from *Colchicum autumnale*. (Onion/garlic placed here in NCERT; modern APG – Amaryllidaceae)
Poaceae (Gramineae)	Hollow internodes (culm), sheathing leaf base, ligule; spikelets with glumes, lemma, palea; **lodicules** (reduced perianth); 3 stamens, versatile anthers; feathery stigma (wind pollination); **caryopsis**	% ♀♂ P_{2} (lodicules) A_3 $\underline{G}_{1}$ (ovary unilocular, 1 ovule; rice has A_6)	**Rice, wheat, maize, millets, sugarcane, bamboo**
Brassicaceae (Cruciferae)	**Cruciform** corolla (4 petals); **tetradynamous** stamens (2 short + 4 long); bicarpellary, **parietal** with false septum (**replum**); **siliqua**	⊕ ♀♂ K_{2+2} C_4 A_{2+4} $\underline{G}_{(2)}$	**Mustard** (rapeseed), **cabbage, cauliflower, radish, turnip, knol-khol**
Malvaceae (cotton family)	**Epicalyx**; **twisted aestivation**; **monoadelphous** stamens with kidney-shaped **monothecous** anthers; axile placentation; mucilage	⊕ ♀♂ Epicalyx $K_{(5)}$ C_5 $A_{(\infty)}$ $\underline{G}_{(5)}$	**Cotton (*Gossypium*), okra (bhindi)**, *Hibiscus* (China rose), mesta/kenaf; *Bombax* placed here in APG
Asteraceae (Compositae) – **largest dicot family**	**Capitulum** with ray & disc florets; calyx modified as **pappus** (wind dispersal); **syngenesious** stamens; bicarpellary, **inferior** ovary, **basal** placentation; **cypsela**	Disc floret: ⊕ ♀♂ K_{pappus} $C_{(5)}$ $A_{(5)}$ $\bar{G}_{(2)}$	**Sunflower, safflower** (oilseeds); lettuce; marigold, *Chrysanthemum*, *Zinnia*; *Artemisia* (artemisinin); weeds – ***Parthenium***, *Tridax*

MEMORY TRICK

Placentation: "**Pea** on the **Margin**, **Mustard** on the **Wall** (parietal), **Sunflower** sits at the **Base**, **Tomato/China rose** on the **Axis**, **Dianthus** floats **Free**."

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Potato is a modified? → **Stem (tuber)**; sweet potato → **root**.
- Tetradynamous stamens are characteristic of? → **Brassicaceae (Cruciferae)**.
- Edible part of mango / coconut / apple? → **Mesocarp / endosperm / thalamus**.
- Twisted aestivation is found in? → **China rose, cotton, okra**.
- Parthenocarpic fruit develops? → **Without fertilisation** (e.g. banana).
- Pneumatophores are found in? → **Mangroves (*Rhizophora*)**.

6.6 Genetics – Mendelian Inheritance ★★★

- **Gregor Johann Mendel** – "Father of Genetics"; hybridisation experiments on garden pea (***Pisum sativum***) for **7 years (1856–1863)**; results published **1865/1866**. Studied **7 pairs of contrasting characters**.
- Why pea: many true-breeding varieties, short life cycle, **naturally self-pollinating** yet easily cross-pollinated, distinct contrasting traits, bisexual flowers.
- Work **rediscovered in 1900** by **Hugo de Vries, Carl Correns and Erich von Tschermak**.
- Term **genetics – William Bateson (1905)**; **gene – Wilhelm Johannsen (1909)**; Mendel called them "factors". **Alleles** = alternative forms of a gene. Homozygous (TT, tt) vs heterozygous (Tt).

Character	Dominant	Recessive
Stem height	Tall	Dwarf
Flower colour	Violet	White
Flower position	Axial	Terminal
Pod shape / colour	Inflated / Green	Constricted / Yellow
Seed shape / colour	Round / Yellow	Wrinkled / Green

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- **Law of Dominance** – in a heterozygote only one (dominant) allele expresses; explains 3:1.
- **Law of Segregation (purity of gametes)** – alleles do not blend and separate during gamete formation; each gamete gets one allele. **Universal law** (no exceptions).
- **Law of Independent Assortment** – in a dihybrid cross, segregation of one pair is independent of the other; based on dihybrid cross; **not valid for linked genes**.
- **Test cross** – F_1 (or any dominant phenotype) × **homozygous recessive** parent → reveals genotype. Monohybrid test cross ratio **1 : 1**; dihybrid **1 : 1 : 1 : 1**.
- **Back cross** – F_1 × **either parent**; test cross is a special back cross. Back cross with dominant parent → all dominant phenotype.
- **Punnett square** – Reginald C. Punnett.

KEY FORMULAE

- Monohybrid F_2: phenotype **3 : 1**; genotype **1 : 2 : 1**.
- Dihybrid F_2: phenotype **9 : 3 : 3 : 1**; genotype **1:2:1:2:4:2:1:2:1** (9 genotypes); parental types 10/16, recombinants 6/16.
- For *n* heterozygous gene pairs: gametes = 2^n; F_2 phenotypes = 2^n (complete dominance); genotypes = 3^n; F_2 combinations = 4^n.
- Trihybrid F_2 phenotypic ratio = **27 : 9 : 9 : 9 : 3 : 3 : 3 : 1**.
- Polygenic (n gene pairs): F_2 phenotypic classes = **2n + 1** (e.g. 2 pairs → 1:4:6:4:1).
- Recombination frequency (%) = recombinants ÷ total progeny × 100; **1% = 1 map unit (centiMorgan, cM)**.

Deviation	Explanation	Example	F_2 ratio
Incomplete dominance	F_1 intermediate phenotype	**4 o'clock plant (*Mirabilis jalapa*)**, snapdragon (*Antirrhinum*): RR red × rr white → Rr **pink**	**1 : 2 : 1** (phenotype = genotype)
Co-dominance	Both alleles express fully in F_1	**ABO blood group** (I^AI^B → AB), roan cattle	1 : 2 : 1
Multiple alleles	> 2 alleles of a gene in a population (an individual carries only 2)	ABO: **3 alleles (I^A, I^B, i) → 6 genotypes, 4 phenotypes**; self-incompatibility alleles in *Nicotiana*	—
Pleiotropy	One gene affects many traits	**Phenylketonuria**; starch synthesis gene in pea (seed shape + starch grain size)	—
Polygenic inheritance	Several genes, additive effect; continuous variation; environment also acts	**Human skin colour, height**; wheat kernel colour (Nilsson-Ehle)	1:4:6:4:1 (2 genes)
Lethal genes	Homozygote dies	Yellow coat in mice (Cuénot)	**2 : 1**

- Number of genotypes with *n* multiple alleles = **n(n+1)/2**. ABO: n = 3 → 6.
- In pea starch gene: BB – round seed, large starch grains; bb – wrinkled, small grains; Bb – round (dominance for seed shape) but intermediate grain size (incomplete dominance) – dominance depends on the trait examined.

Gene interaction (epistasis)	Modified F_2 ratio	Classic example
Dominant epistasis	**12 : 3 : 1**	Fruit colour in **summer squash** (white : yellow : green); dog coat colour
Recessive epistasis (supplementary)	**9 : 3 : 4**	Coat colour in **mice** (agouti : black : albino)
Complementary genes (duplicate recessive)	**9 : 7**	Flower colour in **sweet pea** (*Lathyrus odoratus*) – Bateson & Punnett
Duplicate dominant genes	**15 : 1**	Capsule shape in **shepherd's purse** (*Capsella*) – triangular : ovoid
Inhibitory genes (dominant & recessive)	**13 : 3**	Feather colour in **poultry** (White Leghorn × White Wyandotte)
Duplicate genes with cumulative effect (polymeric)	**9 : 6 : 1**	Fruit shape in summer squash (disc : spherical : elongated)
Supplementary + comb shape (no ratio change, new phenotypes)	9 : 3 : 3 : 1	Comb shape in poultry (walnut, rose, pea, single) – Bateson & Punnett

MEMORY TRICK

Epistasis ratios add to 16: "**Dog/Squash 12-3-1**, **Mouse 9-3-4**, **Sweet pea 9-7**, **Shepherd 15-1**, **Poultry 13-3**". Dominant epistasis = 12 (dozen dominates); recessive = 9:3:4 (four albino mice).

Chromosomal theory, linkage & crossing over

- **Chromosomal theory of inheritance** – **Walter Sutton & Theodor Boveri (1902)**: genes located on chromosomes; chromosomes, like genes, occur in pairs and segregate. Experimental proof – **Thomas Hunt Morgan** with ***Drosophila melanogaster*** (fruit fly) – Nobel **1933**.
- *Drosophila* advantages: grows on simple synthetic medium, life cycle **~2 weeks**, many progeny, clear sexual dimorphism, hereditary variations visible under low-power microscope.
- **Linkage** (term – Morgan) = physical association of genes on a chromosome; tightly linked genes show low recombination. Morgan: **yellow body–white eye** genes very tightly linked (**1.3%** recombination); **white eye–miniature wing** loosely linked (**37.2%**).
- **Alfred Sturtevant** (Morgan's student) used recombination frequency to construct the **first genetic/chromosome map**.
- Coupling & repulsion phases – **Bateson & Punnett** (sweet pea). Complete linkage – male *Drosophila* (no crossing over in males).
- **Crossing over** = exchange of segments between **non-sister chromatids** of homologous chromosomes at **pachytene**; produces recombinants. Frequency ∝ distance between genes. Maximum recombination frequency = **50%**.

Sex determination

Mechanism	Female	Male	Examples
XX–XY (male heterogametic)	XX	XY	**Humans**, *Drosophila*, *Melandrium* (plant)
XX–XO (male heterogametic)	XX	**XO** (one chromosome less)	**Grasshopper**, many insects (cockroach)

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ZW–ZZ (female heterogametic)	**ZW**	ZZ	**Birds** (poultry), some reptiles, butterflies/moths
Haplo-diploidy	Diploid (2n = 32) from fertilised egg	**Haploid (n = 16)** by parthenogenesis	**Honey bee**; males produce sperm by mitosis, have no father and no sons but a grandfather and grandsons

- **Henking (1891)** found the "X body" in insect spermatogenesis. In humans, sex is decided by the **father's sperm** (X or Y); probability of a male/female child = **50%** each.
- Temperature-dependent sex determination in turtles/crocodiles.

Pedigree & genetic disorders

- Pedigree symbols: □ **male,** ○ **female**, shaded = affected; **double line = consanguineous mating**; ◇ = sex unspecified; half-shaded/dot = carrier.

Disorder	Inheritance	Key fact
Haemophilia	**X-linked recessive**	Blood fails to clot ("royal disease" – **Queen Victoria** was a carrier); female affected only if mother carrier & father haemophilic (very rare)
Colour blindness	X-linked recessive	Red–green; **~8% males**, **~0.4% females**; son of carrier woman has 50% chance
Sickle-cell anaemia	**Autosomal recessive**	Hb^S: **glutamic acid → valine** at **6th position of β-globin** chain; codon **GAG → GUG** (point mutation); RBC sickle-shaped at low O_2; heterozygotes (Hb^AHb^S) are carriers, resistant to malaria
Phenylketonuria	Autosomal recessive	Lacks enzyme **phenylalanine hydroxylase** → phenylalanine/phenylpyruvic acid accumulate → mental retardation
Thalassaemia	Autosomal recessive	**Quantitative** defect – reduced synthesis of α or β globin (sickle-cell = qualitative defect)
Cystic fibrosis	Autosomal recessive	CFTR gene
Huntington's disease, myotonic dystrophy	**Autosomal dominant**	Late onset neurodegeneration (Huntington)

Chromosomal disorder	Karyotype	Features
Down's syndrome (Langdon Down, 1866)	**47, trisomy 21**	Short stature, small round head, furrowed tongue, partially open mouth, **palm crease**, mental retardation; risk rises with maternal age
Klinefelter's syndrome	**47, XXY**	**Male**, sterile, **gynaecomastia** (breast development), masculine with feminine traits
Turner's syndrome	**45, XO**	**Female**, sterile, **rudimentary ovaries**, lack of secondary sexual characters, short stature
Patau's / Edwards' syndrome	Trisomy **13** / trisomy **18**	Severe, often fatal in infancy

- Cause of aneuploidy: **non-disjunction** (failure of chromatid/homologue segregation). **Aneuploidy** = gain/loss of one or few chromosomes (2n ± 1); **polyploidy** = whole sets increased (common in plants – wheat is hexaploid, 6x = 42; banana triploid). Polyploidy induced by **colchicine**.
- Trisomy = 2n + 1; monosomy = 2n – 1; nullisomy = 2n – 2; tetrasomy = 2n + 2.

Mutation

- Term **mutation – Hugo de Vries** (on *Oenothera lamarckiana*, evening primrose). Mutation = sudden heritable change in DNA sequence.
- **H.J. Muller (1927)** – induced mutations with **X-rays** in *Drosophila* (Nobel 1946). L.J. Stadler – X-ray mutations in barley & maize. Mutagens: physical (X-rays, γ-rays, **UV → thymine dimers**), chemical (**EMS**, nitrous acid, 5-bromouracil – base analogue, **acridine dyes – frameshift**).
- **Point mutation** – change in a single base pair (e.g. sickle-cell). **Transition** = purine ↔ purine or pyrimidine ↔ pyrimidine; **transversion** = purine ↔ pyrimidine.
- **Frameshift mutation** – insertion or deletion of 1 or 2 bases shifts the reading frame; insertion/deletion of **3 bases** (or multiples) adds/removes amino acid(s) without frameshift.
- Silent (same amino acid), missense (different amino acid), **nonsense** (creates stop codon).
- Chromosomal aberrations: **deletion, duplication, inversion, translocation** (e.g. Philadelphia chromosome 9–22 in chronic myeloid leukaemia). Mutation breeding in India – e.g. **Sharbati Sonora** wheat (γ-ray mutant of Sonora 64).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- F_2 ratio in incomplete dominance in *Mirabilis jalapa*? → **1 : 2 : 1** (red : pink : white).
- 9 : 7 ratio indicates? → **Complementary gene interaction**.
- Dominant epistasis ratio? → **12 : 3 : 1**.
- Karyotype of Turner's syndrome? → **45, XO**; Klinefelter's → **47, XXY**.
- Sex determination in birds? → **ZW (female) – ZZ (male)**; female heterogametic.
- Who constructed the first genetic map? → **Alfred Sturtevant**.

6.7 Molecular Genetics & Biotechnology ★★★

DNA as genetic material

- **Friedrich Miescher (1869)** – first isolated DNA ("nuclein") from pus cells.
- **Griffith (1928)** – **transformation** in *Streptococcus pneumoniae* (S strain virulent, R strain non-virulent; heat-killed S + live R killed mice). **Avery, MacLeod & McCarty (1944)** – transforming principle is **DNA**.
- **Hershey & Chase (1952)** – **T2 bacteriophage**; ^{32}P (DNA) entered bacteria, ^{35}S (protein) did not → **DNA is genetic material** (blender experiment).
- RNA is genetic material in some viruses (e.g. **TMV**, QB bacteriophage). DNA preferred as stable genetic material (2'-OH of RNA makes it reactive; thymine more stable than uracil). RNA was likely the first genetic material ("RNA world").

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DNA structure

- **Double helix – James Watson & Francis Crick (1953)**, based on X-ray diffraction data of **Maurice Wilkins & Rosalind Franklin**. Nobel Prize **1962** (Watson, Crick, Wilkins).
- Two **antiparallel** polynucleotide chains (5'→3' and 3'→5'); sugar-phosphate backbone outside, bases inside. Bases pair by **hydrogen bonds**: **A = T (2 H-bonds)**, **G ≡ C (3 H-bonds)** – purine always pairs with pyrimidine → uniform diameter.
- **B-DNA** (Watson–Crick form): **right-handed**; pitch **3.4 nm (34 Å)**; **~10 bp per turn** (10.5 in solution); rise **0.34 nm per bp**; diameter **~2 nm (20 Å)**; major & minor grooves. **A-DNA** right-handed, ~11 bp/turn (dehydrated); **Z-DNA left-handed**, ~12 bp/turn, zig-zag backbone.
- **Chargaff's rule**: in double-stranded DNA **A = T and G = C** → **purines = pyrimidines** (A + G = T + C); ratio (A + T)/(G + C) varies between species. Not valid for single-stranded DNA (e.g. φX174).
- Phosphodiester bond links 3'-OH of one nucleotide to 5'-phosphate of next; **N-glycosidic bond** links base to C-1' of sugar.
- Genome sizes: φX174 – **5386 nucleotides**; bacteriophage λ – **48,502 bp**; *E. coli* – **4.6×10^6 bp**; human haploid – **3.3×10^9 bp** (diploid 6.6×10^9 bp; length ≈ **2.2 m**).
- **Nucleosome**: **histone octamer** (2 each of H2A, H2B, H3, H4) wrapped by DNA; one nucleosome ≈ **200 bp**; **H1** = linker histone; "beads-on-string" under EM. Histones are **positively charged** (rich in **lysine, arginine**). **Euchromatin** – loosely packed, transcriptionally active; **heterochromatin** – densely packed, inactive.

KEY FORMULAE

- Length of DNA = number of bp × **0.34 nm** (e.g. 6.6×10^9 bp × 0.34×10^{-9} m ≈ 2.2 m).
- Number of turns = bp ÷ 10 (B-DNA).
- Chargaff: if A = 20%, then T = 20%, G = C = 30% each.
- Number of H-bonds = 2(A–T pairs) + 3(G–C pairs).

Replication

- **Semi-conservative** (each daughter DNA has one parental + one new strand) – proposed by Watson & Crick; proved by **Meselson & Stahl (1958)** using **^{15}N** (heavy) labelled *E. coli* shifted to ^{14}N medium; separated by **CsCl density-gradient centrifugation**: after 1 generation all hybrid (^{15}N/^{14}N); after 2 generations **1 hybrid : 1 light**. **Taylor (1958)** – similar proof in ***Vicia faba*** using radioactive thymidine.
- Main enzyme: **DNA-dependent DNA polymerase** – polymerises only **5' → 3'**; *E. coli* replicates its 4.6×10^6 bp in **~18 min** (~2000 bp/s). Substrates = deoxyribonucleoside triphosphates (also give energy).
- Replication starts at **origin (ori)**; small opening = **replication fork**. **Leading strand** – continuous (template 3'→5'); **lagging strand** – discontinuous **Okazaki fragments**, joined by **DNA ligase**.
- Other enzymes: **helicase** (unwinds), **topoisomerase/DNA gyrase** (relieves supercoiling), **primase** (RNA primer), SSB proteins. In eukaryotes replication occurs in **S phase**.

Transcription

- **Central dogma** (Crick): **DNA → RNA → protein**; **reverse transcription** (RNA → DNA) in retroviruses – **Temin & Baltimore** (reverse transcriptase).
- Template (antisense) strand: **3'→5'**; **coding strand** (5'→3') has same sequence as RNA (T instead of U) – not copied. Transcription unit = **promoter** (upstream, at 5' end of coding strand) – **structural gene** – **terminator**.
- Prokaryotes: single **DNA-dependent RNA polymerase**; initiation by **σ (sigma) factor**, termination by **ρ (rho) factor**; transcription & translation coupled (same compartment); mostly **polycistronic** structural genes.
- Eukaryotes: **RNA pol I** – rRNAs (28S, 18S, 5.8S); **RNA pol II** – hnRNA (precursor of mRNA); **RNA pol III** – tRNA, 5S rRNA, snRNAs. Genes **monocistronic** and **split** (exons + introns).
- hnRNA processing: **splicing** (introns removed, exons joined; spliceosome), **capping** (methyl guanosine triphosphate at **5' end**), **tailing** (poly-A, 200–300 adenylates at **3' end**, template-independent).

Genetic code & translation

- Triplet code proposed by **George Gamow** ($4^3 = 64$). **Nirenberg & Matthaei** – cell-free system; **poly-U → poly-phenylalanine** (UUU = Phe). **Har Gobind Khorana** – chemical synthesis of RNA with defined repeats. Nobel **1968**: Holley, Khorana, Nirenberg. **Severo Ochoa** – polynucleotide phosphorylase (template-independent RNA synthesis).
- **64 codons**: **61 code for amino acids**, **3 stop (nonsense) codons – UAA (ochre), UAG (amber), UGA (opal)**.
- **AUG** = start codon, codes **methionine** (formyl-methionine in prokaryotes) – **dual function**. Some bacteria also use GUG as start.
- Properties: triplet, **degenerate** (some amino acids coded by > 1 codon; e.g. Leu, Ser, Arg – 6 codons each; Met & Trp – only 1 each), **unambiguous & specific** (one codon → one amino acid), **nearly universal** (exceptions in mitochondria, some protozoa), **non-overlapping**, **comma-less** (read contiguously). **Wobble hypothesis – Crick (1966)**: third base pairing is flexible.
- **tRNA** = **adapter molecule** (Crick term; earlier sRNA – soluble RNA); **clover-leaf** 2-D structure (secondary), inverted **L-shape** 3-D; has anticodon loop and amino acid acceptor end (CCA 3'). Specific tRNA for each amino acid; no tRNA for stop codons. Structure – **R.W. Holley**.
- **Charging** (aminoacylation) by **aminoacyl-tRNA synthetase** using ATP. Peptide bond formation catalysed by **23S rRNA** in bacteria – a **ribozyme** (peptidyl transferase).
- Ribosome large subunit has 2 sites (A and P) for tRNA binding (NCERT; modern texts add a third, E – exit site). mRNA has **untranslated regions (UTRs)** at both 5' and 3' ends for efficient translation. Translation ends when release factor binds stop codon.

Gene regulation – lac operon

- **Operon concept – François Jacob & Jacques Monod (1961)**, in ***E. coli***; Nobel 1965 (with Lwoff). Example of **inducible operon** under **negative control**.
- Components: **i (regulator) gene** – codes **repressor** constitutively (has own promoter); **promoter (p)**; **operator (o)**; structural genes **z, y, a**.
- **z → β-galactosidase** (hydrolyses lactose → glucose + galactose); **y → permease** (lactose entry); **a → transacetylase**.
- Absence of lactose: repressor binds **operator** → RNA polymerase blocked → no transcription. Presence of lactose (**inducer**; actually

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allolactose; synthetic inducer IPTG): inducer binds repressor → repressor inactivated → transcription of z, y, a.

- Lac operon also under positive control by **CAP–cAMP** (glucose low). **trp operon** = **repressible** (tryptophan acts as co-repressor).

Human Genome Project & DNA fingerprinting

- **HGP launched 1990, completed 2003** (13-year project; coordinated by US DOE & NIH; UK Wellcome Trust a major partner; also Japan, France, Germany, China). Last chromosome sequenced = **chromosome 1** (May 2006).
- Salient features (NCERT): genome has **3164.7 million bp**; average gene 3000 bases; largest known human gene = **dystrophin, 2.4 million bases**; **~30,000 genes** estimated then (current estimate **~20,000** protein-coding); **99.9% of bases identical** in all people; **< 2%** of genome codes proteins; **chromosome 1 has most genes (2968)**, **Y the fewest (231)**; **~1.4 million SNPs** identified; repeated sequences make up a large part.
- Methods: **Expressed Sequence Tags (ESTs)** and **sequence annotation**; DNA cloned in **BAC** (bacterial artificial chromosome) & **YAC** (yeast artificial chromosome) vectors; automated sequencers based on **Frederick Sanger**'s method. First complete gap-free (**telomere-to-telomere, T2T**) human genome reported in **2022**.
- **DNA fingerprinting – Sir Alec Jeffreys (1984–85)**, UK. Uses **VNTR (Variable Number of Tandem Repeats; minisatellites)** as probe – a type of **satellite DNA** (repetitive DNA forming separate satellite peak in density-gradient centrifugation). VNTR size 0.1–20 kb; highly polymorphic.
- Steps: DNA isolation → **digestion with restriction endonucleases** → separation by **gel electrophoresis** → **Southern blotting** (transfer to nitrocellulose/nylon membrane) → **hybridisation** with labelled VNTR probe → detection by **autoradiography**. Today mostly **PCR-based STR** (microsatellite) analysis.
- Uses: forensic identification, **paternity disputes**, population & evolutionary studies. India: **Dr. Lalji Singh** ("Father of Indian DNA fingerprinting") – CCMB Hyderabad; **CDFD (Centre for DNA Fingerprinting & Diagnostics), Hyderabad**.

Tools of recombinant DNA technology

- First recombinant DNA: **Stanley Cohen & Herbert Boyer (1972)** – antibiotic-resistance gene linked to a plasmid of *Salmonella typhimurium*. Three basic steps: identify DNA with desirable gene → introduce into host → maintain & transfer to progeny.
- **Restriction endonucleases** = **"molecular scissors"**; first restriction endonuclease characterised – **Hind II** (cuts at a specific 6-bp sequence). More than **900** restriction enzymes isolated from > 230 strains of bacteria. Recognise **palindromic** sequences (same reading 5'→3' on both strands), e.g. 5'-GAATTC-3'.
- **EcoRI** naming: **E** = genus *Escherichia*, **co** = species *coli*, **R** = strain RY13, **I** = first enzyme isolated from that strain. EcoRI cuts **G↓AATTC** (between G and A) → **sticky ends** (5' overhang AATT). Sticky ends allow ligation.
- **Exonucleases** remove nucleotides from ends; **endonucleases** cut within DNA. **DNA ligase** = **"molecular glue"** – joins DNA fragments.
- **Gel electrophoresis**: medium **agarose** (natural polymer from **seaweeds**); DNA (negatively charged) moves towards **anode (+)**; smaller fragments move farther (sieving); stained with **ethidium bromide** – **bright orange bands under UV**; bands cut out = **elution**.

Vector / tool	Key facts
pBR322 (*E. coli* plasmid; named after **Bolivar & Rodriguez**)	**ori**; **rop** (proteins for replication); selectable markers **amp^R** & **tet^R**; restriction sites: **BamHI, SalI in tet^R**; **PstI, PvuI in amp^R**; also EcoRI, HindIII, ClaI, PvuII. Insertion into tet^R → loss of tetracycline resistance = **insertional inactivation**
Blue–white selection	Insert in **lacZ (β-galactosidase)** gene; with chromogenic substrate (X-gal): non-recombinants → **blue** colonies; **recombinants → white/colourless**
Ti plasmid (***Agrobacterium tumefaciens***)	Causes **crown gall** in dicots by transferring **T-DNA**; disarmed Ti plasmid used as plant vector – "natural genetic engineer". **Ri plasmid** of *A. rhizogenes* → hairy root
Retroviruses / viral vectors	Disarmed retroviruses used in animals/gene therapy; bacteriophages (λ) for bacteria
Gene transfer methods	Bacteria made **competent** by **divalent cations ($CaCl_2$) + heat shock (42 °C)**; **microinjection** (animal nucleus); **biolistics / gene gun** (gold or tungsten particles – plants); electroporation; disarmed pathogen vectors
PCR – Kary Mullis (1983), Nobel 1993	In-vitro amplification; three steps per cycle: **denaturation (~94–96 °C)**, **annealing of primers** (~50–65 °C), **extension (~72 °C)**; enzyme **Taq polymerase** from ***Thermus aquaticus*** (thermostable); **~1 billion copies after 30 cycles** (2^{30}); used for early diagnosis (HIV, cancer), forensics
Bioreactors	Large-volume (100–1000 L) vessels; **stirred-tank** most common; then **downstream processing** (separation, purification, formulation, quality control)

KEY FORMULAE

- PCR copies after *n* cycles = 2^n (per starting molecule).
- Frequency of a restriction site of length *n* bp (random sequence) = 1 in 4^n (6-bp site → once in 4096 bp).

MEMORY TRICK

"**E**-co-**R**-**I** = Escherichia-coli-RY13-First"; PCR temperatures "**94 – 55 – 72**" = **D**enature – **A**nneal – **E**xtend ("**DAE**"). pBR322: "**B**am and **S**al sit in **T**et; **P**st and **P**vuI sit in **A**mp".

Applications & GM crops

- **Bt toxin** from soil bacterium ***Bacillus thuringiensis***; produced as inactive **protoxin** crystals → activated in **alkaline pH** of insect gut → binds midgut epithelium, creates pores → swelling, lysis, death. Genes: **cry**. **cryIAc & cryIIAb** control **cotton bollworms**; **cryIAb** controls **corn borer**. Bt toxin does not kill the bacterium itself.
- **RNA interference (RNAi)**: nematode ***Meloidogyne incognita*** (root-knot) in **tobacco** – nematode-specific genes introduced via *Agrobacterium* → dsRNA silences parasite mRNA.
- **Golden Rice** – enriched with **β-carotene (pro-vitamin A)** – Ingo Potrykus & Peter Beyer. **Flavr Savr tomato** (USA, 1994) – first commercial GM food, delayed ripening.
- **Humulin** (human insulin) – **Eli Lilly (1983)**: A and B chains produced separately in *E. coli* and joined by disulphide bonds. First **gene therapy (1990)** – 4-year-old girl with **ADA (adenosine deaminase) deficiency**. **Rosie** (1997) – transgenic cow producing milk with human **α-lactalbumin**.

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- Biopiracy: **Basmati rice patent** by US company **RiceTec (1997)**; also turmeric and neem cases. Indian Parliament passed the second amendment of the Indian Patents Bill to address such issues.

GM crop (India)	Status / facts
Bt cotton	Approved for commercial cultivation by GEAC in **March 2002** (Bollgard I, **Mahyco–Monsanto**; single gene **cry1Ac**); **Bollgard II** (cry1Ac + cry2Ab) – **2006**. **Only GM crop approved for commercial cultivation in India**; covers > 90% of India's cotton area. Pink bollworm has developed resistance.
Bt brinjal (Mahyco; cry1Ac)	GEAC cleared in 2009, but **indefinite moratorium in February 2010** by MoEF. (Bangladesh commercialised Bt brinjal in 2014.)
GM mustard – DMH-11 (Dhara Mustard Hybrid-11)	Developed by **Prof. Deepak Pental**, Centre for Genetic Manipulation of Crop Plants (CGMCP), **University of Delhi**; uses **barnase–barstar** system (from *Bacillus amyloliquefaciens*) for male sterility/fertility restoration + **bar** gene (herbicide glufosinate tolerance). GEAC recommended **environmental release in October 2022**. In **July 2024** the **Supreme Court gave a split verdict** on the approval, referred the matter to a larger bench and asked the Centre to frame a **national policy on GM crops**. As of late 2025 the case was still pending (status quo on planting) – commercial cultivation not permitted.
Genome-edited rice	In **May 2025** ICAR released India's first two genome-edited rice varieties (claimed as the world's first): **DRR Dhan 100 (Kamala)** – from Samba Mahsuri, **ICAR-IIRR Hyderabad** (higher yield, early maturity) and **Pusa DST Rice 1** – from MTU 1010 (Cottondora Sannalu), **ICAR-IARI New Delhi** (**salinity & alkalinity tolerance**; edits the *DST* – drought & salt tolerance – gene). Developed by **CRISPR-Cas** (SDN-1/SDN-2) – contain **no foreign DNA**, hence **not regulated as GMOs** (SDN-1 & SDN-2 exempted by MoEFCC in **March 2022**).

CODE UPDATE

Genome editing ≠ GM: SDN-1 (site-directed nuclease, small deletions/insertions) and SDN-2 (template-guided small edits) products are free of exogenous DNA and are exempt from Rules 7–11 of the 1989 Rules (MoEFCC order, March 2022); SDN-3 (insertion of a foreign gene) is regulated like GM. Bt cotton remains the only GM crop under commercial cultivation in India.

- **GEAC – Genetic Engineering Appraisal Committee** (name changed from "Approval" to "**Appraisal**" in **2010**): statutory body under **MoEFCC**, constituted under the "**Rules for the Manufacture, Use, Import, Export & Storage of Hazardous Micro-organisms/Genetically Engineered Organisms or Cells, 1989**" notified under the **Environment (Protection) Act, 1986**. Appraises large-scale use and **environmental release** of GMOs; chaired by Special Secretary/Additional Secretary of MoEFCC, co-chaired by a DBT nominee.
- Other bodies: **RCGM** (Review Committee on Genetic Manipulation) – under **DBT**, approves research & confined trials; **IBSC** (Institutional Biosafety Committee) – institution level; State/District biotechnology coordination committees – monitoring.
- International: **Cartagena Protocol on Biosafety** (adopted **2000**, in force **2003**; under CBD) – governs transboundary movement of living modified organisms; India is a party.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Semi-conservative replication was proved by? → **Meselson & Stahl (1958)** using ^{15}N.
- Pitch of B-DNA and number of base pairs per turn? → **3.4 nm; 10 bp**.
- Stop codons are? → **UAA, UAG, UGA**; start codon → **AUG**.
- Thermostable enzyme used in PCR is obtained from? → ***Thermus aquaticus*** (Taq polymerase).
- DNA fingerprinting technique was developed by? → **Alec Jeffreys**, using **VNTR** probes.
- The only GM crop approved for commercial cultivation in India? → **Bt cotton (2002)**; regulator → **GEAC (MoEFCC)**.

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7. Botany II – Classification, Diversity, Ecology & Plant Physiology

> **NOTE**
>
> This chapter covers B.Sc / NCERT 11–12 botany that comes up again and again in FCI/CWC/SWC technical MCQs. Expect questions on **who proposed what** (Whittaker, Bentham & Hooker, Lindeman, Blackman, Münch), on **first products and numbers** (PGA vs OAA, 3 ATP + 2 NADPH, net 2 ATP, RQ values), on **examples** (agar alga, C_4 plant, CAM plant, SDP/LDP) and on **current counts** (36 hotspots, 18 biosphere reserves). Hormones and photosynthesis tie in directly with how stored grain behaves: dormancy, sprouting, ripening and respiration losses in storage.

7.1 Plant Classification & Taxonomy ★★★

- **Theophrastus** = "Father of Botany" (*Historia Plantarum*; grouped plants into trees, shrubs, undershrubs, herbs). **A.P. de Candolle** coined the term **taxonomy** (1813).
- **Gaspard Bauhin** first used a two-word style of naming (*Pinax*, 1623). **Carolus Linnaeus** standardised **binomial nomenclature** in **Species Plantarum (1753)**, so he is the "Father of Taxonomy". For plant names, priority dates from **1 May 1753**.
- **Binomial** = generic name + specific epithet, e.g. *Mangifera indica* L. Rules: Latin or Latinised; **genus starts with a capital, epithet in small letters**; printed in **italics**, or **underlined separately** when handwritten; the author's name comes after the epithet in roman type, abbreviated (L. = Linnaeus).
- **Tautonyms** (genus and epithet the same, e.g. *Naja naja*, *Rattus rattus*) are **allowed in zoology but not in botany**.
- **Taxon** = a group at any rank. **Systematics** = taxonomy plus evolutionary relationships. The word *systematics* comes from Latin *systema*, used by Linnaeus in *Systema Naturae*.
- **Species** = the basic unit of classification. The **biological species concept** (interbreeding populations) was given by **Ernst Mayr**.
- Kinds of taxonomy: **numerical** (computers; all characters weighted equally; OTUs; Sneath & Sokal), **cytotaxonomy** (chromosome number and structure), **chemotaxonomy** (chemical constituents), **alpha** taxonomy (classical, based on morphology), **omega** taxonomy (uses all available data).

Rank (hierarchy)	Ending (plants)	Mango	Wheat
Kingdom	–	Plantae	Plantae
Division (≈ Phylum)	-phyta	Angiospermae	Angiospermae
Class	-opsida / -eae	Dicotyledonae	Monocotyledonae
Order	**-ales**	Sapindales	Poales
Family	**-aceae**	Anacardiaceae	Poaceae
Genus	–	*Mangifera*	*Triticum*
Species	–	*indica*	*aestivum*

- Going up the hierarchy (species → kingdom), the number of **common characters falls** and the number of organisms in each taxon rises.
- Old family names still accepted as alternatives: Gramineae = **Poaceae**, Leguminosae = **Fabaceae**, Cruciferae = **Brassicaceae**, Compositae = **Asteraceae**, Umbelliferae = Apiaceae, Labiatae = Lamiaceae, Palmae = Arecaceae, Guttiferae = Clusiaceae.

System	Type	Proposer / Work	Key point
Sexual system	**Artificial**	Linnaeus, *Species Plantarum* (1753)	24 classes based on **number and features of stamens**; uses only a few characters
Natural	**Natural**	**Bentham & Hooker**, *Genera Plantarum* (1862–83)	Based on overall similarity; **202 families** (Polypetalae, Gamopetalae, Monochlamydeae); gymnosperms placed between dicots and monocots; long followed in Indian and Commonwealth herbaria
Phylogenetic	Phylogenetic	**Engler & Prantl**, *Die natürlichen Pflanzenfamilien* (1887–1915)	Simple (unisexual, apetalous) flowers treated as primitive; monocots before dicots
Phylogenetic	Phylogenetic	**Hutchinson**, *The Families of Flowering Plants* (1926, 1934)	Dicots split into **Lignosae** (woody) and **Herbaceae**; Magnoliales treated as primitive
Phylogenetic	Phylogenetic	Takhtajan; Cronquist (1981)	Based on evolutionary relationships
APG	Molecular phylogenetic	**Angiosperm Phylogeny Group**: APG I (1998) to **APG IV (2016)**	Based on **DNA sequences** (rbcL, matK etc.); classifies by monophyletic clades

Kingdom system	By	Kingdoms
Two-kingdom	Linnaeus (1758)	Plantae, Animalia
Three-kingdom	Haeckel (1866)	+ **Protista**
Four-kingdom	Copeland (1956)	+ **Monera**
Five-kingdom	**R.H. Whittaker (1969)**	**Monera, Protista, Fungi, Plantae, Animalia**
Three-domain	**Carl Woese (1990)**	**Bacteria, Archaea, Eukarya**, based on **16S rRNA** sequences (archaea first recognised in 1977)

- Whittaker's criteria: **cell structure, body organisation, mode of nutrition, reproduction, phylogenetic relationships**. Fungi were separated from plants on the basis of **heterotrophic absorptive nutrition** and **chitin** walls.
- In the five-kingdom system, **Monera = prokaryotes** (bacteria, cyanobacteria, archaebacteria) and **Protista = unicellular eukaryotes** (diatoms, dinoflagellates, euglenoids, slime moulds, protozoans). Viruses, viroids and lichens are **left out** of the system.
- **Herbarium** = a store of **pressed, dried, poisoned specimens mounted on sheets** (standard sheet ≈ **29 × 41 cm**), labelled with name, locality, date and collector. It serves as a quick reference

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system. **Kew (England)** holds one of the world's largest herbaria (~7 million specimens). India's **Central National Herbarium (CAL)** is at **Howrah** (BSI).

- **Type specimens**: **holotype** (the single specimen the author designated), **isotype** (duplicate of the holotype), **lectotype** (chosen later when no holotype was designated), **neotype** (chosen when all original material is lost), **paratype**, **syntype**.
- **Botanical gardens** = collections of **living plants** for reference. Examples: **Royal Botanic Gardens, Kew** (England; UNESCO World Heritage Site); **Acharya Jagadish Chandra Bose Indian Botanic Garden, Howrah** (founded **1787** by **Col. Robert Kyd**; home of the **Great Banyan**); **NBRI Lucknow**; **Lloyd Botanical Garden, Darjeeling**.
- Other taxonomic aids: **museums** (preserved specimens), **zoological parks**, **keys** (usually **dichotomous**: pairs of contrasting characters called **couplets**, each statement a **lead**), **flora**, **manuals**, **monographs** (one taxon only), **catalogues**.
- **Botanical Survey of India (BSI)**: est. **1890**, HQ **Kolkata**. **Zoological Survey of India (ZSI)**: est. **1916**, Kolkata.
- **Codes**: plants follow **ICBN**, renamed **ICN (International Code of Nomenclature for algae, fungi, and plants)** at the **Melbourne Congress (2011)**. The code is revised after each International Botanical Congress (Shenzhen Code 2018 → Madrid Congress 2024). Animals follow **ICZN**, bacteria **ICNP** (formerly ICNB), viruses **ICTV**, and cultivated plants **ICNCP** (cultivar names, e.g. *Rosa* 'Peace').
- Since **2012**, a new plant name can be validly published with a diagnosis in **English or Latin**, and electronic publication (PDF) counts as effective publication.

MEMORY TRICK

Hierarchy: "**K**ing **D**avid **C**ame **O**ver **F**or **G**ood **S**oup" (Kingdom, Division, Class, Order, Family, Genus, Species). Order names end in **-ales** and family names in **-aceae**: "the order ALEs, the family ACEs".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Binomial nomenclature was introduced in which book? → **Species Plantarum (1753), Linnaeus**.
- Five-kingdom classification was proposed by? → **R.H. Whittaker (1969)**.
- The *Genera Plantarum* natural system belongs to? → **Bentham & Hooker**.
- Three-domain system based on 16S rRNA? → **Carl Woese**.
- Indian Botanic Garden is located at? → **Howrah (Shibpur), West Bengal**.
- Duplicate of a holotype is called? → **isotype**.

7.2 Plant Diversity ★★★

Algae

- Simple, chlorophyll-bearing, **thalloid**, autotrophic and mostly **aquatic**. Algae carry out about **half of all CO_2 fixation on Earth** and are the primary producers of aquatic food chains. The study of algae is called **phycology**; in India, **M.O.P. Iyengar** is called the "Father of Indian Phycology".
- Reproduction: vegetative (fragmentation), asexual (**zoospores**), and sexual by **isogamy** (*Chlamydomonas*, *Spirogyra* with non-flagellated gametes), **anisogamy** (*Chlamydomonas* spp., *Eudorina*) or **oogamy** (*Volvox*, *Fucus*).

Feature	Chlorophyceae (green)	Phaeophyceae (brown)	Rhodophyceae (red)
Pigments	Chl **a, b**	Chl a, **c**, **fucoxanthin**	Chl a, **d**, **r-phycoerythrin**
Stored food	**Starch** (pyrenoids)	**Laminarin**, mannitol	**Floridean starch**
Cell wall	Cellulose	Cellulose + **algin**	Cellulose, pectin, polysulphate esters
Flagella	2–8, equal, apical	2, **unequal, lateral**	**Absent**
Habitat	Fresh, brackish, salt water	Mostly **marine**	Mostly marine; grow at the **greatest depths**
Examples	*Chlamydomonas*, *Volvox*, *Ulothrix*, *Spirogyra*, *Chara*	*Ectocarpus*, *Dictyota*, *Laminaria*, *Sargassum*, *Fucus*	*Polysiphonia*, *Porphyra*, *Gracilaria*, *Gelidium*

- **Agar** (used in culture media, jellies and ice-cream) comes from **red algae *Gelidium* and *Gracilaria***. **Carrageenan** also comes from **red algae** (*Chondrus crispus* or Irish moss, *Kappaphycus*, *Eucheuma*). **Algin** comes from **brown algae**.
- ***Chlorella*** (a unicellular green alga) and ***Spirulina*** (strictly a **cyanobacterium**) are rich in protein and used as **single-cell protein (SCP)**; *Chlorella* was also tested as food for space travellers. Calvin used *Chlorella* to work out the C_3 cycle.
- Edible algae: *Porphyra*, *Laminaria*, *Sargassum*. Kelps (*Macrocystis*, *Laminaria*) are the **largest algae**. **Diatoms** have **silica** walls and form **diatomaceous earth**; Whittaker placed them in Protista. Red tides are caused by dinoflagellates such as *Gonyaulax*.

Fungi

- Heterotrophic and achlorophyllous. Cell wall of **chitin**; reserve food is **glycogen** and oil. The body is a **mycelium** of **hyphae**, which may be **coenocytic** (aseptate, multinucleate) or septate. Yeast is unicellular. The study of fungi is **mycology**.

Class	Mycelium	Sexual spore	Examples
Phycomycetes	Aseptate, coenocytic	**Zygospore / oospore**; asexual zoospores or aplanospores	*Mucor*, *Rhizopus* (bread mould), *Albugo* (white rust of mustard)
Ascomycetes (sac fungi)	Septate, branched	**Ascospores** formed **endogenously** in asci (fruiting body: **ascocarp**); asexual **conidia**	*Aspergillus*, *Penicillium*, *Claviceps*, *Neurospora*, *Saccharomyces* (yeast), morels, truffles
Basidiomycetes (club fungi)	Septate, **dikaryotic**	**Basidiospores** formed **exogenously** on a basidium (fruiting body: **basidiocarp**); no sex organs	*Agaricus* (mushroom), *Ustilago* (smut), *Puccinia* (rust), bracket fungi, puffballs
Deuteromycetes (fungi imperfecti)	Septate	**No sexual stage known**; reproduce only by conidia	*Alternaria*, *Colletotrichum*, *Trichoderma*

- *Neurospora* is used heavily in **biochemical genetics** (one gene–one enzyme; Beadle & Tatum). **Penicillin** comes from *Penicillium*

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notatum (Fleming 1928); industrial strains use *P. chrysogenum*. *Claviceps purpurea* causes **ergot** of rye.

- **Lichens** = a symbiosis between an alga or cyanobacterium (**phycobiont**, which makes food) and a fungus (**mycobiont**, which gives shelter and absorbs water and minerals). Lichens **do not grow in polluted areas** because they are **very sensitive to SO_2**, so they serve as **pollution indicators**. They are **pioneers on bare rock**. Litmus is obtained from *Roccella*.
- **Mycorrhiza** = fungus + higher-plant root (term by Frank, 1885). **Ectomycorrhiza**: the fungus forms a sheath around the root (***Pinus***, whose seeds do not germinate and establish without it). **Endomycorrhiza (VAM, AMF)**: e.g. *Glomus*; it helps mainly in **phosphorus uptake**.

Bryophytes, Pteridophytes, Gymnosperms, Angiosperms

Group	Dominant phase	Vascular tissue	Key features	Examples
Bryophytes	**Gametophyte (n)**; sporophyte is **dependent** on it	**Absent**; rhizoids instead of roots	Called the **"amphibians of the plant kingdom"**; need water for fertilisation (antherozoids). Liverworts reproduce by **gemmae**; mosses have a **protonema** stage	Liverworts *Riccia*, *Marchantia*; mosses *Funaria*, *Polytrichum*, ***Sphagnum***; hornwort *Anthoceros*
Pteridophytes	**Sporophyte (2n)**; gametophyte is a free-living **prothallus**	**First terrestrial plants with xylem & phloem**	No seeds; still need water for fertilisation. **Heterospory** (*Selaginella*, *Salvinia*, *Azolla*, *Marsilea*) is the **precursor of the seed habit**	*Psilotum* (Psilopsida), *Lycopodium*, *Selaginella* (Lycopsida), *Equisetum* (Sphenopsida, horsetail), *Dryopteris*, *Pteris*, *Adiantum* (Pteropsida, ferns)
Gymnosperms	Sporophyte	Present (xylem has **no vessels**, except Gnetales)	**Naked ovules and seeds** (no ovary, no fruit); wind pollination; **endosperm haploid (n)**; heterosporous; cones	***Cycas***, ***Pinus***, *Ginkgo*, *Gnetum*, *Ephedra*, *Taxus*, *Sequoia*, *Cedrus*
Angiosperms	Sporophyte	Present (with vessels)	Seeds **enclosed in an ovary** (fruit); **double fertilisation**; **triploid (3n) endosperm**	Dicots and monocots

- ***Sphagnum*** (peat moss) forms **peat**, used as fuel and, thanks to its water-holding capacity, as packing material for living plants. Mosses and lichens are the first colonisers of rock.
- ***Azolla*** (a water fern) carries the N-fixing cyanobacterium ***Anabaena azollae*** and is used as a **biofertiliser in rice**.
- ***Cycas*** has **coralloid roots** with **cyanobacteria** (*Anabaena/Nostoc*). It has the **largest ovules, egg and sperm (antherozoids)** in the plant kingdom. ***Pinus*** roots carry **ectomycorrhiza**.
- ***Ginkgo biloba*** (maidenhair tree) is a **"living fossil"**. *Ephedra* yields **ephedrine** (used for asthma); *Taxus* yields **taxol** (anticancer). *Pinus* gives turpentine and resin.
- **Tallest tree**: ***Sequoia sempervirens*** (coast redwood, ~115 m). **Largest tree by volume**: *Sequoiadendron giganteum* ("General Sherman"). Tallest angiosperm: ***Eucalyptus*** (*E. regnans*, >100 m). Smallest flowering plant: ***Wolffia***. Largest flower: *Rafflesia arnoldii*. Largest seed: *Lodoicea maldivica* (double coconut).

Alternation of generations and life-cycle patterns

- **Alternation of generations** (first shown by **Hofmeister**, 1851): a haploid **gametophyte** makes gametes by **mitosis**, and a diploid **sporophyte** makes spores by **meiosis**. The **zygote** is the first cell of the sporophyte; the **spore** is the first cell of the gametophyte.

Pattern	Dominant phase	Meiosis in	Examples
Haplontic	Gametophyte (n); only the zygote is 2n	**Zygote (zygotic meiosis)**	*Volvox*, *Spirogyra*, *Chlamydomonas*, many algae
Diplontic	Sporophyte (2n); gametophyte reduced to a few cells	Gamete/spore formation	**Gymnosperms, angiosperms**; the alga ***Fucus***
Haplo-diplontic	Both multicellular	Spore formation	**Bryophytes** (gametophyte dominant), **pteridophytes** (sporophyte dominant); algae *Ectocarpus*, *Polysiphonia*, kelps

MEMORY TRICK

"**B**ryophytes = **G**ametophyte; **P**teridophytes onwards = s**P**orophyte." Red algae give the "**R**ed **G**els": aGar, carrageenan, from **G**elidium and **G**racilaria. **B**rown gives **A**lgin.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Agar-agar is obtained from? → ***Gelidium* / *Gracilaria* (red algae)**.
- "Amphibians of the plant kingdom"? → **Bryophytes**.
- First vascular land plants? → **Pteridophytes**.
- Coralloid roots with cyanobacteria are found in? → ***Cycas***.
- Lichens are good indicators of? → **SO_2 (air) pollution**.
- Haplontic life cycle is seen in? → ***Volvox* / *Spirogyra* / *Chlamydomonas***.

7.3 Ecology & Environment ★★★

- The term **ecology** was coined by **Ernst Haeckel (1866/1869)**; **ecosystem** by **A.G. Tansley (1935)**. **E.P. Odum** is called the father of modern ecosystem ecology, and **Ramdeo Misra** the father of ecology in India.
- **Ecosystem components**: **abiotic** (light, temperature, water, soil, nutrients) and **biotic**. Biotic components are **producers** (autotrophs), **consumers** (primary = herbivores, secondary and tertiary = carnivores) and **decomposers** (bacteria and fungi, called **saprotrophs**).

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- Ecosystem functions: **productivity, decomposition, energy flow, nutrient cycling**. Energy flow is **unidirectional** (follows the 2nd law of thermodynamics); nutrients **cycle**.
- **Grazing food chain (GFC)** starts with producers. **Detritus food chain (DFC)** starts with dead organic matter. In **aquatic** ecosystems the GFC is the main channel; in **terrestrial** ecosystems **more energy flows through the DFC**. Interlinked food chains form a **food web**.
- Decomposition steps: **fragmentation** (by detritivores such as earthworms) → **leaching** → **catabolism** → **humification** (humus, which is highly resistant) → **mineralisation**. Decomposition is **faster when warm and moist** and when detritus is rich in N and sugars; it is **slower** with **lignin and chitin** and in cold or anaerobic conditions.
- **PAR** (photosynthetically active radiation) is **<50%** of incident solar radiation. Plants capture only **2–10% of PAR**, and this energy sustains the whole living world.
- **10% law**: only about **10% of energy** passes from one trophic level to the next. Proposed by **Raymond Lindeman (1942)**, working on Cedar Bog Lake. This is why food chains rarely have more than **4–5 trophic levels**.

Ecological pyramid	Upright example	Inverted / other shape
Pyramid of **numbers**	Grassland, pond	**Inverted**: a single tree with many insects, or a **parasitic** food chain (tree → insects → hyperparasites). Spindle shape: tree → insects → birds
Pyramid of **biomass**	Grassland, forest	**Inverted in the sea / pond**: the biomass of fish exceeds that of phytoplankton at any one time
Pyramid of **energy**	**Always upright**	**Never inverted** (energy is lost as heat at each step)

- Limitations of pyramids: they do not cover the **same species at two or more trophic levels**, they assume simple food chains, and they ignore **saprophytes**.
- **Standing crop** = the mass of living material at a trophic level at a given time. **Standing state** = the amount of nutrients in the soil at a given time.

KEY FORMULAE

- **NPP = GPP − R** (R = respiration losses). Secondary productivity = rate at which consumers form new organic matter.
- Annual NPP of the whole biosphere ≈ **170 billion tonnes** (dry weight) of organic matter; oceans contribute only ≈ **55 billion t** despite covering ~70% of the surface.
- Exponential growth: **dN/dt = rN**; $N_t = N_0e^{rt}$ (J-shaped curve).
- Logistic growth (Verhulst–Pearl): **dN/dt = rN (K − N)/K**, where K = carrying capacity (S-shaped / sigmoid curve).
- Species–area relation (Humboldt): **log S = log C + Z log A**; Z ≈ **0.1–0.2** for small regions, **0.6–1.2** for whole continents.

Biogeochemical cycles

- **Gaseous cycles** (reservoir in the atmosphere): **carbon, nitrogen**, oxygen. **Sedimentary cycles** (reservoir in the Earth's crust): **phosphorus, sulphur**.
- **Carbon** makes up about **49% of the dry weight** of organisms. About **71% of carbon is dissolved in the oceans**. Roughly 4×10^{13} kg of carbon is fixed each year by photosynthesis.
- **Phosphorus** reservoir = **phosphate rocks**. The P cycle has **no significant gaseous exchange** with the atmosphere (unlike carbon).
- Nitrogen cycle microbes: see 7.6.

Ecological succession

- **Succession** = the gradual, predictable change in species composition of an area that ends in a **climax community** in equilibrium with the climate. The successive stages are called **seres (seral stages)**. Concept developed by **F.E. Clements**.
- **Primary succession** begins on bare areas with no soil (bare rock, cooled lava, a new pond) and is **very slow**. **Secondary succession** begins where the previous community was destroyed but soil remains (abandoned farmland, burnt or cut forest, flooded land) and is **faster**.
- **Pioneer species**: **lichens** on rock (xerosere); **phytoplankton** in water (hydrosere).
- **Hydrosere** (in water): phytoplankton → submerged plants → floating (rooted-floating) plants → reed swamp → marsh-meadow (sedges) → scrub → forest.
- **Xerosere** (on dry rock): crustose lichens → foliose lichens → **mosses** → herbs (annuals, then perennials) → shrubs → forest.
- Both seres move towards **mesic** (medium-water) conditions. Other seres: **halosere** (saline), **psammosere** (sand), **lithosere** (rock).

Population interactions

Interaction	Species A	Species B	Examples
Mutualism	+	+	Lichens, mycorrhiza, **fig & fig wasp**, *Yucca* & moth; the orchid *Ophrys* uses **sexual deceit** to get a bee to pollinate it
Commensalism	+	0	**Orchid growing as an epiphyte on a mango branch**, barnacles on whales, **cattle egret & grazing cattle**, clownfish & sea anemone
Parasitism	+	−	*Cuscuta* (dodder) on hedge plants, lice, liver fluke; **brood parasitism**: koel/cuckoo lays eggs in a crow's nest
Predation	+	−	Tiger–deer, herbivory; **prickly pear cactus** in Australia brought under control by a cactus-feeding moth (*Cactoblastis*)
Competition	−	−	Abingdon tortoise wiped out after goats arrived on the Galápagos; flamingos and fish competing for zooplankton
Amensalism	−	0	***Penicillium* inhibiting bacteria**; allelopathy

- **Gause's competitive exclusion principle**: two closely related species competing for the same resource cannot coexist indefinitely. Coexistence through **resource partitioning** was shown in MacArthur's warblers.
- Prey defences: **camouflage**; distasteful chemicals (the **monarch butterfly** gets them from a weed it feeds on as a caterpillar); ***Calotropis*** produces cardiac glycosides; nicotine, caffeine, quinine and strychnine are plant defences.

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Biodiversity & conservation

- The term **biodiversity** was popularised by **E.O. Wilson** (the word was coined by W.G. Rosen, 1985). Its three levels are **genetic** (e.g. *Rauwolfia vomitoria* varying in reserpine content, >50,000 strains of rice, 1,000+ mango varieties in India), **species** and **ecological** diversity.
- India has only **2.4% of the world's land area** but **~8.1% of global species diversity**, making it one of the **17 megadiverse countries**. About **45,000 plant species** have been recorded in India, and roughly twice as many animal species (NCERT).
- Biodiversity **decreases from the equator towards the poles**; the tropics are richest. The Amazon rainforest is the richest region on Earth.
- Causes of loss, the **"Evil Quartet"** (Jared Diamond's term): **habitat loss & fragmentation** (the most important), **over-exploitation** (Steller's sea cow, passenger pigeon), **alien species invasion** (Nile perch in Lake Victoria; *Parthenium*, *Lantana*, *Eichhornia*; African catfish *Clarias gariepinus*) and **co-extinction**.
- Recent extinctions: **dodo** (Mauritius), **quagga** (Africa), **thylacine** (Australia), **Steller's sea cow** (Russia), and the Bali, Javan and Caspian tigers. The **rivet popper hypothesis** is Paul Ehrlich's.
- **Biodiversity hotspots**: concept by **Norman Myers (1988)**. Criteria: **≥1,500 endemic vascular plant species** and **≥70% of original habitat lost**. There are **36 hotspots** worldwide (the 36th, the North American Coastal Plain, was added in 2016). Together they cover only **~2.5% of the land surface** but hold more than half of all endemic plant species.
- India has **4 hotspots**: **Himalaya, Indo-Burma, Western Ghats & Sri Lanka, Sundaland** (Nicobar Islands). **NCERT (older edition) lists 34 hotspots worldwide and 3 in India**, leaving out Sundaland. In the exam, choose **36 / 4** unless the options follow NCERT.

In-situ conservation (on site)	Ex-situ conservation (off site)
Biosphere reserves, **national parks**, wildlife sanctuaries, **sacred groves**, hotspots, Ramsar wetlands	Zoos, **botanical gardens**, wildlife safari parks, **seed banks / gene banks**, **cryopreservation at −196 °C** (liquid N_2), tissue culture, pollen banks

- **Biosphere reserves** come under **UNESCO's Man and Biosphere (MAB) programme, launched in 1971**. They have three zones: **core** (no human activity), **buffer** (research and education) and **transition** (manipulation zone, where people live and work).
- India has **18 biosphere reserves**. The first was **Nilgiri (1986)** and the latest, the 18th, is **Panna (2020)**. The largest is the **Great Rann of Kutch**. **13 of the 18** are in UNESCO's World Network; **Cold Desert** (Himachal Pradesh) became the 13th in **September 2025**.
- **National parks** in India number about **106**. The first was **Hailey NP (1936)**, now **Jim Corbett NP**. Laws and projects: **Wildlife (Protection) Act 1972**; **Project Tiger 1973**.
- **Sacred groves**: **Khasi & Jaintia Hills** (Meghalaya), Aravalli Hills (Rajasthan), Western Ghats of Karnataka and Maharashtra, and Sarguja, Chanda and Bastar (MP and Chhattisgarh).
- Gene banks: **NBPGR, New Delhi** (National Gene Bank) and the **Svalbard Global Seed Vault** (Norway).
- **Red Data Book / Red List**: maintained by the **IUCN** (founded 1948; HQ **Gland, Switzerland**). Categories: Extinct (EX), Extinct in the Wild (EW), **Critically Endangered (CR)**, Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), Not Evaluated (NE). CR, EN and VU together count as "**threatened**". In the printed book, **pink pages = critically endangered** and **green pages = species formerly endangered but now recovered**. BSI has published the *Red Data Book of Indian Plants*.
- Global agreements: **Earth Summit, Rio 1992** (gave rise to the **CBD**); **WSSD Johannesburg 2002**; **Kunming–Montreal Global Biodiversity Framework 2022** (**"30×30"**, i.e. protect 30% of land and sea by 2030). India's **Biological Diversity Act** dates from **2002**.

Pollution & global environmental issues

Issue	Cause	Key facts
Greenhouse effect / global warming	CO_2, CH_4, CFCs, N_2O, water vapour	NCERT shares of the warming effect: **CO_2 60%**, CH_4 20%, CFCs 14%, N_2O 6%. The Earth's mean temperature is **~15 °C**; without the greenhouse effect it would be **~−18 °C**. Kyoto Protocol 1997; **Paris Agreement 2015** (well below 2 °C, aiming for 1.5 °C)
Ozone depletion	**CFCs** release Cl atoms in the stratosphere; Cl acts as a catalyst	Ozone is measured in **Dobson units (DU)**. The "ozone hole" is over **Antarctica** (found 1985). **Montreal Protocol 1987** (in force 1989); **Kigali Amendment 2016** phases down HFCs. Ozone Day is **16 September**. UV-B causes **snow-blindness**, cataract and skin cancer
Acid rain	**SO_2 and NO_x** → H_2SO_4, HNO_3	Rain with **pH < 5.6**; corrodes the marble of the **Taj Mahal** ("marble cancer"); acidifies lakes
Eutrophication	**N and P** from sewage and fertiliser run-off	Natural ageing of a lake; when accelerated by humans it is **cultural (accelerated) eutrophication**. Causes **algal blooms**, high **BOD**, O_2 depletion and fish kills. *Eichhornia* (water hyacinth) is called the **"Terror of Bengal"**
Biomagnification	Non-biodegradable toxins: **DDT**, Hg	DDT rises from **0.003 ppb in water to 25 ppm in fish-eating birds**. It disturbs calcium metabolism and causes **thin eggshells**, so eggs break prematurely

- **Pollution diseases**: **Minamata (Hg, Japan)**; **Itai-itai (Cd)**; **blue-baby syndrome (nitrate in water → methaemoglobinaemia)**; **fluorosis** (F); **blackfoot disease (As)**.
- Air pollution control: the **electrostatic precipitator** removes **>99% of particulate matter**; **scrubbers** remove SO_2; **catalytic converters** (Pt–Pd–Rh) need **unleaded** petrol. **PM2.5** is the most harmful size fraction. **Bharat Stage VI** norms apply from **1 April 2020**. Noise above **150 dB** can damage eardrums.
- Indian laws: **Water Act 1974**, **Air Act 1981** (noise added in 1987), **Environment (Protection) Act 1986**. Movements: **Chipko 1974** (Garhwal Himalaya); **Amrita Devi Bishnoi** (1731, Khejarli, Rajasthan, protecting *Khejri* trees). **Joint Forest Management** began in the 1980s.
- The **National Forest Policy 1988** aims at **33% forest cover** in the plains and **67%** in the hills. **ISFR 2023**: forest cover is **21.76%** of India's area, and forest + tree cover together is **25.17%**.

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- India's **Ramsar sites** (wetlands of international importance; Ramsar Convention 1971, Iran) number **103 as of October 2026** (latest additions: **Sukhna Lake**, Chandigarh and **Sauj Jheel**, UP). The number keeps rising, so check the latest figure before the exam.

MEMORY TRICK

India's four hotspots are "**H**is **I**ndian **W**ife **S**miles": **H**imalaya, **I**ndo-Burma, **W**estern Ghats–Sri Lanka, **S**undaland. Energy pyramids are "**E**ver **E**rect": never inverted.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Which ecological pyramid is always upright? → **Pyramid of energy**.
- 10% law of energy transfer was given by? → **Lindeman (1942)**.
- Pioneer species in a xerosere? → **Crustose lichens**.
- Orchid growing on a mango tree is an example of? → **Commensalism**.
- Number of biosphere reserves in India? → **18** (13 in UNESCO's network).
- Thin eggshells in birds are due to? → **DDT biomagnification**.

7.4 Photosynthesis ★★★

KEY FORMULAE

- **$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$** (light, chlorophyll). The simple form is $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$.
- Photolysis: **$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$** (at PS II; needs **Mn, Ca^{2+}, Cl^-**).
- Calvin cycle cost: **3 ATP + 2 NADPH per CO_2**; per glucose (6 turns) = **18 ATP + 12 NADPH**.
- C_4 cost: **5 ATP + 2 NADPH per CO_2**, i.e. **30 ATP** per glucose.
- Quantum requirement ≈ **8 quanta (photons) per O_2** evolved (or per CO_2 fixed); quantum yield = 1/8 ≈ **0.125**. Some texts give 8–10.

Scientist	Contribution
Joseph Priestley (1770)	Bell jar with candle and mouse: plants "restore" the air (O_2)
Jan Ingenhousz	**Sunlight** is essential, and only **green parts** release O_2
Julius von Sachs (1854)	Glucose is formed (stored as starch) in the **chloroplasts** of green parts
T.W. Engelmann	First **action spectrum**, using the alga *Cladophora*, a prism and aerobic bacteria: peaks in **blue and red** light
Cornelius van Niel	Purple and green sulphur bacteria use H_2S; deduced that **O_2 comes from H_2O**, not CO_2
Ruben & Kamen (1941)	Proved this with **^{18}O**: the O_2 released comes from water
Robin Hill (1937)	Isolated chloroplasts evolve O_2 in light when an electron acceptor is present (**Hill reaction**)
Melvin Calvin	C_3 pathway worked out with ^{14}C in *Chlorella* (Nobel 1961)
Hatch & Slack (1966)	C_4 pathway (Kortschak had made earlier observations in sugarcane)
F.F. Blackman (1905)	Law of limiting factors
Robert Emerson (1957)	**Red drop** and **enhancement effect** → evidence for two photosystems

Pigments

Pigment	Colour (TLC)	Role
Chlorophyll a	Bright / blue-green	**Primary pigment**, the reaction centre (P680, P700). Absorption peaks ≈ **430 nm (blue)** and **662 nm (red)**
Chlorophyll b	Yellow-green	Accessory pigment (peaks ≈ 453 and 642 nm)
Xanthophylls	Yellow	Accessory pigments
Carotenoids (carotenes)	Yellow to yellow-orange	Accessory pigments that **protect chlorophyll from photo-oxidation**

- Chlorophyll has a **porphyrin head with Mg** at its centre and a **phytol tail**. Chl a = $C_{55}H_{72}O_5N_4Mg$ (–CH_3 group); chl b = $C_{55}H_{70}O_6N_4Mg$ (–CHO group). **Fe is not part of chlorophyll** but is needed to make it.
- **PAR = 400–700 nm**. Accessory pigments widen the range of wavelengths that can be used and pass the energy on to chl a.
- The site is the **chloroplast**. The **light reaction** takes place in the **thylakoid membranes (grana)**; the **dark (carbon) reactions** take place in the **stroma**.

Light reaction

- **PS I**: reaction centre **P700**. Found in stroma lamellae and on the outer, non-appressed grana membranes.
- **PS II**: reaction centre **P680**. Found in the **appressed grana**; it is linked with **photolysis of water** through the Mn cluster.
- Each photosystem has a **light-harvesting complex (antenna)** of a few hundred pigment molecules around one reaction centre.
- **Z-scheme** (non-cyclic electron flow): H_2O → PS II (P680) → **plastoquinone** → **cytochrome b_6f** → **plastocyanin (Cu)** → PS I (P700) → **ferredoxin (Fe–S)** → **$NADP^+$ reductase** → **NADPH**.
- **ATP** is made by **chemiosmosis (Peter Mitchell)**. Protons build up in the **lumen** (from photolysis and from PQ), and the proton gradient drives **ATP synthase (CF_0–CF_1)**. The CF_1 head faces the **stroma**.

Feature	Non-cyclic photophosphorylation	Cyclic photophosphorylation
Photosystems	**PS II + PS I**	**PS I only**
Electron path	Open; electrons end in NADPH	Electrons return to PS I
Products	**ATP + NADPH + O_2**	**ATP only**
Photolysis	Yes	**No**
Location	Grana	**Stroma lamellae** (which lack PS II and NADP reductase)
When dominant	Normal light	When only light **above 680 nm** is available, or when the cell needs extra ATP

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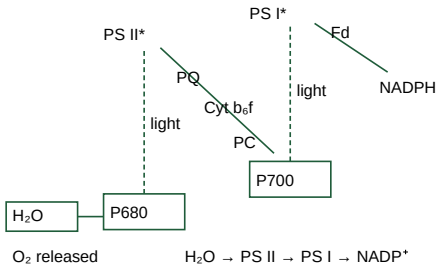
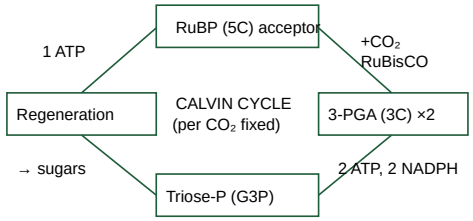


Z-scheme, simplified. Two light-driven "uphill" steps (dashed) at P680 and P700, with downhill electron transport (PQ → cytochrome b_6f → plastocyanin) between them.

Calvin cycle (C_3 cycle)

- Three phases: **carboxylation** → **reduction** → **regeneration** of RuBP.
- **Carboxylation**: **RuBP (5C) + CO_2 → 2 × 3-PGA (3C)**, catalysed by **RuBisCO** (ribulose-1,5-bisphosphate carboxylase-oxygenase), the **most abundant protein on Earth**.
- **First stable product = 3-phosphoglyceric acid (PGA, 3C)**, which is why these are called C_3 plants. **Primary CO_2 acceptor = RuBP**.
- **Reduction**: PGA → triose phosphate (G3P), using **ATP and NADPH**. **Regeneration** of RuBP uses **1 ATP** per CO_2.
- The cycle occurs in all photosynthetic plants, C_3 and C_4. Most crops (wheat, rice, potato, pulses, oilseeds) are C_3.



Calvin cycle, clockwise. Carboxylation (RuBisCO) → reduction (2 ATP + 2 NADPH) → regeneration of RuBP (1 ATP). Total = 3 ATP + 2 NADPH per CO_2.

C_4 pathway, CAM and photorespiration

- **C_4 (Hatch–Slack) pathway**: in the **mesophyll**, the **primary acceptor PEP (phosphoenolpyruvate, 3C)** combines with CO_2, catalysed by **PEP carboxylase (PEPcase)**, to give the **first stable product oxaloacetic acid (OAA, 4C)**. OAA becomes malate or aspartate, which moves to the **bundle sheath** and is **decarboxylated**. The released CO_2 then enters the Calvin cycle. Pyruvate returns to the mesophyll and PEP is regenerated.
- **Kranz anatomy** ("wreath"): large **bundle-sheath cells** in a ring around the veins, with **many chloroplasts**, **thick walls impervious to gas** and **no intercellular spaces**. **RuBisCO is found only in the bundle sheath**; **PEPcase is absent there** (it is in the mesophyll). The chloroplasts are **dimorphic**: bundle-sheath chloroplasts are often **agranal**.
- C_4 examples: **maize, sugarcane, sorghum**, *Amaranthus*, bajra (pearl millet), many tropical grasses; *Euphorbia* (some species), *Atriplex*.
- **CAM (Crassulacean Acid Metabolism)**: **stomata open at night**. CO_2 is fixed by PEPcase into OAA and stored as **malic acid** in the **vacuole**, so the cell sap becomes **more acidic at night**. By day it is decarboxylated and the CO_2 goes to the Calvin cycle while stomata stay closed. This is a **temporal** separation; C_4 uses a **spatial** one. Examples: **pineapple**, **cactus (*Opuntia*)**, *Bryophyllum/Kalanchoe*, *Agave*, sedum.
- **Photorespiration (C_2 cycle)**: at high O_2 and high temperature, RuBisCO acts as an **oxygenase**: RuBP + O_2 → 1 PGA + 1 **phosphoglycolate (2C)**. It involves **three organelles: chloroplast → peroxisome → mitochondrion**. CO_2 is released in the **mitochondria** (2 glycine → serine + CO_2 + NH_3). It makes **no ATP or NADPH** and is a **wasteful** process. It is **absent (negligible) in C_4 plants** because they concentrate CO_2 at RuBisCO.

Feature	C_3	C_4	CAM
Primary CO_2 acceptor	**RuBP**	**PEP**	PEP (night), RuBP (day)
First stable product	**3-PGA**	**OAA**	**OAA → malic acid**
Carboxylating enzyme	RuBisCO	PEPcase (mesophyll) + RuBisCO (bundle sheath)	PEPcase + RuBisCO, in the same cell
Kranz anatomy	Absent	**Present**	Absent
Photorespiration	**High**	Negligible	Negligible
Optimum temperature	20–25 °C	**30–40 °C**	~35 °C
CO_2 compensation point	High (~50 ppm)	**Low (0–10 ppm)**	Low (in the dark)
ATP per CO_2	3	**5**	~6.5
Water-use efficiency	Low	High	**Highest**
Productivity	Moderate	**High**	Low
Examples	Wheat, rice, potato, soybean	Maize, sugarcane, sorghum	Pineapple, *Opuntia*, *Agave*

Factors affecting photosynthesis

- **Blackman's law of limiting factors (1905)**: when a process depends on several factors, its rate is set by the factor **nearest its minimal value**. Example: a leaf in bright light but low CO_2 is limited by CO_2. (Compare **Liebig's law of the minimum** for nutrients.)
- **Light**: rate rises linearly at low intensity. **Light saturation** occurs at about **10% of full sunlight**, so except for plants in shade or dense forest, light is rarely limiting. Very high light causes photo-oxidation (solarisation).
- **CO_2**: present at ~0.03–0.04% of the atmosphere and the **main limiting factor** in nature. C_4 plants saturate at **~360 µL L^{-1}**; C_3 plants keep responding and saturate only **beyond ~450 µL L^{-1}**. Greenhouse crops such as **tomato and bell pepper** are given extra CO_2 for higher yield.
- **Temperature**: the dark (enzymatic) reactions are temperature-sensitive. **Water** has an indirect effect: water stress **closes stomata** and reduces leaf area.
- **Compensation point** = the light intensity, or CO_2 concentration, at which photosynthesis = respiration (net exchange zero).
- **Emerson's red drop**: the rate (quantum yield) falls sharply in light **beyond 680 nm**. **Emerson enhancement effect**: red (<680 nm) and far-red (>680 nm) light given together produce a rate **greater than the sum** of each given alone. This proved that **two photosystems** work in series.

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MEMORY TRICK

"**3–2–1** for C_3": **3** ATP, **2** NADPH, **1** CO_2. "**P680 = PS II**" because both are "two-looking" (8 looks like a doubled 0). C_4 crops are the "Mighty Sugary Sorghum": **M**aize, **S**ugarcane, **S**orghum. CAM is "**C**actus **A**nd **M**alic acid by night", or simply "pineapple at night".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Source of O_2 released in photosynthesis? → **Water (photolysis)**.
- First stable product of C_4 pathway? → **Oxaloacetic acid (4C)**.
- Most abundant protein on Earth? → **RuBisCO**.
- Reaction centre of PS II? → **P680**.
- Kranz anatomy is characteristic of? → **C_4 plants (maize, sugarcane)**.
- Law of limiting factors was given by? → **F.F. Blackman (1905)**.

7.5 Respiration ★★★

KEY FORMULAE

- **$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy** ($\Delta G \approx -686$ kcal mol^{-1} ≈ -2870 kJ mol^{-1}).
- **RQ = volume of CO_2 evolved ÷ volume of O_2 consumed**.
- Tripalmitin: $2C_{51}H_{98}O_6 + 145O_2 \rightarrow 102CO_2 + 98H_2O$; RQ = 102/145 ≈ **0.7**.
- Malic acid: $C_4H_6O_5 + 3O_2 \rightarrow 4CO_2 + 3H_2O$; RQ = **1.33**.

- **Respiration** = the oxidation of food (respiratory substrate, usually **glucose**) to release energy, which is trapped as **ATP** ("energy currency"). It is a **catabolic** process. Plants have **no special respiratory organs**; gas exchange happens through **stomata and lenticels**.
- **Aerobic respiration** uses O_2 and gives complete oxidation to CO_2 + H_2O. **Anaerobic respiration / fermentation** needs no O_2, gives incomplete oxidation and much less energy.
- **Pasteur effect**: **O_2 inhibits fermentation** (glycolysis slows under aerobic conditions).

Stage	Site	Key points	Yield (per glucose)
Glycolysis (EMP pathway) – Embden, Meyerhof, Parnas	**Cytoplasm** (in all organisms)	Glucose (6C) → **2 pyruvate (3C)** in 10 steps. ATP is used at 2 steps (hexokinase, **phosphofructokinase (PFK, the key regulatory enzyme)**) and made at 2 steps (phosphoglycerate kinase, pyruvate kinase), each occurring twice per glucose = 4 ATP. Needs no O_2	**Net 2 ATP + 2 NADH** (4 made − 2 used)
Link reaction (oxidative decarboxylation)	**Mitochondrial matrix**	Pyruvate → **acetyl CoA** + CO_2, by the **pyruvate dehydrogenase** complex (needs Mg^{2+}, NAD^+, CoA)	2 NADH, 2 CO_2
Krebs cycle (TCA / citric acid cycle) – Hans Krebs	**Mitochondrial matrix**	Acetyl CoA (2C) + **OAA (4C) → citric acid (6C)**; OAA is regenerated. **Succinate dehydrogenase** is the only TCA enzyme bound to the **inner membrane**	6 NADH, 2 $FADH_2$, **2 ATP/GTP** (substrate-level), 4 CO_2
ETS & oxidative phosphorylation	**Inner mitochondrial membrane** (cristae)	Complex I (NADH dehydrogenase) → **ubiquinone** → Complex III (cyt bc_1) → **cytochrome c** → Complex IV (**cytochrome c oxidase**: cyt a, a_3, Cu). $FADH_2$ enters at Complex II. **O_2 is the final electron acceptor** and forms **water**	Bulk of the ATP, made by **ATP synthase (Complex V)**

- **ATP synthase**: F_0 is embedded in the membrane and forms the **proton channel**; F_1 is the head piece that projects into the matrix and is the **site of ATP synthesis**. For each ATP made, ~2–3 H^+ pass through F_0 (2 per NCERT). The mechanism is Mitchell's chemiosmotic hypothesis.
- **Inhibitors**: **cyanide, CO and azide** block Complex IV; **rotenone** blocks Complex I; **antimycin A** blocks Complex III; **oligomycin** blocks F_0; **2,4-DNP** is an **uncoupler**.
- Respiration is an **amphibolic pathway**: it both breaks down (catabolism) and supplies intermediates for synthesis (anabolism). Fats enter as acetyl CoA (fatty acids) or as PGAL (glycerol); proteins enter as amino acids at pyruvate, acetyl CoA or Krebs-cycle intermediates.

ATP balance per glucose	Old textbook (P/O: NADH = 3, $FADH_2$ = 2)	Modern (NADH = 2.5, $FADH_2$ = 1.5)
Glycolysis: 2 ATP + 2 NADH	2 + 6 = 8	2 + 5 (or 3 via glycerol-phosphate shuttle)
Link: 2 NADH	6	5
Krebs: 2 ATP + 6 NADH + 2 $FADH_2$	2 + 18 + 4 = 24	2 + 15 + 3 = 20
Total	**38** (prokaryotes; NCERT net gain); **36** in eukaryotes (2 ATP spent moving cytosolic NADH into mitochondria)	**~30–32**

- NCERT gives the net aerobic gain as **38 ATP** and points out that this is a theoretical exercise. In MCQs, take **38 = theoretical / prokaryote**, **36 = eukaryote** and **30–32 = modern estimate**.

Fermentation (anaerobic respiration)

Type	Organism	Pathway	Enzymes
Alcoholic	**Yeast**, some plant tissues (waterlogged roots)	Pyruvate → acetaldehyde + **CO_2** → **ethanol**	**Pyruvic acid decarboxylase**, **alcohol dehydrogenase**
Lactic acid	**Lactobacillus**, animal **muscle** under O_2 debt, RBCs	Pyruvate → **lactic acid** (no CO_2)	**Lactate dehydrogenase**

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- Fermentation gives only **2 ATP per glucose** (net). It releases **<7% of the energy** in glucose, and NADH is reoxidised to NAD^+. Yeast **poisons itself** when alcohol reaches **~13%.**
- **Storage relevance**: moist grain and its microflora respire intensely, giving heat, CO_2, moisture and **dry-matter loss** (hot spots). Hermetic storage works because respiration uses up O_2. Respiration roughly **doubles for each 10 °C rise** ($Q_{10} \approx 2$).

Respiratory substrate	RQ
Carbohydrates (glucose)	**1.0**
Fats (tripalmitin)	**~0.7** (<1; fats are O_2-poor and need more O_2)
Proteins	**~0.8–0.9**
Organic acids	**>1** (malic acid 1.33; oxalic acid 4.0)
Anaerobic respiration	**Infinity (∞)** (CO_2 released, no O_2 taken)
Germinating oil seeds (fat → carbohydrate)	<1 (often ~0.3–0.7)
CAM succulents at night	~0 (CO_2 fixed, not released)

MEMORY TRICK

"**G**lycolysis in **G**eneral cytoplasm, **K**rebs in **K**ernel (matrix), **E**TS on the **E**dge (inner membrane)." For RQ remember "**A**cid > **C**arb (1) > **P**rotein (0.9) > **F**at (0.7)": "**A C**ool **P**lant **F**ruit".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Glycolysis takes place in? → **Cytoplasm**; net gain **2 ATP**.
- Krebs cycle occurs in? → **Mitochondrial matrix**.
- Final electron acceptor in ETS? → **Oxygen**.
- RQ of fats? → **~0.7**; of carbohydrates? → **1**.
- RQ of anaerobic respiration? → **Infinity**.
- First product of the Krebs cycle? → **Citric acid**.

7.6 Transport, Water Relations & Mineral Nutrition ★★☆

- **Diffusion** = passive movement from high to low concentration; the only way gases move inside a plant. It depends on the gradient, membrane permeability, temperature and pressure. **Facilitated diffusion** uses carrier or channel proteins (**aquaporins** for water), still with no ATP. Carriers can be **uniport**, **symport** (same direction) or **antiport** (opposite directions).
- **Active transport** moves substances **against the gradient**, uses **ATP** and relies on pumps. It is specific and can be saturated.
- **Osmosis** = diffusion of water across a **semi-permeable membrane** from **higher to lower water potential**. **Osmotic pressure** = the pressure needed to stop water entering; it equals the numerical value of the osmotic (solute) potential.

KEY FORMULAE

- $\Psi_w = \Psi_s + \Psi_p$ (water potential = solute potential + pressure potential). Units: **pascals (MPa)**.
- Pure water at standard temperature and atmospheric pressure: $\Psi_w = 0$ (the maximum). Adding solute makes Ψ_s **negative**. Ψ_p is usually **positive** (turgor) but **negative in xylem under tension**.
- Water always moves from **less negative to more negative Ψ_w**.
- Older terms: DPD = OP − TP (suction pressure).

External solution	Effect on cell
Hypotonic (more dilute)	Water enters; cell becomes **turgid** (endosmosis)
Isotonic	No net movement; cell **flaccid**. At **incipient plasmolysis**, $\Psi_p = 0$
Hypertonic (more concentrated)	Water leaves (exosmosis); protoplast shrinks away from the wall: **plasmolysis**. Placing the cell back in a hypotonic solution reverses this (**deplasmolysis**)

- Salting pickles and sugaring jams preserve food because they **plasmolyse microbes**. Excess fertiliser near roots causes "**burning**" through exosmosis.
- **Imbibition** = water uptake by **hydrophilic colloids** (cellulose, pectin, proteins) causing swelling. It drives the first step of **seed germination** and the swelling of wooden doors in monsoon; ancient workers used it to split rocks with wooden pegs. It generates a large **imbibition pressure** and works through **matric potential**.
- **Water absorption pathways**: **apoplast** (through cell walls and intercellular spaces; non-living; blocked at the endodermis by the **Casparian strip of suberin**) and **symplast** (cytoplasm to cytoplasm via **plasmodesmata**). Mycorrhiza adds a large absorbing surface.
- **Root pressure** = a **positive** pressure in the xylem caused by active ion uptake, seen as **bleeding** from cut stems. It is too weak to account for the ascent of sap in tall trees.
- **Guttation** = loss of **liquid water** through **hydathodes** (water pores at leaf margins and tips) at **night or early morning**, when root pressure is high and transpiration low. Seen in grasses, tomato, *Colocasia* and *Tropaeolum*.
- **Ascent of sap**: the accepted theory is **cohesion–tension (transpiration-pull)**, from **Dixon & Joly (1894)**. It rests on **cohesion** (between water molecules), **adhesion** (to xylem walls), **surface tension** and a **continuous water column** in the xylem pulled up by transpiration. The theory of **J.C. Bose** (pulsation, a vital theory) has been rejected.

Transpiration

- Loss of water as **vapour** from aerial parts. Types: **stomatal** (the major part, ~90%+), **cuticular** and **lenticular**. Plants use **less than 1%** of the water they absorb; most of the rest is transpired. Curtis called it a "**necessary evil**".
- Benefits: **transpiration pull**, mineral transport, **cooling the leaf** (by up to 10–15 °C) and keeping cells turgid.
- **Stomata**: guard cells are **kidney-shaped in dicots** and **dumb-bell-shaped in grasses**. The inner wall is thick and elastic, and cellulose microfibrils are arranged **radially**, so the stoma opens when guard cells become turgid. Dorsiventral dicot leaves have more stomata on the **lower surface**; isobilateral monocot leaves have about equal numbers; floating leaves (lotus) have them only on the **upper surface**.
- **K^+ ion theory** of stomatal movement (Levitt; Fujino, 1967): in light, K^+ enters the guard cells (proton pump; malate as the counter-ion), Ψ_w falls, water enters and the **stoma opens**. The older **starch–sugar hypothesis** (Sayre; Steward) explained opening by starch → sugar at high pH.
- **ABA closes stomata** under water stress, acting as an **anti-transpirant** hormone. Other anti-transpirants: phenyl mercuric acetate, CO_2, wax coatings. High CO_2 also closes stomata.
- Measurement: **Ganong's potometer** (water uptake ≈ transpiration); **cobalt chloride paper** (blue when dry → **pink**

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when moist).

- Factors **increasing** transpiration: **high temperature, light, wind, low humidity**. **Xerophytic** adaptations reduce it: sunken stomata, thick cuticle, hairs, rolled leaves, CAM.

Phloem transport

- Food moves as **sucrose** in the **sieve tubes** (supported by companion cells), from **source (leaf) → sink** (roots, fruits, storage organs). Transport is **bidirectional**; xylem transport is unidirectional (upwards).
- The accepted theory is the **pressure-flow (mass-flow) hypothesis** of **Ernst Münch (1930)**. Sugar is **actively loaded** at the source, water enters by osmosis, and turgor pressure pushes the sap to the sink, where sugar is unloaded.
- **Girdling (ringing) experiment**: remove a ring of bark (phloem) and the bark **above the ring swells** as food collects there; the roots eventually starve. This proves that phloem carries food.
- **Aphid stylets** are used to sample phloem sap.

Mineral nutrition

- **Hydroponics** (soil-less culture) was demonstrated by **Julius von Sachs (1860)**. The **criteria of essentiality** were set out by **Arnon & Stout (1939)**: the element must be **absolutely necessary** to complete the life cycle, must **not be replaceable** by another element, and must be **directly involved** in metabolism.
- **17 essential elements** are generally accepted. **Macronutrients** (>10 mmol kg^{-1} dry matter): **C, H, O, N, P, K, S, Ca, Mg**. **Micronutrients** (<10 mmol kg^{-1}): **Fe, Mn, Cu, Mo, Zn, B, Cl, Ni**. **Beneficial** elements: Na, Si, Co, Se.
- **Mobile** elements (**N, P, K, Mg**) are moved to younger tissue, so deficiency symptoms appear **first in older leaves**. **Immobile** elements (**Ca, S**, Fe, B, Cu) show symptoms **first in young leaves**.
- **Chlorosis** is caused by deficiency of **N, K, Mg, S, Fe, Mn, Zn, Mo**. **Necrosis** is caused by **Ca, Mg, Cu, K**. **Delayed flowering** results from low N, S or Mo. **Mn toxicity** induces deficiencies of Fe, Mg and Ca, showing as brown spots surrounded by chlorotic veins.

Element	Main role	Deficiency / disorder
N	Proteins, nucleic acids, chlorophyll, hormones	Chlorosis of older leaves, stunting
P	ATP, nucleic acids, **phospholipids** (membranes)	**Purple/dark-green leaves**, poor roots, delayed maturity
K	**Stomatal opening**, anion–cation balance, enzyme activation, turgor	Marginal scorching of older leaves, lodging
Ca	**Middle lamella (Ca-pectate)**, mitotic spindle, membranes	Death of meristems/tips; **blossom-end rot** of tomato
Mg	**Centre of chlorophyll**; activates RuBisCO and PEPcase; ribosome structure	**Interveinal chlorosis of older leaves**
S	Amino acids **cysteine, methionine**; CoA, biotin, thiamine, ferredoxin	Chlorosis of young leaves; low oil in oilseeds
Fe	Cytochromes, **ferredoxin**; catalase; needed to **make chlorophyll**	**Interveinal chlorosis of young leaves**
Mn	**Photolysis of water** (O_2 evolution); activates enzymes	**Grey speck of oats**, marsh spot of pea
Zn	Carboxylases; **auxin synthesis**	**Khaira of rice**, little leaf, white bud of maize
Cu	**Plastocyanin**, redox enzymes	**Die-back / exanthema of citrus**
B	**Pollen germination**, Ca uptake, cell differentiation, carbohydrate translocation	**Heart rot of beet**, browning/hollow stem of cauliflower, internal cork of apple
Mo	**Nitrogenase, nitrate reductase** (N metabolism)	**Whiptail of cauliflower**
Cl	Photolysis of water (with Na^+/K^+, solute balance)	Wilting, bronzing
Ni	**Urease**	Urea toxicity, leaf-tip necrosis

Nitrogen fixation & the nitrogen cycle

- N_2 has a very stable **triple bond (N≡N)**. Fixation can be **physical** (lightning, UV), **industrial** (Haber–Bosch) or **biological (BNF)**.
- **Nitrogenase** is a **Mo–Fe protein** and works only under **anaerobic** conditions: $N_2 + 8e^- + 8H^+ + 16\ ATP \rightarrow 2NH_3 + H_2$.
- **Free-living** N-fixers: **Azotobacter**, *Beijerinckia* (aerobic); ***Rhodospirillum*** (anaerobic, photosynthetic); *Clostridium* (anaerobic); cyanobacteria ***Anabaena, Nostoc*** (fixation takes place in **heterocysts**).
- **Symbiotic** N-fixers: ***Rhizobium*** in **legume root nodules**; ***Frankia*** in non-legume nodules (*Alnus*, *Casuarina*); *Anabaena* in *Azolla*; *Nostoc* in *Anthoceros* and *Cycas*.
- **Nodule formation**: root releases chemical signals → Rhizobia multiply and attach → **root hair curls** → an **infection thread** carries bacteria into the cortex → cortical cells divide to form the nodule → bacteria change into **bacteroids**.
- **Leghaemoglobin** = a **pink** oxygen scavenger in the nodule. It **protects nitrogenase from O_2**. Its haem part comes from the bacterium and its globin part from the plant gene.
- Nitrogen cycle steps: **ammonification** (decay); **nitrification**: $NH_3 \rightarrow NO_2^-$ by ***Nitrosomonas/Nitrococcus***, then $NO_2^- \rightarrow NO_3^-$ by ***Nitrobacter*** (chemoautotrophs); **denitrification**: $NO_3^- \rightarrow N_2$ by ***Pseudomonas, Thiobacillus***.
- NH_4^+ is assimilated by **reductive amination** (glutamate) and **transamination**. The amides **asparagine and glutamine** carry N in the **xylem**; soybean nodules export **ureides**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Water potential of pure water? → **Zero**.
- Cohesion–tension theory of ascent of sap was proposed by? → **Dixon & Joly**.
- Guttation occurs through? → **Hydathodes**.
- Pressure-flow hypothesis of phloem transport? → **Münch**.
- Pink colour of root nodules is due to? → **Leghaemoglobin**.
- Whiptail of cauliflower is due to deficiency of? → **Molybdenum**.

7.7 Plant Growth, Hormones & Movements ★★★

- Growth is **irreversible, permanent increase in size**. Plants show **open growth** because their meristems stay active throughout life. Phases: **meristematic → elongation → maturation**.
- Plotting growth against time gives a **sigmoid (S-shaped) curve** with **lag, log (exponential) and stationary** phases. Growth is measured with an **auxanometer**. **J.C. Bose** invented the **crescograph** to record plant growth.
- Plants show **differentiation → dedifferentiation** (e.g. interfascicular cambium, cork cambium) → **redifferentiation**.

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Plasticity means plants form different structures depending on environment or life stage, e.g. **heterophylly** in cotton, coriander and larkspur (developmental) and in buttercup (environmental).

KEY FORMULAE

- Arithmetic growth: $L_t = L_0 + rt$ (linear curve; e.g. root elongating at a constant rate).
- Geometric growth: $W_1 = W_0 e^{rt}$ (r = relative growth rate, the "efficiency index").
- Absolute growth rate = growth per unit time; relative growth rate = growth per unit time per unit initial size.

Hormone (PGR)	Discovery	Chemical nature / examples	Key effects & uses
Auxin (Greek *auxein*, "to grow")	**Charles & Francis Darwin (1880)**: coleoptile of canary grass bends to light. **F.W. Went (1928)** isolated it from ***Avena*** coleoptile tips (**Avena curvature test**)	Natural (indole compounds): **IAA**, IBA. Synthetic (non-indole): **NAA**, **2,4-D**, 2,4,5-T	**Apical dominance** (removing the tip, or **decapitation**, gives bushy plants, used in tea plucking and hedges); rooting of stem cuttings (IBA, NAA); prevents early fruit and leaf drop; promotes abscission of older parts; **parthenocarpy** (tomato); xylem differentiation; **2,4-D kills dicot weeds** in monocot crops; phototropism and geotropism
Gibberellins (GA)	**E. Kurosawa (1926)**: **bakanae ("foolish seedling") disease of rice**, caused by ***Gibberella fujikuroi*** (= *Fusarium*)	Acidic, terpenoid; >100 known; **GA_3 (gibberellic acid)** was the first and is the most studied	**Stem/internode elongation** (dwarf → tall); **bolting** (rosette plants such as cabbage and beet, before flowering); **larger grape bunches and berries** (**seedless grapes**, longer stalks); elongates apple to improve shape; delays senescence; **sugarcane yield up by ~20 t/acre**; **malting** (induces α-amylase in the **aleurone** of barley); breaks seed dormancy; early seed production in conifers
Cytokinins	**Skoog & Miller**: **kinetin** from autoclaved **herring-sperm DNA**; **zeatin** from **corn kernels** and **coconut milk**	Adenine (purine) derivatives; kinetin = 6-furfurylaminopurine (not found naturally in plants)	**Cell division (cytokinesis)**; new leaves, chloroplasts, lateral shoots, adventitious shoots; **overcomes apical dominance**; **delays leaf senescence (Richmond–Lang effect, 1957)**; nutrient mobilisation. Made mainly in **root tips**. In tissue culture, a **high auxin:cytokinin ratio gives roots** and a **low ratio gives shoots**
Ethylene	**H.H. Cousins (1910)**: ripe oranges hastened the ripening of bananas	**Gaseous**, simple hydrocarbon (C_2H_4); made from **methionine**; commercial source **ethephon** (releases ethylene)	**Fruit ripening** (triggers the **respiratory climacteric**); senescence and **abscission**; **triple response** (horizontal growth of seedlings, swelling of axis, apical hook); breaks dormancy (peanut seed, potato tuber sprouting); elongation of **deep-water rice** internodes; root hairs; **flowering in pineapple** and mango; more **female flowers in cucumber**. The **most widely used PGR** in agriculture
Abscisic acid (ABA)	Three groups independently found abscisin II (Addicott), **dormin** (Wareing) and inhibitor-B; all proved to be **ABA** (1960s)	Terpenoid made from **carotenoids**; a **growth inhibitor**	**"Stress hormone"**; **stomatal closure**; **seed dormancy** and bud dormancy; inhibits germination; seed maturation and desiccation tolerance; **antagonist of GA**

- Promoters: auxin, GA, cytokinin. Inhibitor: **ABA**. Ethylene acts largely as an inhibitor but also promotes some processes. Other PGRs include **brassinosteroids**, **jasmonates**, **salicylic acid** (systemic acquired resistance) and **strigolactones**. **Morphactins** and **maleic hydrazide** are synthetic inhibitors; MH is used to **prevent sprouting** of stored onion and potato.
- **Storage link**: ethylene scrubbing ($KMnO_4$) and **1-MCP** (blocks ethylene receptors) extend the shelf life of fruit. Calcium carbide (acetylene) for artificial ripening is **banned** under FSS Regulations.

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Photoperiodism & vernalisation

- **Photoperiodism** = the flowering response to **day length** (really to the length of the dark period). Discovered by **Garner & Allard (1920)** in **Maryland Mammoth tobacco**. The photoperiod is **perceived by the leaves**; the stimulus moves to the shoot apex.
- **Florigen** = the hypothetical flowering hormone (**Chailakhyan**, 1936–37). It is now identified with the **FT protein**, which moves through the phloem.

Type	Needs	Examples
Short-day plants (SDP), i.e. **long-night plants**	Day **shorter** than the critical length (an uninterrupted long night)	***Xanthium***, **soybean** (Biloxi), **chrysanthemum**, Maryland Mammoth tobacco, **rice**, dahlia, cosmos, *Poinsettia*
Long-day plants (LDP), i.e. short-night plants	Day **longer** than the critical length	**Wheat**, oat, barley, **radish**, spinach, lettuce, sugar beet, *Hyoscyamus niger* (henbane)
Day-neutral plants (DNP)	Flower regardless of day length	**Tomato**, cucumber, **sunflower**, maize, cotton, chilli

- **Night-break effect**: a brief flash of **red light** in the middle of the dark period **stops SDP from flowering** and helps LDP to flower. A following **far-red** flash reverses the effect. This proves that the **dark period** is what counts.
- **Phytochrome** (Borthwick & Hendricks, 1952) is a **blue-green chromoprotein** with two interconvertible forms. **Pr** absorbs **red (~660 nm)** and changes to **Pfr**; Pfr absorbs **far-red (~730 nm)** and changes back to Pr. Pfr also reverts slowly to Pr in the dark. **Pfr is the active form**. Phytochrome controls **lettuce seed germination** (red promotes, far-red inhibits), de-etiolation and flowering.
- **Vernalisation** (term coined by **T.D. Lysenko**, 1928) = promotion of flowering by a period of **low temperature** (~0–10 °C). Examples: **winter wheat, barley and rye**, and **biennials** (sugar beet, cabbage, carrot). The cold is **perceived by the shoot apex (meristem)**. Vernalisation stops **precocious reproductive development late in the growing season**. It can be reversed by high temperature (**devernalisation**), and **GA can replace the cold requirement** in some biennials.

Seed dormancy & germination

- **Dormancy** = a viable seed failing to germinate even under favourable conditions; the cause is internal. **Quiescence** = a seed not germinating only because external conditions are unfavourable.
- Causes: **hard or impermeable seed coat** (legumes, "hard seeds"); **chemical inhibitors** (**ABA**, phenolic acids, para-ascorbic acid); **immature or rudimentary embryo**; need for light or chilling.
- Breaking dormancy: **scarification** (mechanical abrasion, or acid such as conc. H_2SO_4); **stratification** (moist chilling); **GA_3**; KNO_3; thiourea; ethylene; red light.
- Germination needs **water, O_2 and a suitable temperature**. **Imbibition** is the first step, followed by enzyme activation: GA from the embryo induces α-amylase in the **aleurone layer**.
- **Epigeal** germination (cotyledons pushed above the soil by hypocotyl elongation): bean, castor, cotton, groundnut, **onion**, gourds. **Hypogeal** germination (cotyledons stay below; epicotyl elongates): **pea, gram, maize, rice, wheat, mango**.
- **Vivipary** = germination while the seed is still attached to the parent: **mangroves (*Rhizophora*)**. Pre-harvest sprouting in cereals is a form of vivipary, linked to low ABA.
- The **tetrazolium (TZ) test** is a quick viability test: live embryo tissue stains **red** (formazan).

Plant movements

Type	Nature	Examples
Tropic (growth movement, **direction set by the stimulus**)	Usually growth curvature caused by unequal auxin distribution	**Phototropism** (shoots +ve, roots −ve); **geotropism/gravitropism** (roots +ve, shoots −ve; sensed by **statoliths**, i.e. starch-filled amyloplasts in the root cap); **hydrotropism** (roots towards water); **thigmotropism** (**tendrils** coiling on touch); **chemotropism** (**pollen tube** growing towards the ovule)
Nastic (direction **not set by the stimulus**)	Usually turgor changes or differential growth	**Seismonasty / thigmonasty**: ***Mimosa pudica*** (touch-me-not) leaflets fold through **loss of turgor in the pulvinus**; **nyctinasty** (sleep movements of legume leaves, e.g. *Albizia*, tamarind); **photonasty** (flowers opening in light); **thermonasty** (tulip, crocus); **haptonasty** (tentacles of *Drosera*, closing of *Dionaea* leaves)
Tactic (movement of a **whole organism or cell**)	Free locomotion	**Phototaxis** (*Chlamydomonas*, *Volvox*), **chemotaxis** (antherozoids of bryophytes and ferns swimming to archegonia), thermotaxis
Autonomic (spontaneous)	Internal causes	**Cyclosis** (cytoplasmic streaming in *Hydrilla*, *Vallisneria*); oscillating leaflets of *Desmodium gyrans* (telegraph plant)

MEMORY TRICK

Hormone in one word each: **A**uxin = **A**pex (apical dominance); **G**A = **G**iant (elongation, bolting); **C**ytokinin = **C**ell division and **C**an't age (delays senescence); **E**thylene = **E**ats fruit (ripening); **ABA** = "**A**bort, **B**rake, **A**larm" (dormancy, stomatal closure, stress). Photoperiod: "**S**DP = **S**oybean, **X**anthium, **C**hrysanthemum; LDP = **W**heat, **R**adish, **S**pinach".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Bakanae disease of rice led to the discovery of? → **Gibberellins**.
- Hormone that delays leaf senescence (Richmond–Lang effect)? → **Cytokinin**.
- Gaseous plant hormone that hastens fruit ripening? → **Ethylene**.
- Hormone that closes stomata during water stress? → **Abscisic acid**.
- Active form of phytochrome? → **Pfr (far-red absorbing)**.
- Folding of *Mimosa pudica* leaves on touch is? → **Seismonasty (turgor movement)**.

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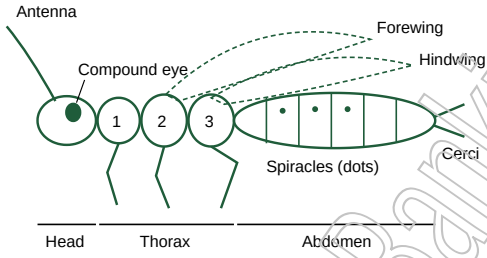
8. Zoology I – Insects, Organ Systems & Heredity

> **NOTE**
> CWC protects stored grain mainly against **insects**, so insect morphology, physiology (spiracles → fumigant entry; cuticle → contact poisons; moulting hormones → IGRs) and the **orders/families of storage pests** are the highest-yield zoology topics. Questions are one-liners: "antenna of housefly?", "pupa of housefly?", "largest insect order?", "excretory organ of insects?". The second half covers NCERT human physiology and genetics, which are asked at Class 11–12 level.

8.1 Insect Morphology ★★★

- Phylum **Arthropoda** (largest phylum, about **2/3 of all named animal species**) → Class **Insecta (Hexapoda)**. About **1 million** insect species have been described. Insects make up **more than half** of all known animal species (some texts: about three-quarters).
- Characters of Insecta: body in **3 regions** (head, thorax, abdomen); **1 pair of antennae**; **3 pairs of legs** (on the thorax); usually **2 pairs of wings**; tracheal respiration; **Malpighian tubules**; open circulation; chitinous exoskeleton.
- Compare other arthropods: **Arachnida** (spiders, mites, ticks) – cephalothorax + abdomen, **4 pairs of legs**, no antennae; **Crustacea** – 2 pairs of antennae; **Chilopoda** (centipedes) – 1 pair of legs per segment; **Diplopoda** (millipedes) – 2 pairs of legs per segment.



Generalised insect, side view: 1 = prothorax, 2 = mesothorax, 3 = metathorax. Each thoracic segment bears one pair of legs. Wings arise from segments 2 and 3 only.

Head

- The head is formed by the fusion of **6 segments**. It bears the antennae, compound eyes, ocelli (usually 3) and mouthparts.
- The head capsule is divided by sutures (epicranial "Y"-shaped suture, frontoclypeal suture) into the vertex, frons, clypeus, gena and occiput.

Head type	Position of mouthparts	Examples
Hypognathous (orthognathous)	Directed **downward**; long axis of head vertical (most primitive and common)	Grasshopper, cockroach
Prognathous	Directed **forward**; head horizontal	Ground beetles (Carabidae), many beetle larvae, earwigs
Opisthognathous (opisthorhynchous)	Directed **backward**, between the forelegs	Bugs (Hemiptera: aphids, leafhoppers)

Antennae

- The antenna has **3 parts**: **scape** (basal), **pedicel** (2nd segment, which contains **Johnston's organ**, the organ of hearing in male mosquitoes) and **flagellum** (the rest).
- Functions: touch and smell (olfaction). In male mosquitoes the antenna is also used for hearing. Antennae are absent in the order Protura.

Antenna type	Shape	Example
Filiform	Thread-like; segments uniform	Grasshopper, cockroach, ground beetle
Setaceous	Bristle-like, tapering	Dragonfly, damselfly, cicada
Moniliform	Bead-like (segments rounded)	**Termite**
Serrate	Saw-like (segments triangular)	Click beetle, jewel beetle, **pulse beetle**
Pectinate	Comb-like (processes on one side)	Some sawflies, fire-coloured beetle, male *Callosobruchus chinensis*
Bipectinate	Double comb	Male **silkworm moth** and many male moths
Clavate	Gradually thickened towards the tip (club)	**Butterflies**, carrion beetle
Capitate	Tip abruptly enlarged into a knob	**Red flour beetle** (Tribolium), some other beetles
Lamellate	Terminal segments form flat, leaf-like plates	**Scarabaeidae**: rhinoceros beetle, dung beetle, white grub beetle
Geniculate	Elbowed (long scape)	**Honeybee, ants**, weevils (geniculate-clavate)
Aristate	3rd segment enlarged and bears a dorsal bristle (**arista**)	**Housefly** (Cyclorrhapha)
Plumose	Feathery; long dense hairs	**Male mosquito**

Mouthparts

- The basic (chewing) set has **labrum** (upper lip; not a true appendage), **2 mandibles**, **2 maxillae** (each with cardo, stipes, galea, lacinia and maxillary palp), **labium** (lower lip, formed by the **fused second maxillae**; it has glossae, paraglossae and labial palps) and **hypopharynx** (tongue-like).
- The **chewing (mandibulate)** type is the most **primitive** type. Most other types are derived from it.
- Larvae of Lepidoptera have chewing mouthparts (they are the damaging stage), while the adults have siphoning mouthparts. Silk is secreted by the **labial (salivary) glands** and comes out through the spinneret.

Type	Key features	Examples
Biting & chewing	Strong toothed mandibles that move sideways	**Grasshopper**, cockroach, beetles, caterpillars, termites

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Piercing & sucking	Mandibles and maxillae form **stylets**. Bugs have **4 stylets**: the maxillary stylets interlock to form the **food canal and salivary canal**. The labium forms a sheath (**rostrum/beak**). The female mosquito has **6 stylets** (labrum, hypopharynx, 2 mandibles, 2 maxillae) inside the labium.	**Bugs** (aphids, jassids, whiteflies), female **mosquito**
Siphoning	Long coiled **proboscis** formed by the two **galeae** of the maxillae. Mandibles absent or vestigial.	Adult **butterflies and moths**
Sponging	Fleshy proboscis ending in a **labellum** with **pseudotracheae**. The fly pours saliva on food and mops up the liquid. Mandibles absent.	**Housefly**
Chewing & lapping	Mandibles mould wax. The long **glossa** ("tongue") laps nectar.	**Honeybee**
Rasping & sucking	**Asymmetrical** cone. Only the **left mandible** is present (the right is absent). The insect rasps tissue and sucks the oozing sap.	**Thrips**
Cutting & sponging	Blade-like mandibles cut the skin and blood is sponged up	Horsefly (Tabanus)
Mask (modified labium)	Prehensile, extensible labium that catches prey	Dragonfly **naiad**

Thorax & legs

- The thorax has **3 segments**: **prothorax, mesothorax and metathorax**. The meso- and metathorax together are the **pterothorax** because they bear the wings. Each segment has a dorsal **tergum (notum)**, a ventral **sternum** and lateral **pleura**.
- Leg segments (proximal → distal): **coxa → trochanter → femur → tibia → tarsus** (1–5 tarsomeres) → **pretarsus** (claws, with arolium or pulvilli).
- The **pulvilli** (pads with sticky hairs) let the housefly walk on glass and ceilings. In butterflies and houseflies, taste receptors are on the tarsi.

Leg modification	Function	Example
Cursorial	Fast running (long, slender legs)	**Cockroach**, ground beetle
Saltatorial	Jumping (enlarged hind femur)	**Hind legs of grasshopper**, flea beetle, cricket
Raptorial	Grasping prey (spiny femur and tibia)	**Forelegs of praying mantis**, giant water bug
Fossorial	Digging (broad, toothed tibia)	**Forelegs of mole cricket** (Gryllotalpa), cicada nymph
Natatorial	Swimming (flattened, fringed with hairs)	**Hind legs of water beetle** (Dytiscus), backswimmer
Scansorial	Clinging to hair (single large claw)	**Head louse**, crab louse
Pollen-collecting	**Corbicula** (pollen basket) on the hind tibia; pollen comb	Hind leg of **worker honeybee**
Prolegs (false legs)	Fleshy, unjointed, on the abdomen, with **crochets**	Caterpillars: usually 5 pairs, on abdominal segments 3–6 and 10

Wings

- Wings are outgrowths of the body wall, borne on the **mesothorax and metathorax**. The veins carry haemolymph, nerves and tracheae. The standard vein-naming system is the **Comstock–Needham system**.
- **Apterygota** (primitively wingless): silverfish. **Secondarily wingless** (wings lost in evolution): fleas, lice.
- Wing-coupling: **hamuli** (hooks on the hindwing) in Hymenoptera; **frenulum & retinaculum** in moths; **amplexiform** (overlapping lobe) in butterflies; jugum in primitive moths.

Wing type	Description	Order / example
Elytra	Hard, horny **forewings**; protective, not used in flight	**Coleoptera** (beetles)
Hemelytra	Forewing with a **leathery base** (corium, clavus) and a **membranous tip**	**Hemiptera–Heteroptera** (true bugs)
Tegmina	**Leathery, parchment-like forewings** with veins	**Orthoptera** (grasshopper), cockroach, mantis
Halteres	Knob-like **hindwings** that act as gyroscopic **balancers**	**Diptera** (flies, mosquito)
Pseudohalteres	Forewings reduced to balancers	Male Strepsiptera
Scaly wings	Covered with overlapping **scales**	Lepidoptera
Fringed wings	Narrow, with long marginal hairs	**Thysanoptera** (thrips)
Membranous	Thin, transparent, with veins (hamuli in Hymenoptera)	Hymenoptera, Odonata, Neuroptera

Abdomen & genitalia

- The abdomen primitively has **11 segments**, but usually **10 or fewer** are visible. It carries no legs in adults. It bears **8 pairs of spiracles** (on segments 1–8).
- **Cerci** = paired appendages of the **11th segment**. They are sensory (in cockroaches) or form forceps in earwigs.
- **Ovipositor**: formed from appendages of segments **8 and 9**. The **sting** of the worker honeybee, wasps and ants is a **modified ovipositor**, so **only females sting**. Male genitalia (aedeagus) are on segment **9**.
- Aphids have **cornicles (siphunculi)**, paired tubes on the abdomen that secrete defensive fluid.
- **Cockroach (NCERT)**: *Periplaneta americana*; abdomen of **10 segments**; **anal cerci** in both sexes but **anal styles only in males**; mushroom-shaped gland (male accessory gland) in segments **6–7**; females lay **9–10 oothecae** of about **14–16 eggs** each; nymphs moult about **13 times**.

MEMORY TRICK

Leg segments in order: "**C**an **T**he **F**ly **T**ake **T**ea **P**lease" → Coxa, Trochanter, Femur, Tibia, Tarsus, Pretarsus.
Wing names: "**E**very **H**alf **T**ough **H**indwing" → Elytra (beetles), Hemelytra (bugs), Tegmina (grasshoppers), Halteres (flies, hindwing).

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PREVIOUSLY ASKED / LIKELY QUESTIONS

- Type of antenna of the housefly? → **Aristate**. Termite? → **Moniliform**. Male mosquito? → **Plumose**.
- Mouthparts of thrips? → **Rasping-sucking**; of honeybee? → **Chewing-lapping**.
- The proboscis of a butterfly is formed by? → **Galeae of the maxillae**.
- Halteres are modified? → **Hindwings (Diptera)**.
- Forelegs of the praying mantis are? → **Raptorial**. Hind legs of the grasshopper? → **Saltatorial**.
- The sting of the honeybee is a modified? → **Ovipositor**.

8.2 Insect Physiology ★★★

Integument & cuticle

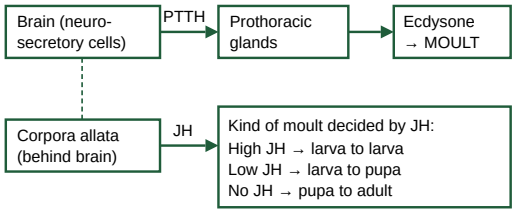
- Integument layers (outside → in): **cuticle** → **epidermis** (a single cell layer that secretes the cuticle) → **basement membrane**.
- The cuticle has three layers:
  - **Epicuticle**: outermost and thinnest, **no chitin**. It has cement, a **wax layer** (the waterproof barrier) and cuticulin.
  - **Exocuticle**: hard and dark, made of **sclerotised (tanned)** protein (sclerotin) plus chitin.
  - **Endocuticle**: soft, flexible chitin plus protein.

  The exocuticle and endocuticle together are called the **procuticle**.
- **Chitin** = a polysaccharide of **N-acetyl-D-glucosamine** joined by **β-1,4 links**. It is insoluble in water, alcohol, dilute acids and alkalis. Chitin is also found in the cell walls of **fungi**. Arthropodin and resilin (an elastic protein in the wing hinges and the jumping mechanism of fleas) are cuticle proteins.
- **Sclerotisation** (tanning) = cross-linking of proteins by quinones. **Bursicon** hormone controls tanning after a moult.
- **Inert dusts** (silica aerogel, diatomaceous earth, activated clay) used in grain storage **abrade the wax layer**, so the insect dies of **desiccation**.

Moulting (ecdysis) & its hormones

- **Moulting** = periodic shedding of the old cuticle. The stage between two moults is an **instar**, and the time between two moults is a **stadium**. Apolysis (the cuticle separating from the epidermis) comes before ecdysis (the old cuticle being cast off).
- **Moulting fluid** (chitinase and protease) digests the old endocuticle, and up to about 90% of it is reabsorbed.

Hormone	Source	Action
PTTH (prothoracicotropic hormone; "brain hormone")	**Neurosecretory cells of the brain**; released via the corpora cardiaca (corpora allata in Lepidoptera)	Stimulates the prothoracic glands
Ecdysone (moulting hormone; a steroid; active form **20-hydroxyecdysone**)	**Prothoracic glands**	**Starts the moult**
Juvenile hormone (JH) (a sesquiterpenoid; "status quo hormone")	**Corpora allata**	**Keeps larval characters**. High JH → larva moults into a larva. Low JH → pupa. No JH → adult. Also needed for egg maturation in adults.
Bursicon	Neurosecretory cells (ventral nerve cord)	**Tanning (hardening)** of the new cuticle



Hormonal control of moulting. Ecdysone decides when a moult happens, and JH decides what kind of moult it is. The dashed line shows that the brain also controls the corpora allata.

- **Insect growth regulators (IGRs)** act on this system. They are relatively safe for mammals.
  - **JH analogues**: **methoprene**, hydroprene, **pyriproxyfen**, fenoxycarb.
  - **Chitin synthesis inhibitors** (benzoylphenylureas): **diflubenzuron**, lufenuron, novaluron, **buprofezin** (a thiadiazine used against hoppers and whiteflies).
  - **Ecdysone agonists**: tebufenozide, methoxyfenozide.
  - **Anti-JH** compounds (precocenes, from *Ageratum*) cause early metamorphosis.

Digestive system

Region	Origin / lining	Parts & role
Foregut (stomodaeum)	**Ectoderm**, lined with cuticle	Pharynx, oesophagus, **crop** (food storage), **proventriculus/gizzard** (grinding; the cockroach gizzard has **6 chitinous teeth**). Stomodaeal valve.
Midgut (mesenteron / ventriculus)	**Endoderm**, no cuticle	**Main site of digestion and absorption**. Gastric caeca (6–8 in cockroach). **Peritrophic membrane** (matrix).
Hindgut (proctodaeum)	**Ectoderm**, lined with cuticle	Ileum, colon, **rectum** (rectal pads/papillae **reabsorb water** and ions). Malpighian tubules open at the **midgut–hindgut junction**.

- **Peritrophic membrane**: a thin layer of **chitin + protein** lining the midgut. It protects the epithelium from abrasion and pathogens. It is absent in most Hemiptera and adult Lepidoptera (fluid feeders). **Bt toxin** (Cry protein) acts on the **midgut epithelium** after being activated in an **alkaline gut** (lepidopteran larvae).
- **Filter chamber**: found in sap-sucking **Hemiptera** (cicadas, leafhoppers, scales). The front and back of the gut lie in close contact, so **excess water passes straight to the hindgut** and the dilute sap is concentrated. The surplus sugary fluid is excreted as **honeydew**, which supports **sooty mould**.
- Digestive enzymes match the diet. Wood is digested in lower termites with the help of **symbiotic flagellates** (e.g. *Trichonympha*). Clothes moth and dermestid larvae digest **keratin**.
- **Fat body**: the insect equivalent of the **liver**. It stores fat, glycogen and protein, synthesises **vitellogenin** (yolk protein) and detoxifies. The main blood sugar is **trehalose** (a disaccharide).

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Excretion

- Excretory organs: **Malpighian tubules** (discovered by Marcello **Malpighi**). They are blind tubules that lie free in the haemolymph and open at the **midgut–hindgut junction**. The cockroach has **100–150** of them.
- Insects are **uricotelic**: the chief nitrogenous waste is **uric acid**. It needs little water and is ideal for land life. Excreted solids leave with the faeces, called **frass**.
- Malpighian tubules are **absent in aphids** and Collembola.
- **Cryptonephridial system**: the tubule tips are embedded around the rectum to save as much water as possible. It is found in **Tenebrionidae** (e.g. the mealworm and flour beetles) and caterpillars. This helps stored-grain beetles survive on **dry grain** (8–12% moisture).

Respiration

- Insects breathe through a **tracheal system** that delivers O_2 **directly to the tissues**, so the blood does not carry oxygen.
- **Spiracles** (external openings) → **tracheae** (ectodermal tubes lined with cuticle and stiffened by spiral **taenidia**) → **tracheoles** (less than 1 µm across, intracellular, tips filled with fluid; not shed at moulting) → cells. Air sacs help ventilation and flight.
- Maximum spiracles = **10 pairs**: **2 thoracic** (meso- and metathorax) + **8 abdominal**. This is the **holopneustic** arrangement (e.g. cockroach, grasshopper). Fewer spiracles in other insects: e.g. **metapneustic** (only the last pair; mosquito larvae), **apneustic** (none; many aquatic larvae).
- **Fumigants** (phosphine, methyl bromide) enter through the **spiracles**. Insects keep their spiracles closed under stress, so fumigants are less effective at **low temperature** and against **dormant/diapausing stages** (eggs, pupae). A higher CO_2 level makes spiracles open, which is the basis of **CO_2-enriched fumigation**. Under **hermetic storage** (low O_2), insects die from lack of oxygen.
- Aquatic insects: **tracheal gills** (mayfly naiads; damselfly naiads have 3 caudal gills), **rectal gills** (dragonfly naiads), a **respiratory siphon** (*Culex* and *Aedes* larvae; *Anopheles* larvae lack a siphon and lie **parallel** to the water surface), and a **plastron** or air bubble (water beetles).

Circulation

- Insects have an **open circulatory system**: the blood (**haemolymph**) bathes the organs in the body cavity, the **haemocoel**.
- The **dorsal vessel** has two parts: the posterior **heart** (chambered, with lateral valves called **ostia**; the cockroach heart has **13 chambers**) and the anterior **aorta**. Blood flows **backward → forward** (towards the head) in the dorsal vessel. **Alary muscles** support the heart, and accessory pulsatile organs help circulation in the wings, legs and antennae.
- Haemolymph is colourless, greenish or yellowish. It usually **has no respiratory pigment**. Exception: ***Chironomus* larvae** ("blood worms") have **haemoglobin**.
- Functions of haemolymph: transport of nutrients, hormones and wastes; immunity (haemocytes – plasmatocytes, granulocytes – carry out phagocytosis, nodulation and encapsulation); clotting; hydrostatic pressure for moulting and expanding the wings.

Nervous system & sense organs

- **Brain** (supra-oesophageal ganglion) has three parts: **protocerebrum** (compound eyes and ocelli), **deutocerebrum** (antennae) and **tritocerebrum** (labrum, stomatogastric system).
- The **suboesophageal ganglion** controls the mouthparts.
- A **double, solid, ganglionated ventral nerve cord** runs below the gut (the cockroach has 3 thoracic and 6 abdominal ganglia).
- Insecticide targets in the nervous system:
  - **Acetylcholinesterase** (AChE) is inhibited by **organophosphates and carbamates**.
  - The **nicotinic ACh receptor** is the target of **neonicotinoids** (imidacloprid) and spinosad.
  - The **GABA-gated chloride channel** is blocked by **fipronil** and cyclodienes. Avermectins act on glutamate-gated chloride channels.
  - **Sodium channels** are kept open by **pyrethroids and DDT**.
  - The **ryanodine receptor** (in muscle) is the target of **diamides** (chlorantraniliprole, flubendiamide).
  - **Phosphine** inhibits cytochrome c oxidase (respiration).
- **Compound eye** = many **ommatidia** (housefly about **4,000** per eye; dragonfly about **28,000**; cockroach about **2,000**). It gives **mosaic vision**. Each ommatidium has a corneal lens, **crystalline cone**, retinula cells and a **rhabdom** (made of rhodopsin-containing rhabdomeres).
  - **Apposition eye** (day-active insects): each ommatidium is optically isolated by pigment.
  - **Superposition eye** (nocturnal moths and beetles): light from several facets is combined.
- Insects detect **UV light** (the basis of **UV light traps**). Honeybees **cannot see red**.
- Simple eyes: **ocelli** (dorsal, in adults and nymphs) and **stemmata** (lateral eyes of larvae, e.g. caterpillars).
- Hearing organs:
  - **Tympanal organs**: grasshoppers (Acrididae) on the **1st abdominal segment**; crickets and katydids on the **fore tibiae**; many moths on the thorax or abdomen.
  - Johnston's organ in the antenna (mosquito).
- Other sense organs: chemoreceptors (sensilla on the antennae, palps and tarsi); mechanoreceptors (trichoid hairs, campaniform sensilla).

Reproduction & development

- Insects are mostly **oviparous**, with internal fertilisation. Sperm are stored in the female's **spermatheca**. Eggs are laid singly, in masses or in an **ootheca** (cockroach, mantis). Sperm enter the egg through the **micropyle**.
- Ovariole types:
  - **Panoistic**: no nurse cells (Orthoptera, termites).
  - **Polytrophic**: nurse cells alternate with oocytes (Lepidoptera, Diptera, Hymenoptera).
  - **Telotrophic** (acrotrophic): nurse cells at the tip (Hemiptera, Coleoptera).
- **Parthenogenesis** (development without fertilisation):
  - **Arrhenotoky**: unfertilised eggs give males. Honeybee **drones (haploid)** arise this way, giving **haplodiploid** sex determination in Hymenoptera.

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- **Thelytoky**: only females are produced (aphids in summer, some scales).
- Deuterotoky: both sexes are produced.

- Special modes of reproduction:
  - **Viviparity**: aphids (parthenogenetic and viviparous in the warm season); tsetse fly (adenotrophic: one larva at a time, fed by "milk glands").
  - **Polyembryony**: one egg gives many embryos (*Copidosoma*, *Platygaster* – parasitic Hymenoptera).
  - **Paedogenesis**: larvae reproduce (*Miastor*, a gall midge).
- **Diapause** = a hormone-controlled state of suspended development triggered by photoperiod or temperature (e.g. diapausing **khapra beetle larvae** survive for years and tolerate fumigants). **Quiescence** is a direct response to bad conditions that ends as soon as conditions improve.

Metamorphosis	Stages	Young called	Examples
Ametabolous (none)	Egg → young → adult (look alike; adults keep moulting)	Young	**Silverfish** (Thysanura), Collembola
Paurometabolous (gradual)	Egg → **nymph** → adult; nymph and adult live in the same habitat	**Nymph**	Grasshopper, cockroach, termites, bugs, lice
Hemimetabolous (incomplete, strict sense)	Egg → **aquatic naiad** (with gills) → terrestrial adult	**Naiad**	**Dragonfly**, mayfly, stonefly
Holometabolous (complete)	Egg → **larva** → **pupa** → adult; wings develop inside the body (**endopterygota**)	Larva	Beetles, moths, flies, bees, lacewings, fleas
Intermediate (neometabolous)	Has 1–2 quiescent "prepupa/pupa" stages	Nymph	**Thrips**, whiteflies, male scale insects
Hypermetamorphosis	The larval instars differ in form (the first is an active **triungulin**)	Larva	**Blister beetles** (Meloidae), Strepsiptera

The term **"hemimetabolous"** is often used broadly for all incomplete metamorphosis (nymph + naiad). Insects with incomplete metamorphosis are **exopterygota**: their wings develop outside the body as wing pads.

Larva type	Description	Example
Eruciform (polypod)	Caterpillar: 3 pairs of thoracic legs + prolegs	**Lepidoptera**; sawfly larvae (6–8 pairs of prolegs, no crochets)
Campodeiform (oligopod)	Long, flattened, active, long legs, prognathous	**Lacewing** (aphid lion), ladybird grub, ground beetle
Scarabaeiform (oligopod)	**C-shaped**, fleshy, sluggish, short legs	**White grub** (Scarabaeidae)
Elateriform (oligopod)	Hard, cylindrical, short legs	**Wireworm** (click beetle)
Apodous – eucephalous	Legless; well-developed head	**Weevil grubs** (Sitophilus), mosquito larva, Buprestidae
Apodous – hemicephalous	Legless; head partly reduced	Crane fly, horsefly larvae
Apodous – **acephalous**	Legless and headless; **maggot**	**Housefly, fruit fly**

Pupa type	Description	Example
Obtect	Appendages **glued to the body** by a secretion; often inside a **cocoon** (moths) or a naked **chrysalis** (butterflies)	**Lepidoptera**, mosquito ("tumbler", active pupa)
Exarate	Appendages **free** from the body	**Coleoptera**, Hymenoptera, Neuroptera
Coarctate	An exarate pupa inside a hardened last-larval skin, the **puparium**	**Housefly**, fruit fly (cyclorrhaphous Diptera)

Pheromones & semiochemicals

- **Pheromone** – a chemical released by one individual that affects another individual of the **same species**. The term was coined by **Karlson & Lüscher (1959)**. The first pheromone identified was **bombykol**, the sex pheromone of the silkworm moth, by **Butenandt (1959)**.
- Allelochemicals act **between species**:
  - **Allomone** benefits the emitter (e.g. defensive secretions).
  - **Kairomone** benefits the receiver (e.g. host odour used by a parasitoid).
  - **Synomone** benefits both.

Pheromone type	Example
Sex (usually released by females)	**Gossyplure** – pink bollworm; **Helilure** – *Helicoverpa armigera*; Spodolure – *Spodoptera litura*; *Leucinodes* lure – brinjal shoot & fruit borer
Aggregation (attracts both sexes)	Stored-grain beetles: *Tribolium* (**4,8-dimethyldecanal**), *Sitophilus* (sitophilure), *Rhyzopertha* (dominicalure); red palm weevil (ferrugineol); rhinoceros beetle
Alarm	Aphids – **(E)-β-farnesene**; honeybee – isopentyl acetate (released at the sting)
Trail	Ants, termites
Queen substance (primer)	Honeybee – **9-ODA** (from the mandibular glands); suppresses the ovaries of workers
Para-pheromone / male lure	**Methyl eugenol** – oriental fruit fly (*Bactrocera dorsalis*) males; **cue-lure** – melon fly (*Zeugodacus cucurbitae*)

- Uses of pheromones: **monitoring** pest populations (e.g. probe/pitfall and pheromone traps in warehouses), **mass trapping**, **mating disruption** (confusion) and lure-and-kill.
- Pheromones are species-specific and leave no residue.

MEMORY TRICK

"JH keeps you Junior": juvenile hormone holds the insect in the larval stage. **"Ecdysone = Exit the skin"**.
Pupae: **O**btect = **O**ne piece (glued); **E**xarate = **E**xposed appendages; **C**oarctate = **C**ase (puparium).

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PREVIOUSLY ASKED / LIKELY QUESTIONS

- Excretory organs of insects? → **Malpighian tubules**; chief excretory product? → **Uric acid**.
- Juvenile hormone is secreted by? → **Corpora allata**. Ecdysone? → **Prothoracic glands**.
- Insect blood with haemoglobin? → ***Chironomus* larva**.
- Pupa of housefly? → **Coarctate**. Larva of housefly? → **Maggot (apodous, acephalous)**.
- First pheromone identified? → **Bombykol** (silkworm moth).
- Fumigants enter the insect body through? → **Spiracles**.

8.3 Insect Taxonomy – Orders & Families ★★★

- Insects are classified into about **29–31 orders** (the number depends on the scheme). They fall into **Apterygota** (primitively wingless) and **Pterygota** (winged). Pterygota are split into **Exopterygota** (incomplete metamorphosis) and **Endopterygota** (complete).
- Order names mostly end in **-ptera** ("wing"). Family names end in **-idae**, subfamilies in **-inae** and tribes in **-ini**.
- **Largest order: Coleoptera** (about **4 lakh** species; about **40%** of insects and about 25% of all animals). Then **Lepidoptera**, Hymenoptera and Diptera, all holometabolous. **Hemiptera** is the largest order with incomplete metamorphosis.

Order (meaning)	Common name	Examples	Key characters	Metamorphosis
Thysanura (fringed tail)	Silverfish, bristletails	*Lepisma saccharina*	**Primitively wingless**; **3 caudal filaments**; scales; chewing; pest of paper, books, starch	Ametabolous
Odonata (toothed jaws)	Dragonflies, damselflies	*Pantala*, *Agriocnemis*	Large compound eyes; 2 pairs of net-veined wings; predators; naiad has a **mask** (labium)	Hemimetabolous (**naiad**)
Orthoptera (straight wing)	Grasshoppers, locusts, crickets, katydids	**Desert locust** *Schistocerca gregaria*; *Hieroglyphus banian* (rice grasshopper); mole cricket	**Tegmina**; **saltatorial** hind legs; chewing; tympanum; stridulation	Paurometabolous
Dictyoptera (net wing): **Blattodea** + **Mantodea**	Cockroaches; praying mantids	*Periplaneta americana*, *Blattella germanica*; *Mantis religiosa*	Tegmina; eggs in an **ootheca**; cockroach has cursorial legs; mantis has **raptorial forelegs** (predator)	Paurometabolous
Isoptera (equal wing)	**Termites** ("white ants")	*Odontotermes obesus*, *Microtermes*, *Coptotermes*	**Social**; castes (king, physogastric **queen**, workers, soldiers); 2 pairs of **equal wings** shed after swarming; **moniliform** antennae; chewing; feed on cellulose	Paurometabolous
Phthiraptera	Lice (sucking – Anoplura; chewing – Mallophaga)	Head and body louse *Pediculus humanus*; cattle and poultry lice	Wingless ectoparasites; **dorsoventrally flattened**; scansorial legs; body louse transmits **epidemic typhus**	Pau
Hemiptera (half wing)	True bugs, aphids, jassids, whiteflies, scales, mealybugs, planthoppers	BPH *Nilaparvata lugens*; whitefly *Bemisia tabaci*; red cotton bug; **lac insect** *Kerria lacca*	**Piercing–sucking** (rostrum); Heteroptera have **hemelytra**; Homoptera have uniform wings; many are **virus vectors**; honeydew	Pau (wh inte
Thysanoptera (fringed wing)	Thrips	*Thrips tabaci* (onion), *Scirtothrips dorsalis* (chilli)	Minute; **fringed wings**; **rasping–sucking** (left mandible only); tospovirus vectors	Inte
Neuroptera (nerve wing)	Lacewings, antlions	***Chrysoperla zastrowi sillemi*** (green lacewing)	Net-veined wings; larvae predatory with **sucking jaws** ("aphid lion"); stalked eggs	Hol
Coleoptera (sheath wing)	**Beetles & weevils**	Rice weevil, khapra, red flour beetle, pulse beetle, ladybird	**Elytra**; chewing; **largest order**; exarate pupa	Hol
Lepidoptera (scale wing)	Butterflies & moths	*Helicoverpa*, rice moth, Angoumois moth, silkworm *Bombyx mori*	Wings and body covered with **scales**; adults **siphoning**, larvae chewing; obtect pupa	Hol
Diptera (two wing)	True flies, mosquitoes, midges	Housefly *Musca domestica*; fruit fly; *Anopheles*, *Aedes*; rice gall midge	**One pair of wings** (mesothoracic) + **halteres**; mouthparts sponging/piercing; maggots; coarctate pupa	Hol
Siphonaptera (tube, wingless)	**Fleas**	Rat flea *Xenopsylla cheopis*	Wingless; **laterally compressed**; jumping hind legs (resilin); rat flea is the vector of **plague** (*Yersinia pestis*)	Hol
Hymenoptera (membrane wing)	Bees, wasps, ants, sawflies, parasitoids	Honeybee; ***Trichogramma*** (egg parasitoid); *Bracon*	2 pairs of membranous wings joined by **hamuli**; **petiole** ("wasp waist") in Apocrita; ovipositor/sting; **haplodiploidy**	Hol

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TAXONOMY UPDATE

Modern classifications place **termites inside Blattodea** (as the group Termitoidae/"Isoptera"), because termites evolved from wood-feeding cockroaches. **Bruchidae** is now the subfamily **Bruchinae of Chrysomelidae**. Most yellow/stem borers once in Pyralidae are now in **Crambidae**. **Thysanura** is split into **Zygentoma** (silverfish) and Archaeognatha (bristletails). Exams still use the older names, so learn both.

Diptera – vectors of human disease

Vector	Disease (pathogen)
Female *Anopheles*	**Malaria** (*Plasmodium*)
Aedes aegypti	**Dengue**, chikungunya, Zika, yellow fever (viruses)
Culex	**Filariasis** (*Wuchereria bancrofti*), Japanese encephalitis
Sandfly *Phlebotomus*	**Kala-azar** (*Leishmania donovani*)
Tsetse fly *Glossina*	Sleeping sickness (*Trypanosoma*)
Housefly (mechanical carrier)	Typhoid, cholera, dysentery

Important families (stored-grain & field pests)

Family (Order)	Key feature	Important species
Curculionidae (Coleoptera) – weevils	Head prolonged into a **snout (rostrum)**; geniculate–clavate antennae; legless grubs develop **inside the kernel**	**Rice weevil** *Sitophilus oryzae*; granary weevil *S. granarius*; maize weevil *S. zeamais*; red palm weevil; sweet potato weevil (*Cylas*, Brentidae)
Bostrichidae (Coleoptera)	Cylindrical; **head hidden under a hood-like pronotum** (hypognathous); adults and larvae both bore into grain	**Lesser grain borer** *Rhyzopertha dominica* (strong flier, primary pest; phosphine resistance reported); bamboo borer *Dinoderus*
Tenebrionidae (Coleoptera) – darkling beetles	5-5-4 tarsal formula; **secondary pests** of flour and broken grain; produce **quinones** (flour turns greyish-yellow with a pungent odour)	**Red flour beetle** *Tribolium castaneum*; confused flour beetle *T. confusum*; long-headed flour beetle *Latheticus oryzae*; mealworm *Tenebrio molitor*
Dermestidae (Coleoptera)	Larvae **very hairy** (cause irritation); **only the larva damages**; larvae can **diapause** for years in cracks and resist fumigants	**Khapra beetle** *Trogoderma granarium* (native to India; a **quarantine pest** in many countries); hide beetle *Dermestes*; carpet beetle *Anthrenus*
Bruchidae / **Chrysomelidae** (Coleoptera)	Bruchids are pulse beetles: serrate antennae; elytra shorter than the abdomen (pygidium exposed); **infestation starts in the field**; grub inside the seed; round exit hole. Chrysomelidae proper are leaf beetles.	**Pulse beetle** *Callosobruchus chinensis*, *C. maculatus*; leaf beetles – red pumpkin beetle *Aulacophora foveicollis*; flea beetles; *Zygogramma* (bio-agent of Parthenium)
Coccinellidae (Coleoptera) – ladybird beetles	Dome-shaped, brightly spotted; tarsi appear 3-segmented; mostly **predators** of aphids, scales and mealybugs	*Coccinella septempunctata*; ***Cryptolaemus montrouzieri*** ("mealybug destroyer"); **exception (plant feeder)**: *Henosepilachna* (**hadda / epilachna beetle**)
Pyralidae (Lepidoptera) – snout moths	Larvae web the grain and flour with **silk**, forming lumps; secondary pests	**Rice moth** *Corcyra cephalonica* (also used to mass-rear *Trichogramma*); **Indian meal moth** *Plodia interpunctella*; almond moth *Ephestia (Cadra) cautella*
Gelechiidae (Lepidoptera)	Small moths with **fringed, pointed hindwings**; larvae bore inside the seed	**Angoumois grain moth** *Sitotroga cerealella* (primary pest; field-to-store infestation); **pink bollworm** *Pectinophora gossypiella*; potato tuber moth *Phthorimaea operculella*
Noctuidae (Lepidoptera) – owlet moths	Night-flying, attracted to light; larvae often **semiloopers** or cutworms	***Helicoverpa armigera*** (gram pod borer/American bollworm – very polyphagous); tobacco caterpillar *Spodoptera litura*; **fall armyworm** *S. frugiperda*; cutworm *Agrotis ipsilon*
Aphididae (Hemiptera) – aphids/plant lice	Soft-bodied; **cornicles**; **parthenogenetic and viviparous**; honeydew → sooty mould; the most important **virus vectors**	Mustard aphid *Lipaphis erysimi*; cotton aphid *Aphis gossypii*; green peach aphid *Myzus persicae*
Apidae (Hymenoptera) – bees	**Corbicula** (pollen basket); social; wax glands on worker sternites; royal jelly from the **hypopharyngeal glands**	*Apis mellifera* (Italian), *A. cerana indica* (Indian), *A. dorsata* (rock bee, the largest), *A. florea* (little bee, the smallest)

- **Primary stored-grain pests** attack **whole, sound grain**: rice weevil, lesser grain borer, khapra beetle, pulse beetle, Angoumois grain moth.
- **Secondary pests** attack damaged grain and flour: red flour beetle, saw-toothed grain beetle (*Oryzaephilus surinamensis*, Silvanidae), flat grain beetle (*Cryptolestes*, Laemophloeidae), rice moth, Indian meal moth.
- **Honeybee biology**:
  - Development time: queen **16 days**, worker **21 days**, drone **24 days**. Queens and workers are diploid; drones are **haploid**.
  - A larva fed **royal jelly** throughout becomes a queen.
  - "Dance language" (round and waggle dances) was decoded by **Karl von Frisch** (Nobel Prize 1973).
  - Beekeeping is called **apiculture**.
- **Silkworm** (Bombycidae):
  - Silk is made of **fibroin** (core) and **sericin** (gum).
  - Mulberry silkworm: *Bombyx mori*. Others: tasar (*Antheraea mylitta*), muga (*A. assamensis*, found only in Assam), eri (*Samia ricini*).

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- Silkworm rearing is **sericulture**; rearing the lac insect is **lac culture** (*Kerria lacca*; the main lac-producing state is Jharkhand).

- **Fall armyworm** (*Spodoptera frugiperda*) is native to the Americas. It was first reported in India on **maize in Karnataka in 2018**. Identifying marks: an inverted "Y" on the head and 4 spots in a square on the 8th abdominal segment.

MEMORY TRICK

Primary grain pests: "**Real Lazy Kings Prefer Apples**" → **R**ice weevil, **L**esser grain borer, **K**hapra, **P**ulse beetle, **A**ngoumois moth. Honeybee development in days: "**16-21-24** = Queen–Worker–Drone" (royalty is fastest).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Largest insect order? → **Coleoptera**.
- Khapra beetle belongs to the family? → **Dermestidae**; damaging stage? → **Larva (grub)**.
- Lesser grain borer (*Rhyzopertha dominica*) family? → **Bostrichidae**.
- Angoumois grain moth family? → **Gelechiidae**. Rice moth? → **Pyralidae**.
- Phytophagous (plant-feeding) coccinellid? → ***Henosepilachna* (hadda beetle)**.
- Order with one pair of wings and halteres? → **Diptera**. Order of termites? → **Isoptera**.

8.4 Animal Kingdom & Human Organ Systems

★★★

Basis of classification (NCERT)

- **Level of organisation**:
  - **Cellular**: Porifera.
  - **Tissue**: Cnidaria, Ctenophora.
  - **Organ**: Platyhelminthes.
  - **Organ-system**: Aschelminthes onwards.
- **Symmetry**:
  - **Asymmetrical**: most sponges.
  - **Radial**: Cnidaria, Ctenophora, **adult echinoderms**.
  - **Bilateral**: Platyhelminthes onwards. Echinoderm **larvae** are bilateral.
- **Germ layers**:
  - **Diploblastic** (ectoderm + endoderm, with mesoglea between): Cnidaria, Ctenophora.
  - **Triploblastic**: Platyhelminthes onwards.
- **Coelom** (a body cavity lined by mesoderm):
  - **Acoelomate**: Platyhelminthes.
  - **Pseudocoelomate** (mesoderm in scattered pouches): **Aschelminthes**.
  - **Coelomate**: Annelida, Arthropoda, Mollusca, Echinodermata, Hemichordata, Chordata. In arthropods the true coelom is reduced, and the body cavity is a blood-filled **haemocoel**.
- **Metamerism** (true segmentation): Annelida, Arthropoda, Chordata. **Notochord**: present only in Chordata.

Phylum	Distinctive features	Examples
Porifera (sponges)	Canal system; **choanocytes** (collar cells); ostia → spongocoel → **osculum**; spicules or spongin fibres	*Sycon*, *Spongilla* (freshwater), *Euspongia* (bath sponge)
Cnidaria (Coelenterata)	**Cnidoblasts** (stinging cells); polyp and medusa; **metagenesis** (alternation of the two forms) in *Obelia*	*Hydra*, *Physalia* (Portuguese man-of-war), *Adamsia* (sea anemone), *Aurelia*, corals (*Meandrina*, *Pennatula*, *Gorgonia*)
Ctenophora (comb jellies)	8 rows of ciliated **comb plates**; **bioluminescence**; only sexual reproduction	*Pleurobrachia*, *Ctenoplana*
Platyhelminthes (flatworms)	Dorsoventrally flat; **flame cells** for excretion; hooks and suckers; mostly parasites	*Taenia* (tapeworm), *Fasciola* (liver fluke), *Planaria* (high **regeneration**)
Aschelminthes (roundworms / Nematoda)	Circular in cross-section; **pseudocoelom**; complete gut with muscular pharynx; sexes separate (dimorphic)	*Ascaris*, *Wuchereria* (filarial worm), *Ancylostoma* (hookworm); plant nematodes (*Meloidogyne*)
Annelida	**Metameric** segmentation; **nephridia**; closed circulation; parapodia (*Nereis*)	*Pheretima* (earthworm), *Hirudinaria* (leech; anticoagulant **hirudin**), *Nereis*
Arthropoda	**Largest phylum**; **jointed appendages**; chitinous exoskeleton; open circulation; Malpighian tubules or green glands	*Apis*, *Bombyx*, *Laccifer*, *Anopheles*, locust; *Limulus* (**living fossil**, king crab)
Mollusca	2nd largest phylum; soft body with a **mantle**; calcareous shell; **radula** (rasping organ)	*Pila* (apple snail), *Pinctada* (pearl oyster), *Sepia* (cuttlefish), *Loligo* (squid), *Octopus*
Echinodermata	Spiny skin; **water vascular system** (tube feet); calcareous endoskeleton; **all marine**; no excretory system	*Asterias* (starfish), *Echinus* (sea urchin), *Antedon* (sea lily), *Cucumaria* (sea cucumber), *Ophiura* (brittle star)
Hemichordata	Body has a proboscis, collar and trunk; **stomochord** (not a true notochord); proboscis gland for excretion	*Balanoglossus*, *Saccoglossus*
Chordata	**Notochord**, **dorsal hollow nerve cord**, pharyngeal gill slits, post-anal tail; ventral heart	Fishes, amphibians, reptiles, birds, mammals

Digestion

- Human dental formula (each half of the jaws, upper/lower) = **2123/2123**, giving 32 permanent teeth. Humans are **diphyodont** (two sets of teeth) and **thecodont** (teeth in sockets).
- Glands of the stomach lining:
  - **Chief (peptic) cells** secrete pepsinogen.
  - **Parietal (oxyntic) cells** secrete **HCl** and the **intrinsic factor** needed to absorb vitamin B_{12}.
  - **Mucus neck cells** secrete mucus.

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- **Liver** = the largest gland (about 1.2–1.5 kg). It secretes **bile**, which contains **no enzyme**. **Bile salts emulsify fats**. Bile pigments are bilirubin and biliverdin.
- The small intestine is the main site of **digestion and absorption**. Fats are absorbed as **chylomicrons** into the **lacteals**. Water is absorbed in the small and large intestines.
- **Secretin** was the first hormone discovered (**Bayliss & Starling, 1902**). Other gut hormones: **gastrin** (gastric juice), CCK (bile and pancreatic enzymes), GIP.

Enzyme	Source	Substrate → product
Salivary amylase (ptyalin)	Salivary glands (pH 6.8)	Starch → **maltose**; about **30%** of starch is digested in the mouth
Pepsin (from pepsinogen, activated by **HCl**)	Chief cells of the stomach (pH about 1.8)	Proteins → proteoses, peptones
Rennin	Stomach of infants	Coagulates milk protein (**casein**)
Trypsin (trypsinogen activated by **enterokinase**), chymotrypsin, carboxypeptidase	Pancreas	Proteins, peptones → dipeptides
Pancreatic amylase	Pancreas	Polysaccharides → disaccharides
Lipase	Pancreas (main); intestine	Fats (after emulsification) → di- and monoglycerides, fatty acids, glycerol
Nucleases	Pancreas	Nucleic acids → nucleotides
Dipeptidases, **maltase, lactase, sucrase**, nucleotidases, nucleosidases	Intestinal juice (**succus entericus**, brush border)	Dipeptides → amino acids; maltose → glucose + glucose; lactose → glucose + galactose; sucrose → glucose + fructose

Respiration

- Breathing is controlled by the **respiratory rhythm centre** in the **medulla**, modulated by the **pneumotaxic centre** in the **pons**. A chemosensitive area responds mainly to **CO_2 and H^+**.
- Normal breathing rate: 12–16 per minute. Pulmonary ventilation ≈ **6000–8000 mL/min**.
- Partial pressures (mm Hg):
  - pO_2: alveoli **104**, deoxygenated blood 40, oxygenated blood 95, tissues 40.
  - pCO_2: alveoli **40**, deoxygenated blood 45, tissues 45.

  CO_2 is **20–25 times more soluble** than O_2.
- O_2 transport: about **97% as oxyhaemoglobin** and 3% dissolved. One haemoglobin molecule carries up to **4 O_2** molecules (4 haem groups, each with Fe^{2+}). Normal Hb = **12–16 g/100 mL**. Every 100 mL of oxygenated blood delivers about **5 mL O_2** to the tissues.
- CO_2 transport: **20–25% as carbamino-haemoglobin**, **about 70% as bicarbonate** (formed by **carbonic anhydrase** in RBCs) and about 7% dissolved. Every 100 mL of deoxygenated blood delivers about 4 mL CO_2 to the alveoli.
- The **O_2-dissociation curve** is **sigmoid**. It shifts **right** (Hb gives up O_2 more easily) with high pCO_2, H^+ (low pH), temperature and 2,3-BPG. This is the **Bohr effect**.
- **Carbon monoxide** binds Hb about **200–250 times** more strongly than O_2, forming carboxyhaemoglobin.

Lung volume / capacity	Value (NCERT)
Tidal volume (TV)	**≈ 500 mL**
Inspiratory reserve volume (IRV)	2500–3000 mL
Expiratory reserve volume (ERV)	1000–1100 mL
Residual volume (RV) – cannot be breathed out	1100–1200 mL
Inspiratory capacity = TV + IRV; Expiratory capacity = TV + ERV	—
Functional residual capacity = ERV + RV	≈ 2100–2300 mL
Vital capacity = ERV + TV + IRV	≈ 4.0–4.6 L
Total lung capacity = VC + RV	≈ 5–6 L

Circulation & blood

- Blood = plasma (**55%**) + formed elements (45%). Plasma proteins: fibrinogen (clotting), globulins (defence), albumin (osmotic balance).
- Blood cell counts:
  - **RBC**: 5–5.5 million/mm^3; lifespan **120 days**; destroyed in the **spleen** ("graveyard of RBCs").
  - **WBC**: 6000–8000/mm^3. **Neutrophils** are the most numerous WBC (60–65%); **basophils** the fewest (0.5–1%).
  - **Platelets**: 1.5–3.5 lakh/mm^3; they help clotting.
- Clotting: thrombokinase converts **prothrombin → thrombin**, and thrombin converts **fibrinogen → fibrin**. **Ca^{2+}** is needed, and **vitamin K** is needed to make prothrombin.
- **ABO blood groups** were discovered by **Karl Landsteiner (1900–01)**.
  - **O** = **universal donor**; **AB** = **universal recipient**.
  - Genes: I^A and I^B are **co-dominant**, and i is recessive. These are **multiple alleles**, giving 6 genotypes and 4 phenotypes.
- **Rh factor** was found by Landsteiner & Wiener (1940) in **Rhesus monkeys**. An Rh^- mother carrying an Rh^+ foetus can make antibodies that harm a **second** Rh^+ baby: **erythroblastosis foetalis**. It is prevented with anti-Rh antibodies given to the mother.
- Heart: human heart is **4-chambered**, made of mesoderm, and enclosed in the **pericardium**. Humans have **double circulation** (pulmonary + systemic). Blood circulation was discovered by **William Harvey (1628)**. Fish have a 2-chambered heart; amphibians and most reptiles 3 chambers (crocodile 4); birds and mammals 4.
- Conducting system: **SA node** (the **pacemaker**, 70–75 beats/min) → **AV node** → **bundle of His** → **Purkinje fibres**. The heart is **myogenic** (the beat starts in the heart muscle itself).
- Cardiac cycle = **0.8 s** (at 72 beats/min).
  - **Stroke volume** ≈ **70 mL**.
  - **Cardiac output** = stroke volume × heart rate ≈ **5 L/min**.
  - Heart sounds: "**lub**" = AV (tricuspid and bicuspid) valves closing; "**dub**" = semilunar valves closing.
  - Normal BP = **120/80 mm Hg**. Hypertension = ≥ 140/90.
- **ECG** (electrocardiograph invented by **Einthoven**):
  - **P wave** = atrial depolarisation (atrial contraction).
  - **QRS complex** = ventricular depolarisation (start of ventricular contraction).
  - **T wave** = ventricular repolarisation (end of systole).

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- Counting QRS complexes gives the heart rate.

Excretion

- Excretory products by type of animal:
  - **Ammonotelic** (excrete ammonia; most toxic, needs the most water): bony fishes, aquatic amphibians, aquatic insects.
  - **Ureotelic** (excrete urea): **mammals**, terrestrial amphibians, marine fishes.
  - **Uricotelic** (excrete uric acid; least water): **birds, reptiles, insects**, land snails.
- Urea is made in the **liver** by the **ornithine (urea) cycle** (Krebs–Henseleit). About 25–30 g of urea is excreted per day.
- Each kidney has about **1 million nephrons**.
  - A nephron consists of the **glomerulus**, **Bowman's capsule** (together the Malpighian/renal corpuscle), **PCT**, **loop of Henle**, **DCT** and the **collecting duct**.
  - Cortical nephrons have short loops; juxtamedullary nephrons have long loops.
- Filtration and reabsorption:
  - **GFR ≈ 125 mL/min** (≈ **180 L/day**).
  - About **99%** of the filtrate is reabsorbed, leaving **1–1.5 L** of urine per day.
  - The **PCT** reabsorbs the most (**70–80%** of electrolytes and water).
  - The **counter-current mechanism** (loop of Henle + vasa recta) concentrates urine.
- Hormonal control:
  - **ADH (vasopressin)** increases water reabsorption. A deficiency causes **diabetes insipidus**.
  - The **JGA** releases **renin**, which triggers the RAAS and the release of **aldosterone** (Na^+ reabsorption).
  - **ANF** (from the heart) works against the RAAS.
- Excretory organs in other animals:
  - **Flame cells** (protonephridia): flatworms.
  - **Nephridia**: annelids.
  - **Malpighian tubules**: insects.
  - **Green / antennal glands**: prawn and other crustaceans.

Nervous & endocrine systems

- **Resting membrane potential ≈ −70 mV**. The **Na^+/K^+ pump** moves **3 Na^+ out** for every **2 K^+ in**.
- A nerve impulse is caused by **Na^+ flowing in** (depolarisation). Impulses pass between neurons at synapses, chemically by neurotransmitters such as **acetylcholine**.
- Parts of the brain:
  - **Forebrain**: cerebrum (largest part; its two halves are joined by the **corpus callosum**), thalamus and hypothalamus.
  - **Midbrain**.
  - **Hindbrain**: pons, **cerebellum** (balance and posture) and **medulla** (breathing, heart, swallowing, vomiting).
- The **hypothalamus** controls body temperature, hunger, thirst and the pituitary.

Gland	Hormone	Action / disorder
Hypothalamus	Releasing / inhibiting hormones (GnRH, somatostatin); ADH and oxytocin are made here and released from the posterior pituitary	Controls the pituitary
Anterior pituitary	**GH**, TSH, ACTH, **FSH, LH**, **prolactin**	GH: too much → **gigantism** (in children) or **acromegaly** (in adults); too little → **dwarfism**
Posterior pituitary	**Oxytocin**; **ADH (vasopressin)**	Oxytocin: childbirth contractions and milk ejection; ADH deficiency → **diabetes insipidus**
Pineal	**Melatonin**	Day–night (diurnal) rhythm, sleep
Thyroid	**T_3, T_4** (contain iodine); **thyrocalcitonin**	Low → **cretinism** (children), **myxoedema** (adults), **goitre** (iodine deficiency). High → **Graves' disease** (exophthalmic goitre). TCT lowers blood Ca.
Parathyroid	**PTH**	**Raises blood Ca^{2+}** (hypercalcaemic)
Thymus	Thymosins	T-lymphocyte maturation; the gland shrinks with age
Adrenal cortex	**Cortisol** (glucocorticoid), **aldosterone** (mineralocorticoid), androgens	Too little → **Addison's disease**; too much cortisol → Cushing's syndrome
Adrenal medulla	**Adrenaline, noradrenaline** (catecholamines)	"Emergency" or **fight-or-flight** hormones
Pancreas (islets of Langerhans)	α cells → **glucagon**; β cells → **insulin**	Glucagon raises blood sugar (hyperglycaemic). Insulin lowers it (hypoglycaemic). Lack of insulin → **diabetes mellitus**.
Testis (Leydig cells)	**Testosterone** (androgen)	Spermatogenesis and male secondary sex characters
Ovary	Oestrogen (Graafian follicle); **progesterone** (corpus luteum)	Female sex characters; maintains pregnancy
Other tissues	ANF (heart); **erythropoietin** (kidney); gastrin, secretin, CCK, GIP (gut)	Erythropoietin stimulates RBC production

Locomotion & musculoskeletal system

- The adult human skeleton has **206 bones**: **axial 80** + **appendicular 126**.
  - Skull 22 bones (8 cranial + 14 facial), plus the hyoid and 6 ear ossicles, giving 29.
  - **Vertebral column 26** (7 cervical, 12 thoracic, 5 lumbar, 1 sacrum, 1 coccyx).
  - Sternum 1.
  - Ribs **12 pairs**: 7 pairs true, 3 pairs false (vertebrochondral) and 2 pairs floating.
- The smallest bone is the **stapes** (ear). The longest is the **femur**. Almost all mammals have **7 cervical vertebrae**.

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- **Sliding filament theory** of muscle contraction:
  - Thin **actin** filaments form the I-band; thick **myosin** filaments form the A-band.
  - The functional unit is the **sarcomere**, the part between two **Z-lines**.
  - Ca^{2+} binds to **troponin**, exposing binding sites on actin. Myosin heads (cross-bridges) use **ATP** to pull the filaments. During contraction the I-band shortens and the A-band stays the same length.
  - **Red fibres** are rich in **myoglobin** and aerobic. White fibres are anaerobic and fatigue quickly.
- Types of joint:
  - **Fibrous** (no movement): skull **sutures**.
  - **Cartilaginous** (limited movement): between vertebrae.
  - **Synovial** (free movement):
    - **Ball & socket**: shoulder, hip.
    - **Hinge**: knee, elbow.
    - **Pivot**: atlas–axis.
    - **Gliding**: between carpals.
    - **Saddle**: carpal–metacarpal joint of the thumb.

Reproduction

- Male reproductive system:
  - The testes sit in the **scrotum**, which keeps them **2–2.5 °C below body temperature**.
  - Sperm are made in the **seminiferous tubules**. **Sertoli cells** nourish them, and **Leydig (interstitial) cells** make testosterone.
  - One ejaculate contains about **200–300 million** sperm. For normal fertility, at least 60% should have normal shape and at least 40% vigorous motility.
- Female reproductive system:
  - **Oogenesis** begins in the **foetus**. Spermatogenesis begins at **puberty**.
  - Menstrual cycle ≈ **28 days**. Ovulation occurs around **day 14**, triggered by the **LH surge**.
  - Fertilisation takes place at the **ampullary–isthmic junction** of the oviduct.
  - The **blastocyst** implants in the endometrium.
  - Pregnancy hormones: **hCG, hPL**, relaxin. Human gestation ≈ **9 months**.
  - **Colostrum** (the first milk) is rich in **IgA** antibodies.
- Sex-determination systems:
  - Human: **XX–XY** (male heterogametic).
  - Grasshopper and cockroach: **XX–XO**.
  - Birds: **ZW–ZZ** (female heterogametic).
  - Honeybee: **haplodiploid**.

Insect vs human – comparison

Feature	Insect	Human (mammal)
Skeleton	**Exoskeleton** (chitin); growth by moulting	**Endoskeleton** (bone, cartilage); continuous growth
Circulation	**Open**; dorsal tubular heart; haemolymph	**Closed**, double; ventral 4-chambered heart
Respiratory pigment	Usually none (O_2 goes by trachea)	Haemoglobin in RBCs
Respiration	Tracheae and spiracles	Lungs (alveoli)
Excretion	Malpighian tubules; **uric acid**	Kidneys (nephrons); **urea**
Nerve cord	**Ventral, solid, double, ganglionated**	**Dorsal, hollow, single**
Eyes	Compound (ommatidia; mosaic image) + ocelli	Camera-type single lens
Development hormones	Ecdysone, JH, PTTH	GH, thyroxine, sex hormones
Sex determination	XO, XY or haplodiploidy	XX–XY

KEY FORMULAE

- Vital capacity = ERV + TV + IRV; TLC = VC + RV; FRC = ERV + RV.
- Cardiac output = stroke volume × heart rate = 70 mL × 72 ≈ **5 L/min**.
- Minute (pulmonary) ventilation = TV × breathing rate = 500 × 12–16 = 6–8 L/min.
- Daily filtrate = GFR × 1440 min = 125 mL × 1440 ≈ **180 L/day**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Pseudocoelomates? → **Aschelminthes**. Water vascular system? → **Echinodermata**.
- Pacemaker of the heart? → **SA node**. T wave of the ECG shows? → **Ventricular repolarisation**.
- Most CO_2 is carried as? → **Bicarbonate (about 70%)**.
- Enzyme that activates trypsinogen? → **Enterokinase**.
- Hormone deficient in diabetes insipidus? → **ADH**.
- Insects are uricotelic, while mammals are? → **Ureotelic**.

8.5 Heredity, Variation & Evolution ★★☆

- **Heredity** = passing of traits from parents to offspring. **Variation** = differences between individuals. **Genetics** = the study of both; the word was coined by **Bateson** (1905). **Mendel** is the father of genetics.
- Mendel's laws, linkage, gene interaction and DNA structure are covered in the **Botany – Genetics chapter**. This section covers variation, evolution and human genetic disorders.

Variation	Features	Examples
Continuous (quantitative)	Small, graded differences; **polygenic**; bell-shaped (normal) curve; strongly affected by environment	Human height, **skin colour**, weight, IQ; grain yield
Discontinuous (qualitative)	Distinct classes; usually one gene (Mendelian)	Tall/dwarf pea, **ABO blood groups**, tongue rolling, sickle-cell trait
Somatic (acquired)	Arise in body cells through environment or use; **not inherited**	Muscle building, scars, sun tan
Germinal (blastogenic)	Arise in germ cells; **inherited**; the raw material of evolution	Mutations, recombinants

- Sources of heritable variation:

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- **Mutation**: the ultimate source of new alleles. Gene (point) mutations or chromosomal changes (deletion, duplication, inversion, translocation, polyploidy, aneuploidy). Mutagens include **UV**, X-rays and chemicals.
- **Recombination**: **crossing over** (at the **pachytene** stage of prophase I; enzyme **recombinase**), **independent assortment** and random fertilisation.
- **Gene flow** (migration).
- **Genetic drift**: chance changes in small populations (founder effect, bottleneck).

Theories of evolution

Scientist	Theory / work	Key points
Lamarck	*Philosophie Zoologique* (**1809**)	**Use and disuse** of organs; **inheritance of acquired characters** (long neck of the giraffe). Disproved by **Weismann** (cut the tails of mice for about 22 generations; **germplasm theory**).
Charles Darwin	*On the Origin of Species* (**1859**); voyage of **HMS Beagle**	**Natural selection**: overproduction → struggle for existence → variation → **survival of the fittest** (phrase by **Herbert Spencer**). Influenced by **Malthus** on population. **Galápagos finches** (adaptive radiation). **Alfred Russel Wallace** reached the same idea independently (Malay Archipelago).
Hugo de Vries	**Mutation theory** (1901), working on the evening primrose *Oenothera lamarckiana*	New species arise by **sudden, large, heritable changes** (mutations; **saltation**), not by small continuous variations. He coined the term "mutation" and was one of the rediscoverers of Mendel's laws (1900).
Hardy (G.H.) & **Weinberg** (W.)	Hardy–Weinberg principle (**1908**)	Allele frequencies stay constant from generation to generation when no evolutionary force acts (genetic equilibrium)

KEY FORMULAE

- Allele frequencies: $\mathbf{p + q = 1}$ (p = frequency of the dominant allele A; q = frequency of the recessive allele a).
- Genotype frequencies: $\mathbf{p^2 + 2pq + q^2 = 1}$ → AA = p^2, Aa (carriers) = 2pq, aa = q^2.
- Example: 16% of a population is recessive (aa). Then $q^2 = 0.16$ → $q = 0.4$ → $p = 0.6$. AA = 0.36, carriers (Aa) = $2 \times 0.6 \times 0.4 =$ **0.48**.
- Equilibrium needs: a large population, random mating, no mutation, no migration (gene flow), no selection and no genetic drift. The five factors that disturb it are **gene migration, genetic drift, mutation, recombination and natural selection**.

- Types of natural selection:
  - **Stabilising**: favours the average (e.g. human birth weight).
  - **Directional**: favours one extreme (e.g. resistance).
  - **Disruptive**: favours both extremes.
- **Industrial melanism** in the **peppered moth *Biston betularia*** (England):
  - Before industrialisation, **white (light) moths** were more common on pale, lichen-covered trees.
  - After about **1850**, soot-darkened bark meant **dark (melanic) moths** escaped bird predators and became more common.
  - **Kettlewell** confirmed this experimentally.
  - After pollution control, light moths increased again.
- Evolution caused by human action (anthropogenic):
  - **Antibiotic resistance** in bacteria.
  - **Herbicide resistance** in weeds (e.g. *Phalaris minor* to isoproturon).
  - **Insecticide resistance**: DDT resistance in houseflies and mosquitoes; pyrethroid resistance in *Helicoverpa*; **pink bollworm resistance to Bt cotton** (Bollgard II, reported from about 2014–15); **phosphine resistance** in *Rhyzopertha dominica* and *Tribolium castaneum*, which is why fumigation needs **proper gas-tight sealing and full exposure time**.

  Resistance is **pre-adaptive**: the resistant mutants already exist, and the chemical only selects them.
- Evidence for evolution:
  - **Homologous organs** (same origin, different function → **divergent evolution**): forelimbs of whale, bat, cheetah and human; thorn of *Bougainvillea* and tendril of *Cucurbita*.
  - **Analogous organs** (different origin, same function → **convergent evolution**): wings of a butterfly and a bird; eye of an octopus and a mammal; flippers of a penguin and a dolphin; sweet potato (root) and potato (stem).
  - Adaptive radiation: Darwin's finches; Australian marsupials.
  - Vestigial organs: appendix, nictitating membrane.
  - Fossils; connecting links (*Archaeopteryx* links reptiles and birds).

Human genetic disorders

- **X-linked recessive** traits show **criss-cross inheritance**: an affected father passes the gene through his carrier daughter to his grandson. Males are affected far more often because they have only one X (they are **hemizygous**). A carrier mother passes the gene to half her sons (affected) and half her daughters (carriers).
- **Y-linked (holandric)** genes pass from father to son only, e.g. **hypertrichosis of the ear pinna** (hairy ears).

Disorder	Inheritance	Defect / key fact
Haemophilia ("bleeder's disease")	**X-linked recessive**	A clotting factor is missing (factor VIII in haemophilia A), so blood fails to clot. **Queen Victoria** was a carrier ("royal disease"). Affected females are very rare (they need a carrier mother and a haemophilic father).
Colour blindness (red–green)	**X-linked recessive**	Defective red or green cone pigment genes. Affects about **8% of males** and about **0.4% of females**.
Sickle-cell anaemia	**Autosomal recessive**	**Glutamic acid → valine** at the **6th position of the β-globin** chain, because one codon changes (**GAG → GUG**). Sickle-shaped RBCs under low O_2. Heterozygotes (HbA/HbS, the "sickle-cell trait") are carriers and are **resistant to malaria** (heterozygote advantage).

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Thalassaemia	**Autosomal recessive**	**Reduced synthesis** of globin chains, a **quantitative** defect (sickle-cell is a **qualitative** defect, a wrong amino acid). **α-thalassaemia**: genes HBA1, HBA2 on **chromosome 16**. **β-thalassaemia**: gene HBB on **chromosome 11**.
Phenylketonuria (PKU)	**Autosomal recessive**	An inborn error of metabolism: the enzyme **phenylalanine hydroxylase** is missing, so phenylalanine cannot be converted to tyrosine. Phenylalanine builds up and is converted to **phenylpyruvic acid**, causing **mental retardation**; it is excreted in the urine. (Gene on chromosome 12.)
Huntington's disease; myotonic dystrophy	**Autosomal dominant**	One copy of the defective allele is enough to cause the disease
Down syndrome	Chromosomal: **trisomy 21** (47 chromosomes)	Described by Langdon Down (1866). Short stature, round head, furrowed tongue, partly open mouth, palm crease, mental retardation. Risk rises with the mother's age.
Klinefelter syndrome	**47, XXY**	Male; sterile; **gynaecomastia** (breast development); tall
Turner syndrome	**45, XO**	Female; sterile (rudimentary ovaries); short stature; no secondary sex characters

- Humans have **46 chromosomes** (23 pairs: 22 pairs of autosomes + 1 pair of sex chromosomes). The human genome is about **3×10^9 bp** with about **20,000–25,000 genes** (Human Genome Project). Insects vary: *Drosophila* has 2n = 8.

MEMORY TRICK

"**Sickle = Single swap; Thalassaemia = Too little**": sickle-cell is a qualitative defect (one amino acid wrong), while thalassaemia is quantitative (too little globin made).
Hardy–Weinberg disturbers: "**My Dog Must Run Slowly**" → Migration (gene flow), Drift, Mutation, Recombination, Selection.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Inheritance of acquired characters was proposed by? → **Lamarck**. Mutation theory? → **Hugo de Vries**.
- In a population, the frequency of carriers (heterozygotes) is given by? → **2pq**.
- Industrial melanism was seen in? → **Peppered moth (*Biston betularia*)**.
- Haemophilia and colour blindness are inherited as? → **X-linked recessive** traits.
- In sickle-cell anaemia, glutamic acid is replaced by? → **Valine** (6th position of β-globin).
- Karyotype of Klinefelter syndrome? → **47, XXY**. Turner syndrome? → **45, XO**.

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9. Microorganisms, Food Safety & Public Health

> **NOTE**
> Warehouses store living grain, and microbes are its silent enemy. Moulds, mycotoxins, rodent-borne diseases and food-safety law (FSSAI, HACCP) tie microbiology directly to CWC's work. Exam questions are mostly "who discovered", "which organism produces", "which vector transmits", "what temperature or limit" and "which test detects". Learn the tables in this chapter thoroughly.

9.1 Microbiology Basics & History ★★★

- **Microbiology** = study of organisms too small to see with the naked eye (< ~0.1 mm): bacteria, archaea, viruses, fungi, protozoa and microscopic algae.
- **Robert Hooke** (1665, *Micrographia*) coined the word **"cell"** after looking at cork.
- **Antonie van Leeuwenhoek** (Dutch, 1670s) made **single-lens microscopes** (~200–300×). He was the first to see bacteria and protozoa and called them **"animalcules"**. He is usually called the **Father of Microbiology** and sometimes the Father of Bacteriology.
- **Spontaneous generation** (abiogenesis) was disproved by Redi (1668, meat and flies), then Spallanzani, and finally **Louis Pasteur** with his **swan-neck flask** experiment (1859–61). Tyndall later showed that heat-resistant forms exist, which led to **Tyndallisation**.
- **Louis Pasteur** (French) is the **Father of Modern Microbiology**. His work:
  - fermentation is caused by microbes (yeast makes alcohol), and some microbes live without O_2; he coined the word **"anaerobic"**
  - **pasteurisation**, first used for wine and beer
  - **germ theory of disease**
  - vaccines made by **attenuation**: chicken cholera, **anthrax** (1881) and **rabies (1885, first given to the boy Joseph Meister)**
  - he coined the word **"vaccine"** in honour of Jenner
- **Robert Koch** (German) is the **Father of Medical Microbiology / Bacteriology**. He proved that *Bacillus anthracis* causes anthrax (1876), discovered ***Mycobacterium tuberculosis* (1882; announced 24 March, now World TB Day)** and *Vibrio cholerae* (1883), developed **pure culture on solid media**, and won the **Nobel Prize in 1905**.
- **Agar** as a solidifying agent was suggested by **Fanny Hesse** (1882). The **Petri dish** was introduced by **Julius Petri** (1887).
- **Edward Jenner** (1796) made the **smallpox vaccine** using **cowpox** material and tested it on James Phipps. He is the **Father of Immunology** (some books name Pasteur). WHO declared smallpox **eradicated in 1980**.
- **Joseph Lister** (1867) introduced **antiseptic surgery** using **carbolic acid (phenol)**. He is the **Father of Antiseptic Surgery**.
- **Alexander Fleming** discovered **penicillin in 1928** from ***Penicillium notatum***, which inhibited *Staphylococcus*. He also discovered **lysozyme** (1922). **Florey & Chain** purified penicillin, and all three shared the **Nobel Prize in 1945**.
- **Paul Ehrlich** is the **Father of Chemotherapy**. He gave the "magic bullet" idea and made **Salvarsan (compound 606)** for syphilis (1910). **Domagk** made **Prontosil**, the first sulphonamide (1935).
- **Selman Waksman** coined the word **"antibiotic"**. He and his student Schatz discovered **streptomycin** (1943–44), the first drug against TB, and Waksman won the Nobel Prize in 1952.
- **Winogradsky** discovered chemoautotrophy and the Winogradsky column; he is called the Father of Soil Microbiology. **Beijerinck** isolated *Rhizobium* (1888) and *Azotobacter* (1901) and introduced the enrichment culture technique.
- Indian connections:
  - **Waldemar Haffkine** developed a **cholera vaccine (1892)** and a **plague vaccine (1897, Bombay)**; the Haffkine Institute in Mumbai is named after him
  - **Ronald Ross** showed at **Secunderabad (1897)** that mosquitoes transmit malaria and won the Nobel Prize in 1902
  - **S.N. De** (Kolkata) discovered **cholera toxin** (1959)
- **Christian Gram** devised the **Gram stain (1884)**. **Carl Woese** (1977) used **16S rRNA** to identify **Archaea** and later proposed the **three domains** (Bacteria, Archaea, Eukarya, 1990). **Whittaker** proposed the **five-kingdom** system (1969), in which bacteria fall under **Monera**.

Scientist	Remember for
Leeuwenhoek	Animalcules; first to see bacteria; **Father of Microbiology**
Pasteur	Swan-neck flask; **pasteurisation**; germ theory; **rabies vaccine (1885)**
Koch	**Postulates**; TB bacillus (1882); cholera (1883); pure culture
Jenner	**Smallpox vaccine (1796)**; Father of Immunology
Lister	**Antiseptic** surgery with **phenol**
Fleming	**Penicillin (1928)**; lysozyme
Ehrlich	Salvarsan; **Father of Chemotherapy**
Waksman	Streptomycin; coined "antibiotic"
Ivanowsky / Beijerinck	**TMV**, the first virus discovered (1892 / 1898)

- **Koch's postulates** (four):
  - The organism is present in **every case** of the disease and absent from healthy hosts.
  - It can be isolated in **pure culture**.
  - The pure culture **causes the same disease** when put into a healthy susceptible host.
  - The organism can be **re-isolated** from that experimentally infected host.

  Exceptions are organisms that cannot be grown in culture, such as *M. leprae* and *Treponema pallidum*.

Microscopy

Microscope	Key point
Compound light (bright field)	Resolution limit ≈ **0.2 µm**; maximum useful magnification ≈ 1000–1500×. The **oil-immersion objective (100×)** uses **cedarwood or immersion oil** (refractive index ≈ 1.51) to raise the numerical aperture.
Dark field	Bright object on a dark background; used for **spirochaetes** (*Treponema*, *Leptospira*)

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Phase contrast	**Living, unstained** cells; invented by **Zernike** (Nobel 1953)
Fluorescence	UV light with fluorochromes (e.g. auramine for TB); immunofluorescence
Transmission EM (TEM)	Internal structure; resolution ~**0.2 nm**; electron beam; built by **Knoll & Ruska (1931)**
Scanning EM (SEM)	**3-D surface** image

Staining

- **Simple stain** uses one basic dye (methylene blue, crystal violet). **Negative stain** uses **India ink or nigrosin**, which stain the background; it is used to show **capsules** (e.g. *Cryptococcus*).
- **Gram stain** (a differential stain), in order:
  - **Crystal violet** (primary stain), 1 min
  - **Gram's iodine** (**mordant**); it forms a CV–iodine complex
  - **Alcohol or acetone** (**decoloriser**), the critical step
  - **Safranin** (counterstain)
- **Gram-positive cells stay purple/violet.** Their thick peptidoglycan (20–80 nm) and teichoic acids keep the complex. **Gram-negative cells turn pink/red.** Their thin peptidoglycan and lipid-rich **outer membrane (LPS)** lose the dye.
- **Acid-fast stain (Ziehl–Neelsen)**: carbol fuchsin, then acid-alcohol, then methylene blue. Acid-fast bacilli (*Mycobacterium*, which has **mycolic acid**) stain **red**.
- **Endospore stain (Schaeffer–Fulton)**: **malachite green** with heat; spores look green and cells pink. **Albert stain** shows the metachromatic (volutin) granules of *Corynebacterium diphtheriae*.

MEMORY TRICK

Gram steps: **"Come In And Stain"** = Crystal violet → Iodine → Alcohol → Safranin. "**P**ositive = **P**urple."

Sterilisation & Disinfection

- **Sterilisation** kills **all** microbes, including **spores**. **Disinfection** removes pathogens from inanimate objects; spores may survive. **Antiseptic** means a disinfectant that is safe to use on living tissue.
- **Moist heat beats dry heat** because it **coagulates proteins**, whereas dry heat works by oxidation and needs a higher temperature for longer.

Method	Conditions	Used for / note
Autoclave (moist heat under pressure; Chamberland)	**121 °C, 15 psi (≈1.05 kg/cm²), 15–20 min**	Culture media, glassware, surgical items. Test organism: spores of *Geobacillus stearothermophilus*
Hot air oven (dry heat)	**160 °C for 2 h** (170 °C for 1 h, 180 °C for 30 min)	Glassware, oils, powders, metal instruments. Test organism: *Bacillus atrophaeus* spores
Incineration / red heat / flaming	Direct flame	Inoculating loops (red heat), waste
Tyndallisation (intermittent sterilisation)	Steam at 100 °C for ~20–30 min on **3 successive days**	Sugar and gelatin media; spores that germinate between heatings are killed
Filtration	Membrane filter, **0.22 µm** pore size; HEPA filters for air	Heat-labile liquids: antibiotics, serum, vitamins. Does **not** remove viruses
Ionising radiation (γ-rays from **Cobalt-60**)	"**Cold sterilisation**"	Disposable syringes, catheters; food irradiation
UV radiation (~260 nm; germicidal lamp 254 nm)	Forms **thymine dimers**; penetrates poorly	Surfaces, laminar air-flow cabinets, operating rooms
Ethylene oxide gas	Alkylating agent	Heat-sensitive plastics
Pasteurisation (not true sterilisation)	**LTLT/holder: 63 °C for 30 min**; **HTST: 72 °C (71.7 °C) for 15 s**; **UHT: 135–150 °C for 1–4 s**	Milk. Target organism: *Coxiella burnetii* (earlier *M. tuberculosis*). Checked by the **alkaline phosphatase test**

- **70% ethanol** disinfects better than absolute alcohol because water is needed to coagulate proteins. **Phenol coefficient** (**Rideal–Walker test**) compares a disinfectant's power with phenol.

Culture Media

- **Agar** comes from **red algae** (*Gelidium*, *Gracilaria*). It melts at about **85–100 °C** and sets at about **32–40 °C**. Solid media use **1.5–2%** agar; semi-solid media use 0.2–0.5%. Most microbes cannot digest agar.

Medium type	Example	Purpose
Basal / simple	Nutrient agar, peptone water	General growth
Enriched	**Blood agar**, chocolate agar	Fastidious organisms; blood agar also shows haemolysis
Selective	**TCBS** (*Vibrio cholerae*); **Löwenstein–Jensen** (*M. tuberculosis*)	Suppresses unwanted organisms
Differential	**MacConkey agar** (lactose fermenters pink); **EMB** (*E. coli* gives a **metallic green sheen**)	Tells organisms apart (MacConkey is also selective for Gram-negatives)
Enrichment (liquid)	Selenite F broth, tetrathionate broth	*Salmonella* from stool
Anaerobic	**Robertson's cooked meat**, thioglycollate broth	*Clostridium*
Fungal	**Sabouraud dextrose agar** (pH ~5.6), **potato dextrose agar (PDA)**	Fungi; the acid pH suppresses bacteria

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Standard autoclaving conditions? → **121 °C, 15 psi, 15–20 min**.
- Mordant in the Gram stain? → **Gram's iodine**.
- Colour of Gram-negative bacteria after staining? → **Pink/red (safranin)**.
- Who disproved spontaneous generation with the swan-neck flask? → **Louis Pasteur**.
- Pore size of a bacteriological membrane filter? → **0.22 µm**.
- Test used to check that milk was properly pasteurised? → **Alkaline phosphatase test**.

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9.2 Bacteria, Viruses, Fungi & Protozoa ★★★

Bacteria: Shape & Structure

- Bacteria are **prokaryotes**. They have no nuclear membrane (a **nucleoid** instead), no membrane-bound organelles, **70S ribosomes** (50S + 30S) and a single **circular DNA** chromosome, often with extra **plasmids**. They are usually **0.5–5 µm** long.
- The smallest free-living bacterium is ***Mycoplasma*** (PPLO, ~0.1–0.3 µm). It has **no cell wall**, so it is resistant to penicillin, and it is pleomorphic. The largest known bacteria are *Thiomargarita* species (*T. magnifica*, ~1 cm, described in 2022).

Shape	Name	Example
Spherical	**Coccus**: diplococcus (pairs), **streptococcus (chains)**, **staphylococcus (grape-like clusters)**, tetrad, sarcina (cube of 8)	*Streptococcus pneumoniae*, *Staphylococcus aureus*
Rod	**Bacillus**	*E. coli*, *Bacillus*, *Clostridium*
Comma	**Vibrio**	*Vibrio cholerae*
Rigid spiral	**Spirillum**	*Spirillum minus*
Flexible spiral	**Spirochaete**	*Treponema*, *Leptospira*

- **Cell wall** = **peptidoglycan (murein)**: chains of **NAG** (N-acetylglucosamine) and **NAM** (N-acetylmuramic acid) joined by **β-1,4 bonds** and cross-linked by short peptides.
  - **Lysozyme** (in tears and saliva) breaks the β-1,4 bond.
  - **Penicillin** blocks the **transpeptidation** (cross-linking) step, so it acts on growing cells, mainly Gram-positives.
- **LPS (lipopolysaccharide)** of Gram-negative bacteria = the **endotoxin**; its **Lipid A** part causes fever. **Exotoxins** are proteins secreted by the cell and are usually heat-labile (botulinum, tetanus, diphtheria toxins).
- **Glycocalyx** = a slime layer (loose) or a **capsule** (firm). The capsule gives virulence and protects against phagocytosis.
- **Flagella** are made of **flagellin** protein. Arrangements: monotrichous (one), lophotrichous (tuft at one end), amphitrichous (both ends), peritrichous (all over the cell). **Pili/fimbriae** are used for attachment; the **sex pilus** is used in conjugation.
- **Mesosome** = an infolding of the plasma membrane that helps in wall formation, DNA replication and respiration.
- **Endospores** are formed by *Bacillus* and *Clostridium*. They contain **dipicolinic acid with calcium**, resist heat, drying and chemicals, are **not a means of reproduction** (one cell gives one spore), and can survive for decades.
- **Reproduction** is mainly **binary fission** (asexual). *E. coli* divides every **~20 min** under optimum conditions.

Genetic Recombination in Bacteria

Process	What is transferred	Discovered by
Transformation	Uptake of **naked DNA** from the surroundings	**Griffith (1928)**, using *Streptococcus pneumoniae* in mice: heat-killed S (smooth, virulent) cells plus live R (rough) cells killed the mice. **Avery, MacLeod & McCarty (1944)** showed the "transforming principle" was **DNA**.
Transduction	DNA carried by a **bacteriophage**	**Zinder & Lederberg (1952)**, *Salmonella* with phage P22
Conjugation	DNA passed through **cell-to-cell contact (sex pilus)**; $F^+ \rightarrow F^-$; Hfr strains	**Lederberg & Tatum (1946)**, *E. coli*

- **Hershey & Chase (1952)** used T2 phage labelled with ^{32}P and ^{35}S and proved that **DNA is the genetic material**.

Bacterial Growth Curve

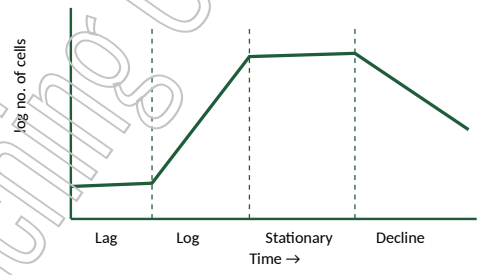

Fig. 9.1 Bacterial growth curve in a batch (closed) culture

Phase	Features
Lag	Cells adjust to the medium and make enzymes; they get bigger but do not divide
Log (exponential)	Fastest division at a constant generation time; cells are **most uniform** and **most sensitive to antibiotics**; primary metabolites are made
Stationary	Births = deaths; nutrients run out and toxins build up; **secondary metabolites (antibiotics)** and spores are made (the "idiophase")
Decline / death	Death rate is higher than division; cells lyse

KEY FORMULAE

- $N = N_0 \times 2^n$, where n = number of generations.
- $n = (\log N - \log N_0) \div \log 2 = (\log N - \log N_0) \div \mathbf{0.301}$.
- Generation (doubling) time $g = t \div n$.
- Example: 1 cell with g = 20 min gives $2^3 =$ **8 cells after 1 h**.

Group	Basis	Range / example
Psychrophiles	Temperature	0–20 °C (optimum ~15 °C)
Psychrotrophs	Temperature	Grow at fridge temperature (*Listeria*, *Pseudomonas*); spoil chilled foods
Mesophiles	Temperature	20–45 °C; **most pathogens have an optimum of 37 °C**
Thermophiles	Temperature	45–80 °C (*Geobacillus*, *Thermus aquaticus*, the source of **Taq polymerase**)
Hyperthermophiles	Temperature	> 80 °C (Archaea: *Pyrolobus*, *Pyrococcus*)

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Obligate aerobe / anaerobe	O_2	*M. tuberculosis* / *Clostridium*
Facultative anaerobe	O_2	*E. coli*, yeast
Microaerophile	O_2	*Campylobacter*, *Helicobacter*
Halophile / osmophile / xerophile	Salt / sugar / dryness	*Halobacterium* / osmophilic yeasts / xerophilic moulds (*Aspergillus*, *Eurotium*)

Viruses

- Viruses are **obligate intracellular parasites**. They are acellular and inert crystals outside a host. Each contains **either DNA or RNA, never both**, inside a protein coat called the **capsid**, which is made of **capsomeres**. Some have a lipid **envelope**. Size is about **20–300 nm**. They pass through bacterial filters and are not affected by antibiotics.
- **Dmitri Ivanowsky (1892)** showed that the agent of tobacco mosaic passed through bacteria-proof filters. **M.W. Beijerinck (1898)** called it **"contagium vivum fluidum"** (infectious living fluid). **W.M. Stanley (1935)** crystallised **TMV**, showing viruses can be crystallised. **TMV was the first virus discovered.**
- **TMV** is a **rod** (~300 × 18 nm) with **helical** symmetry and **ssRNA**. Most **plant viruses have ssRNA**; most **animal viruses have dsDNA or RNA**; most **bacteriophages have dsDNA**.
- **Bacteriophage** = a virus that infects bacteria. It was discovered by **Twort (1915)** and **d'Herelle (1917)**, who coined the name. **T4 phage** is tadpole-shaped (head, tail and tail fibres) and contains dsDNA. Phages can follow a **lytic cycle** (virulent phage; the host bursts) or a **lysogenic cycle** (temperate phage; DNA joins the host chromosome as a **prophage**, as in phage λ).
- **Retroviruses** (e.g. HIV) carry RNA and the enzyme **reverse transcriptase** (RNA → DNA), discovered by Temin & Baltimore (1970).
- **Viroids** were discovered by **T.O. Diener (1971)** in **potato spindle tuber disease**. They are **free, circular ssRNA without a protein coat**, much smaller than viruses (~250–400 nucleotides), and their RNA has low molecular weight.
- **Prions** = **proteinaceous infectious particles** with **no nucleic acid**. They are misfolded PrP protein and were named by **Stanley Prusiner (1982; Nobel 1997)**. They cause **BSE (mad cow disease)**, **scrapie** (sheep), **CJD** and **kuru** (humans).

Fungi, Protozoa & Archaea

- **Fungi** are eukaryotic heterotrophs: saprophytes, parasites or symbionts. Their cell wall is made of **chitin** (and glucans), their membrane sterol is **ergosterol** (the target of antifungal drugs), and they store food as **glycogen** and oil. The body is a **mycelium** made of **hyphae** (septate or coenocytic).
- **Yeasts** are unicellular and reproduce by **budding** (*Saccharomyces*) or fission (*Schizosaccharomyces*). **Moulds** are filamentous (*Aspergillus*, *Penicillium*, *Rhizopus*). **Dimorphic** fungi switch between yeast and mould forms (*Candida*, *Histoplasma*).
- **Pier Antonio Micheli** is the Father of Mycology. **E.J. Butler** is the Father of Indian Mycology and Plant Pathology.

Fungal class (NCERT)	Spores	Examples
Phycomycetes	Zoospores / aplanospores; sexual: zygospore or oospore; aseptate, coenocytic hyphae	*Mucor*, *Rhizopus* (bread mould), *Albugo*
Ascomycetes (sac fungi)	Conidia; sexual: **ascospores** in asci	***Aspergillus***, ***Penicillium***, *Claviceps*, *Neurospora*, **yeast**, morels, truffles
Basidiomycetes (club fungi)	Sexual: **basidiospores**; no asexual spores	*Agaricus* (mushroom), *Ustilago* (smut), *Puccinia* (rust)
Deuteromycetes (fungi imperfecti)	Only asexual (conidia)	*Alternaria*, *Colletotrichum*, *Trichoderma*

- **Protozoa** are unicellular eukaryotic heterotrophs (kingdom **Protista**). Four groups:
  - **Amoeboid**, moving by pseudopodia: *Amoeba*, *Entamoeba*
  - **Flagellated**: *Trypanosoma*, *Leishmania*, *Giardia*
  - **Ciliated**: *Paramecium*
  - **Sporozoans**, with no locomotory organ: ***Plasmodium***
- **Archaea** are prokaryotes. They have **no peptidoglycan** (some have pseudomurein), **ether-linked branched lipids**, and enzymes resembling eukaryotes. Types: **methanogens** (in the cattle rumen and marshes; they produce biogas), **halophiles** (salty lakes) and **thermoacidophiles** (hot springs).
- **Cyanobacteria (BGA)** are photosynthetic prokaryotes. Some have **heterocysts** that fix nitrogen (*Nostoc*, *Anabaena*).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- The first virus discovered? → **Tobacco Mosaic Virus**.
- Who discovered viroids? → **T.O. Diener (1971)**.
- The cell wall of bacteria is made of? → **Peptidoglycan (murein)**; of fungi → **chitin**.
- Transfer of DNA by a bacteriophage is called? → **Transduction**.
- In which growth phase are antibiotics produced? → **Stationary phase** (secondary metabolites).
- Bacteria without a cell wall? → ***Mycoplasma***.

9.3 Useful Microbes ★★☆

Product	Microbe	Remarks
Ethanol, beer, wine, bread	***Saccharomyces cerevisiae*** (brewer's and baker's yeast)	Wine and beer are **not distilled**; whisky, brandy and rum **are distilled**
Citric acid	***Aspergillus niger***	Also gluconic acid
Acetic acid (vinegar)	***Acetobacter aceti***	Oxidises ethanol to acetic acid
Lactic acid	***Lactobacillus*** (e.g. *L. delbrueckii*)	Homofermentative lactic acid bacteria (LAB)
Butyric acid	***Clostridium butylicum***	Anaerobic
Penicillin	***Penicillium notatum*** (Fleming); industrial: ***P. chrysogenum***	First antibiotic; β-lactam
Streptomycin	***Streptomyces griseus***	Waksman; first anti-TB drug
Tetracycline (chlortetracycline)	*Streptomyces aureofaciens*	Broad spectrum
Chloramphenicol	*Streptomyces venezuelae*	Typhoid

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Erythromycin	*Saccharopolyspora erythraea* (formerly *Streptomyces erythreus*)	Macrolide
Griseofulvin	*Penicillium griseofulvum*	Antifungal (ringworm)
Cyclosporin A	***Trichoderma polysporum*** (NCERT; also given as *Tolypocladium inflatum*)	**Immunosuppressant** in organ transplants
Statins	***Monascus purpureus*** (called a yeast in NCERT; actually a mould)	Lower blood cholesterol by inhibiting **HMG-CoA reductase**
Streptokinase	***Streptococcus*** (genetically modified)	"**Clot buster**" for myocardial infarction
Lipases	Bacteria / fungi	Remove oily stains in **detergents**
Pectinase & protease	*Aspergillus*	Clear fruit juices
Glutamic acid (MSG), lysine	*Corynebacterium glutamicum*	Amino acids
Vitamin B_{12}	*Pseudomonas denitrificans*, *Propionibacterium*	Made **only by microbes**
Gibberellins	*Gibberella fujikuroi*	Causes **bakanae** (foolish seedling) of rice
Taq polymerase	***Thermus aquaticus***	Heat-stable enzyme for **PCR**

Dairy & Fermented Foods

- **Curd (dahi)**: ***Lactobacillus*** and other **lactic acid bacteria (LAB)** turn lactose into lactic acid. The acid **coagulates and partly digests milk proteins**, and the bacteria **raise vitamin B_{12}**. In the stomach, LAB also **check disease-causing microbes** (NCERT).
- **Yoghurt**: ***Streptococcus thermophilus* + *Lactobacillus delbrueckii* subsp. *bulgaricus***, usually 1:1, incubated at ~40–45 °C.
- **Cheese**: milk is set with **rennet (chymosin)**, now often recombinant.
  - **Swiss cheese**: ***Propionibacterium shermanii*** produces CO_2, which makes the **large holes**
  - **Roquefort**: ***Penicillium roqueforti*** (blue-veined)
  - **Camembert**: *P. camemberti*
- **Idli/dosa** batter is fermented by ***Leuconostoc mesenteroides***, *Enterococcus faecalis* and *Pediococcus*; the CO_2 makes it puffy. **Bread dough** rises from CO_2 released by **baker's yeast**.
- Other fermented foods:
  - **Toddy**: fermented palm sap (south India)
  - **Sauerkraut**: cabbage fermented by *Leuconostoc* and then *L. plantarum*
  - **Soy sauce**: *Aspergillus oryzae*
  - **Tempeh**: *Rhizopus oligosporus*
  - **Kefir**: yeast plus LAB grains
- **Probiotics** = live beneficial microbes (*Lactobacillus acidophilus*, *Bifidobacterium*). **Prebiotics** = non-digestible food for them (inulin, FOS).
- **Single-cell protein (SCP)**: ***Spirulina*** (~60–70% protein). NCERT example: 250 g of *Methylophilus methylotrophus* can make about **25 tonnes of protein** a day.
- **Edible mushrooms**: *Agaricus bisporus* (button), *Pleurotus* (oyster/dhingri), *Volvariella volvacea* (paddy straw).

Biofertilisers

Biofertiliser	Type	Crop / note
Rhizobium	**Symbiotic** N_2-fixer in **root nodules**; **leghaemoglobin** protects nitrogenase from O_2	**Legumes**; crop-specific (cross-inoculation groups)
Azotobacter	**Free-living, aerobic** N_2-fixer	Non-legumes: wheat, vegetables, cotton
Azospirillum	**Associative** (micro-aerophilic) N_2-fixer	Cereals, millets, grasses (sorghum, maize)
Acetobacter (*Gluconacetobacter*) *diazotrophicus*	Endophytic N_2-fixer	**Sugarcane**
BGA (*Anabaena*, *Nostoc*, *Oscillatoria*, *Aulosira*)	Free-living, photosynthetic; fix N in **heterocysts**	**Paddy** fields; also add organic matter
Azolla (a water fern) + *Anabaena azollae*	Symbiotic	Paddy; green manure
Frankia (an actinomycete)	Symbiotic in non-legumes	*Alnus*, *Casuarina*
VAM / AM fungi (*Glomus*)	Mycorrhiza (fungus–root symbiosis)	**Phosphorus** uptake; drought and pathogen tolerance
PSB (*Pseudomonas striata*, *Bacillus megaterium* var. *phosphaticum*); PSF (*Aspergillus awamori*, *Penicillium*)	Phosphate-solubilising (they secrete organic acids)	All crops

- The **nitrogenase** enzyme needs **Mo and Fe** and works only when **O_2 is low**. Its product is **ammonia (NH_3)**.

Biopesticides / Biocontrol

- ***Bacillus thuringiensis* (Bt)** makes **Cry (crystal) proteins**, which are protoxins. The **alkaline gut** of **lepidopteran caterpillars** activates them; they make pores in the gut and kill the larva. **Bt cotton** (*cry1Ac*; Bollgard-II adds *cry2Ab*) was **approved in India in 2002**. **Bt brinjal** is approved in Bangladesh but under moratorium in India (2010).
- ***Trichoderma*** (*T. viride*, *T. harzianum*) is a free-living fungus in the root zone. It controls **soil-borne fungal pathogens** (seed treatment).
- **Baculoviruses** (genus ***Nucleopolyhedrovirus*, NPV**) are species-specific and narrow-spectrum, attack insects and arthropods, and are ideal for **IPM**, e.g. *Helicoverpa* NPV.
- **Entomopathogenic fungi**:
  - ***Beauveria bassiana***: white muscardine
  - ***Metarhizium anisopliae***: green muscardine
  - *Verticillium (Lecanicillium) lecanii*: against sucking pests

Pseudomonas fluorescens is a bacterial biocontrol agent.

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Sewage Treatment & Biogas

- **Primary treatment** is **physical**: screening, grit removal, sedimentation. The solids that settle are the **primary sludge**, and the liquid above is the effluent.
- **Secondary treatment** is **biological**. In **aeration tanks**, aerobic microbes form **flocs** (bacteria plus fungal filaments) that consume organic matter and **cut BOD sharply**. The flocs then settle as **activated sludge**; part is returned as **inoculum** and the rest goes to **anaerobic sludge digesters**, where anaerobes produce **biogas** (CH_4, H_2S, CO_2).
- **BOD** (Biochemical Oxygen Demand) = the O_2 that microbes would use to oxidise all the organic matter in **1 litre** of water, measured over **5 days at 20 °C**. High BOD means high pollution.
- River clean-up programmes: **Ganga Action Plan (1985)**, **Yamuna Action Plan (1993)**, **Namami Gange (2014)**.
- **Biogas** is mainly **methane (~50–70%)** plus **CO_2 (~30–40%)** and traces of H_2S and H_2. It is made by **methanogens** (e.g. ***Methanobacterium***, which are **archaea**) under **anaerobic** conditions. Methanogens also live in the **cattle rumen**, so cattle dung (gobar) is rich in them. In India, biogas technology was developed mainly by **IARI and KVIC**.
- Biogas forms in four stages: **hydrolysis → acidogenesis → acetogenesis → methanogenesis**. The slurry left over is good manure.

MEMORY TRICK

"**Cit**rus is **Nig**ht-black": citric acid comes from *A.* ***niger***. "**Strep**tomycin from **Grey** Streptomyces (*griseus*)". "**Mon**ascus **Mon**itors cholesterol (statins)". "**Tri**choderma **Tri**cks the immune system (cyclosporin)".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Large holes in Swiss cheese are due to? → ***Propionibacterium shermanii*** (CO_2).
- The immunosuppressant cyclosporin A is produced by? → ***Trichoderma polysporum***.
- Which microbes produce biogas? → **Methanogens** (e.g. *Methanobacterium*).
- Associative N_2-fixer used for cereals? → ***Azospirillum***.
- Bt toxin is most effective against larvae of? → **Lepidoptera** (alkaline gut).
- BOD is measured over how many days and at what temperature? → **5 days at 20 °C**.

9.4 Food Spoilage, Mycotoxins & Storage Microbiology ★★★

- **Food spoilage** = any change that makes food unfit to eat (off-odour, slime, discolouration, souring, gas or toxin). Its agents are **microbes** (bacteria, yeasts, moulds), **enzymes** already in the food, **insects and mites**, **rodents and birds**, and **chemical or physical** changes (rancidity, bruising).
- Typical spoilage by food type:
  - **Bacteria** spoil high-moisture, near-neutral foods: meat, fish, milk, eggs
  - **Yeasts** spoil high-sugar, acidic foods: juices, jams, honey (osmophilic yeasts)
  - **Moulds** spoil low-moisture, acidic foods: **stored grain**, bread, fruits, nuts

Factors Affecting Microbial Growth in Food

Factor	Key facts
Water activity (a_w)	a_w = **p / p_0** = vapour pressure of the food ÷ vapour pressure of pure water at the same temperature. Pure water = **1.0**. **ERH (%) = a_w × 100**
Moisture content	The main controllable factor in grain storage. **Every 1% rise above the safe limit sharply raises mould and insect activity**
Temperature	Most spoilage organisms are mesophiles. The food-safety **danger zone is 5–60 °C** (WHO/Codex; USDA uses 4–60 °C, i.e. 40–140 °F)
pH	Bacteria prefer pH 6.5–7.5; yeasts and moulds tolerate pH 2–8.5. **pH ≤ 4.6** is the dividing line between **acid foods** and **low-acid foods**; *C. botulinum* cannot grow at pH ≤ 4.6
Oxygen / redox potential (Eh)	Aerobes spoil surfaces; anaerobes spoil cans and the inside of meat. Hermetic storage uses up O_2
Nutrient content, antimicrobial constituents, biological structures	Intrinsic factors (e.g. lysozyme in egg white, seed coat, husk)
Relative humidity (RH) & gas atmosphere	Extrinsic factors. **CO_2-rich atmospheres** suppress moulds and insects (controlled-atmosphere storage)

Microbe group	Minimum a_w for growth (approx.)
Most spoilage bacteria	**0.91**
Most spoilage yeasts	**0.88**
Most spoilage moulds	**0.80**
Staphylococcus aureus	0.86 (the most tolerant food-poisoning bacterium)
Halophilic bacteria	0.75
Xerophilic moulds (*Eurotium* / *A. glaucus* group, *A. restrictus*)	**0.61–0.70**
Osmophilic yeasts	0.60–0.61
No microbial growth	**< 0.60**

- Approximate a_w of foods: fresh meat, fruit and milk 0.97–0.99; bread ~0.95; jam ~0.80–0.85; **dry grain at safe moisture ≈ 0.65–0.70**; dried pulses and biscuits < 0.60. Preservation by **drying, salting or sugaring** works by **lowering a_w**.

Safe Moisture for Grain Storage

- Grain is **hygroscopic**. It gains or loses moisture until it is in **equilibrium** with the air around it; this is the **equilibrium moisture content (EMC)**. Wheat at **~13.5–14% moisture** is in equilibrium with about **70% RH** at ~25 °C.
- **Storage fungi start growing at about 65–70% ERH**, which corresponds to roughly 13.5–14.5% moisture in starchy cereals and lower in oilseeds. **Most stored-grain insects multiply poorly below ~10–11% moisture.**

Commodity	Commonly cited safe moisture for storage
Wheat	**≤ 12%** (FCI/CWC procurement specification 12%; up to 14% accepted with value cut). Long-term storage ~10–12%

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Rice (milled)	**≤ 14%** (FCI uniform specification); 12–13% for long storage
Paddy	**≤ 17%** (procurement); ~12–14% for safe long storage
Maize, jowar, bajra, ragi	**≤ 14%** for maize, jowar, bajra; **≤ 12%** for ragi (procurement); ~12% for long storage
Pulses	**~9–12%** (sources vary)
Oilseeds (groundnut kernels, mustard)	**~7–9%**. Oil-rich seeds hold less water, so their safe moisture is lower

KEY FORMULAE

- Moisture content (wet basis) = $W_{water} \div (W_{water} + W_{dry\ matter}) \times 100$. This is the basis used in trade and storage.
- Moisture content (dry basis) = $W_{water} \div W_{dry\ matter} \times 100$. It is always higher than the wet-basis figure.
- Respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + **heat (~2870 kJ/mol)**. Grain, mould and insect respiration all produce **heat and water**, which feeds more spoilage.
- **Harrington's thumb rules** (seeds): each **1% drop in moisture** (between 5 and 14%) or each **5 °C drop in temperature** (between 0 and 50 °C) **doubles seed life**. Also, **RH (%) + temperature (°F) should not exceed 100**.

Hot Spots, Moisture Migration & Caking

- A **hot spot** is a local pocket of heating in bulk grain, caused by **insect or mould respiration** in damp patches. Grain conducts heat poorly, so the heat builds up.
- How hot each cause makes the grain:
  - **Insect activity in dry grain**: up to about **42 °C** ("dry-grain heating")
  - **Mould activity in damp grain**: up to about **55–62 °C**
  - **Thermophilic bacteria**: up to about 70–75 °C
  - Chemical oxidation beyond that can cause **spontaneous combustion**
- **Moisture migration**: temperature differences between the grain bulk and the outer walls set up **convection currents**. In **winter** the warm, moist air rises from the centre and **condenses below the cool top surface**, leading to **top crusting** and caking.
- Signs of mould spoilage:
  - musty odour
  - discoloured or **germ-damaged** ("sick") wheat
  - caking or lumping
  - loss of germination
  - rising **free fatty acids (FFA)**
  - heating
  - CO_2 build-up (**CO_2 sensors detect spoilage early**)
- Monitor grain with **thermocouples or temperature probes**, moisture meters, CO_2 measurement and regular sampling with a **grain probe (spear)**.

Field Fungi vs Storage Fungi (Christensen)

Feature	Field fungi	Storage fungi
Genera	***Alternaria*, *Cladosporium*, *Fusarium*, *Helminthosporium***	***Aspergillus*** (*A. restrictus*, *A. glaucus* group, *A. candidus*, *A. flavus*) and ***Penicillium***
When they invade	In the field, before harvest	After harvest, during storage
Moisture needed	High: grain moisture **≥ 20–22%**, a_w > 0.90	Low: **~13.5–18%** grain moisture, a_w 0.65–0.90
Behaviour in store	Die out slowly in dry storage	**Spread and cause spoilage** if moisture is not kept low
Toxins	Fusarium toxins (DON, zearalenone, fumonisin)	Aflatoxin, ochratoxin

- Storage fungi damage grain by:
  - **killing the germ (embryo)**, which lowers viability
  - discolouration
  - heating
  - mustiness
  - **loss of dry matter**
  - **mycotoxin production**
- *A. restrictus* and the *A. glaucus* group invade first, at the lowest moisture. *A. candidus* and *A. flavus* follow as moisture and heat rise. *Penicillium* prefers cooler, damper grain.

Mycotoxins

- **Mycotoxins** = toxic **secondary metabolites of moulds**. They are **heat-stable** and **not destroyed by normal cooking**. Their effect on health is called **mycotoxicosis**.

Mycotoxin	Fungus	Main foods	Effect / note
Aflatoxins (B_1, B_2, G_1, G_2, M_1)	***Aspergillus flavus*** (B type), ***A. parasiticus*** (B and G)	**Groundnut**, **maize**, cottonseed, chillies, spices, tree nuts	**Hepatotoxic and carcinogenic (liver cancer). B_1 is the most toxic**; IARC **Group 1** carcinogen
Ochratoxin A	*Aspergillus ochraceus*, ***Penicillium verrucosum***	Wheat, barley, coffee, wine, dried fruit	**Nephrotoxic (kidney)**; linked to Balkan endemic nephropathy
Fumonisins (FB_1)	***Fusarium verticillioides*** (*F. moniliforme*), *F. proliferatum*	**Maize**	Equine leukoencephalomalacia, porcine pulmonary oedema; linked to oesophageal cancer
Deoxynivalenol (DON, **vomitoxin**), a trichothecene	*Fusarium graminearum*, *F. culmorum*	Wheat, maize, barley	Vomiting and feed refusal
T-2 toxin (trichothecene)	*Fusarium sporotrichioides*	Over-wintered cereals	**Alimentary toxic aleukia (ATA)** in the USSR during WWII
Zearalenone	*Fusarium graminearum*	Maize	**Oestrogenic** (vulvovaginitis in pigs)
Patulin	***Penicillium expansum***	**Apples** (blue mould rot), **apple juice**	Gastrointestinal effects; genotoxic
Ergot alkaloids (ergotamine, ergometrine)	***Claviceps purpurea*** (**sclerotia** replace the grains)	**Rye**, wheat, barley; ergot of **bajra** is *Claviceps fusiformis*	**Ergotism** ("St. Anthony's fire"): gangrenous or convulsive. Lysergic acid (LSD precursor)

- **Aflatoxin facts**:
  - The name comes from **A**spergillus **fla**vus **toxin**.

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- It was discovered after **Turkey X disease** (England, **1960**), when about 100,000 turkeys died after eating contaminated **Brazilian groundnut meal**.
- Under **UV light (365 nm)**, the **B** types fluoresce **blue** and the **G** types fluoresce **green**.
- **Aflatoxin M_1** is a hydroxylated metabolite of B_1. It appears in the **milk** of animals fed contaminated feed (M = milk).
- Production is favoured by **~25–35 °C**, **high humidity (a_w > ~0.85)**, drought stress and insect damage in the field.

- India: the **1974 hepatitis outbreak** in Rajasthan and Gujarat was caused by eating **aflatoxin-contaminated maize** and killed about 100 people.
- **Detection**:
  - **TLC** (thin-layer chromatography, the classic method)
  - **HPLC** (fluorescence detector)
  - **ELISA** kits
  - immunoaffinity columns
  - the **BGYF (bright greenish-yellow fluorescence)** presumptive test for maize under UV
- **Detoxification and control**:
  - sorting or hand-picking discoloured and shrivelled kernels
  - **ammoniation** (for feed)
  - adsorbent clays (bentonite) in feed
  - sunlight
  - above all, **prevention**: dry quickly to safe moisture, avoid damage, and store cool and dry
- **Lathyrism** (from *Lathyrus sativus*, khesari dal, toxin **BOAA/β-ODAP**; spastic paralysis of the legs) and **epidemic dropsy** (argemone oil) are **not** mycotoxin diseases. They are plant toxins and adulterants.

Toxin	FSSAI maximum limit (FSS Contaminants, Toxins & Residues Regulations, 2011, as amended)
Aflatoxins, cereals & cereal products	**15 µg/kg** (ppb); the same for pulses. The old PFA rule was **30 µg/kg** for all foods
Aflatoxins, spices	30 µg/kg
Aflatoxin M_1, milk	**0.5 µg/kg** (Codex value; the EU limit is 0.05)
Ochratoxin A, wheat, barley, rye	20 µg/kg
Patulin, apple juice	50 µg/kg
Deoxynivalenol, wheat	1000 µg/kg (1 ppm)
Ergot, foodgrains	**0.05% by weight**

Prevention of Microbial Spoilage in Stored Grain

- **Harvest at maturity and dry quickly** to safe moisture by sun-drying or mechanical driers. **Clean and grade** the grain to remove broken kernels, dust and weed seeds, where moulds start.
- Use **clean, dry, disinfested godowns** with **moisture-proof floors**. Stack on **dunnage** (wooden crates or polythene sheets) and keep about **0.75–1 m gaps** between stacks and from walls (aisle space), so air can circulate and grain can be inspected.
- **Aerate** on dry, cool days. Seal stores tightly in humid weather. Repair leaks before the monsoon.
- Control insects, which raise both heat and moisture and spread spores, using prophylactic and curative measures and **fumigation**.
- **Hermetic storage** (airtight bags or cocoons) lowers O_2 and raises CO_2, which checks moulds and insects. **Cold storage** (< 15 °C) slows both.
- Chemical preservatives for feed grain: **propionic acid**, which is a mould inhibitor. **Sodium benzoate** (acid foods) and **potassium metabisulphite** (KMS, for colourless foods) are used in processed foods. **Sorbates** inhibit moulds.
- Follow **FIFO (first in, first out)** and inspect regularly for heating, odour and moisture.

MEMORY TRICK

Aflatoxin types: **B** = **B**lue, **G** = **G**reen, **M** = **M**ilk. Organ targets: "**A**flatoxin attacks the liver; **O**chratoxin attacks the kidney (**O**rgan that filters)". Water activity order: **B**acteria 0.91 > **Y**easts 0.88 > **M**oulds 0.80 = "**BYM**, descending".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- The most toxic and carcinogenic aflatoxin? → **Aflatoxin B_1**.
- Aflatoxin is mainly produced by? → ***Aspergillus flavus*** and ***A. parasiticus***.
- Minimum water activity for most moulds? → **0.80** (xerophilic moulds ≈ 0.61).
- Typical maximum temperature of an insect-caused hot spot in dry grain? → **About 42 °C**.
- FSSAI limit for ergot in foodgrains? → **0.05% by weight**.
- Patulin is mainly a contaminant of? → **Apples and apple juice**.

9.5 Public Health & Diseases ★★★

- **Health** (WHO, 1948) = "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity".
- **Communicable diseases** are infectious and spread person to person or via vectors. **Non-communicable diseases** include diabetes, cancer and hypertension.
- Key terms:
  - **Incubation period**: the time from infection to the first symptoms
  - **Carrier**: an infected person without symptoms who spreads the disease (e.g. "Typhoid Mary")
  - **Vector**: a living carrier, usually an arthropod
  - **Reservoir**: where the pathogen normally lives
  - **Endemic**: always present in an area. **Epidemic**: a sudden rise. **Pandemic**: spread worldwide

Bacterial Diseases

Disease	Pathogen	Transmission	Notes
Tuberculosis	***Mycobacterium tuberculosis*** (Koch, 1882)	Airborne droplets	**BCG vaccine** (live attenuated *M. bovis*); **Mantoux test** (PPD tuberculin). Programme: **NTEP** (formerly RNTCP), DOTS
Typhoid (enteric fever)	***Salmonella* Typhi**	**Faeco-oral**: contaminated food and water; flies	**Widal test**; ulcers of the intestine (Peyer's patches)

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Cholera	***Vibrio cholerae*** (O1, O139)	Contaminated **water**	"**Rice-water**" stools, severe dehydration; treat with **ORS**; TCBS medium
Plague	***Yersinia pestis***	Bite of the **rat flea *Xenopsylla cheopis***; pneumonic form by droplets	Bubonic, septicaemic and pneumonic forms; "Black Death". **Surat outbreak, 1994**
Leptospirosis (Weil's disease)	***Leptospira interrogans*** (a spirochaete)	Contact of skin or mucosa with water or soil contaminated by **rodent urine**	Occupational risk for farmers, sewage workers and **warehouse workers**; peaks after floods
Diphtheria	*Corynebacterium diphtheriae*	Droplets	Toxoid vaccine (DPT)
Pertussis (whooping cough)	*Bordetella pertussis*	Droplets	DPT
Tetanus (lockjaw)	*Clostridium tetani*	Soil entering wounds	Tetanospasmin; TT/Td vaccine
Leprosy	*Mycobacterium leprae* (Hansen, 1873)	Prolonged close contact, droplets	**MDT**; cannot be cultured *in vitro*
Pneumonia	*Streptococcus pneumoniae*, *Haemophilus influenzae*	Droplets	Alveoli fill with fluid; PCV and Hib vaccines
Anthrax	*Bacillus anthracis*	Contact with animals or spores	Zoonotic; spores survive in soil for decades
Brucellosis (Malta / undulant fever)	*Brucella*	**Raw milk**, animal contact	Zoonotic; causes abortion in cattle

Viral Diseases

Disease	Virus	Transmission / vector	Notes
Dengue	Dengue virus (Flavivirus, **4 serotypes**)	***Aedes aegypti*** (also *Ae. albopictus*); **day-biter**, breeds in **clean stagnant water**	"Breakbone fever"; **platelet fall**; NS1 antigen test. National Dengue Day **16 May**
Chikungunya	Alphavirus (Togaviridae)	***Aedes***	Severe joint pain
Zika	Flavivirus	***Aedes***; also sexual and mother-to-foetus	**Microcephaly** in newborns
Japanese encephalitis (JE)	Flavivirus	***Culex*** (*C. tritaeniorhynchus*), which breeds in paddy fields	**Pigs** are amplifying hosts; ardeid birds are the reservoir; JE vaccine in UIP (endemic districts)
Rabies (hydrophobia)	Lyssavirus (Rhabdoviridae; **bullet-shaped**)	Bite or scratch of a rabid animal (**dogs** cause ~95–97% of cases in India)	**Almost 100% fatal** once symptoms appear; Negri bodies; post-exposure vaccination. World Rabies Day **28 Sept**
COVID-19	**SARS-CoV-2** (β-coronavirus, +ssRNA, spike protein binds **ACE2**)	Respiratory droplets and aerosols	WHO declared a pandemic on **11 March 2020**; India's first case was in Kerala on **30 Jan 2020**
Polio	Poliovirus (Enterovirus)	Faeco-oral	OPV (Sabin, live) and IPV (Salk, killed). India's **last case was Jan 2011**; India was certified **polio-free on 27 March 2014**
Hepatitis A / E	HAV / HEV	**Faeco-oral** (food, water)	HEV is dangerous in pregnancy
Hepatitis B / C	HBV (DNA) / HCV	Blood, sexual contact, mother to child	Recombinant HBV vaccine (yeast-made)
HIV/AIDS	HIV (retrovirus)	Sexual contact, blood, mother to child	Destroys **helper T (CD4) cells**; ELISA test. World AIDS Day **1 Dec**
Influenza (H1N1, H5N1 bird flu)	Orthomyxovirus	Droplets; birds and pigs	Antigenic drift and shift
Nipah	Henipavirus (Paramyxoviridae)	**Fruit bats (*Pteropus*)**, contaminated fruit and sap, person to person	Kerala outbreaks (2018 onwards)
Kyasanur Forest Disease ("monkey fever")	Flavivirus	**Tick** (*Haemaphysalis spinigera*)	Karnataka (Shimoga, 1957)

Protozoan, Helminthic & Fungal Diseases

Disease	Pathogen	Transmission / vector	Notes

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Malaria	***Plasmodium***: *P. vivax* (benign tertian), ***P. falciparum*** (malignant tertian, **cerebral malaria, most dangerous**), *P. malariae* (quartan), *P. ovale*	Bite of the **female *Anopheles*** (*An. culicifacies* is the main rural vector in India; *An. stephensi* the urban vector)	Man is the intermediate host and the mosquito is the definitive host. **Sporozoites** infect man; **gametocytes** pass to the mosquito. **Haemozoin** causes the chill and fever cycle (every 48 h in vivax). Drugs: chloroquine, quinine (*Cinchona*), **artemisinin** (*Artemisia annua*). Ross 1897, Laveran 1880. World Malaria Day **25 April**
Kala-azar (visceral leishmaniasis)	***Leishmania donovani***	**Sandfly** (*Phlebotomus argentipes*)	Endemic in Bihar, Jharkhand, West Bengal and UP; enlarged spleen and liver; PKDL is a skin sequel
Amoebiasis (amoebic dysentery)	***Entamoeba histolytica***	Faeco-oral (**cysts**); **houseflies** are mechanical carriers	Stools with mucus and blood; liver abscess
Ascariasis	***Ascaris lumbricoides*** (roundworm)	Eggs in contaminated soil, water, vegetables	Intestinal blockage
Filariasis (elephantiasis)	***Wuchereria bancrofti***, *Brugia malayi*	***Culex quinquefasciatus*** (*Mansonia* for *Brugia*)	Lymphatic blockage; **MDA** with DEC + albendazole (+ ivermectin in the triple-drug IDA regimen)
Hookworm	*Ancylostoma duodenale*, *Necator americanus*	Larvae **penetrate the skin** (barefoot walking)	Iron-deficiency anaemia
Taeniasis / cysticercosis	*Taenia solium* (pork), *T. saginata* (beef)	Undercooked meat; eggs (cysticercosis)	Neurocysticercosis causes epilepsy
Guinea worm	*Dracunculus medinensis*	Water containing *Cyclops*	India certified free in **2000**
Ringworm	*Microsporum*, *Trichophyton*, *Epidermophyton*	Contact, towels; warm, moist skin	Fungal; dry scaly lesions
Mucormycosis ("black fungus")	*Rhizopus*, *Mucor*	Spores in the environment	Rose after COVID-19 in diabetic and steroid-treated patients

- **National Deworming Day**: **10 February and 10 August** (albendazole for children aged 1–19).

Zoonoses & Rodent-Borne Diseases (relevant to warehouses)

- **Zoonosis** = a disease passed naturally from vertebrate animals to man. Examples: rabies, plague, leptospirosis, anthrax, brucellosis, bovine TB, JE, KFD, bird flu, Nipah, Q fever, hydatid disease (*Echinococcus*, from dogs) and toxoplasmosis (cats). **World Zoonoses Day is 6 July**, marking Pasteur's first rabies vaccination in 1885.
- **Rodent-borne diseases**: **plague** (via fleas), **leptospirosis** (urine), **salmonellosis** (droppings contaminate grain), **murine typhus** (*Rickettsia typhi*, via rat fleas), **rat-bite fever** (*Streptobacillus moniliformis*, *Spirillum minus*), hantavirus and lymphocytic choriomeningitis.
- **Scrub typhus**: *Orientia tsutsugamushi*, spread by **chigger mites** (*Leptotrombidium* larvae) on rodents in scrub vegetation.
- **Flea index** (fleas per rat) is used in plague surveillance. A **cheopis index above 1.0** signals a risk of plague outbreak.

Food-Borne Illness

- **Food intoxication** is caused by a **toxin already formed in the food**. It has a short incubation and no fever (*S. aureus*, *C. botulinum*, emetic *B. cereus*). **Food infection** happens when live organisms multiply in the gut. It has a longer incubation and often fever (*Salmonella*, *Campylobacter*).

Organism	Typical foods	Incubation	Key point
Staphylococcus aureus	Custards, cream, ham, salads handled by people	**1–6 h**	**Heat-stable enterotoxin**, so reheating does not help; comes from food handlers' **nose, skin and boils**; vomiting
Clostridium botulinum	**Low-acid canned foods** (pH > 4.6), home preserves; honey (infant botulism)	12–36 h	**Botulinum neurotoxin**, the **most potent toxin known**. It blocks acetylcholine release and causes **flaccid paralysis**. The toxin is **heat-labile** (destroyed by boiling ~10 min). Bulging cans are a warning sign
Salmonella (non-typhoidal: *S.* Enteritidis, *S.* Typhimurium)	**Poultry, eggs**, meat, raw milk	6–72 h (usually 12–36)	Infection; fever, diarrhoea. Rodent and bird droppings contaminate stored food
Clostridium perfringens	Meat gravies, large batches cooled slowly	8–16 h	Spores survive cooking; toxin is released in the gut
Bacillus cereus	**Fried rice** (emetic); meats and vegetables (diarrhoeal)	1–6 h / 8–16 h	"Fried rice syndrome"
Listeria monocytogenes	Soft cheese, deli meat	Days to weeks	**Grows at refrigerator temperature**; causes abortion in pregnancy
E. coli O157:H7 (EHEC)	Undercooked beef, raw sprouts	3–4 days	Bloody diarrhoea; **HUS** (kidney failure)

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Campylobacter jejuni	Poultry, raw milk	2–5 days	A leading bacterial cause of diarrhoea worldwide
Norovirus	Shellfish, ready-to-eat food	12–48 h	**Commonest cause of food-borne gastroenteritis outbreaks**

- **WHO "Five Keys to Safer Food"**:
  - Keep clean.
  - Separate raw and cooked food.
  - Cook thoroughly (core temperature ≥ **70 °C**).
  - Keep food at safe temperatures (< 5 °C or > 60 °C).
  - Use safe water and raw materials.
- **Canning** uses the **12D concept**: enough heat (at 121 °C) to cut *C. botulinum* spores by 10^{12}. **D-value** = the time at a given temperature that kills **90%** (one log) of the population.

Immunity

Type	Features
Innate (non-specific, present from birth)	Barriers of four kinds: **Physical**: skin, mucus **Physiological**: stomach HCl, saliva, tears (lysozyme) **Cellular**: neutrophils (PMNL), monocytes, macrophages, NK cells **Cytokine**: **interferons**, released by virus-infected cells, protect neighbouring cells
Acquired (specific, adaptive)	Has **memory**. The **primary response** is weak; the **secondary (anamnestic) response** is fast and strong. **B cells** give **humoral** (antibody) immunity; **T cells** give **cell-mediated** immunity (graft rejection)
Active	The body makes its own antibodies after **infection or vaccination**. Slow to develop, **long-lasting**
Passive	Ready-made antibodies: **colostrum (IgA)**, **placenta (IgG)**, anti-tetanus serum, **anti-venom**, monoclonal antibodies. Quick but short-lived

- An **antibody** (immunoglobulin) has **4 polypeptide chains, 2 heavy and 2 light (H_2L_2)**, joined by disulphide bonds in a **Y shape**. Fab binds the antigen; Fc does the effector work.

Ig class	Structure	Key feature
IgG	Monomer	**Most abundant in serum (~75–80%)**; the **only one that crosses the placenta**; dominates the secondary response
IgA	Monomer, or **dimer** in secretions	**Secretions**: milk/**colostrum**, saliva, tears, mucus. Mucosal immunity
IgM	**Pentamer**, the largest	**First antibody made in the primary response**; best at agglutination
IgE	Monomer	**Allergy** (binds mast cells, which release histamine); defence against **helminths**
IgD	Monomer	Antigen receptor on B cells; lowest in serum

- Lymphoid organs:
  - **Primary**: **bone marrow** and **thymus** (where T cells mature)
  - **Secondary**: spleen, lymph nodes, tonsils, Peyer's patches, appendix
  - **MALT** forms about 50% of the body's lymphoid tissue
- **Allergy** is mediated by IgE, with histamine and serotonin released from mast cells. It is treated with antihistamines, adrenaline and steroids. **Autoimmunity** is an attack on the body's own cells (e.g. rheumatoid arthritis).

Vaccine type	Examples
Live attenuated	**BCG**, **OPV** (Sabin), measles/MR/MMR, rotavirus, yellow fever, varicella
Inactivated (killed)	**IPV** (Salk), rabies (cell-culture), hepatitis A, whole-cell pertussis, **Covaxin** (Bharat Biotech + ICMR-NIV)
Toxoid	**Tetanus, diphtheria** (inactivated toxins)
Subunit / recombinant	**Hepatitis B** (HBsAg made in yeast, the first recombinant vaccine), HPV
Conjugate	Hib, pneumococcal (PCV)
Viral vector	**Covishield** (ChAdOx1, chimpanzee adenovirus)
mRNA	Pfizer–BioNTech, Moderna; India: GEMCOVAC (Gennova)
DNA (plasmid)	**ZyCoV-D** (Zydus, 2021), the **world's first DNA vaccine approved for humans**

National Health Programmes

- **NVBDCP** (National Vector Borne Disease Control Programme) is now run by the **National Center for Vector Borne Diseases Control (NCVBDC)**. It covers **six diseases**: **malaria, dengue, chikungunya, Japanese encephalitis, kala-azar and lymphatic filariasis**. India's National Framework for Malaria Elimination targets elimination by **2030**.
- **Universal Immunization Programme (UIP)** began in **1985**, building on EPI (1978). It gives free vaccines against **12 diseases**:
  - **nationally against 11**: diphtheria, pertussis, tetanus, polio, measles, rubella, severe childhood TB, hepatitis B, Hib meningitis and pneumonia, rotavirus diarrhoea, pneumococcal pneumonia
  - **sub-nationally against JE** (endemic districts)

  The **pentavalent vaccine** combines DPT, hepatitis B and Hib. The **U-WIN** portal digitises UIP records.
- **Mission Indradhanush** was launched on **25 December 2014** to reach children not vaccinated or only partly vaccinated. It is named after the **7 colours of the rainbow** because it first targeted **7 diseases**, with a goal of **≥ 90% full immunisation coverage**. **Intensified Mission Indradhanush (IMI)** followed in **2017**, and **IMI 5.0** ran in 2023.
- **Pulse Polio** began in 1995. Other programmes: **NTEP** (TB elimination target 2025, ahead of the SDG target of 2030), **Pradhan Mantri TB Mukt Bharat Abhiyaan** (2022), **IDSP** (Integrated Disease Surveillance Programme, 2004), NACP (AIDS, NACO 1992), NLEP (leprosy) and the National Rabies Control Programme.
- Health days:
  - World Health Day: **7 April** (WHO founded 1948)
  - World TB Day: **24 March**
  - World Malaria Day: **25 April**
  - World Hand Hygiene Day: **5 May**
  - Global Handwashing Day: **15 Oct**
  - World Polio Day: **24 Oct**

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MEMORY TRICK

Mosquito–disease pairs: "**A**nopheles → m**A**laria; **A**edes → DCZ (**D**engue, **C**hikungunya, **Z**ika); **C**ulex → **C**ulex-JE and filaria (elephantiasis)". "**S**andfly → **S**pleen (kala-azar)". Antibodies: "**GAMED**", where **G** crosses the placenta, **A** is in secretions, **M** is made first, **E** is for allergy and **D** sits on B cells.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Vector of plague? → **Rat flea *Xenopsylla cheopis***.
- Leptospirosis spreads mainly through? → **Water or soil contaminated with rodent urine**.
- The only antibody that crosses the placenta? → **IgG**.
- The most dangerous malaria parasite? → ***Plasmodium falciparum***.
- Vector of Japanese encephalitis? → ***Culex* mosquito** (*C. tritaeniorhynchus*).
- Mission Indradhanush was launched in? → **December 2014**.

9.6 Food Safety, Hygiene & Standards ★★★

- **Food safety** = assurance that food will not harm the consumer when prepared and eaten as intended. **Food hygiene** = all the conditions and measures needed to ensure food is safe and suitable at every stage of the food chain.
- **Food hazards** are of three types:
  - **Biological**: bacteria, viruses, parasites, moulds
  - **Chemical**: pesticide residues, mycotoxins, heavy metals, allergens, adulterants
  - **Physical**: stones, glass, metal, hair

FSSAI & the Food Safety and Standards Act, 2006

- The **Food Safety and Standards (FSS) Act** was passed in **2006** (Act No. 34 of 2006). It replaced the **Prevention of Food Adulteration (PFA) Act 1954** and orders such as the Fruit Products Order 1955, Meat Food Products Order 1973, Milk & Milk Products Order 1992, Vegetable Oil Products (Control) Order 1947 and Edible Oils Packaging Order 1998, bringing **multiple laws under one integrated law**.
- The **Food Safety and Standards Authority of India (FSSAI)** was **established in 2008** (5 September) under the **Ministry of Health & Family Welfare**. It is headquartered in **New Delhi** and run by a Chairperson and a CEO.
- The **FSS Regulations, 2011** (notified in 2011; in force from **5 August 2011**) include:
  - Licensing & Registration of Food Businesses
  - Food Products Standards & Food Additives
  - Packaging & Labelling (now split into separate 2020 regulations)
  - Contaminants, Toxins & Residues
  - Laboratory & Sampling Analysis
  - Prohibition & Restrictions on Sales
- **Licensing of food business operators (FBOs)**:
  - **Registration**: petty FBOs with annual turnover **up to ₹12 lakh**
  - **State licence**: ₹12 lakh to ₹20 crore
  - **Central licence**: **above ₹20 crore**, plus importers, exporters and units in central government premises

  The licence number has **14 digits**. Applications go online through **FoSCoS** (Food Safety Compliance System), which replaced FLRS in 2020. **Storage and warehouse operators also need FSSAI registration or a licence.**
- **Enforcement chain**: **Commissioner of Food Safety** (State) → **Designated Officer** (district) → **Food Safety Officer (FSO)**, who takes samples. Samples are tested by a **Food Analyst**, with appeal to a **Referral Food Laboratory**. Penalties are imposed by an **Adjudicating Officer** (not below ADM rank). Appeals go to the **Food Safety Appellate Tribunal**.

Offence (FSS Act, 2006)	Penalty
Sub-standard food (Sec 51)	Up to ₹5 lakh
Misbranded food (Sec 52)	Up to ₹3 lakh
Misleading advertisement (Sec 53)	Up to ₹10 lakh
Food containing extraneous matter (Sec 54)	Up to ₹1 lakh
Unsafe food causing **death** (Sec 59)	Imprisonment of **not less than 7 years, up to life**, and a fine of **not less than ₹10 lakh**

- FSSAI initiatives:
  - **Eat Right India** (2018)
  - **State Food Safety Index** (released on World Food Safety Day)
  - **FoSTaC** (food safety training and certification)
  - Food Safety on Wheels (mobile labs)
  - **Clean Street Food Hubs**
  - **Eat Right Station** and BHOG (temple prasad)
  - Hygiene Rating
  - **"+F" logo** for fortified foods (rice, wheat flour, oil, milk, salt)
  - **DART** (Detect Adulteration with Rapid Test) booklet
- Other food marks:
  - **Agmark**: agricultural produce, under the Agricultural Produce (Grading & Marking) Act **1937**, run by the **Directorate of Marketing & Inspection (DMI)**
  - **ISI mark**: industrial and processed products, by **BIS**
  - **Green dot**: vegetarian; **brown dot**: non-vegetarian
  - **Jaivik Bharat** logo: organic food

Food Adulteration & Simple Tests

Food	Adulterant	Simple test / effect
Milk	Water	**Lactometer** (low reading); a drop of pure milk on a slope leaves a white trail
Milk, paneer, khoa	**Starch**	Add **iodine**: it turns **blue**
Milk	Detergent, urea	Lather on shaking (detergent); urease test (urea)
Ghee / butter	**Vanaspati**, mashed potato	**Baudouin test** (conc. HCl + sugar/furfural gives **crimson red** because vanaspati contains **sesame oil**); iodine test (blue) for potato
Mustard oil	**Argemone oil**	**Nitric acid test** gives an **orange-red** colour. Causes **epidemic dropsy** (alkaloid **sanguinarine**)
Edible oil	Mineral oil	Saponification test gives turbidity

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Turmeric, dal	**Metanil yellow** (a non-permitted dye)	Add **conc. HCl**: it turns **pink/magenta**
Turmeric	Lead chromate	Colour leaches into water
Chilli powder	Brick powder, sand	**Settles** at the bottom of water; gritty feel
Black pepper	**Dried papaya seeds**	Papaya seeds **float in alcohol**; they are shrunken and oval
Coffee	**Chicory**	Coffee floats on water; chicory sinks quickly and leaves **colour streaks**
Sugar	Chalk powder	Settles in water
Honey	Sugar syrup	Pure honey stays as a lump in water; adulterated honey disperses
Silver leaf (varak)	**Aluminium foil**	Silver burns to a shiny ball; aluminium leaves grey ash
Green peas, chillies	**Malachite green**	Cotton dipped in liquid paraffin turns green
Arhar / tur dal	**Khesari dal** (*Lathyrus sativus*)	Wedge-shaped (angular) seeds; **lathyrism** (BOAA)
Wheat / foodgrains	**Ergot**, **dhatura seeds**, kernel-bunt-affected grains	Ergot sclerotia **float in 20% salt solution**; dhatura seeds are flat with edges and dark brown

HACCP, GMP, Codex & ISO 22000

- **HACCP (Hazard Analysis and Critical Control Point)** was developed by the **Pillsbury Company with NASA** and the US Army Natick Labs in the **1960s** for **safe space food**. It is a **preventive**, science-based system that controls hazards at critical points instead of relying on testing the finished product.
- **Codex HACCP** has **12 steps**: **5 preliminary steps** (assemble the HACCP team, describe the product, identify intended use, draw a flow diagram, confirm it on site) followed by the **7 principles**.
- **CCP (Critical Control Point)** = a step where control is **essential** to prevent, eliminate or reduce a hazard to an acceptable level, e.g. cooking, pasteurisation or metal detection. CCPs are found with a **decision tree**. **Critical limit** = the value that separates acceptable from unacceptable, e.g. 72 °C for 15 s.

No.	HACCP principle (Codex)
1	**Conduct a hazard analysis** (identify hazards and control measures)
2	**Determine the Critical Control Points (CCPs)**
3	**Establish critical limits** for each CCP
4	**Establish a monitoring system** for each CCP
5	**Establish corrective actions** for when a CCP is out of control
6	**Establish verification procedures**
7	**Establish documentation and record keeping**

- **Prerequisite programmes (PRPs)** are the foundation for HACCP:
  - **GMP** (Good Manufacturing Practices): premises, equipment, processes
  - **GHP** (Good Hygiene Practices): cleaning, pest control, personal hygiene
  - **GAP** (Good Agricultural Practices)
  - **GLP** (Good Laboratory Practices)
  - Good Storage/Warehousing Practices

FSSAI sets GHP/GMP requirements in **Schedule 4** of the Licensing & Registration Regulations.

- **Codex Alimentarius Commission** ("food code") was set up in **1963 by FAO and WHO**. Its secretariat is in **Rome** (FAO HQ). India has been a member since **1964**, and **FSSAI** is India's **National Codex Contact Point**. Codex standards are the reference standards under the **WTO SPS Agreement**.
- **ISO 22000** = **Food Safety Management System**. It was first issued in **2005** and revised in **2018**. It combines **HACCP + PRPs + management system elements** (the ISO 9001-type structure) and applies to **all organisations in the food chain**, including storage and transport. **FSSC 22000** is a GFSI-recognised certification scheme based on it. Related standards: **ISO 9001** (quality), **ISO 14001** (environment), **ISO 45001** (occupational health and safety), **ISO/IEC 17025** (testing laboratories). ISO was founded in **1947** and is based in **Geneva**.
- **BIS (Bureau of Indian Standards)** replaced the **Indian Standards Institution (ISI, 1947)** under the **BIS Act 1986** and was established in **1987**. The new **BIS Act 2016** came into force in 2017. BIS is under the **Ministry of Consumer Affairs, Food & Public Distribution**, the same ministry as CWC and FCI. It sets standards such as **IS 10500** (drinking water) and IS 14543 (packaged drinking water).

Warehouse Sanitation & Hygiene

- **Before stocking**:
  - sweep and clean the godown
  - remove old grain residues, dust and cobwebs
  - fill cracks and crevices, which shelter insects and moulds
  - repair the roof and drains
  - disinfest with a **prophylactic spray** of an approved insecticide on walls, floors and dunnage
- **Dunnage** (wooden crates or polythene sheets) prevents moisture moving up from the floor. Stacks should stand on marked plinths with proper **aisles/alleyways** between them.
- **Rodent proofing**:
  - **rat-proof plinth** and **rat guards** on pipes
  - self-closing doors
  - wire mesh on ventilators
  - baiting (e.g. **bromadiolone**, an anticoagulant)
  - burrow fumigation
- Use **bird-proof** wire netting on ventilators and eaves, because **bird and rodent droppings carry *Salmonella***.
- **Spillage** must be swept up and disposed of promptly, as it attracts pests and moulds. Infested and spoiled stock must be **segregated**. Sound and damaged stock must be kept separate.
- Keep drainage clear, prevent water logging and clear vegetation around the godown. There should be **no stagnant water**, to avoid mosquito breeding.

Personal Hygiene of Food Handlers

- Food handlers should have a **medical examination** before employment and every year after (FSSAI Schedule 4). Anyone with diarrhoea, vomiting, fever, jaundice, skin infection or discharging wounds must be **kept away from food handling**.
- **Handwashing** with soap and water for at least **20 s** (WHO full procedure 40–60 s) is required before work, after using the toilet, after handling raw food or waste, and after coughing or sneezing.

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- Wear clean protective clothing, head covering and gloves. Keep nails short. No jewellery, smoking, spitting, chewing tobacco or eating in food areas. Cover cuts with waterproof dressings.

Waste Disposal

- **Segregate waste at source** into **wet/biodegradable (green bin)** and **dry/recyclable (blue bin)**, plus domestic hazardous waste (**Solid Waste Management Rules, 2016**).
- Disposal methods:
  - **composting** and **vermicomposting** (*Eisenia fetida*)
  - **biomethanation** (biogas)
  - **sanitary landfill** (for inert rejects)
  - **incineration** (hazardous waste, some biomedical waste)
- **Bio-Medical Waste Management Rules, 2016** colour codes:
  - **Yellow**: anatomical and soiled waste, for incineration
  - **Red**: contaminated recyclable plastics
  - **White (translucent)**: sharps
  - **Blue**: glassware
- **Spoiled or damaged foodgrains** are disposed of under laid-down procedures: as cattle or poultry feed, industrial use or manure depending on the damage category, or by destruction, so that they **never re-enter the human food chain**.

Safe Drinking Water Basics

Parameter (IS 10500:2012)	Acceptable limit	Permissible limit (no alternative source)
pH	**6.5–8.5**	No relaxation
Total dissolved solids (TDS)	**500 mg/L**	2000 mg/L
Total hardness (as $CaCO_3$)	200 mg/L	600 mg/L
Fluoride	**1.0 mg/L**	1.5 mg/L
Nitrate	**45 mg/L**	No relaxation
Arsenic	**0.01 mg/L**	No relaxation (old IS 10500 allowed 0.05)
Residual free chlorine	**Minimum 0.2 mg/L**	1 mg/L
***E. coli* / coliform bacteria**	**Must not be detectable in any 100 mL sample**	

- ***E. coli* is the indicator of faecal contamination.** It is detected by the **MPN (multiple-tube) method** or **membrane filtration**.
- **Disinfecting water**:
  - **Boiling** (a rolling boil for 1 min) is the simplest and kills all pathogens.
  - **Chlorination** uses **bleaching powder** ($CaOCl_2$, ~33% available chlorine) or chlorine tablets. WHO requires **≥ 0.5 mg/L free residual chlorine after 30 min contact**. **Break-point chlorination** means adding chlorine until all demand is met and free residual chlorine appears.
  - Other methods: UV, ozone, RO filters, SODIS (solar disinfection).
- **Water-quality diseases**:
  - excess fluoride: **fluorosis**
  - nitrate: **blue-baby syndrome** (methaemoglobinaemia)
  - arsenic: **arsenicosis** and black-foot disease (West Bengal, Bihar)
  - mercury: **Minamata** disease
  - cadmium: **itai-itai** disease
- **Jal Jeevan Mission** (2019) aims to give every rural household a **Functional Household Tap Connection (FHTC)** supplying **55 litres per capita per day** of potable water.

Important Days

- **World Food Safety Day: 7 June**. It was declared by the UN General Assembly in Dec 2018 and **first observed in 2019**, facilitated by **WHO and FAO**. Themes: 2024 "Food safety: prepare for the unexpected"; 2025 "Food Safety: Science in Action". FSSAI releases the **State Food Safety Index** on this day.

CODE UPDATE

FSSAI split the old Packaging & Labelling Regulations 2011 into the **FSS (Packaging) Regulations 2018** and the **FSS (Labelling & Display) Regulations 2020**. Online licensing moved from FLRS to **FoSCoS** in 2020. Aflatoxin limits were tightened from the old blanket **30 µg/kg** to commodity-wise limits (**15 µg/kg for cereals**).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- FSSAI was established under which Act? → **Food Safety and Standards Act, 2006** (Authority set up in 2008).
- How many principles does HACCP have? → **Seven** (the first is hazard analysis).
- Codex Alimentarius Commission was set up by? → **FAO and WHO (1963)**.
- Argemone oil in mustard oil causes? → **Epidemic dropsy** (nitric acid test).
- Metanil yellow in turmeric is detected with? → **Conc. HCl** (pink/magenta colour).
- World Food Safety Day is observed on? → **7 June**.

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10. Storage Pests, Rodents, Insecticides & Toxicology

NOTE

This is the core chapter for a CWC technical post. CWC's main job is **scientific storage**: keeping grain dry and cool, controlling insects, rodents and birds, and running **prophylactic and curative (fumigation) pest control**, including its own Pest Control Services. Expect 12–18 MCQs from here. Typical questions ask for a pest's scientific name, order or family and damaging stage; primary versus secondary pests; aluminium phosphide chemistry and dosage; methyl bromide status; rodenticide bait strengths and antidotes; the LD_{50} colour-band table; insecticide modes of action; and banned or restricted pesticides.

10.1 Scientific Storage of Foodgrains ★★★

- **Scientific storage** keeps grain safe in **quantity and quality** by controlling **moisture, temperature, insects, micro-organisms, rodents and birds**, using proper structures, hygiene, prophylactic sprays and fumigation.
- **Storage losses** come in several forms: **quantitative** (weight loss), **qualitative** (nutrient loss, off-odour, discolouration, mycotoxins, contamination by insect fragments, uric acid and rodent hair or droppings), loss of **germination** in seed, and **economic** loss (lower price, rejection).
- Causes are **biotic** (insects, moulds, rodents, birds, mites) and **abiotic** (moisture, temperature, RH, O_2, poor structures, leaky roofs, rough handling).
- **ICAR-CIPHET (Ludhiana) study, 2015** (data for 2012–14): harvest and post-harvest losses were cereals **4.65–5.99%**, pulses **6.36–8.41%**, oilseeds **3.08–9.96%**, fruits & vegetables **4.58–15.88%**. The value of the loss was **≈ ₹92,651 crore/year**.
- A later **NABCONS study (2022, for MoFPI)** put total losses at **≈ ₹1.53 lakh crore** (2020–22). Losses in cereals and pulses were lower than in 2015; for example, paddy ≈ 4.8% and wheat ≈ 4.2%.

Factors affecting stored grain

Factor	Key facts
Moisture content (m.c.)	**The single most important factor.** High m.c. raises respiration, heating, mould and insect activity. Most insects need grain m.c. > ≈ 9–10%. Mites need ≈ 13–14% or more (they do not breed below ≈ 65% RH). Moulds grow at ≈ 14% or more (RH above ≈ 70%). **Khapra** can survive on very dry grain (≈ 2% m.c.).
Relative humidity	Grain is **hygroscopic** and reaches **equilibrium moisture content (EMC)** with the surrounding air. RH below ≈ **65–70%** is safe. Storage fungi (*Aspergillus*, *Penicillium*) grow above ≈ 70% RH; *A. flavus* produces **aflatoxin**.
Temperature	Optimum for most storage insects is **≈ 25–35 °C** (peak ≈ 30 °C). Development nearly stops below ≈ **15–17 °C**. Insects die above ≈ **40–45 °C**. Tropical India is therefore ideal for storage pests.
Oxygen / CO_2	Insects and moulds need O_2. In **hermetic storage**, respiration lowers O_2 (to below ≈ 2–5%) and raises CO_2, which kills insects.
Grain respiration	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + **heat (≈ 2870 kJ/mol)**. The heat and water released lead to **hot spots**.
Insects	Cause **"dry grain heating"** (up to ≈ 42 °C).
Moulds	Cause **"damp/wet grain heating"** (can go above 60 °C, leading to caking and, in extreme cases, charring).
Rodents, birds	Eat grain, cut bags, and contaminate with droppings, urine and hair. They spread diseases such as **plague, leptospirosis and salmonellosis**.

- **Moisture migration**: in bulk storage, a temperature difference sets up **convection currents**. In cold weather, warm moist air rises through the centre and condenses at the **cool top surface**, causing crusting and sprouting there.
- **Hot spot**: a pocket of heated grain from insect or mould activity. Detect it with **thermometers or temperature probes** (thermocouple cables in silos).

Safe storage moisture

Commodity	Safe m.c. for storage (approx.)	Note
Cereals (wheat, maize, sorghum, milled rice)	**10–12%** (≤ 12% for long storage)	FCI uniform specification maximum m.c.: **wheat 12%, rice 14%, coarse grains 14%**
Paddy	≈ **13–14%** (dry before storage)	FCI procurement maximum m.c. for paddy = **17%**
Pulses	**≈ 9–10%**	Bruchids are the main pest
Oilseeds (groundnut kernel, mustard)	**≈ 7–8%** (groundnut kernel ≈ 7%)	Oil-rich seeds absorb less water, so they need a lower m.c. They are prone to rancidity and aflatoxin.

KEY FORMULAE / RULES

- Moisture % (wet basis) = $(W_{water} \div W_{wet\ grain}) \times 100$. Moisture % (dry basis) = $(W_{water} \div W_{dry\ matter}) \times 100$. Wet basis is used in trade.
- Weight after drying: $W_2 = W_1 \times (100 - M_1) \div (100 - M_2)$.
- **Harrington's thumb rules** (seed): each **1% fall in seed m.c.** or each **5 °C fall in temperature** roughly **doubles seed life**. Safe storage when **RH% + temperature (°F) ≤ 100**.

Storage structures

Structure	Type / material	Key features
Kothi / mud kothi	Traditional; mud with straw and cow dung, or wood	Indoor farm-level bin. Not rodent- or moisture-proof.
Bukhari	Traditional; cylindrical, of bamboo or wood plastered with mud, on a raised platform	Outdoor. Common in eastern India (Bihar).
Morai	Traditional; ropes of straw or grass coiled on a raised platform, tapering at the bottom	Paddy and maize storage in eastern and southern India
Kothar	Traditional wooden box-type store on raised pillars	Larger capacity (paddy, south India)
Pusa bin	Improved; developed by **IARI (Pusa)**. Unburnt mud bricks with a **polythene film sandwiched** in floor, walls and roof.	Moisture-proof, cheap, farm-level; has a bottom outlet

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Hapur tekka	Improved; rubberised-cloth cylinder on a bamboo/metal frame	Bottom outlet; developed at Hapur (now IGMRI, Hapur)
Metal bins (GI sheet)	Improved; farm and household use	Rodent-proof and fumigable
CAP (Cover & Plinth)	Open storage on a raised **brick/cement plinth** with **wooden crate dunnage**. Stacks covered with **black LDPE covers** and tied down with nylon ropes or nets.	Low-cost, **temporary/short-term** storage used by FCI for **wheat (and paddy)**. Stacks are given a dome-shaped top so rain runs off.
Conventional godown	Permanent covered warehouse with bagged storage	Raised rat-proof plinth, dunnage, stacks with gangways, ventilators. Can be sealed for fumigation.
Silos	Vertical **steel** (or RCC) bins for **bulk** grain	Mechanised handling, **aeration** and **temperature cables**, little floor space, low handling loss. The Govt's action plan for **100 LMT steel silos** uses PPP / hub-and-spoke models.
Hermetic storage	Air-tight bags or "cocoons" (e.g. triple-layer **PICS bags**, super grain bags)	O_2 depletion and CO_2 build-up kill insects. No chemicals are used.

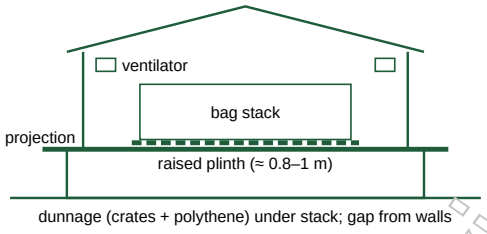

Fig. 10.1 Cross-section of a conventional godown. The raised plinth with a projection (overhang) stops rats climbing; stacks stand on dunnage, clear of the walls.

Godown norms & practices

- **Site**: high, well-drained land with a pucca approach road and rail/road access, away from water-logging. Long axis roughly **east–west**, to reduce sun on the long walls.
- **Plinth**: raised ≈ **0.8 m** above ground (NABARD rural godown model). Road-fed godowns match truck-floor height; rail-fed godowns match wagon height. A **projection (overhang) of ≈ 15–18 cm** at plinth level makes it **rat-proof**.
- **Floor**: cement concrete with a **damp-proof course (DPC)**. Walls are plastered and free of cracks, and roofs leak-proof.
- **Ventilators** are placed near the top of the walls and covered with **wire mesh** against birds and rats. **Ventilate on dry, sunny days** and **close in rain or humid weather**.
- **Dunnage** is the material placed under stacks to stop **moisture rising from the floor** and to allow air flow: **wooden or plastic crates**, polythene sheets, bamboo mats. Grain bags must **never touch the floor or walls directly**.
- **Stacks**: the standard FCI-type stack is **≈ 9.1 m × 6.1 m** (30 ft × 20 ft), with an ideal height of **≈ 4.5 m** (15 ft). Stacks are built in a **criss-cross/interlocking** pattern for stability (NABARD model: 9.15 m × 6.1 m × 4.57 m). Each stack is kept **clear of the walls** (typically **≈ 0.6–1 m**; FSSAI warehouse guidance: **≥ 1 m** from walls and from the next stack), with **gangways/alleys** (typically ≈ 1–2 m wide, about a quarter of the floor area) between stacks for inspection, spraying and fumigation.
- **Bags**: jute (gunny, B-Twill, 50 kg) or **HDPE/PP woven** bags. New bags are preferred; old bags are disinfested before reuse.
- **Hygiene & sanitation**: clean the godown before loading; sweep daily; remove and burn sweepings and spilled or infested grain; fill cracks and crevices (insect hideouts); disinfest empty godowns, bags, vehicles and crates; keep a separate quarantine area for infested stock; and **store pesticides away from foodgrains**.
- **Stack card**, displayed at each stack, records the stack no., commodity and variety, crop year, depositor, date of receipt, number of bags and weight, and the dates and dosages of **prophylactic and curative treatments** and inspections.
- **FIFO** (First-In-First-Out): the oldest stock is issued first, which avoids long storage and deterioration. FEFO (First-Expiry-First-Out) is used for packaged goods.
- **Inspection**: technical staff inspect stocks at regular intervals (**fortnightly**, per WDRA advisory to warehousemen) for insects, moulds, heating, moisture, rodent and bird activity, and leaks.
- **Sampling**: bags are sampled with a **bag trier / spear (probe)** pushed diagonally into the bag. Bulk grain is sampled with a **double-tube (compartment) probe** at several depths. The composite sample is reduced by **quartering** or a **Boerner/riffle divider**.

Prophylactic treatment	Curative treatment
Preventive: applied **before infestation** appears, or to keep surfaces free of insects	Applied **after infestation is detected**, to kill all insect stages
Contact insecticide sprays (malathion 50% EC, deltamethrin 2.5% WP) on **bag surfaces, floors, walls and alleys**; plus disinfestation of empty godowns	**Fumigation** (aluminium phosphide → phosphine) under gas-proof covers, or of a sealed godown
Kills **exposed or crawling** insects; **does not reach hidden stages inside grain**	Fumigant gas **penetrates bags and kernels** and kills internal stages
Repeated at intervals (malathion ≈ fortnightly; deltamethrin ≈ quarterly)	Done as needed after inspection; exposure period ≈ 7 days (≥ 7 days per FAO)

MEMORY TRICK

Safe moisture "**12–10–8**": **cereals 12**, **pulses 10**, **oilseeds 8** (each about 2 points lower; an oilier seed needs drier storage).
"**Spray prevents, gas cures**": spray = prophylactic, fumigation = curative.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Most important factor deciding the safe storage of grain? → **Moisture content**.
- CAP storage stands for? → **Cover and Plinth** (open storage on a plinth under polythene covers).
- Material placed under bag stacks to prevent moisture rise? → **Dunnage** (wooden or plastic crates, polythene sheets).
- Pusa bin was developed by? → **IARI, New Delhi**: mud bricks with a polythene film inside.
- Stock-issue principle followed in warehouses? → **FIFO** (First-In-First-Out).
- Safe moisture for storing oilseeds? → **≈ 7–8%**.

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10.2 Stored Grain Insect Pests ★★★

- Most stored-grain pests belong to **Coleoptera** (beetles and weevils, the largest group) and **Lepidoptera** (moths). In moths **only the larva** damages grain. In beetles, adults and grubs often both feed. Exception: in **khapra** and **bruchids**, only the larva feeds on the grain.
- **Primary pests** attack **sound, whole grains**.
  - **Internal feeders** complete their development **inside the kernel**: rice weevil, maize weevil, lesser grain borer, Angoumois grain moth, pulse beetle.
  - **External feeders** feed from outside, often starting at the germ: **khapra beetle**. Some texts list khapra as a secondary pest.
- **Secondary pests** cannot easily attack sound grain. They feed on **broken, damaged grain, flour and milled products**, often after primary pests. Examples: red flour beetle, saw-toothed grain beetle, flat grain beetle, rice moth, almond moth, Indian meal moth.
- **Field-to-store carry-over** pests infest the crop before harvest: **maize weevil, Angoumois grain moth, pulse beetle** (on pods), and lesser grain borer.
- **Hidden infestation**: internal feeders live inside the kernel, so grain can look sound while it carries eggs, larvae or pupae.

Common name	Scientific name	Order : Family	Damaging stage	Main hosts / key ID
PRIMARY – internal feeders				
Rice weevil	***Sitophilus oryzae***	Coleoptera : Curculionidae	**Adult and grub**	Rice, wheat, maize, sorghum. Adult has a snout (**rostrum**) and 4 reddish spots on the elytra. The female chews a hole, lays an egg and seals it with a **gelatinous egg plug**. The grub feeds inside and the adult exits through a round hole.
Maize weevil	*S. zeamais*	Coleoptera : Curculionidae	Adult and grub	Maize. Slightly larger than the rice weevil and a **strong flier** that infests the crop in the field.
Lesser grain borer	***Rhyzopertha dominica***	Coleoptera : **Bostrichidae**	**Adult and grub**	Wheat, paddy, rice. Cylindrical body with the **head hidden under a hood-like pronotum**. Produces a lot of **floury frass**. Strong flier. A major **phosphine-resistant** pest.
Angoumois grain moth	***Sitotroga cerealella***	Lepidoptera : **Gelechiidae**	**Larva** (internal)	Paddy, maize wheat. Infes the **surface layer** of bulk grain. The adult escape through a th "**window**" in the grain. Hi wings are narrow and pointed, wit long fringes. Field carry-over.
Pulse beetle (bruchid)	***Callosobruchus chinensis***, *C. maculatus* (cowpea weevil)	Coleoptera : **Chrysomelidae (Bruchinae)**, formerly Bruchidae	**Grub** (internal)	All pulses. **Eg are glued** to the seed surface. The grub bores i and develop inside one seed, and th adult leaves **round exit hole**. Infestation starts on **poo in the field**. Adults are short-lived.
PRIMARY – external feeder				
Khapra beetle	***Trogoderma granarium***	Coleoptera : **Dermestidae**	**Only the larva** (adults do not feed or fly)	Wheat and other cereal pulses, oilseeds. The larva is **hairy** (barbed/spe headed hairs It can enter **facultative diapause** in cracks for lo periods without food which makes **tolerant of fumigants**. Thrives in **ho dry** areas (N India). A serious **quarantine pest** worldw and one of t "**100 worst invasive species**".
SECONDARY pests				

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Red flour beetle	***Tribolium castaneum***	Coleoptera : **Tenebrionidae**	Adult and grub	Flour, broken grain, rice bran. Antenna has an **abrupt 3-segmented club** (in *T. confusum* the club is gradual). Secretes **benzoquinones** that give flour a **pungent odour and pinkish tinge**. Highly phosphine-resistant.
Saw-toothed grain beetle	*Oryzaephilus surinamensis*	Coleoptera : Silvanidae	Adult and grub	Broken grain, dried fruits. Has **6 saw-like teeth on each side of the prothorax**.
Flat grain beetle	*Cryptolestes* spp. (*C. pusillus*, *C. ferrugineus*)	Coleoptera : Laemophloeidae (formerly Cucujidae)	Grub (feeds on **germ**)	Very small, flat beetle with long antennae. *C. ferrugineus* shows **strong phosphine resistance**.
Cigarette beetle	*Lasioderma serricorne*	Coleoptera : **Anobiidae**	Grub	Tobacco, **spices, turmeric**, coriander, dry fish. Has **serrate antennae** and a deflexed head (humped look).
Drugstore beetle	*Stegobium paniceum*	Coleoptera : Anobiidae	Grub	Drugs, spices, biscuits. Antenna has a loose 3-segmented club and the elytra are striated.
Rice moth	***Corcyra cephalonica***	Lepidoptera : Pyralidae	Larva	Milled rice, flour, oilseeds. The larva spins dense **silken webbing** that forms lumps. Used in labs to **mass-rear *Trichogramma*** **and *Chrysoperla***.
Indian meal moth	*Plodia interpunctella*	Lepidoptera : Pyralidae (Phycitinae)	Larva	Dried fruits, nuts, grain products. Forewing is **two-coloure** the basal pa pale and the outer two-thirds coppe red. Larvae web the produce.
Almond moth (fig moth)	*Cadra* (*Ephestia*) *cautella*	Lepidoptera : Pyralidae (Phycitinae)	Larva	Bagged grai surfaces, da groundnut. Grey forewings. Larvae web surface of b and stacks.
Groundnut bruchid	*Caryedon serratus*	Coleoptera : Chrysomelidae (Bruchinae)	Grub	Stored **groundnut pods** and tamarind. Th grub bores through the pod into the kernel.
Psocids (booklice)	*Liposcelis* spp.	Psocoptera : Liposcelididae	Nymph and adult	Tiny, soft-bodied and wingless. Thrive in **hig humidity** an feed on mou and broken grain. Tolera of phosphin
Grain / flour mite	*Acarus siro*	**Acari** (Arachnida) : Acaridae (not an insect; 8 legs)	All stages	Damp grain and flour (m ≥ ≈ 13–14%) Gives a **mint sickly odour** and causes "**grocer's itc** dermatitis.

- The **granary weevil** *Sitophilus granarius* **cannot fly** (its hind wings are vestigial) and is a pest of cooler climates.
- Most damaging pests of stored **wheat** in India: **khapra beetle, lesser grain borer and rice weevil**. Of **pulses**: **pulse beetle**. Of **milled rice and flour**: **red flour beetle and rice moth**. Of **spices and tobacco**: **cigarette beetle**.
- A rice weevil female lays ≈ 300–400 eggs, one per grain. At ≈ 30 °C and 70% RH, its life cycle takes about **4–5 weeks**.

Detection of infestation

Method	Principle / what it detects
Visual inspection, sieving	Live or dead insects, webbing, **frass**, exit holes, insects on bags, walls and ceilings (better at dusk and dawn).
Traps	**Probe/pitfall traps** pushed into bulk grain. **Pheromone traps**: aggregation pheromones for *Tribolium* and *Trogoderma*, sex pheromones for moths and *Lasioderma*. Light traps for moths.
Grain temperature	**Hot spots** found with probes or cables

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Uric acid test	Insect excreta contain uric acid. The FSSAI limit for foodgrains is **≤ 100 mg/kg**.
Hidden (internal) infestation tests	
Staining	**Acid fuchsin** stains weevil **egg plugs cherry-red**. **Gentian violet** or iodine are also used. **Berberine sulphate** makes egg plugs and feeding holes fluoresce under UV.
Flotation	Infested, hollow kernels have lower density and **float** in water or a salt/specific-gravity solution.
Cracking-flotation	Grain is ground and insect fragments are separated by oil-water flotation. Used as a "**filth test**".
X-ray radiography	Shows **larvae, pupae and cavities** inside kernels without destroying them. Very accurate.
CO_2 measurement	Infested samples respire more and give off more CO_2. This shows the **level** of hidden infestation.
Ninhydrin test	Grain is crushed on ninhydrin-treated paper. Insect body fluids, which are rich in amino acids, leave **purple spots**.
Acoustic detection; NIR spectroscopy; ELISA (insect myosin)	Detect feeding sounds, spectral change, or insect protein

MEMORY TRICK

Primary internal "WeB MoP": **We**evils (*Sitophilus*), **B**orer (*Rhyzopertha*), **Mo**th (*Sitotroga*), **P**ulse beetle (*Callosobruchus*). **Secondary "FIRST SAW Flat"**: **F**lour beetle (*Tribolium*), **I**ndian meal moth, **R**ice moth (*Corcyra*), **SAW**-toothed beetle, **Flat** grain beetle. **Khapra = "Kid only"**: only the larva damages.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Stored-grain pest in which only the larva damages and which is a major quarantine pest? → **Khapra beetle, *Trogoderma granarium*** (Dermestidae).
- Lesser grain borer belongs to family? → **Bostrichidae** (*Rhyzopertha dominica*).
- Stain used to detect weevil egg plugs? → **Acid fuchsin** (cherry-red).
- Rice moth is scientifically known as? → ***Corcyra cephalonica***, used to rear *Trichogramma*.
- Prothorax with six saw-like teeth on each side? → ***Oryzaephilus surinamensis***.
- Pest of turmeric, spices and tobacco in storage? → **Cigarette beetle (*Lasioderma serricorne*)**.

10.3 Rodents, Birds & Their Control ★★★

- Rodents belong to order **Rodentia** and rats and mice to family **Muridae**. They have a pair of **continuously growing incisors**, have **no canines** (the gap is the **diastema**), and must **gnaw** to keep the incisors short. Rats **cannot vomit**, which is why single-dose acute poisons work.
- Rodents are prolific breeders: gestation is ≈ **3 weeks** and rats are sexually mature at ≈ 2–3 months. They are nocturnal, **neophobic** (suspicious of new objects), and have keen smell, taste and touch but poor eyesight.
- Losses: grain eaten and hoarded (bandicoots hoard grain in burrows); much more is **contaminated** by droppings, urine and hair; bags, structures and electric wires are damaged.
- Rodent-borne diseases: **plague** (*Yersinia pestis*, spread by the rat flea *Xenopsylla cheopis*), **leptospirosis** (Weil's disease, via urine), salmonellosis, murine typhus and rat-bite fever.

Rodent	Scientific name	Habit / identification
House rat / roof rat / black rat	***Rattus rattus***	Commensal. Good **climber** that lives on roofs and rafters. **Tail longer than head + body.** Large ears, pointed snout. Spindle-shaped droppings.
Norway / brown / sewer rat	***Rattus norvegicus***	Large and heavy. **Burrows** under floors and foundations, near drains and ports. **Tail shorter than head + body.** Blunt snout, small ears. Capsule-shaped droppings.
Lesser bandicoot rat	***Bandicota bengalensis***	**The most widespread and destructive rodent in India**, in both fields and godowns. Prolific **burrower** that **hoards** grain and grunts when disturbed. Main pest of godowns and urban areas.
Large bandicoot	*Bandicota indica*	Very large and burrowing. Found in wet areas and paddy fields.
House mouse	***Mus musculus***	Small. Lives in stacks and bags. Small rod-shaped droppings. Can pass through ≈ **6 mm** gaps.
Soft-furred field rat	*Millardia meltada*	Field rat with soft fur, in irrigated and dry crops
Indian gerbil (antelope rat)	*Tatera indica*	Field pest in dry areas
Indian desert gerbil	*Meriones hurrianae*	Desert (Rajasthan) rodent

- **Signs of rodent infestation**: droppings (the most reliable sign; fresh ones are soft and shiny), **runways**, **rub marks** (greasy smudges), **gnawing marks**, cut bags with spilled grain, **burrows** with fresh soil, **tracks** (seen on tracking powder or dust), urine stains (which fluoresce under UV), odour, sounds, and live or dead rodents.
- **Rodent-proofing a godown**:
  - Raised plinth with a **projection/overhang (≈ 15–18 cm)** that rats cannot climb past.
  - **Close-fitting doors** with **metal sheeting on the lower part**; gaps under doors kept below ≈ 6 mm.
  - **Wire mesh** on ventilators, drains and windows.
  - Conical **rat guards/flanges** on pipes and cables.
  - **Movable steps**, removed when not in use.
  - No trees or creepers touching the building.
  - Holes and cracks sealed with cement and glass pieces or metal.
- **Sanitation**: remove spilled grain, rubbish and weeds around the godown to deny food and shelter.
- **Mechanical control**: snap (break-back) traps, **cage / multiple-catch "wonder" traps**, **glue boards**, and the **Tanjore bow trap** for field rodents. Place traps along runways and walls, and pre-bait them.
- **Biological control**: predators such as owls (the barn owl), snakes and cats.

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Rodenticides

Feature	Acute (single-dose, fast) rodenticides	Chronic / anticoagulant rodenticides
Examples	**Zinc phosphide (Zn_3P_2)**; barium carbonate (old); **aluminium phosphide** as a **burrow fumigant**	**First generation, multiple-dose**: **warfarin** (the first, a hydroxycoumarin), **coumatetralyl**, chlorophacinone. **Second generation, single-dose**: **bromadiolone**, brodifacoum, difenacoum.
Bait strength (commonly used)	**Zinc phosphide 2%** bait: ≈ 96 parts cereal (broken grain/flour) + 2 parts edible oil + 2 parts ZnP	**Bromadiolone 0.005%** (1 part 0.25% CB + 49 parts bait); **warfarin ≈ 0.025%**; coumatetralyl ≈ 0.0375%
Mode of action	ZnP + **stomach HCl → phosphine (PH_3)**, a respiratory poison. Death in a few hours. Has a **garlic odour**.	**Inhibit vitamin K epoxide reductase**, which lowers clotting factors **II, VII, IX and X** and causes **internal haemorrhage**. Death in ≈ 4–10 days.
Pre-baiting	**Essential**: 2–3 days of plain (poison-free) bait to overcome **neophobia**	Not needed
Bait shyness	**Yes**. Sub-lethal doses make rats sick, and they learn to avoid the bait. Do not repeat ZnP for ≈ 3 months; switch to an anticoagulant.	**No bait shyness**, because symptoms appear late
Antidote	No specific antidote (supportive treatment)	**Vitamin K_1 (phytonadione)**
Hazard to non-targets	Highly toxic to all animals. Use only in tamper-proof bait stations.	Safer because of the antidote, but secondary poisoning of predators is possible with 2nd-generation compounds. Resistance to warfarin is known (the "super rats" of Europe).

- **Burrow fumigation**: place **aluminium phosphide** (typically **2 pellets of 0.6 g**; some texts 1 tablet of 3 g) in each **live burrow** and **close all openings with mud**. Live burrows are identified by first closing all burrows and seeing which are reopened the next day.
- **Integrated rodent management**: proofing + sanitation + trapping + baiting (acute first, then an anticoagulant to clear survivors) + monitoring.
- Rodenticide formulations: CB (concentrate bait), RB (ready-to-use bait), wax blocks/cakes for damp places, and tracking powder.

Bird control

- Pest birds in godowns include **house sparrows, pigeons (rock dove), crows and mynas**. They eat grain, contaminate it with droppings and feathers, damage bags, and spread disease (salmonellosis, **histoplasmosis** and psittacosis/ornithosis from droppings).
- Control is **exclusion and scaring, not poisoning**: **bird-proof wire mesh/netting** on ventilators and windows, doors kept closed, **no spilled grain**, removal of nests, anti-perching spikes, reflective tapes, scare guns and distress calls. Most wild birds are protected under the **Wild Life (Protection) Act, 1972**.

KEY REACTIONS

- Zn_3P_2 + 6HCl (stomach) → $3ZnCl_2$ + **$2PH_3$ ↑**
- Bait preparation: **% in bait = (% a.i. of concentrate × parts of concentrate) ÷ total parts**. Example: 0.25% CB × 1 ÷ 50 = **0.005%** bromadiolone.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Most destructive rodent of Indian agriculture and godowns? → **Lesser bandicoot, *Bandicota bengalensis***.
- Rodent that burrows and has a tail shorter than head + body? → **Norway/brown rat, *Rattus norvegicus***.
- Bait concentration of zinc phosphide used for rats? → **2%** (acute; needs pre-baiting).
- Single-dose (2nd-generation) anticoagulant rodenticide? → **Bromadiolone** (0.005% bait).
- Antidote for anticoagulant rodenticide poisoning? → **Vitamin K_1**.
- Learned avoidance of a poison bait after a sub-lethal dose is called? → **Bait shyness**.

10.4 Fumigation & Fumigants ★★★

- A **fumigant** is a chemical that, at the required **temperature and pressure**, exists in the **gaseous state** in enough concentration to kill pests. It **penetrates** commodities (bags, kernels) and kills hidden stages.
- **Fumigation** means applying a fumigant in a **gas-tight enclosure** (a stack under a gas-proof cover, a sealed godown, a silo, a container or a chamber) for a **set exposure period**.
- **Fumigation is curative**. It has **no residual protection**, so the commodity can be re-infested immediately after aeration.
- Efficacy depends on the **Ct product** (concentration × time, g·h/m³), temperature (efficacy falls at low temperature), gas-tightness, commodity sorption, insect species and stage, and resistance. For phosphine, **time matters more than concentration**.
- **Properties of an ideal fumigant**: highly toxic to all insect stages (including eggs and pupae); low mammalian toxicity; good penetration and diffusion and quick aeration; **non-flammable** and non-explosive; non-corrosive; no residue, taint or odour left in food; **no effect on germination** or baking quality; easily **detectable** (warning odour); cheap, stable and easy to apply; ozone-safe.

Phosphine (PH_3) from aluminium phosphide: the main fumigant in CWC/FCI godowns

- **Formulation**: **aluminium phosphide (AlP) 56%** as **3 g tablets** (brand e.g. Celphos, Quickphos) or **0.6 g pellets**, plus sachets/bags. Tablets also contain **ammonium carbamate**, which releases **NH_3 and CO_2** to reduce fire hazard and give a warning odour.
- **Reaction**: AlP reacts with **atmospheric moisture**: **$AlP + 3H_2O \rightarrow Al(OH)_3 + PH_3$ ↑**. The grey-white residue is aluminium hydroxide.
- One **3 g tablet → ≈ 1 g PH_3**; one **0.6 g pellet → ≈ 0.2 g PH_3**. Gas release starts after ≈ 1–4 h and is complete in ≈ 1–3 days, depending on temperature and humidity.
- **Properties of PH_3**: colourless gas, molecular weight **34**, boiling point **−87.7 °C**, **slightly heavier than air** (≈ 1.2), highly diffusive and penetrating. **Pure phosphine is odourless.** The **garlic/carbide**

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(fishy) odour comes from **impurities** such as diphosphine (P_2H_4). Because of this, **odour is not a reliable warning**.

- **Flammable/explosive** above **≈ 1.8% v/v** (lower explosive limit ≈ 1.79%, about 17,900 ppm). It can **ignite spontaneously** because of diphosphine. **Never heap tablets or wet them**; spread them on trays or paper.
- It **corrodes copper, brass, silver and gold**, so it damages electrical wiring, switches and electronics. Remove or protect such items.
- **Advantages**: leaves almost **no residue** (it converts to harmless phosphate), does **not affect germination** at normal doses, is easy to apply, and penetrates well. It is the **most widely used grain fumigant** worldwide.
- **Limitations**: **slow action** (needs a long exposure); eggs and pupae are tolerant; needs **≥ 15 °C** (below this, avoid or extend exposure); **high resistance** has developed in India in *R. dominica*, *T. castaneum*, *S. oryzae*, *Cryptolestes* and psocids, caused by repeated under-dosing and leaky covers.
- **Mode of action**: a **respiratory poison** that inhibits **cytochrome c oxidase** in mitochondria and causes oxidative stress. IRAC group **24A**.

Situation	Aluminium phosphide dosage (standard values)	Exposure
Bag stacks under gas-proof cover (CWC/FCI practice)	**9 g AlP per tonne = 3 tablets of 3 g per tonne** (≈ 3 g PH_3/t). FAO range: 3–5 g PH_3/t.	**7 days** at > 25 °C; ≈ 10 days at 15–25 °C; not below 15 °C (FAO). Some Indian texts: 5–7 days.
Bulk grain in gas-tight silos/bins	FAO: ≈ **2–4 g PH_3 per tonne** (≈ 2–4 tablets/t)	7 days or more
Space fumigation of an empty, sealed godown	FAO: ≈ **1 g PH_3/m³** (≈ 1 tablet per m^3)	≈ 5–7 days
Rodent burrows	≈ 2 pellets (0.6 g) per live burrow (some texts: 1 tablet of 3 g)	Burrow sealed

Magnesium phosphide

- **$Mg_3P_2 + 6H_2O \rightarrow 3Mg(OH)_2 + 2PH_3\uparrow$**
- Supplied as **plates, strips** and pellets.
- **Releases gas faster** than AlP and works better at lower temperature and humidity.
- Leaves less residue.

Other fumigants

Fumigant	Key facts	Status
Methyl bromide (CH_3Br, MB)	Boiling point **3.6 °C** (a gas at room temperature). **≈ 3.3 times heavier than air** and **odourless**, so ≈ **2% chloropicrin** is added as a warning agent. **Fast** (24–48 h exposure), kills all stages, penetrates well. Can **reduce germination** and leaves bromide residues. Detected with a **halide leak detector lamp** (the flame turns blue-green). Non-flammable.	**Ozone-depleting substance** controlled under the **Montreal Protocol (1987)**. Phased out in developed countries in 2005 and in developing (Art. 5) countries such as **India by 1 Jan 2015**, **except for QPS uses** (Quarantine & Pre-Shipment), which are exempt. In India it is a **restricted pesticide**, used only by Govt or approved PCOs under expert supervision, mainly for **plant-quarantine / export (QPS) fumigation** by accredited agencies.
Ethylene dibromide (EDB)	A liquid fumigant once used for grain and fruit-fly treatment. Carcinogenic.	**Banned in India**
EDCT (ethylene dichloride + carbon tetrachloride, 3 : 1)	Older liquid fumigant mixture for farm storage	Obsolete (CCl_4 is an ozone-depleting substance)
Carbon disulphide (CS_2)	Old liquid fumigant, heavier than air, **highly flammable** (ignites easily) with a rotten-cabbage odour	Obsolete
Hydrogen cyanide (HCN)	Very fast and very toxic to mammals. Once supplied as calcium cyanide.	Calcium cyanide banned; sodium cyanide banned for insecticidal use (2018 order)
Sulfuryl fluoride (SO_2F_2)	Odourless, non-flammable, fast, penetrating. **Not ozone-depleting**, but a greenhouse gas. **Weak against eggs**. Used as an MB alternative in mills and structures.	MB alternative
Ethyl formate	A natural compound that breaks down to **ethanol + formic acid**. Fast-acting with low residue, but flammable (used mixed with CO_2). Suits dried fruits and quick treatments.	MB alternative
CO_2 / N_2 (modified or controlled atmosphere)	Either **CO_2 above ≈ 35% for 10–15 days** (FAO: start > 70%, hold > 35% for ≥ 10 days), or **N_2 flushing to O_2 below ≈ 1%**. Hermetic storage is a "bio-generated" modified atmosphere. Leaves **no chemical residue**, so it is suitable for organic produce, but it is slow and needs very gas-tight structures.	Eco-friendly

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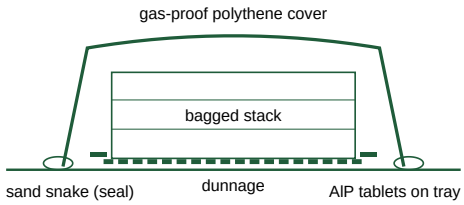

Fig. 10.2 Fumigating a bag stack under a gas-proof cover. AlP tablets are spread on trays at the stack base inside the cover, and the cover edges are sealed to the floor with sand snakes.

Fumigation procedure (stack fumigation)

- **Step 1.** Inspect the stock and confirm infestation. Calculate the stack volume or tonnage and the dose. Arrange the cover, tablets, gas masks, detector and warning signs. **Never fumigate alone**; work in a team of at least 2, with a trained, licensed operator.
- **Step 2.** Check the **cover for holes** and repair it. Gas-proof covers are **LDPE** sheets (traditionally ≈ 200–250 µm, i.e. ≈ 800–1000 gauge; 1 µm ≈ 4 gauge) or, in current Govt procurement, **cross-laminated thermoplastic (HDPE) fumigation covers of ≥ 200 GSM** (IS 14611, heavy-duty).
- **Step 3.** Spread the tablets on trays or paper **at the base, along the sides, inside the cover**, and place them quickly. Wear **gas masks** if the operation takes long.
- **Step 4. Seal** the cover edges to the floor with **sand snakes** (long sand-filled tubes) or mud plaster.
- **Step 5.** Display **"DANGER – FUMIGATION IN PROGRESS – POISONOUS GAS"** signs with skull and crossbones, the date and the operator's name. Lock the godown.
- **Step 6. Check for leaks** with a detector and re-seal as needed. Keep the stack under gas for **≈ 7 days** (longer in cool weather).
- **Step 7. De-gassing (aeration)**: lift the cover from the leeward side and open doors and ventilators. Allow re-entry only when PH_3 is **below the TLV**. Dispose of the spent residue ($Al(OH)_3$ with a little unreacted AlP) by burying it, or deactivate it in water outdoors.
- **Step 8. Evaluate**: check for live insects or use **bio-assay cages** of test insects. Record the treatment on the **stack card**.

Safety in fumigation

Item	Value / practice
TLV of phosphine	**0.3 ppm (8-h TWA)**; STEL 1 ppm. This is the value in Indian texts and labels (same as OSHA PEL / NIOSH REL). **ACGIH lowered the TWA to 0.05 ppm** (STEL 0.15 ppm) in **2017**. IDLH (NIOSH) = **50 ppm**.
TLV of methyl bromide	≈ **1 ppm** (ACGIH TWA)
Respiratory protection	**Full-face gas mask with a canister** specific to the fumigant. Canisters have a limited life and must be replaced. Use **self-contained breathing apparatus (SCBA)** at high or unknown concentrations.
Gas detection	PH_3: **silver nitrate ($AgNO_3$) paper turns black/brown** (qualitative); **detector tubes** (Dräger, Gastec); electronic monitors. MB: **halide lamp** and detector tubes.
Phosphine poisoning symptoms	Headache, dizziness, nausea, vomiting, chest tightness, cough, breathlessness, then **pulmonary oedema**, cardiac shock and death. **There is no specific antidote**; give fresh air, rest and supportive treatment.
Fire precautions	Do not heap tablets; keep them away from water and liquid; open tins outdoors (flash risk); do not smoke; keep sand handy. **Never use water on burning AlP**.

Prophylactic spraying (godown surfaces and stacks)

Insecticide	Dilution (CWC/FCI practice)	Spray volume	Interval
Malathion 50% EC	**1 : 100** (1 L in 100 L water, ≈ 0.5% a.i.)	**3 L of spray per 100 m²**	≈ **Fortnightly**
Deltamethrin 2.5% WP	**40 g per litre of water** (≈ 1 : 25)	**3 L per 100 m²**	≈ **Quarterly (every 3 months)**; long residual action
DDVP (dichlorvos) 76% EC	Formerly used for **aerosol / space treatment** (vapour action)	–	**Banned in India from 31 Dec 2020**

- Prophylactic sprays go on **bag stack surfaces, floors, walls, alleys and dunnage**, **never directly on loose or bulk grain for consumption**. Spraying is **not done immediately after fumigation** while gas is present, and spray schedules are alternated to delay resistance.
- **Residue concept**: residues in grain must stay below the **MRL** (Maximum Residue Limit) set by FSSAI (and by Codex internationally). **Phosphine** leaves very little residue; the Codex MRL for cereals is **0.1 mg/kg**. Grain protectants such as malathion leave residues, so they are applied to bag surfaces.

KEY FORMULAE

- $AlP + 3H_2O \rightarrow Al(OH)_3 + PH_3$. With MW AlP = 58 and PH_3 = 34, a 3 g tablet with 56% AlP holds 1.68 g AlP, which gives 1.68 × 34/58 ≈ **1 g PH_3**.
- Tablets for a stack = tonnage × 3. Example: a 150 t stack needs 450 tablets (1.35 kg).
- Ct product = concentration (g/m³) × exposure time (h).
- ppm (v/v) = mg/m³ × 24.45 ÷ MW (at 25 °C). For PH_3, 1 ppm ≈ 1.39 mg/m³.
- Spray needed = area (m²) × 3 L ÷ 100. Example: 2,000 m² needs 60 L of spray, which takes 0.6 L of malathion 50% EC at 1 : 100.

MEMORY TRICK

"**3–1–3–7**": a **3** g tablet gives **1** g PH_3; use **3** tablets per tonne and keep it covered for **7** days.
"**Phosphine smells of garlic only when impure**, and above **1.8%** it's a fire."
Malathion every **fortnight** and deltamethrin every **quarter**: both at **3 L/100 m²**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Gas released by aluminium phosphide tablets? → **Phosphine (PH_3)**, from reaction with atmospheric moisture.
- Amount of PH_3 released by one 3 g AlP tablet? → **≈ 1 g**.
- Fumigant phased out under the Montreal Protocol but allowed for QPS? → **Methyl bromide**.
- Warning agent added to methyl bromide? → **Chloropicrin**.
- Lower flammable limit of phosphine? → **≈ 1.8% v/v**.
- Detecting phosphine using paper? → **Silver nitrate paper** turns black.

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10.5 Insecticides – Classification & Mode of Action ★★★

- **Pesticide** is the general term (insecticide, fungicide, herbicide, rodenticide, nematicide, acaricide). In India they are regulated under the **Insecticides Act, 1968**, which uses "insecticide" broadly for all pesticides.
- Generations of insecticides:
  - **1st generation**: inorganics (arsenicals, fluorides, sulphur) and botanicals.
  - **2nd generation**: synthetic organics (DDT onwards).
  - **3rd generation**: hormone-based insect growth regulators (term by **Carroll Williams**).
  - **4th generation**: anti-juvenile hormones (precocenes) and pheromones.

Classification by mode of entry

Type	How it acts	Examples
Stomach poison	Must be **ingested**. Works against chewing insects.	Arsenicals (lead arsenate, old), **Bt**, baits, chlorantraniliprole (mainly by ingestion)
Contact poison	Enters through the **cuticle** on contact	Pyrethroids, **malathion**, DDT, pyrethrum
Fumigant	Enters through the **spiracles** (respiratory system) as a gas	**Phosphine, methyl bromide**, dichlorvos (vapour)
Systemic	**Absorbed and translocated** in plant sap. Works best against **sucking pests** (aphids, jassids, whitefly) and is safe for natural enemies on the surface.	**Imidacloprid**, thiamethoxam, dimethoate, monocrotophos, carbofuran, phorate (granules)
Translaminar	Moves from the upper to the lower leaf surface	Abamectin, spinosad (partly)
Repellent / antifeedant	Prevents feeding or settling	**Neem (azadirachtin)**, citronella

- Classification by **physiological action**:
  - **Nerve poisons**: OP, carbamates, organochlorines, pyrethroids, neonicotinoids.
  - **Respiratory poisons**: phosphine, HCN, rotenone.
  - **Physical poisons**: mineral oils that suffocate insects, and inert dusts such as **activated clay or diatomaceous earth**, which abrade the cuticle wax and cause **desiccation**.
  - **Protoplasmic poisons**: arsenicals, mercury.
  - **Chitin-synthesis inhibitors**: IGRs.

Classification by chemistry and mode of action

Group (IRAC No.)	Examples	Target / mode of action	Key facts
Organochlorines (2A cyclodienes; 3B DDT)	**DDT**, BHC/HCH (**lindane** = γ-HCH), **endosulfan**, aldrin, dieldrin, heptachlor	DDT keeps **Na^+ channels open**. Cyclodienes and lindane block the **GABA-gated Cl^- channel**.	**Persist soluble bioma** was sy **Zeidler** its inse action **Paul M Nobel** DDT sh **negati tempe coeffic** are ba India.
Organophosphates (1B)	**Malathion**, **chlorpyrifos**, **dichlorvos (DDVP)**, **monocrotophos**, dimethoate, quinalphos, profenofos, acephate	**Inhibit acetylcholinesterase (AChE)** by **phosphorylation (near-irreversible)**. ACh builds up and causes continuous nerve firing.	Thio (P are **act oxons** the bo **Malath mamm toxicity** mamm carbox detoxif used in and pu Non-pe
Carbamates (1A)	**Carbaryl** (Sevin), **carbofuran** (Furadan 3G, systemic), propoxur (Baygon), methomyl, carbosulfan	**AChE inhibition by carbamylation, which is reversible**	Derive **physos** (calaba antidot **atropi**
Synthetic pyrethroids (3A)	**Deltamethrin**, **cypermethrin**, fenvalerate, lambda-cyhalothrin, permethrin, bifenthrin	**Keep voltage-gated Na^+ channels open**, giving rapid "**knock-down**"	Modell natura Very **lo** a.i./ha) pyreth an α-cy deltam cyperm fenvale more p **Type I** (perme **Highly and be** mamm toxicity use lea **resurg** mites a Resista **kdr** (kn resista
Neonicotinoids (4A)	**Imidacloprid** (the first), thiamethoxam, clothianidin, acetamiprid, thiacloprid, dinotefuran	**Agonists of the nicotinic acetylcholine receptor (nAChR)**	**System** against **pests** a treatm **Harmf honeyl** banned use of imidac clothia thiame 2018.

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Phenylpyrazoles (2B)	**Fipronil**	**Blocks the GABA-gated Cl^- channel**	Used against rice stem borer and termites. Toxic to bees and fish.
Spinosyns (5)	**Spinosad**, spinetoram	**nAChR allosteric modulator**	Fermentation product of the actinomycete ***Saccharopolyspora spinosa***. Also a stored-grain protectant in some countries.
Avermectins (6)	**Emamectin benzoate**, abamectin	**Activate the glutamate-gated Cl^- channel**	From ***Streptomyces avermitilis***. Used against lepidopteran larvae and mites.
Diamides (28)	**Chlorantraniliprole** (Rynaxypyr; Coragen), cyantraniliprole, flubendiamide	**Ryanodine receptor modulators**: uncontrolled Ca^{2+} release, feeding stops and the insect becomes paralysed	Lepidopteran borers. Low mammalian toxicity.
Insect growth regulators (IGRs)	**Chitin-synthesis inhibitors**: **diflubenzuron**, novaluron, lufenuron (benzoylureas, 15); **buprofezin** (16; hoppers, whitefly). **JH mimics**: methoprene, pyriproxyfen, fenoxycarb (7). **Ecdysone agonists**: tebufenozide, methoxyfenozide (18).	Disrupt **moulting and metamorphosis**	Act slowly, are **selective**, and are safe to vertebrates. They are called the **3rd generation** of insecticides.
Botanicals	**Pyrethrum** (pyrethrins from flowers of *Chrysanthemum (Tanacetum) cinerariifolium*); **nicotine** (*Nicotiana tabacum*; nAChR agonist; **nicotine sulphate is now banned in India**); **rotenone** (roots of *Derris/Lonchocarpus*; **mitochondrial complex I inhibitor**; fish poison); **neem** (**azadirachtin**, a limonoid from *Azadirachta indica*, Meliaceae)	Neem acts as an **antifeedant, repellent, oviposition deterrent and IGR** (disrupts ecdysone)	Biodegradable. Pyrethrins break down fast in light. Neem leaves and neem seed kernel extract (NSKE 5%) are traditional grain and field protectants.
Microbials	***Bacillus thuringiensis* (Bt)**: *kurstaki* (Lepidoptera), *israelensis* (mosquitoes), *tenebrionis* (Coleoptera). Fungi: *Beauveria bassiana*, *Metarhizium anisopliae*. Viruses: **NPV**.	Bt **Cry toxins** (δ-endotoxin) dissolve in the **alkaline midgut**, bind receptors and **lyse midgut cells** (IRAC 11)	Bt is a s **poison** highly s and saf **cotton** *cry1Ac*
Fumigants (24A, 8)	**Phosphine** (24A), methyl bromide (8A), sulfuryl fluoride (8C)	Respiratory (24A) / non-specific multi-site inhibitors (8)	See §1

Insecticide resistance

- **Resistance** is the **inherited** ability of a pest population to survive a dose that would normally kill it. It is **selected** by repeated use of the same chemical. The first recorded case was **San José scale against lime sulphur (Melander, 1914)**.
- **Mechanisms**:
  - **Metabolic**: more detoxifying enzymes (esterases, **cytochrome P450 monooxygenases**, GSTs).
  - **Target-site**: **kdr** (Na^+ channel) against DDT and pyrethroids; altered AChE against OPs and carbamates.
  - **Reduced penetration** through the cuticle.
  - **Behavioural** avoidance.
- **Cross-resistance** means resistance to one chemical gives resistance to another with the same mechanism. **Multiple resistance** means separate mechanisms for different chemicals.
- **IRAC** (Insecticide Resistance Action Committee, an industry body formed in **1984**) groups insecticides by **mode of action (MoA) numbers**. The strategy is to **rotate MoA groups**, not just products, and to use IPM and correct doses.
- **Resurgence**: the pest population increases after spraying, because natural enemies were killed or reproduction was stimulated (e.g. BPH after synthetic pyrethroids). **Secondary pest outbreak**: a minor pest becomes major.
- Phosphine resistance in stored-product insects is linked to the **rph1 and rph2** genes; rph2 is the dihydrolipoamide dehydrogenase gene. It is managed by using **gas-tight covers, a full dose and the full exposure period**.

Formulations

Code	Formulation	Note
EC	Emulsifiable concentrate	a.i. + solvent + emulsifier. Forms a **milky emulsion** in water. Example: malathion 50% EC.
WP	Wettable powder	a.i. + carrier + wetting agent. Forms a **suspension** in water and needs agitation. Example: deltamethrin 2.5% WP. Preferred on **porous surfaces** (walls, bags).
SP / SL	Soluble powder / soluble liquid	Forms a true solution
SC	Suspension concentrate (flowable)	Solid a.i. suspended in water

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WG / WDG	Water-dispersible granules	Dust-free
DP / D	Dust	Applied dry. Low a.i. (e.g. 2–5%).
G / GR	Granules	Soil and whorl application, often systemic (e.g. carbofuran 3G)
CS	Capsule suspension (micro-encapsulated)	Slow release, safer handling
ULV	Ultra-low-volume liquid	Below 5 L/ha. Used for locusts and fogging.
FS / DS	Flowable / dry seed treatment	For seed treatment
Aerosol, smoke generator, fumigant tablet, bait (RB, CB)	–	Space treatment and rodent control

KEY FORMULAE

- Quantity of formulation = (required concentration % × spray volume) ÷ % a.i. in formulation. Example: a 0.05% spray in 500 L from 50% EC needs 0.05 × 500 ÷ 50 = **0.5 L**.
- Formulation needed per ha = (a.i. dose, kg/ha × 100) ÷ % a.i.
- 1 ppm = 1 mg/kg = 1 mg/L (of water); 1% = 10,000 ppm.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Organophosphates and carbamates act by? → **Inhibiting acetylcholinesterase**.
- Target site of synthetic pyrethroids? → **Voltage-gated sodium channels**.
- Imidacloprid belongs to which group, and what is its target? → **Neonicotinoid**, acting on the **nicotinic ACh receptor**.
- Chlorantraniliprole acts on? → **The ryanodine receptor** (diamide).
- Insecticidal property of DDT was discovered by? → **Paul Müller** (Nobel 1948).
- Diflubenzuron acts by? → **Inhibiting chitin synthesis** (IGR).

10.6 Toxicology & Safety ★★★

- **Toxicology** is the study of the adverse effects of chemicals. "**The dose makes the poison**" (Paracelsus).
- **Toxicity** is the inherent capacity to harm. **Hazard** (risk) = toxicity × **exposure**.
- **LD_{50}** (median lethal dose) is the dose that **kills 50% of test animals** (usually **rats**). It is given in **mg of toxicant per kg body weight**, separately for **acute oral** and **acute dermal** exposure. **The lower the LD_{50}, the more toxic the chemical.** The concept was introduced by **J.W. Trevan (1927)**.
- **LC_{50}** (median lethal concentration) is used for **inhalation** (mg/L or ppm in air, for a stated time) and for **aquatic** toxicity (fish, in mg/L).
- **ED_{50}/EC_{50}** is the dose or concentration that produces an **effect** in 50% of subjects. **KD_{50}** is the time to knock down 50% of insects.
- The **dermal LD_{50} is usually higher** than the oral LD_{50}, because the chemical is absorbed more slowly through the skin.
- **Acute toxicity** follows a single exposure. **Chronic toxicity** follows long-term, low-level exposure and includes cancer, teratogenicity, mutagenicity, neurotoxicity and endocrine disruption.
- **NOAEL/NOEL** is the highest dose that causes no observed (adverse) effect in long-term animal studies.

Toxicity classification and label colour band (Insecticides Rules, 1971)

Colour of the identification band	Toxicity category	Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)	Label symbol / words
Bright RED	**Extremely toxic**	**1–50**	1–200	**Skull & crossbones**, "POISON" in red
Bright YELLOW	**Highly toxic**	**51–500**	201–2000	"POISON"
Bright BLUE	**Moderately toxic**	**501–5000**	2001–20000	"DANGER"
Bright GREEN	**Slightly toxic**	**> 5000**	> 20000	"CAUTION"

- The colour is shown on the **lower triangle of a diamond** (a square set at 45°) on the label and leaflet.
- Labels must also give the antidote, first aid, the "keep out of reach of children" warning, batch no., dates of manufacture and expiry, and the registration no.
- **Aluminium phosphide**, zinc phosphide, monocrotophos and phorate are typical **red-label** (extremely toxic) products.
- **WHO hazard classes** (by oral LD_{50} in rats): **Ia** extremely hazardous (< 5 mg/kg), **Ib** highly hazardous (5–50), **II** moderately hazardous (50–2000), **III** slightly hazardous (> 2000), and **U** unlikely to present acute hazard (≥ 5000).

Residues and safety limits

Term	Meaning
ADI (Acceptable Daily Intake)	The amount of a residue that can be eaten **daily for a lifetime without appreciable risk**, in **mg/kg body weight/day**. **ADI = NOAEL ÷ safety factor (usually 100**: 10 for animal-to-human × 10 for variation between humans). Set by **JMPR** (FAO/WHO Joint Meeting on Pesticide Residues).
MRL (Maximum Residue Limit)	The **maximum legally permitted residue** in or on food, in **mg/kg (ppm)**. International limits come from **Codex Alimentarius**; in India MRLs are set by **FSSAI** (Food Safety & Standards (Contaminants, Toxins and Residues) Regulations, 2011) on the basis of CIB&RC data.
Waiting period / PHI (pre-harvest interval)	The **minimum number of days between the last application and harvest (or consumption)**, so that residues fall below the MRL. It is printed on the label.
Re-entry interval	Time after treatment before people may enter the treated area (e.g. after fumigation, once gas is below the TLV)
TLV / TWA	Threshold limit value: the safe **airborne** concentration for workers over an 8-h day (e.g. PH_3 0.3 ppm traditional; see §10.4)
Persistence (half-life)	Organochlorines are persistent (years). OPs, carbamates and pyrethroids are non-persistent (days to weeks).

Poisoning: symptoms and antidotes

Poison	Symptoms	Antidote / treatment

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Organophosphates	Cholinergic crisis. **Muscarinic** signs ("**SLUDGE/DUMBELS**"): salivation, lacrimation, urination, diarrhoea, GI cramps, emesis, **pinpoint pupils (miosis)**, bronchorrhoea, bradycardia, sweating. **Nicotinic** signs: muscle twitching (fasciculations), weakness, paralysis. CNS signs: confusion, convulsions, coma. Death from **respiratory failure**. Diagnosis: low **cholinesterase** levels.	**Atropine sulphate** (blocks muscarinic receptors; given until secretions dry), plus **pralidoxime (2-PAM)**, an oxime that **reactivates phosphorylated AChE** if given early, before "ageing"
Carbamates	Similar to OPs but **shorter and reversible**	**Atropine only**. **2-PAM is not recommended** (especially for carbaryl), because inhibition reverses on its own.
Organochlorines	CNS **stimulation**: tremors, hyperexcitability, **convulsions**	No specific antidote. Anticonvulsants (diazepam). **Do not give oils or milk**, which increase absorption.
Pyrethroids	Paraesthesia (tingling skin), salivation, tremors (Type I "T-syndrome"), choreoathetosis (Type II "CS-syndrome")	Symptomatic treatment. Low mammalian toxicity.
Aluminium / zinc phosphide (phosphine)	Vomiting, garlic odour on the breath, **shock (hypotension), cardiac arrhythmia**, pulmonary oedema, metabolic acidosis. Very high fatality. **AlP ("celphos") poisoning** is a major cause of suicidal deaths in north India.	**No specific antidote**. Supportive care (oxygen, management of shock).
Anticoagulant rodenticides	Bleeding gums, blood in urine and stools, bruising, delayed haemorrhage	**Vitamin K_1 (phytonadione)**
Paraquat (herbicide)	Lung fibrosis	No antidote. **Fuller's earth** or activated charcoal to adsorb it.
Arsenic / mercury	GI and neurological signs	**BAL (dimercaprol)**

Safe handling, storage and disposal

- **PPE** (personal protective equipment): chemical-resistant (nitrile) **gloves**, **goggles or face shield**, a **respirator or mask** (a canister gas mask for fumigants), long-sleeved overalls or apron, and **gum boots**.
- While spraying: **do not eat, drink or smoke**; spray **with the wind**, not against it; avoid the hot hours of the day; do not spray if you have cuts or wounds; and **wash with soap** and change clothes after work.
- Never blow or suck a blocked nozzle. Women who are pregnant or breastfeeding, children and sick persons must not handle pesticides.
- **Storage**: keep pesticides in their **original labelled containers** in a **separate, locked, well-ventilated store**, **away from foodgrains, feed, water and children**. Keep fumigants dry. Maintain a stock register.
- **Disposal**: **triple-rinse** empty containers and add the rinsate to the spray tank; **puncture and crush** them so they cannot be reused; bury them **away from habitation and water sources**. **Never reuse pesticide containers for food or water.** Leftover spray goes on fallow land, not into ponds or drains.
- **First aid**: move the victim away from exposure, remove contaminated clothing, wash skin and eyes with plenty of water, keep the person warm and lying on their side, and **take the label or container to the doctor**. **Do not induce vomiting** if the person is unconscious or if the product contains a petroleum solvent.

Regulation: Insecticides Act, 1968 & Rules, 1971

Item	Fact
Purpose	Regulates the **import, manufacture, sale, transport, distribution and use** of insecticides (all pesticides) to prevent risk to humans and animals
In force	The Act came into force on **1 August 1971**, together with the **Insecticides Rules, 1971**.
CIB (Central Insecticides Board)	**Advisory** body that advises the Centre and States on technical matters (Section 4)
RC (Registration Committee)	**Registers** pesticides after checking efficacy and safety (Sections 5 and 9). No pesticide may be made, imported or sold without registration.
CIB&RC	Headquarters in **Faridabad (Haryana)**, under the **Directorate of Plant Protection, Quarantine & Storage (DPPQS)**, Ministry of Agriculture & FW
Enforcement	**Licensing officers** (manufacture and sale licences), **insecticide inspectors** (sampling, seizure) and **insecticide analysts**. The Central Insecticides Laboratory (CIL) is at Faridabad.
Proposed replacement	The **Pesticide Management Bill, 2020** (introduced in the Rajya Sabha) was not enacted. A revised **draft Pesticides Management Bill, 2025** was released for public comments in **January 2026**; it would replace the 1968 Act.

Banned and restricted pesticides in India (verified examples)

Status	Examples
Banned (manufacture, import, use)	**BHC/HCH**, **lindane**, aldrin, dieldrin, endrin, chlordane, heptachlor, toxaphene, **endosulfan**, **ethylene dibromide (EDB)**, calcium cyanide, aldicarb, ethyl parathion, pentachlorophenol, **nicotine sulphate**, phenylmercury acetate
Endosulfan	Banned by a **Supreme Court interim order of 13 May 2011**, made final in Jan 2017. It was also listed under the **Stockholm Convention (2011)**. This followed the **Kasaragod (Kerala)** health disaster caused by aerial spraying on cashew.
Pesticides (Prohibition) Order, 2018 (18 pesticides)	**12 banned from 9 Aug 2018**: benomyl, **carbaryl**, diazinon, fenarimol, fenthion, linuron, MEMC, **methyl parathion**, sodium cyanide, thiometon, tridemorph, trifluralin (trifluralin still allowed in wheat). **6 banned from 31 Dec 2020**: alachlor, **dichlorvos (DDVP)**, **phorate**, phosphamidon, triazophos, trichlorfon.

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Order of **3 Oct 2023**	**Dicofol, dinocap and methomyl banned**. **Monocrotophos 36% SL** to be phased out. **Carbofuran** allowed only as the 3% CG. Crop-specific bans, e.g. **chlorpyrifos** banned on ber, citrus and tobacco, and **malathion** banned on several crops (sorghum, pea, soybean, okra, brinjal, apple, mango, grape and others).
Restricted use	**DDT**: agricultural use banned (1989); allowed only for **public health (vector control)**, up to ≈ 10,000 t/yr. **Aluminium phosphide**: pest-control operations only by Govt agencies or approved PCOs under expert supervision, and **10- and 20-tablet tube packs banned**. **Methyl bromide**: Govt or approved operators under expert supervision. **Monocrotophos**: banned on vegetables. **Captafol**: seed dresser only. **Cypermethrin 3% smoke generator**: PCOs only.

Environmental toxicology and disasters

- **Biomagnification** (biological magnification) is the **rise in concentration of a persistent, fat-soluble pollutant at each higher trophic level**. Examples are DDT and mercury: the highest levels occur in **top carnivores** such as fish-eating birds. In those birds, DDE causes **eggshell thinning** (NCERT example: water → zooplankton → small fish → large fish → fish-eating birds).
- **Bioaccumulation** is the build-up of a chemical **within one organism** over time. Biomagnification happens **across the food chain**.
- **Rachel Carson**, ***Silent Spring* (1962)**, exposed the harm DDT did to wildlife.
- **Stockholm Convention on POPs** (persistent organic pollutants) was adopted in **2001** and came into force in 2004. The original "**dirty dozen**" included DDT, aldrin, dieldrin, endrin, chlordane, heptachlor and toxaphene.
- **Rotterdam Convention** (1998) covers **prior informed consent (PIC)** for trade in hazardous chemicals.
- **Bhopal gas tragedy**: night of **2–3 December 1984**, a **methyl isocyanate (MIC, CH_3NCO)** leak from the **Union Carbide India Ltd** pesticide plant, where MIC was an intermediate for **carbaryl (Sevin)**. Thousands died. It led to the **Environment (Protection) Act, 1986** and the Public Liability Insurance Act, 1991.
- **Bihar (Saran) mid-day meal tragedy, July 2013**: 23 children died after eating food contaminated with **monocrotophos**.
- Pesticides are **very toxic to bees** (neonicotinoids, pyrethroids, fipronil) and **to fish** (pyrethroids, endosulfan, rotenone).

MEMORY TRICK

Label colours "**Red-Yellow-Blue-Green = 50-500-5000-above**" (oral LD_{50} limits ×10 each step; dermal limits are 200-2000-20000). Antidotes: "**OP = A + P**" (Atropine + Pralidoxime); "**Carbamate = A only**"; "**Warfarin = K**" (vitamin K_1); "**Phosphine = none**."

PREVIOUSLY ASKED / LIKELY QUESTIONS

- A pesticide with oral LD_{50} of 1–50 mg/kg carries which colour band? → **Red (extremely toxic)**.
- The lower the LD_{50}, the? → **More toxic** the chemical.
- Antidote that reactivates AChE in OP poisoning? → **Pralidoxime (2-PAM)**, given with atropine.
- Pesticides are registered in India by? → **CIB&RC, Faridabad**, under the Insecticides Act, 1968.
- Gas responsible for the Bhopal tragedy (1984)? → **Methyl isocyanate (MIC)**.
- Increase of DDT concentration along the food chain is called? → **Biomagnification**.

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11. Chemistry & Biochemistry

NOTE

Chemistry and biochemistry give a steady block of easy marks in every FCI/CWC/SWC technical paper. Expect one-liners on discoverers, VSEPR shapes and bond angles, pH and gas-law values, common names and formulae of compounds, ores, industrial processes and catalysts, named organic reactions and tests, polymers, and in biochemistry on sugars, amino acids, enzyme classes, fatty acids, oil constants, vitamins and deficiency diseases. Section 11.6 ends with the **biochemistry of stored grain** (moisture, protein, gluten, FFA, mycotoxins), which links straight to warehousing.

11.1 Atomic Structure & Periodic Table ★★★

Particle / discovery	Discoverer (year)	Key fact
Electron	**J.J. Thomson (1897)**	Cathode-ray tube; e/m = **1.758 × 10^{11} C kg^{-1}**; mass **9.109 × 10^{-31} kg** (≈ 1/1837 of a proton)
Charge on electron	**R.A. Millikan (1909)**	Oil-drop experiment; **1.602 × 10^{-19} C**
Canal (anode) rays → proton	**E. Goldstein (1886)**; named proton by **Rutherford (1919–20)**	Mass 1.673 × 10^{-27} kg; charge +1
Nucleus	**Rutherford (1911)**	α-particle scattering on thin **gold foil** (Geiger–Marsden); most α pass straight → atom mostly empty
Neutron	**James Chadwick (1932)**	Bombarded **beryllium with α-particles**; neutral, mass ≈ proton
Atomic model "plum pudding"	Thomson (1898/1904)	Electrons embedded in a positive sphere
Stationary orbits	**Niels Bohr (1913)**	Explained hydrogen spectrum
Wave equation	**Schrödinger (1926)**	Basis of quantum mechanical model; ψ^2 = probability density

- **Bohr postulates**: electrons move in fixed circular orbits (stationary states); angular momentum is quantised, **mvr = nh/2π**; energy is emitted/absorbed only on jumping between orbits, **ΔE = hν**.
- Hydrogen-like species: $\mathbf{E_n = -13.6\ Z^2/n^2}$ **eV** (= $-2.18 \times 10^{-18}\ Z^2/n^2$ J); $\mathbf{r_n = 52.9\ n^2/Z}$ **pm** (Bohr radius a_0 = 0.529 Å). Ionisation energy of H = **13.6 eV** (1312 kJ mol^{-1}).
- Hydrogen spectral series: **Lyman** (to n = 1, **UV**), **Balmer** (to n = 2, **visible**), Paschen (n = 3), Brackett (n = 4), Pfund (n = 5) – last three in IR.
- Bohr model failed for multi-electron atoms, the Zeeman (magnetic) and Stark (electric) effects, and ignored the dual nature of the electron.
- **de Broglie**: λ = **h/mv** (matter waves; basis of the electron microscope). **Heisenberg uncertainty**: Δx · Δp ≥ **h/4π**. Planck's constant h = **6.626 × 10^{-34} J s**.
- **Photoelectric effect** (Einstein 1905): electrons ejected only above a threshold frequency; **Cs** (lowest IE) is used in photocells.

Quantum number	Symbol & values	Tells
Principal	**n** = 1, 2, 3 …	Shell, size, energy; max electrons **$2n^2$**
Azimuthal	**l** = 0 to (n − 1); s = 0, p = 1, d = 2, f = 3	Subshell, **shape**; orbitals per subshell = **2l + 1**
Magnetic	$\mathbf{m_l}$ = −l … 0 … +l	**Orientation** in space
Spin	$\mathbf{m_s}$ = +½ or −½	Spin of electron (Uhlenbeck & Goudsmit)

- Nodes: radial = **n − l − 1**; angular = **l**; total = **n − 1**. s orbital is spherical, p is dumb-bell, d is double dumb-bell (d_{z^2} has a ring/collar).
- **Aufbau principle**: orbitals fill in order of increasing energy, decided by the **(n + l) rule**; if equal, lower n first. Order: 1s 2s 2p 3s 3p **4s 3d** 4p 5s 4d 5p 6s 4f 5d 6p 7s …
- **Pauli exclusion principle**: no two electrons in an atom have all four quantum numbers the same → an orbital holds at most **2 electrons of opposite spin**.
- **Hund's rule of maximum multiplicity**: in degenerate orbitals, pairing starts only after each orbital is singly occupied (e.g. N = $2p^3$ has 3 unpaired electrons).
- **Exceptional configurations** (extra stability of half-filled/fully-filled d): **Cr (24) = [Ar] $3d^5$ $4s^1$**; **Cu (29) = [Ar] $3d^{10}$ $4s^1$**. Similarly Mo, Ag, Au.
- Electrons are removed from **4s before 3d** when transition metals ionise: Fe^{2+} = [Ar] $3d^6$; Fe^{3+} = $3d^5$ (more stable).

Term	Same	Different	Example
Isotopes	Atomic number (Z)	Mass number (A)	^{1}H, ^{2}H (D), ^{3}H (T); ^{12}C, ^{14}C; ^{35}Cl, ^{37}Cl
Isobars	Mass number (A)	Z	^{40}Ar, ^{40}K, ^{40}Ca
Isotones	Number of neutrons	Z and A	^{14}C, ^{15}N, ^{16}O (8 n each)
Isoelectronic	Number of electrons	Z	N^{3-}, O^{2-}, F^-, Ne, Na^+, Mg^{2+}, Al^{3+} (10 e)

- Isotopes have the **same chemical properties** but different physical properties. Tritium is **radioactive** (t½ ≈ 12.3 years); **^{14}C** t½ = **5730 years** (carbon dating – W.F. Libby). ^{60}Co – cancer therapy and **food irradiation** (γ-rays); ^{131}I – thyroid; ^{32}P – tracer in plant nutrition studies.
- In isoelectronic ions, size decreases as nuclear charge rises: **N^{3-} > O^{2-} > F^- > Na^+ > Mg^{2+} > Al^{3+}**.

Periodic table – history

- **Döbereiner** – law of **triads** (1829), e.g. Li, Na, K. **Newlands** – law of **octaves** (1865, compared with music). Lothar Meyer – atomic volume curve.
- **Mendeleev (1869)** – periodic law based on **atomic mass**; left gaps and predicted **eka-aluminium (Ga)**, **eka-silicon (Ge)** and eka-boron (Sc). Anomalies: Ar–K, Co–Ni, Te–I, and the position of isotopes.
- **Moseley (1913)** – X-ray spectra, $\sqrt{\nu} \propto Z$; showed that **atomic number** is the fundamental property. **Modern periodic law**: properties are a periodic function of atomic number.
- Modern (long) form: **18 groups, 7 periods**; **118 elements** (last four named in 2016: nihonium 113, moscovium 115, tennessine

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117, oganesson 118). Lanthanoids (58–71) and actinoids (90–103) placed separately below.

Block	Groups	Last electron enters	General configuration
s-block	1, 2 (+ He)	ns	ns^{1-2}
p-block	13–18	np	$ns^2\ np^{1-6}$
d-block (transition)	3–12	(n−1)d	$(n-1)d^{1-10}\ ns^{0-2}$
f-block (inner transition)	Lanthanoids, actinoids	(n−2)f	$(n-2)f^{1-14}$ $(n-1)d^{0-1}\ ns^2$

Property	Across a period (L → R)	Down a group	Extreme
Atomic radius	Decreases	Increases	Largest **Cs** (Fr); smallest **He**
Ionisation enthalpy	Increases	Decreases	Highest **He** (2372 kJ/mol); lowest Cs
Electron gain enthalpy (EA)	More negative	Less negative	Most negative **Cl** (not F – F is small, e–e repulsion)
Electronegativity (Pauling)	Increases	Decreases	Highest **F = 4.0**, then O (3.5); lowest Cs/Fr (~0.7)
Metallic character	Decreases	Increases	Most metallic Cs/Fr
Reducing power of metals	Decreases	Increases	**Li** strongest reducing agent in water (E° = −3.05 V)

- IE anomalies: **Be > B** and **N > O** (stable $2s^2$ and half-filled $2p^3$). Noble gases have **positive** electron gain enthalpy.
- Cation is smaller than its atom; anion is larger. **Diagonal relationship**: Li–Mg, Be–Al, B–Si.
- **Inert-pair effect** (heavier p-block): lower oxidation state more stable – Tl^+, Pb^{2+}, Bi^{3+}.
- Group names: 1 – **alkali metals**; 2 – **alkaline earth metals**; 15 – pnictogens; 16 – **chalcogens** (ore-forming); 17 – **halogens** (salt-formers); 18 – **noble gases** (zero group).
- **Alkali metals**: soft, kept under **kerosene**; reactivity increases down (Cs most reactive stable one); Li is hardest and has highest m.p. in the group. Flame colours: Li – **crimson red**, Na – **golden yellow**, K – **lilac/violet**, Rb – red-violet, Cs – blue.
- **Alkaline earth**: Ca – **brick red**, Sr – crimson, Ba – **apple green** flame; **Be and Mg give no flame colour**. Be compounds are covalent (small size).
- **Halogens**: F_2 pale yellow gas, Cl_2 greenish-yellow gas, **Br_2 red-brown liquid** (only liquid non-metal), I_2 violet-black solid that **sublimes**. Oxidising power $F_2 > Cl_2 > Br_2 > I_2$.
- **Noble gases**: He (lowest b.p., 4.2 K; balloons, diving mixture), Ne (glow signs), **Ar (most abundant in air, ~0.93%; bulbs)**, Kr, Xe (first compound **$Xe^+[PtF_6]^-$, Neil Bartlett 1962**), Rn (radioactive).
- Liquid metal at room temperature: **Hg** (Ga and Cs melt just above). Abundance in earth's crust: **O > Si > Al > Fe**; Al = most abundant metal. Most abundant element in the universe: **H**.

MEMORY TRICK

Electronegativity **"FON Cl"** – F > O > N ≈ Cl. Electron affinity: **Cl**aims the most electrons (Cl > F).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Neutron was discovered by? → **James Chadwick (1932)**.
- Electronic configuration of Cu? → **[Ar] $3d^{10}\ 4s^1$**.
- Atoms with the same number of neutrons are called? → **Isotones**.
- Element with the highest electron gain enthalpy (most negative)? → **Chlorine**.
- Modern periodic table is based on? → **Atomic number (Moseley)**.
- Maximum number of electrons in a subshell with l = 2? → **10**.

11.2 Chemical Bonding & Molecular Structure ★★★

- **Octet rule** – Kössel & Lewis (1916). Exceptions: incomplete octet (**BF_3, $BeCl_2$**), expanded octet (**PCl_5, SF_6**), odd-electron molecules (**NO, NO_2**).
- **Ionic (electrovalent) bond**: transfer of electrons between a metal of low IE and non-metal of high EA (NaCl). Favoured by high **lattice enthalpy**. Ionic solids: high m.p., conduct in **molten/aqueous** state, soluble in polar solvents.
- **Fajans' rules** – covalent character in an ionic bond rises with a **small, highly charged cation** and a **large anion** (LiI more covalent than LiF; $AlCl_3$ covalent).
- **Covalent bond**: sharing of electron pairs (Lewis). Single = 1σ; double = 1σ + 1π; triple = 1σ + 2π. **σ bond is stronger** than π (head-on overlap). Free rotation is possible only about a σ bond.
- **Coordinate (dative) bond**: both electrons from one atom – NH_4^+, H_3O^+, **CO**, O_3, $NH_3 \rightarrow BF_3$, all metal complexes.
- **Metallic bond**: kernels in a "sea" of delocalised electrons (Drude/electron-sea model) → conductivity, lustre, malleability, ductility.
- **Hydrogen bond**: H attached to a small, highly electronegative atom (**F, O, N**) attracted to another such atom; strength ≈ **10–40 kJ mol^{-1}** (weaker than covalent ~400). **Intermolecular** (H_2O, HF, alcohols – high b.p., solubility) vs **intramolecular** (**o-nitrophenol**, salicylaldehyde – lower b.p., steam-volatile). Holds DNA strands and protein α-helix/β-sheet.
- **van der Waals forces** (weakest): London dispersion (all molecules; rises with size), dipole–dipole, dipole–induced dipole.
- Order of strength: **ionic ≈ covalent > metallic > H-bond > dipole–dipole > London**.

Anomalous property of water (due to H-bonding)	Value / effect
Boiling point	**100 °C** vs H_2S ≈ −60 °C
Maximum density	At **4 °C** (1.000 g cm^{-3})
Ice	**Less dense (0.917 g cm^{-3})** – open cage (tetrahedral, hexagonal) structure → ice floats, lakes freeze top-down
Specific heat	High, **4.18 J g^{-1} K^{-1}** (1 cal g^{-1} $°C^{-1}$)
Latent heat of vaporisation / fusion	≈ 2260 J g^{-1} (40.7 kJ mol^{-1}) / 334 J g^{-1}
Dielectric constant	≈ **78.5** → "universal solvent" for ionic compounds
Bond angle / shape	**104.5°, bent**; dipole moment 1.85 D

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Molecule	Bond pairs : lone pairs	Hybridisation	Shape	Bond angle
$BeCl_2$, CO_2, C_2H_2	2 : 0	sp	**Linear**	180°
BF_3, C_2H_4, SO_3	3 : 0	sp^2	**Trigonal planar**	120°
CH_4, CCl_4, NH_4^+	4 : 0	sp^3	**Tetrahedral**	**109.5°** (109°28′)
NH_3	3 : 1	sp^3	**Trigonal pyramidal**	**107°**
H_2O	2 : 2	sp^3	**Bent (V-shape)**	**104.5°**
PCl_5	5 : 0	sp^3d	**Trigonal bipyramidal**	120° (eq), 90° (ax)
SF_4	4 : 1	sp^3d	See-saw	—
ClF_3	3 : 2	sp^3d	T-shaped	≈ 90°
XeF_2, I_3^-	2 : 3	sp^3d	Linear	180°
SF_6	6 : 0	sp^3d^2	**Octahedral**	90°
BrF_5	5 : 1	sp^3d^2	Square pyramidal	≈ 90°
XeF_4	4 : 2	sp^3d^2	**Square planar**	90°
IF_7	7 : 0	sp^3d^3	Pentagonal bipyramidal	72°, 90°

- **VSEPR** (Sidgwick & Powell; Nyholm & Gillespie): repulsion order **lp–lp > lp–bp > bp–bp** – that is why angle falls CH_4 (109.5°) → NH_3 (107°) → H_2O (104.5°).
- **Hybridisation** (Pauling): mixing of orbitals of nearly equal energy. % s-character: **sp 50%**, sp^2 33.3%, sp^3 25%; more s-character → shorter bond, more electronegative carbon (ethyne H is acidic). **dsp^2** → square planar ($[Ni(CN)_4]^{2-}$).
- In PCl_5, **axial bonds are longer** (more repulsion) than equatorial → PCl_5 is reactive.
- Hybridisation quick formula: **H = ½ (V + M − C + A)** (V = valence e of central atom, M = monovalent atoms, C = cationic charge, A = anionic charge); H = 2, 3, 4, 5, 6 → sp, sp^2, sp^3, sp^3d, sp^3d^2.

Molecular orbital theory (Mulliken, Hund)

KEY FORMULAE

- **Bond order = ½ (N_b − N_a)**; bond order 0 → molecule does not exist (He_2).
- Bond order ∝ bond energy ∝ stability ∝ 1/bond length.
- Dipole moment **μ = q × d**; unit Debye, **1 D = 3.336 × 10^{-30} C m**.
- Magnetic moment (spin-only) **μ = √[n(n+2)] BM** (n = unpaired electrons).

Species	Bond order	Magnetic nature
H_2^+ / H_2	0.5 / 1	Para / Dia
He_2	0	Does not exist
B_2	1	**Paramagnetic**
C_2	2	Diamagnetic
N_2	**3** (bond energy 946 kJ/mol)	Diamagnetic
O_2	**2**	**Paramagnetic** (2 unpaired e in π*) – VBT fails to explain
O_2^+ / O_2^- (superoxide) / O_2^{2-} (peroxide)	2.5 / 1.5 / 1	Para / Para / Dia
F_2	1	Diamagnetic

- Stability order: **O_2^+ > O_2 > O_2^- > O_2^{2-}**; bond length is the reverse.
- **Zero dipole moment** (symmetrical): CO_2, BF_3, CH_4, CCl_4, $BeCl_2$, SF_6, benzene, trans-1,2-dichloroethene, p-dichlorobenzene. Polar: H_2O, NH_3, HCl, $CHCl_3$, SO_2.
- **NH_3 (1.47 D) > NF_3 (0.23 D)** – in NF_3 the lone-pair moment opposes the bond moments.
- % ionic character rises with electronegativity difference; Δχ ≈ 1.7 → ~50% ionic.
- **Resonance**: a molecule is a hybrid of canonical structures – benzene, O_3, CO_3^{2-} (each C–O bond order **1.33**), NO_3^-, carboxylate ion. The hybrid is more stable than any single structure (resonance energy; benzene ≈ 150 kJ mol^{-1}).
- Bond lengths: C–C **154 pm**, C=C **134 pm**, C≡C **120 pm**; benzene C–C **139 pm** (all equal, intermediate).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Shape of NH_3 and its bond angle? → **Trigonal pyramidal, 107°**.
- Hybridisation of S in SF_6? → **sp^3d^2 (octahedral)**.
- Bond order of O_2 and its magnetic nature? → **2, paramagnetic**.
- Why does ice float on water? → **Open H-bonded cage makes ice less dense**.
- Which has zero dipole moment: NH_3, H_2O, BF_3, HCl? → **BF_3**.

11.3 Physical Chemistry Essentials ★★☆

Mole concept & gases

- **Mole** = amount containing **6.022 × 10^{23}** particles (Avogadro number N_A). 1 amu (u) = **1.66 × 10^{-27} kg** = 1/12 mass of ^{12}C atom.
- **Molar volume** of an ideal gas at **STP (0 °C, 1 atm) = 22.4 L**; at IUPAC STP (0 °C, 1 bar) = 22.7 L; at 25 °C, 1 bar ≈ 24.8 L.
- Laws of chemical combination: conservation of mass (Lavoisier), definite proportions (Proust), multiple proportions (Dalton), gaseous volumes (Gay-Lussac), **Avogadro's law (1811)**.

KEY FORMULAE

- Ideal gas: **PV = nRT**; **R = 8.314 J mol^{-1} K^{-1} = 0.0821 L atm mol^{-1} K^{-1} = 1.987 cal mol^{-1} K^{-1}**.
- Boyle: **P ∝ T** (T, n constant). Charles: **V ∝ T** (P constant). Gay-Lussac: **P ∝ T** (V constant). Avogadro: **V ∝ n**.
- Dalton's law of partial pressures: $P_{total} = p_1 + p_2 + ...$; Graham's law: **rate of diffusion ∝ 1/√M**.
- van der Waals: **$(P + an^2/V^2)(V - nb) = nRT$**; a = attraction, b = excluded volume.
- Average KE of a gas molecule = **3/2 kT** – depends only on temperature. 0 K = **−273.15 °C**.

- Real gases behave ideally at **high temperature and low pressure**. A gas cannot be liquefied above its **critical temperature** (CO_2: 30.98 °C).
- Liquids: **boiling point** = vapour pressure equals external pressure (water boils below 100 °C on hills; pressure cooker raises b.p.). Surface tension falls with temperature; viscosity of liquids falls with temperature.
- Solids: crystalline (sharp m.p., anisotropic) vs amorphous (glass, rubber – isotropic, "super-cooled liquids"). Coordination number:

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NaCl **6:6**, CsCl **8:8**, ZnS 4:4.

Solutions & colligative properties

Concentration term	Definition	Temperature-dependent?
Molarity (M)	Moles of solute per **litre of solution**	**Yes** (volume changes)
Molality (m)	Moles of solute per **kg of solvent**	**No**
Normality (N)	Gram-equivalents per litre	Yes
Mole fraction (x)	$n_i/\Sigma n$; sum = 1	No
ppm	Parts per 10^6 (mg/kg or mg/L for dilute water)	—

- **Henry's law**: solubility of a gas ∝ its partial pressure (soda bottles sealed under CO_2 pressure; "bends" in divers – N_2 bubbles). Gas solubility **decreases** with rising temperature.
- **Raoult's law**: p = p°x. Positive deviation – ethanol + water, acetone + CS_2 (min-boiling azeotrope; ethanol–water at **95.6%** ethanol). Negative deviation – chloroform + acetone, HNO_3 + water (max-boiling azeotrope at 68% HNO_3).
- **Colligative properties** depend on the **number** of solute particles, not their nature: (1) relative lowering of vapour pressure, (2) elevation of b.p., (3) depression of f.p., (4) osmotic pressure.
- **Osmotic pressure** is the best method for **molar mass of proteins/polymers** (measurable at room temperature, large values). Isotonic with blood: **0.9% NaCl** (normal saline). Hypertonic → **plasmolysis**; reverse osmosis → **desalination**.
- **van 't Hoff factor i**: NaCl ≈ 2, $CaCl_2$ ≈ 3, $K_4[Fe(CN)_6]$ ≈ 5, glucose/urea = 1, acetic acid in benzene ≈ 0.5 (dimerises).
- Ethylene glycol – **antifreeze**; salt on icy roads lowers f.p.; salting/sugaring preserves food by osmosis.

KEY FORMULAE

- $\Delta T_b = i\,K_b\,m$; $\Delta T_f = i\,K_f\,m$. For water: $\mathbf{K_b = 0.52}$, $\mathbf{K_f = 1.86\ K\ kg\ mol^{-1}}$.
- Osmotic pressure $\boldsymbol{\pi = iCRT}$ (van 't Hoff).
- Relative lowering of VP: $(p° - p)/p° = x_{solute}$.
- pH = $-\log[H^+]$; **pH + pOH = 14** at 25 °C; $K_w = [H^+][OH^-] = \mathbf{1 \times 10^{-14}}$.
- Henderson–Hasselbalch: $\mathbf{pH = pK_a + \log [salt]/[acid]}$.

Acids, bases, pH & buffers

Concept	Acid	Base	Limitation / note
Arrhenius (1884)	Gives H^+ in water	Gives OH^- in water	Only aqueous; cannot explain NH_3 as base
Brønsted–Lowry (1923)	**Proton donor**	**Proton acceptor**	Conjugate pairs: HCl/Cl^-, NH_4^+/NH_3; H_2O is amphiprotic
Lewis (1923)	**Electron-pair acceptor** (BF_3, $AlCl_3$, H^+, metal ions)	**Electron-pair donor** (NH_3, H_2O, OH^-)	Most general

- pH scale – **S.P.L. Sørensen (1909)**. Pure water pH = 7 at 25 °C (falls slightly as temperature rises; still neutral). Stronger acid → weaker conjugate base.
- Typical pH: gastric juice **~1.5–3.5** (HCl), lemon ~2.2, vinegar ~2.8–3, normal rain ~5.6, **acid rain < 5.6**, milk **6.6–6.8**, **blood 7.35–7.45**, sea water ~8.1, milk of magnesia ~10.5.
- **Buffers** resist pH change: acidic buffer – $\mathbf{CH_3COOH + CH_3COONa}$ (pH ≈ 4.76 at equal concentration); basic buffer – $\mathbf{NH_4OH + NH_4Cl}$; blood – $\mathbf{H_2CO_3/HCO_3^-}$ (main), phosphate and protein buffers.
- Salt hydrolysis: strong acid + weak base salt (NH_4Cl, $CuSO_4$) → **acidic**; weak acid + strong base salt (Na_2CO_3, CH_3COONa) → **basic**; NaCl neutral. (Ammonium sulphate is an acid-forming fertiliser.)
- Common-ion effect suppresses ionisation (NH_4Cl suppresses NH_4OH – used in group III analysis). Precipitation occurs when ionic product > $\mathbf{K_{sp}}$.

Indicator	pH range	Acid colour → base colour	Used for
Phenolphthalein	8.2–10	Colourless → **pink**	Weak acid vs strong base
Methyl orange	3.1–4.4	**Red** → yellow	Strong acid vs weak base
Methyl red	4.2–6.3	Red → yellow	Strong acid vs weak base
Litmus	5–8	Red → blue	General test
Bromothymol blue	6.0–7.6	Yellow → blue	Near-neutral; soil pH kits

Redox & electrochemistry

- **Oxidation** = loss of electrons / increase in oxidation number / addition of O / removal of H. The **oxidising agent is itself reduced**.
- Oxidation numbers to remember: Mn in $KMnO_4$ **+7**; Cr in $K_2Cr_2O_7$ **+6**; S in H_2SO_4 +6; O in H_2O_2 **−1**, in OF_2 **+2**, in KO_2 −½; H in NaH **−1**; Fe in Fe_3O_4 +8/3; C in CH_4 −4.
- **Galvanic cell**: chemical → electrical; anode (−) oxidation, cathode (+) reduction. **Electrolytic cell**: anode (+). In both, **oxidation at anode**. Daniell cell (Zn/Cu) = 1.1 V.
- SHE E° = **0.00 V**. Electrochemical series: **Li (−3.05 V)** strongest reducing agent; **F_2 (+2.87 V)** strongest oxidising agent.
- Cells: **dry (Leclanché) cell** – Zn anode, carbon rod cathode with MnO_2, NH_4Cl + $ZnCl_2$ paste, **~1.5 V**; **mercury cell** – 1.35 V, constant; **lead storage battery** – Pb anode, PbO_2 cathode, **~38% H_2SO_4**; H_2–O_2 fuel cell (Apollo missions).
- **Corrosion**: rust = $\mathbf{Fe_2O_3 \cdot xH_2O}$ (needs O_2 + moisture; salt accelerates). Prevention: painting, **galvanising (Zn coating)**, tinning, **sacrificial anode (Mg/Zn)**.
- **Faraday's laws**: m = ZIt; 1 Faraday = **96,485 C mol^{-1}** (charge on 1 mol electrons).

KEY FORMULAE

- Nernst (298 K): $\mathbf{E = E° - (0.059/n) \log Q}$; $\Delta G° = \mathbf{-nFE°}$; $\Delta G° = -RT \ln K$.
- Molar conductivity $\Lambda_m = \kappa/c$; Kohlrausch's law of independent migration of ions.

Kinetics, equilibrium & thermochemistry

Order	Rate law	Half-life	Unit of k
Zero	rate = k	$[A]_0/2k$ (∝ initial conc.)	mol L^{-1} s^{-1}
First	rate = k[A]	$\mathbf{t½ = 0.693/k}$ (independent of initial conc.)	**s^{-1}**

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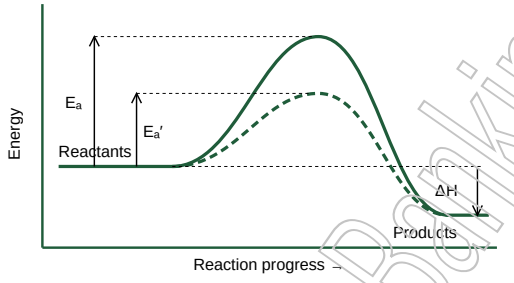
Second	rate = $k[A]^2$	$1/(k[A]_0)$	L mol^{-1} s^{-1}

- **Order** is experimental and may be zero or fractional; **molecularity** is theoretical, always a whole number (1, 2, rarely 3). **Radioactive decay** is first order. For first order, $t_{99.9\%} \approx$ **10 × t½**.
- **Pseudo-first-order**: acid hydrolysis of ethyl acetate and **inversion of cane sugar** (water in large excess).
- **Arrhenius equation**: $k = A\, e^{-Ea/RT}$. Rate roughly **doubles for every 10 °C rise** (temperature coefficient ≈ 2) – why grain deteriorates faster in warm stores.
- **Catalyst** lowers activation energy, speeds forward and backward reactions equally, **does not change ΔH, ΔG or the equilibrium constant**.
- **Le Chatelier's principle**: a system at equilibrium shifts to oppose any change. Haber ($N_2 + 3H_2 \rightleftharpoons 2NH_3$, exothermic, Δn = −2): favoured by **high pressure, low temperature** (optimum ~700 K used for rate). Ice ⇌ water: pressure melts ice.
- **$K_p = K_c(RT)^{\Delta n}$**; if Δn = 0 ($H_2 + I_2 \rightleftharpoons 2HI$), $K_p = K_c$ and pressure has no effect.
- Thermodynamics: first law **ΔU = q + w**; **ΔH = ΔU + Δn_gRT**; Gibbs **ΔG = ΔH − TΔS**; spontaneous if **ΔG < 0**. Exothermic ΔH negative. Bomb calorimeter measures **ΔU** (constant volume).
- **Hess's law** of constant heat summation. $\Delta H_f°$ of elements in standard state = **0**. Enthalpy of neutralisation (strong acid + strong base) = **−57.1 kJ mol^{-1}** (−13.7 kcal); less for weak acids/bases.
- Third law: entropy of a perfect crystal at 0 K = 0. Process types: isothermal (ΔT = 0), adiabatic (q = 0), isobaric (ΔP = 0), isochoric (ΔV = 0).



Energy profile of an exothermic reaction: solid = uncatalysed (E^a), dashed = catalysed (lower E^a′); ΔH is unchanged

MEMORY TRICK

"OIL RIG" – Oxidation Is Loss, Reduction Is Gain (of electrons). **"An Ox, Red Cat"** – Anode = Oxidation, Reduction = Cathode (true for every cell).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Volume of 1 mole of an ideal gas at STP? → **22.4 L**.
- Half-life of a first-order reaction? → **0.693/k** (independent of initial concentration).
- Which concentration unit is independent of temperature? → **Molality**.
- pH of a solution with $[H^+] = 10^{-3}$ M? → **3** (pOH = 11).
- BF_3 is which type of acid? → **Lewis acid** (electron-pair acceptor).
- Best colligative property for molar mass of proteins? → **Osmotic pressure**.

11.4 Inorganic Chemistry ★★★

Hydrogen & water

- Hydrogen – discovered by **Cavendish (1766)**, named by Lavoisier. Isotopes protium, **deuterium** (Urey 1931), **tritium** (radioactive). Most abundant element in the universe; lightest gas.
- **Heavy water (D_2O)** – **moderator** (and coolant) in nuclear reactors; tracer in reaction mechanisms. India's heavy-water plants – Heavy Water Board (DAE).
- **Hydrogen peroxide**: bleach (hair, textiles, paper), antiseptic (perhydrol = 30%), rocket propellant; stored in dark/wax-lined bottles with a little urea/acetanilide as stabiliser. "10-volume" $H_2O_2 \approx 3\%$.
- **Syngas/water gas** = CO + H_2; producer gas = CO + N_2; coal gas = H_2 + CH_4 + CO; **LPG** = butane + propane (odorant ethyl mercaptan); **CNG** = mainly methane; **biogas** = CH_4 (50–75%) + CO_2.

Hardness	Caused by	Removal
Temporary (carbonate)	**Bicarbonates of Ca and Mg**	**Boiling** ($Ca(HCO_3)_2 \rightarrow CaCO_3\downarrow + H_2O + CO_2$; $Mg \rightarrow Mg(OH)_2\downarrow$); **Clark's method** – slaked lime
Permanent (non-carbonate)	**Chlorides and sulphates of Ca and Mg**	**Washing soda**; **Calgon** (sodium hexametaphosphate, $Na_6P_6O_{18}$); **ion-exchange** – zeolite/permutit (hydrated sodium aluminium silicate), synthetic resins (gives deionised water)

- Hardness is expressed as **ppm (mg/L) of $CaCO_3$ equivalent**; estimated by **EDTA titration** (Eriochrome Black T indicator).
- Hard water wastes soap (forms **scum** – calcium/magnesium stearate), forms boiler scale. Detergents work in hard water.
- **BIS drinking water IS 10500:2012** (acceptable / permissible in absence of alternate source): pH **6.5–8.5**; total hardness **200 / 600 mg/L**; TDS **500 / 2000 mg/L**; fluoride **1.0 / 1.5 mg/L**; nitrate 45 mg/L; arsenic **0.01 mg/L**.

s-block compounds

Common name	Formula	Preparation / use
Washing soda	**$Na_2CO_3 \cdot 10H_2O$**	**Solvay (ammonia–soda) process**; removes permanent hardness; glass, soap. Effloresces to monohydrate. (K_2CO_3 cannot be made by Solvay – $KHCO_3$ too soluble)
Baking soda	**$NaHCO_3$**	Antacid, fire extinguisher (soda-acid), baking. **Baking powder** = $NaHCO_3$ + tartaric acid (or another mild acid)
Caustic soda	NaOH	**Chlor-alkali** (Castner–Kellner) electrolysis of brine → NaOH + Cl_2 + H_2; soap making
Plaster of Paris	**$CaSO_4 \cdot \frac{1}{2}H_2O$**	Heating gypsum at ~373–393 K (NCERT X gives 373 K; XI gives 393 K); sets with water to gypsum – casts, statues, fracture plasters. Above ~393 K → anhydrous "**dead-burnt plaster**" (does not set)
Gypsum	**$CaSO_4 \cdot 2H_2O$**	Reclaiming **sodic (alkali) soils**; S and Ca source; added (~2–5%) to cement to **slow setting**

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Bleaching powder	**Ca(OCl)Cl** ($CaOCl_2$)	Cl_2 passed over dry **slaked lime** (Hasenclever plant); disinfecting water; available chlorine ≈ **35%** (theoretical 49%)
Quicklime	**CaO**	Heating limestone (calcination, ~1070–1270 K); "burnt lime"
Slaked lime / lime water / milk of lime	$Ca(OH)_2$	Whitewash; liming acid soils; **Bordeaux mixture** ($CuSO_4$ + lime); lime water turns milky with CO_2 ($CaCO_3$), clears with excess CO_2 ($Ca(HCO_3)_2$)
Limestone / marble / chalk	$CaCO_3$	Agricultural lime; flux in blast furnace
Dolomite	$CaCO_3 \cdot MgCO_3$	Liming material that also supplies Mg
Epsom salt	**$MgSO_4 \cdot 7H_2O$**	Purgative; Mg fertiliser
Milk of magnesia	$Mg(OH)_2$	Antacid, laxative
Muriate of potash (MOP)	KCl	**60% K_2O**; sulphate of potash (K_2SO_4) 50% K_2O
Saltpetre (nitre) / Chile saltpetre	KNO_3 / $NaNO_3$	Gunpowder (KNO_3 + S + C); fertiliser

- Biological role: **Na^+** main extracellular, **K^+** main intracellular cation; Na^+/K^+-ATPase pumps **3 Na^+ out, 2 K^+ in**. **Mg** is the central atom of **chlorophyll**; ~99% of body Ca is in bones/teeth (hydroxyapatite).
- **Portland cement** (Joseph Aspdin, 1824): CaO 50–60%, SiO_2 20–25%, Al_2O_3 5–10%; gypsum controls setting.

p-block & fertiliser chemistry

Process	Product	Reaction	Catalyst & conditions
Haber–Bosch	Ammonia	$N_2 + 3H_2 \rightleftharpoons 2NH_3$; $\Delta H = -92$ kJ	**Iron** (Fe oxide) with K_2O & Al_2O_3 promoters (older texts: Mo); **~200 atm, ~700 K**
Ostwald	Nitric acid	$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$; $NO \rightarrow NO_2 \rightarrow HNO_3$	**Pt/Rh gauze**; NCERT quotes 500 K, 9 bar (industrial gauze runs much hotter, ~1100 K)
Contact	Sulphuric acid	$2SO_2 + O_2 \rightleftharpoons 2SO_3$; $SO_3 + H_2SO_4 \rightarrow$ **oleum ($H_2S_2O_7$)** → diluted	**V_2O_5; 720 K, 2 bar** (old: Pt). SO_3 is not absorbed directly in water (acid mist)
Lead chamber (old)	H_2SO_4 (impure)	—	Oxides of nitrogen
Solvay	Na_2CO_3	$NaCl + NH_3 + CO_2 + H_2O \rightarrow NaHCO_3\downarrow \rightarrow$ heat	By-product $CaCl_2$
Urea synthesis	$CO(NH_2)_2$	$2NH_3 + CO_2 \rightarrow NH_2COONH_4$ (carbamate) → urea + H_2O	High P & T
Hydrogenation of oils	Vanaspati	Unsaturated oil + H_2	**Ni** (Sabatier–Senderens)
Deacon (old)	Cl_2	$4HCl + O_2 \rightarrow 2Cl_2 + 2H_2O$	$CuCl_2$

- **Nitrogen**: 78% of air; N≡N (946 kJ/mol) makes it inert. NH_3 – pyramidal, very soluble (fountain experiment), Lewis base. **N_2O = laughing gas** (anaesthetic, also a GHG). NO_2 – brown, acid rain.
- Fertiliser nutrient contents: **urea 46% N**; ammonium sulphate 20.6% N + 24% S; CAN 25–26% N; **DAP 18–46–0**; SSP 16% P_2O_5 (+ ~11–12% S); TSP 46% P_2O_5. **Superphosphate** = $Ca(H_2PO_4)_2$ + $CaSO_4$, made from rock phosphate (fluorapatite) + H_2SO_4.
- **Phosphorus** allotropes: **white P (P_4)** – most reactive, stored under water, glows in dark (chemiluminescence), poisonous; **red P** – safety matches (striking surface); **black P** – most stable. Phosphine PH_3 – garlic/rotten-fish odour, highly toxic (fumigant gas from AlP).
- **Sulphur**: rhombic (α, most stable at room temperature, S_8 crown) and monoclinic (β, stable above 369 K). H_2S – rotten-egg smell. SO_2 bleaches by **reduction** (temporary); Cl_2 bleaches by **oxidation** (permanent, needs moisture). Conc. H_2SO_4 chars sugar (dehydrating agent) – "king of chemicals".
- **Ozone (O_3)**: bent, resonance hybrid; stratospheric layer absorbs UV-B; measured in **Dobson units**; depleted by CFCs (Montreal Protocol 1987).
- **Halogens**: F – most electronegative, most reactive, isolated by **Moissan**; always −1. **HF** is the weakest hydrohalic acid (H-bonding) but etches glass (kept in wax/polythene bottles); HI is the strongest. Bond energy order **$Cl_2 > Br_2 > F_2 > I_2$**. Chlorine discovered by **Scheele (1774)**; water disinfection residual **~0.2–0.4 ppm**. Iodine deficiency → goitre; fluoride (~1 ppm) prevents dental caries, >1.5 ppm → fluorosis.
- **Carbon allotropes**: diamond (sp^3, hardest natural substance, non-conductor), graphite (sp^2, layered, conductor, lubricant, pencils), **fullerene C_{60}** (buckminsterfullerene, sp^2, 1985), graphene (single layer). **CO** binds haemoglobin ~200× more strongly than O_2 (carboxyhaemoglobin). Solid CO_2 = **dry ice**.
- **Boron & aluminium**: borax $Na_2B_4O_7 \cdot 10H_2O$ (borax-bead test); **boric acid** – weak monobasic **Lewis** acid. Al is amphoteric; **potash alum** $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$ – coagulant for water purification, styptic.

d-block & coordination compounds

- Transition elements: variable oxidation states, **coloured ions** (d–d transitions), paramagnetism, **catalytic activity**, complex and alloy formation, interstitial compounds. **Zn, Cd, Hg** (d^{10}) are not typical transition elements; Sc^{3+}, Ti^{4+}, Zn^{2+}, Cu^+ are colourless.
- **Mn** shows the most oxidation states (+2 to +7). **$KMnO_4$** – purple, oxidant, disinfectant (Condy's crystals); **$K_2Cr_2O_7$** – orange (CrO_4^{2-} is yellow), breath-analyser test for ethanol.
- Records: highest m.p. metal **tungsten (W)** (bulb filaments); lowest m.p. Hg (−38.8 °C); best conductor **Ag**, then Cu; most malleable & ductile **Au**; densest Os/Ir; lightest metal **Li**.
- **Lanthanoid contraction** – steady decrease in size of lanthanoids (poor shielding by 4f) → Zr and Hf have almost the same radius.
- **Werner's theory (Nobel 1913)**: primary valency = oxidation state (ionisable); secondary valency = **coordination number** (non-ionisable, directional).
- Ligands: monodentate (NH_3, H_2O, Cl^-, CN^-, CO), bidentate (ethylenediamine "en", oxalate), **hexadentate EDTA**. A ring formed by a polydentate ligand = **chelate** (more stable). Ambidentate: NO_2^-/ONO^-, SCN^-/NCS^-.
- Spectrochemical series (weak → strong field): $I^- < Br^- < Cl^- < F^- < OH^- < H_2O < NH_3 <$ en $<$ **$CN^- <$ CO**. Strong-field ligands → low-spin complexes. $\Delta_t = (4/9)\,\Delta_o$.

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- Examples: $K_4[Fe(CN)_6]$ – potassium **hexacyanidoferrate(II)** (Fe +2, C.N. 6); $[Co(NH_3)_6]Cl_3$ – hexaamminecobalt(III) chloride; **cisplatin** cis-$[Pt(NH_3)_2Cl_2]$ – anticancer; **Ziegler–Natta** ($TiCl_4 + Al(C_2H_5)_3$) – polythene; **Wilkinson's catalyst** $[RhCl(PPh_3)_3]$ – hydrogenation.
- Biological complexes: **haemoglobin – Fe^{2+}**; **chlorophyll – Mg^{2+}**; **vitamin B_{12} – Co**; haemocyanin – Cu; nitrogenase – Mo & Fe; carbonic anhydrase – Zn.

Metallurgy

Metal	Important ores (formula)
Aluminium	**Bauxite $Al_2O_3 \cdot xH_2O$** (main); cryolite Na_3AlF_6; kaolinite
Iron	**Haematite Fe_2O_3** (main); **magnetite Fe_3O_4** (richest, ~72% Fe); limonite $Fe_2O_3 \cdot 3H_2O$; siderite $FeCO_3$; iron pyrites FeS_2 ("fool's gold" – not used for Fe)
Copper	**Copper pyrites (chalcopyrite) $CuFeS_2$**; copper glance Cu_2S; cuprite Cu_2O; malachite $CuCO_3 \cdot Cu(OH)_2$
Zinc	**Zinc blende (sphalerite) ZnS**; calamine $ZnCO_3$; zincite ZnO
Lead	**Galena PbS**
Mercury	**Cinnabar HgS**
Tin	Cassiterite (tinstone) SnO_2
Silver	Argentite (silver glance) Ag_2S; horn silver AgCl
Others	Pyrolusite MnO_2; chromite $FeCr_2O_4$; rutile/ilmenite (Ti); pitchblende (U); carnallite $KCl \cdot MgCl_2 \cdot 6H_2O$; fluorspar CaF_2

Step	Method	Used for
Concentration	**Froth flotation** (pine oil frother, xanthate collector, NaCN depressant)	**Sulphide ores** (ZnS, PbS, $CuFeS_2$)
	Gravity (hydraulic washing); magnetic separation	Heavy oxide ores; magnetite, chromite, wolframite
	Leaching	**Bayer's process** (bauxite in NaOH); **cyanide process** (Ag, Au – MacArthur–Forrest)
Calcination	Heating **in absence/limited air** – removes CO_2, H_2O	Carbonate and hydrated ores
Roasting	Heating **in excess air** – sulphide → oxide (+ SO_2)	Sulphide ores
Reduction	Smelting with coke in **blast furnace**; flux $CaCO_3$ → slag **$CaSiO_3$**	Fe, Zn (ZnO + C), Pb
	Electrolytic reduction	Highly electropositive: **Na, K, Ca, Mg, Al**
	Aluminothermy (**thermite**, Goldschmidt)	Cr, Mn; welding rails
Refining	Distillation; liquation; **electrolytic**; **zone refining**; vapour-phase (**Mond** – Ni via $Ni(CO)_4$; **van Arkel** – Zr, Ti via iodides)	Zn/Hg; Sn; Cu; **Si, Ge, Ga** (semiconductors); Ni; Zr/Ti

- **Hall–Héroult process**: Al_2O_3 dissolved in molten **cryolite** (lowers m.p., raises conductivity), graphite anode; anode burns away as CO/CO_2.
- Iron forms: **pig iron ~4% C**; cast iron ~3% C (hard, brittle); **wrought iron – purest (< 0.2% C)**; steel 0.2–1.5% C. **Ellingham diagram** – $\Delta G°$ vs T for oxide formation; predicts reducing agent.
- Copper from sulphide → matte (Cu_2S + FeS) → **blister copper** (98%; SO_2 blisters) → electrolytic refining (anode mud contains Ag, Au, Pt).

Alloy	Composition	Use
Brass	**Cu + Zn**	Utensils, fittings
Bronze	**Cu + Sn**	Statues, medals; bell metal ≈ 78% Cu + 22% Sn
German silver	Cu + Zn + **Ni** (no silver)	Utensils
Gun metal	Cu + Sn + Zn	Gears, castings
Stainless steel	Fe + **Cr** (≥ 10.5%) + Ni + C	Corrosion-resistant ware
Solder	Pb + Sn	Joining wires (low m.p.)
Duralumin	Al + Cu + Mg + Mn	Aircraft
Magnalium	Al + Mg	Balance beams, light instruments
Nichrome	Ni + Cr	Heating elements (high resistance)
Invar	Fe + Ni (36%)	Clock pendulums, tapes (low expansion)
Alnico	Al + Ni + Co + Fe	Permanent magnets
Amalgam	**Hg + any metal**	Dental fillings (Ag–Sn–Hg); Fe does not form amalgam
22-carat gold	91.6% Au + Cu/Ag	Jewellery (24 carat = pure)

Common names & formulae

Common name	Chemical / formula	Common name	Chemical / formul
Blue vitriol	$CuSO_4 \cdot 5H_2O$	**Green vitriol**	$FeSO_4 \cdot 7H_2O$
White vitriol	$ZnSO_4 \cdot 7H_2O$	**Oil of vitriol**	H_2SO_4
Muriatic acid	HCl	Aqua fortis	HNO_3
Aqua regia	**3 HCl : 1 HNO_3** (dissolves Au, Pt)	**Laughing gas**	N_2O
Marsh gas	CH_4	Dry ice	Solid CO_2
Lunar caustic	$AgNO_3$ (voter ink)	Philosopher's wool	ZnO
Glauber's salt	$Na_2SO_4 \cdot 10H_2O$	**Hypo**	$Na_2S_2O_3 \cdot 5H_2O$ (photography fixer
Mohr's salt	$FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$	Sal ammoniac	NH_4Cl
Calomel	Hg_2Cl_2	Corrosive sublimate	$HgCl_2$
Red lead (sindur)	Pb_3O_4	Litharge	PbO
Sugar of lead	$(CH_3COO)_2Pb$	Microcosmic salt	$Na(NH_4)HPO_4 \cdot 4H_2$
Carborundum	SiC	Quartz / sand	SiO_2
Formalin	~40% HCHO (aq)	Carbolic acid	Phenol C_6H_5OH
Wood spirit	CH_3OH	Grain alcohol	C_2H_5OH
Vinegar	6–8% CH_3COOH	Chloroform	$CHCl_3$
TNT	2,4,6-Trinitrotoluene	Picric acid	2,4,6-Trinitrophenol

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MEMORY TRICK

Vitriols by colour of the metal ion: **Blue = Cu, Green = Fe, White = Zn**. Washing soda has **10** waters, Epsom/green/white vitriol **7**, blue vitriol **5**, gypsum **2**, PoP **½**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Catalyst used in the contact process? → **V_2O_5**.
- Chemical formula of plaster of Paris? → **$CaSO_4 \cdot ½H_2O$**.
- Temporary hardness of water is due to? → **Bicarbonates of Ca and Mg**.
- Galena is an ore of? → **Lead (PbS)**; cinnabar? → **Mercury (HgS)**.
- Froth flotation is used to concentrate? → **Sulphide ores**.
- Brass is an alloy of? → **Copper and zinc**.

11.5 Organic Chemistry ★★★

Basics & IUPAC

- **Wöhler (1828)** made **urea** from ammonium cyanate – ended the "vital force" theory. Carbon shows **catenation** and tetravalency. Hybridisation: CH_4 sp^3, C_2H_4 sp^2, C_2H_2 sp, benzene sp^2, diamond sp^3, graphite sp^2.
- IUPAC name = **prefix + word root + primary suffix (ane/ene/yne) + secondary suffix** (functional group). Roots: meth (1), eth (2), prop (3), but (4), pent (5), hex (6), hept (7), oct (8), non (9), dec (10).
- Priority of principal group: **–COOH > –SO_3H > anhydride > –COOR > –COX > –$CONH_2$ > –CN > –CHO > >C=O > –OH > –NH_2** > C=C > C≡C. Halo, nitro, alkoxy are always prefixes.
- Structural isomers: C_4H_{10} = **2**; C_5H_{12} = **3**; C_6H_{14} = **5**.

KEY FORMULAE

- Alkane C_nH_{2n+2}; alkene / cycloalkane C_nH_{2n}; alkyne C_nH_{2n-2}.
- Degree of unsaturation (DBE) = **C – H/2 – X/2 + N/2 + 1** (benzene C_6H_6 = 4).
- Number of optical isomers = 2^n (n = chiral centres, no symmetry); Hückel aromaticity **(4n + 2) π electrons**.

Functional group	Structure	Suffix / prefix	Example
Alcohol	–OH	-ol	Ethanol C_2H_5OH
Aldehyde	–CHO	-al	Ethanal CH_3CHO
Ketone	>C=O	-one	Propanone (acetone)
Carboxylic acid	–COOH	-oic acid	Ethanoic acid
Ester	–COOR	alkyl -oate	Ethyl ethanoate (fruity)
Ether	R–O–R	alkoxy-	Ethoxyethane (diethyl ether)
Amine	–NH_2	-amine	Methanamine
Amide	–$CONH_2$	-amide	Ethanamide; urea
Nitrile	–C≡N	-nitrile	Ethanenitrile
Haloalkane	–X	halo-	Chloromethane

Isomerism

- **Structural**: chain (n-butane/isobutane), position (propan-1-ol/propan-2-ol), **functional** (ethanol/dimethyl ether; propanal/propanone), metamerism (diethyl ether/methyl propyl ether), **tautomerism** (keto–enol; dynamic equilibrium).
- **Geometrical (cis–trans)**: due to **restricted rotation about C=C** (or in rings), each doubly-bonded C carrying two different groups – but-2-ene, maleic (cis) / fumaric (trans) acid. Cis usually has higher dipole moment and b.p.; trans higher m.p.
- **Optical isomerism**: molecule non-superimposable on its mirror image (**chiral**), usually a C with **four different groups** (asymmetric carbon). **Enantiomers** rotate plane-polarised light equally in opposite directions (d/+ and l/–); measured by a **polarimeter**. Discovered by **Louis Pasteur** (tartrate crystals).
- **Racemic mixture** (equal d + l) is optically inactive (external compensation). **Meso**-tartaric acid is inactive due to an internal plane of symmetry. Lactic acid and glyceraldehyde are chiral; **glycine** is the only achiral standard amino acid. Stereoisomers that are not mirror images = **diastereomers**.
- D/L (relative to glyceraldehyde) and R/S (Cahn–Ingold–Prelog) are configurations – **not related to the sign of rotation**.

Reaction mechanism basics

Intermediate	Hybridisation / shape	Stability order
Carbocation (C^+)	sp^2, planar	**3° > 2° > 1° > CH_3^+** (benzyl, allyl very stable)
Carbanion (C^-)	sp^3, pyramidal	CH_3^- > 1° > 2° > 3°
Free radical ($C\bullet$)	sp^2, ~planar	3° > 2° > 1° > $CH_3\bullet$
Carbene ($:CH_2$)	Neutral, 6 valence e	Formed in Reimer–Tiemann

- **Homolytic fission** → free radicals (light/peroxide, non-polar); **heterolytic** → ions.
- **Electrophiles** (electron-loving, Lewis acids): H^+, **NO_2^+**, Cl^+, Br^+, R^+, RCO^+, BF_3, **$AlCl_3$**, SO_3. **Nucleophiles** (nucleus-loving, Lewis bases): OH^-, CN^-, RO^-, X^-, NH_3, H_2O, ROH.
- Electronic effects: **inductive** (permanent, through σ bonds; –NO_2, –X are –I; alkyl +I), **resonance/mesomeric**, **hyperconjugation** (Baker–Nathan; no-bond resonance, explains 3° carbocation stability), electromeric (temporary).
- Reaction types: **substitution** (alkanes – free radical; benzene – **electrophilic**; haloalkanes – **nucleophilic**), **addition** (alkenes/alkynes – electrophilic; aldehydes/ketones – **nucleophilic**), **elimination** (dehydrohalogenation with alc. KOH, dehydration of alcohols with conc. H_2SO_4; **Saytzeff rule** – more substituted alkene is major), rearrangement.
- **S_N2**: one step, **inversion (Walden)**, favoured by 1° halides; **S_N1**: two steps via carbocation, **racemisation**, favoured by 3° halides and polar protic solvents.

Hydrocarbons

- **Alkanes** (paraffins – "little affinity"): free-radical halogenation in light; methane from **sodium acetate + soda lime** (decarboxylation – one C less). Knocking: **octane number** (iso-octane = 100, n-heptane = 0); cetane number for diesel.
- **Alkenes** (olefins): electrophilic addition; decolourise **bromine water** and **Baeyer's reagent** (cold dilute alkaline $KMnO_4$) – tests for unsaturation. **Ozonolysis** locates the double bond. Ethylene (ethene) – fruit-ripening hormone.
- **Alkynes**: acetylene from **CaC_2 + H_2O**; oxy-acetylene flame (~3000 °C) for welding. Terminal alkynes are acidic (sp C–H): white ppt with ammoniacal $AgNO_3$, red ppt with ammoniacal Cu_2Cl_2. Lindlar's catalyst → **cis**-alkene; Na/liq. NH_3 → trans.

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- Use of **calcium carbide** to ripen fruit is **prohibited** (FSS Prohibition & Restriction on Sales Regulations, 2011); ethylene gas is the permitted ripening agent.
- **Benzene**: discovered by **Faraday (1825)**; ring structure by **Kekulé (1865)**; planar, all C–C 139 pm, resonance stabilised. **Aromaticity (Hückel)**: cyclic, planar, fully conjugated with **(4n + 2) π electrons** – benzene (6, n = 1), naphthalene (10), pyridine, pyrrole, furan, thiophene, cyclopentadienyl anion, tropylium cation. Cyclobutadiene (4π) is **anti-aromatic**; cyclo-octatetraene (8π, tub-shaped) is non-aromatic.
- Benzene undergoes **electrophilic substitution** (not addition): nitration (conc. HNO_3 + conc. H_2SO_4, electrophile $\mathbf{NO_2^+}$), halogenation ($FeCl_3$), sulphonation, Friedel–Crafts.
- Directing groups: **o/p-directors** –OH, $-NH_2$, $-OCH_3$, $-CH_3$, halogens (halogens are deactivating but o/p); **m-directors** $-NO_2$, –CN, –CHO, –COOH, $-SO_3H$ (deactivating).

Named reaction	What happens
Wurtz	2 RX + 2 Na (dry ether) → **R–R** (higher alkane; methane cannot be made). Wurtz–Fittig: aryl + alkyl halide + Na; Fittig: two aryl halides → biphenyl
Kolbe electrolysis	Electrolysis of Na/K salt of carboxylic acid → **alkane at anode** (CH_3COONa → ethane)
Kolbe (Kolbe–Schmitt)	**Sodium phenoxide + CO_2** (4–7 atm, ~400 K), then acid → **salicylic acid** (→ aspirin)
Friedel–Crafts	Benzene + RCl / RCOCl with **anhydrous $AlCl_3$** → alkylbenzene (toluene) / aryl ketone (acetophenone)
Reimer–Tiemann	Phenol + $CHCl_3$ + NaOH → **salicylaldehyde** (via dichlorocarbene)
Cannizzaro	Aldehydes **without α-H** (HCHO, C_6H_5CHO) + **conc.** NaOH/KOH → alcohol + carboxylate salt (**disproportionation**)
Aldol condensation	Aldehydes/ketones **with α-H + dilute** NaOH → β-hydroxy aldehyde/ketone (aldol, 3-hydroxybutanal) → α,β-unsaturated compound on heating
Markovnikov rule	In addition of HX to an unsymmetrical alkene, **negative part goes to the C with fewer H** (propene + HBr → 2-bromopropane)
Peroxide (Kharasch) effect	Anti-Markovnikov addition in presence of peroxide – **only with HBr** (free radical) → 1-bromopropane
Clemmensen / Wolff–Kishner	>C=O → $>CH_2$ with Zn–Hg/conc. HCl / NH_2NH_2 + KOH in ethylene glycol
Rosenmund reduction	Acyl chloride + H_2/**Pd–$BaSO_4$** → aldehyde
Stephen / Etard	Nitrile + $SnCl_2$/HCl → aldehyde / toluene + CrO_2Cl_2 → benzaldehyde
Hofmann bromamide	Amide + Br_2 + NaOH → 1° amine with **one carbon less**
Gabriel phthalimide	Pure **1° aliphatic amines**
Sandmeyer	Benzenediazonium salt + CuCl/CuBr/CuCN → aryl halide/nitrile
Diazotisation & coupling	Aniline + $NaNO_2$ + HCl at **273–278 K** → diazonium salt; coupling with phenol → orange **azo dye**
Williamson synthesis	RX + R′ONa → ether
Hell–Volhard–Zelinsky	α-Halogenation of carboxylic acids (X_2/red P)
Finkelstein / Swarts	R–Cl + NaI (acetone) → R–I / R–Cl + AgF, Hg_2F_2 → R–F
Esterification	Acid + alcohol (conc. H_2SO_4) ⇌ ester + water; ester + NaOH → soap/salt + alcohol (**saponification**)

Oxygen & nitrogen compounds – properties and tests

- Acidity: **carboxylic acid > phenol > water > alcohol** (pK_a ≈ 4.8, 10, 15.7, ~16). Electron-withdrawing groups raise acidity (**picric acid** is strongly acidic). HCOOH (3.75) is stronger than CH_3COOH (4.76). Only carboxylic acids liberate CO_2 from **$NaHCO_3$**.
- Basicity: aliphatic amines > NH_3 > **aniline** (lone pair delocalised in ring). In water: $(CH_3)_2NH > CH_3NH_2 > (CH_3)_3N > NH_3$.
- **Methanol** (wood spirit) is poisonous – blindness/death. **Ethanol** by fermentation of molasses (yeast enzymes **invertase** and **zymase**); rectified spirit 95.6%; **denatured spirit** = ethanol + $CuSO_4$ (colour) + pyridine (odour)/methanol.
- Phenol is made by the **cumene process** (by-product **acetone**); 0.2% phenol is antiseptic, 1% disinfectant. Chloroform is kept in **dark bottles filled to the brim** – oxidises in air/light to poisonous **phosgene ($COCl_2$)**.
- Natural acids: **formic** – ant/nettle sting; **acetic** – vinegar; **citric** – citrus; **tartaric** – tamarind, grapes; **lactic** – curd/sour milk, muscle fatigue; **malic** – apple; **oxalic** – spinach, tomato (kidney stones as Ca oxalate); **butyric** – rancid butter; benzaldehyde – bitter almonds.

Test / reagent	Positive for	Observation
Tollens' (ammoniacal $AgNO_3$)	**All aldehydes** (aliphatic + aromatic), HCOOH, reducing sugars (incl. fructose)	**Silver mirror**
Fehling's ($CuSO_4$ + Rochelle salt + NaOH) / Benedict's	**Aliphatic aldehydes**, reducing sugars (**not benzaldehyde**, not ketones)	**Red-brown ppt of Cu_2O**
Iodoform (I_2 + NaOH)	$CH_3CO–$ or $CH_3CH(OH)–$ group: **ethanol, acetaldehyde, acetone**, propan-2-ol (**not methanol**)	**Yellow ppt CHI_3** (antiseptic smell)
Lucas (conc. HCl + anhydrous $ZnCl_2$)	Distinguishes alcohols	**3° – immediate turbidity**; 2° – ~5 min; 1° – none at room temp.
Neutral $FeCl_3$	Phenols (enols)	**Violet** colour
Bromine water	Phenol, aniline (also alkenes – decolourised)	**White ppt** 2,4,6-tribromo derivative
2,4-DNP (Brady's)	Aldehydes and ketones	Yellow-orange ppt
Schiff's reagent	Aldehydes	Pink/magenta restored
Carbylamine ($CHCl_3$ + alc. KOH)	**1° amines** only	Foul-smelling isocyanide
Hinsberg ($C_6H_5SO_2Cl$)	Distinguishes 1°, 2°, 3° amines	1° soluble in alkali; 2° insoluble; 3° no reaction
$NaHCO_3$	Carboxylic acids	Brisk effervescence (CO_2)

Polymers

Polymer	Monomer(s)	Type	Use / note

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Polythene (LDPE / HDPE)	Ethene	Addition	LDPE: high P, peroxide initiator (branched); HDPE: **Ziegler–Natta** catalyst (linear)
PVC	**Vinyl chloride** (CH_2=CHCl)	Addition	Pipes, raincoats
Teflon (PTFE)	**Tetrafluoroethene** CF_2=CF_2	Addition	Non-stick cookware; chemically inert
Polystyrene	Styrene	Addition	Thermocol, packing
Orlon / Acrilan (PAN)	Acrylonitrile	Addition	Wool substitute
PMMA (Perspex, Plexiglas)	Methyl methacrylate	Addition	Unbreakable glass, lenses
Buna-S (SBR)	1,3-Butadiene + styrene	Addition copolymer	Tyres, soles
Buna-N	1,3-Butadiene + acrylonitrile	Addition copolymer	**Oil-resistant** seals, hoses
Neoprene	Chloroprene (2-chloro-1,3-butadiene)	Addition	Conveyor belts, gaskets
Natural rubber	**Isoprene** (2-methyl-1,3-butadiene)	Addition (natural)	**cis-1,4-polyisoprene** (Hevea latex); gutta-percha = trans
Nylon-6,6	**Hexamethylenediamine + adipic acid**	Condensation (polyamide)	Carothers (DuPont, 1935); fibres, bristles
Nylon-6	Caprolactam	Condensation (ring-opening)	Tyre cord, ropes
Terylene (Dacron, PET)	**Ethylene glycol + terephthalic acid**	Condensation (polyester)	Crease-resistant fabric, bottles
Bakelite	**Phenol + formaldehyde**	Condensation, **thermosetting**	Baekeland (1907); switches, handles; novolac = linear intermediate
Melamine–formaldehyde	Melamine + HCHO	Condensation	Unbreakable crockery
Glyptal	Ethylene glycol + phthalic acid	Condensation	Paints, lacquers
PHBV / Nylon-2–nylon-6	3-Hydroxybutanoic + 3-hydroxypentanoic acid / glycine + aminocaproic acid	Condensation	**Biodegradable**

- **Vulcanisation** (Charles Goodyear, 1839): heating rubber with **sulphur** (~373–415 K) forms S cross-links → more elastic, stronger, less sticky; tyre rubber ~5% S; heavily vulcanised (~30% S) = ebonite.
- **Thermoplastics** soften on heating, can be remoulded (polythene, PVC, polystyrene); **thermosets** become permanently hard (Bakelite, urea- and melamine-formaldehyde). By intermolecular force: elastomers (weakest) < thermoplastics < **fibres** (strong H-bonds; nylon, terylene).
- Natural polymers: starch, cellulose, proteins, nucleic acids, rubber. Semi-synthetic: **rayon** (artificial silk, regenerated cellulose), cellulose acetate, cellulose nitrate.

Chemistry in everyday life

Drug class	Action	Examples
Analgesics – non-narcotic	Relieve pain, no addiction	**Aspirin (acetylsalicylic acid)** – also anti-clotting; paracetamol, ibuprofen
Analgesics – narcotic	Severe pain; sleep, addiction	Morphine, codeine, heroin (opium alkaloids)
Antipyretics	Lower fever	**Paracetamol**, aspirin
Antacids	Neutralise / reduce gastric acid	$Mg(OH)_2$, $Al(OH)_3$, $NaHCO_3$; H_2-blockers **cimetidine, ranitidine**; proton-pump inhibitors omeprazole
Antihistamines	Block histamine receptors (allergy)	Brompheniramine, terfenadine
Tranquillisers	Stress, anxiety, sleep	Equanil (meprobamate), chlordiazepoxide, Valium; **barbiturates** (veronal, luminal, seconal) – hypnotics; iproniazid, phenelzine – antidepressants
Antibiotics	Kill/inhibit microbes	**Penicillin (Fleming, 1928)**; bactericidal – penicillin, aminoglycosides, ofloxacin; bacteriostatic – erythromycin, tetracycline, chloramphenicol; **broad-spectrum – chloramphenicol** (typhoid), tetracycline
Antiseptics	On living tissue	**Dettol = chloroxylenol + terpineol**; 0.2% phenol; tincture of iodine (2–3% I_2 in alcohol–water); iodoform; boric acid (eyes); bithionol (soaps)
Disinfectants	On non-living objects	1% phenol; Cl_2 0.2–0.4 ppm; low-conc. SO_2
Sulpha drugs / early	Antibacterial	Prontosil → sulphanilamide (Domagk); **Salvarsan** (arsenic; Ehrlich – syphilis)
Antifertility	Synthetic hormones	Norethindrone, ethynylestradiol (novestrol)

Soap	Synthetic detergent
Na/K salts of **long-chain fatty acids** (sodium stearate, palmitate, oleate)	Na salts of **long-chain alkyl benzene sulphonates / alkyl sulphates**
Made by **saponification** of fats/oils with NaOH (hard) or KOH (soft, toilet/shaving); by-product **glycerol**	Made from petroleum chemicals
Fails in hard water (insoluble Ca/Mg soaps – scum) and acidic water	**Works in hard water** (Ca/Mg salts soluble)
Biodegradable	Branched-chain types **non-biodegradable** → foam, eutrophication (phosphate builders)

- Detergent types: **anionic** – sodium dodecylbenzenesulphonate, sodium lauryl sulphate (toothpaste); **cationic** –

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cetyltrimethylammonium bromide (germicidal, hair conditioner); **non-ionic** – polyethylene glycol stearate (dish-wash liquids). Cleansing action via **micelles** (hydrophobic tail in grease, ionic head in water) above the critical micelle concentration.

- **Food preservatives**: salt, sugar, vegetable oil; **sodium benzoate** (metabolised to **hippuric acid** and excreted; acidic foods/squashes); salts of sorbic and propionic acid (bakery – mould); **potassium metabisulphite** (KMS, releases SO_2; light-coloured fruit products – not for naturally red/purple ones as SO_2 bleaches anthocyanins).
- **Antioxidants** in food: **BHA** (butylated hydroxyanisole), **BHT** (butylated hydroxytoluene), TBHQ, propyl gallate, tocopherols, SO_2/sulphites – delay oxidative rancidity.

Artificial sweetener	Sweetness vs cane sugar (NCERT)	Note
Saccharin	**~550 ×**	First popular sweetener; excreted unchanged; for diabetics
Aspartame	~100 ×	Dipeptide methyl ester (Asp–Phe); **unstable at cooking temperature** – cold drinks only; avoid in phenylketonuria
Sucralose	~600 ×	Trichloro derivative of sucrose; **stable at cooking temperature**, no calories
Alitame	~2000 ×	High-potency; sweetness hard to control

Pesticide chemistry link (details in ch10)

Group	Chemistry	Examples	Mode of action
Organochlorines	Chlorinated hydrocarbons; persistent, fat-soluble, **biomagnify**	**DDT** (synthesised Zeidler 1874; insecticidal property – Paul Müller, Nobel 1948), BHC/HCH (**lindane = γ-isomer**), aldrin, dieldrin, endosulfan (banned in India 2011)	Nerve axon Na-channel (DDT); GABA-gated Cl channel (cyclodienes)
Organophosphates	**Esters of phosphoric/thiophosphoric acid**; less persistent	**Malathion** (low mammalian toxicity), chlorpyrifos, **dichlorvos (DDVP)**, fenitrothion, pirimiphos-methyl, parathion	**Irreversible AChE inhibition** (phosphorylation); antidote **atropine + pralidoxime (2-PAM)**
Carbamates	Esters of carbamic acid	Carbaryl (Sevin; Bhopal 1984 – **methyl isocyanate** leak), carbofuran, aldicarb	Reversible AChE inhibition
Synthetic pyrethroids	Analogues of pyrethrins (Chrysanthemum)	Deltamethrin, cypermethrin, permethrin	Na-cha modul
Fumigants	Volatile toxic gases	**Aluminium phosphide** ($AlP + 3H_2O \rightarrow Al(OH)_3 + PH_3$), methyl bromide (ozone-depleting; QPS use only)	Respira inhibit cytoch oxidas

CODE UPDATE

India achieved about **20% ethanol blending in petrol (E20) in 2025**, ahead of the original 2030 target (advanced to ESY 2025-26). Ethanol comes from molasses, cane juice, damaged/surplus foodgrains (FCI rice, maize).

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Monomers of nylon-6,6? → **Hexamethylenediamine and adipic acid**.
- Natural rubber is a polymer of? → **Isoprene (cis-1,4-polyisoprene)**; vulcanised with **sulphur**.
- Cannizzaro reaction is given by aldehydes that? → **Lack α-hydrogen** (e.g. HCHO).
- Iodoform test is NOT given by? → **Methanol**.
- Number of π electrons in an aromatic compound obey? → **Hückel (4n + 2) rule**.
- Sodium benzoate is a? → **Food preservative** (metabolised to hippuric acid).

11.6 Biochemistry ★★★

Carbohydrates

- General formula $C_x(H_2O)_y$; polyhydroxy aldehydes (aldoses) or ketones (ketoses). Simplest: **glyceraldehyde** (aldotriose – reference for D/L) and dihydroxyacetone.
- **Glucose** (dextrose, blood sugar, aldohexose) – forms a 6-membered **pyranose** ring; α (+112°) and β (+19°) anomers interconvert in water → **mutarotation** (equilibrium +52.7°). **Fructose** (laevulose, fruit sugar, ketohexose) – **sweetest natural sugar**; 5-membered furanose in sucrose.
- **Reducing sugars** have a free (hemiacetal) aldehyde/ketone group – **all monosaccharides, maltose, lactose**; reduce Tollens', Fehling's, Benedict's.
- **Invert sugar**: hydrolysis of sucrose (+66.5°) by acid or **invertase** gives equimolar glucose + fructose; rotation changes to **laevo (−)** because fructose (−92°) outweighs glucose (+52.7°).

Sugar	Units / linkage	Reducing?	Source / note
Glucose	Aldohexose	Yes	Grapes, honey; blood sugar (~70–100 mg/dL fasting)
Fructose	Ketohexose	Yes	Fruits, honey; sweetest
Galactose	Aldohexose (C-4 epimer of glucose)	Yes	Part of lactose
Ribose / deoxyribose	Aldopentoses	Yes	RNA / DNA

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Sucrose	**α-glucose (C1) + β-fructose (C2)**, α1→β2	**No** (both anomeric C used)	Cane/beet sugar; "table sugar"
Maltose	2 α-glucose, **α-1,4**	Yes	Malt sugar – from starch by amylase (germinating barley)
Lactose	β-galactose + glucose, **β-1,4**	Yes	Milk sugar (~4.5–5% in cow milk); lactase deficiency → intolerance
Trehalose	2 glucose, α-1,1	No	Insect "blood sugar"; fungi
Raffinose, stachyose	Oligosaccharides (α-galactosides)	No	Pulses – cause **flatulence**
Starch	**Amylose** (15–20%, linear α-1,4, water-soluble, **blue** with I_2) + **amylopectin** (80–85%, branched α-1,4 + **α-1,6**, insoluble, red-violet with I_2)	No	Plant storage; waxy (glutinous) rice ≈ all amylopectin
Glycogen	Like amylopectin but **more branched** (α-1,6 every ~8–12 residues)	No	"Animal starch" – liver & muscle; also fungi
Cellulose	Linear **β-1,4** glucose; H-bonded microfibrils	No	**Most abundant organic compound**; humans lack cellulase; ruminants digest via microbes
Chitin	β-1,4 **N-acetylglucosamine**	No	Insect exoskeleton, fungal cell wall
Inulin	**Fructose** polymer	No	Dahlia, chicory; used to measure GFR
Pectin	Galacturonic acid polymer	No	Middle lamella (Ca pectate); jelly setting

- Carbohydrate tests: **Molisch** – general (violet ring); **Benedict** – reducing sugars; **Barfoed** – monosaccharide vs disaccharide; **Seliwanoff** – ketoses (cherry red); **iodine** – starch (blue-black), glycogen (red-brown).

Proteins

- Built from **20 standard α-amino acids** (all L-form in proteins); 21st selenocysteine, 22nd pyrrolysine. **Glycine** – simplest, only achiral; **proline** – imino acid (helix breaker).
- Classes: aromatic (Phe, Tyr, **Trp** – absorb UV at **280 nm**); **sulphur-containing (Cys, Met)**; acidic (Asp, Glu); basic (Lys, Arg, His); hydroxyl (Ser, Thr, Tyr).
- Amino acids exist as **zwitterions**; at the **isoelectric point (pI)** net charge is zero, solubility minimum and no movement in an electric field.
- **Essential amino acids** (9 for adult humans – must come from diet): **Phe, Val, Thr, Trp, Ile, Met, His, Leu, Lys**; **Arg** semi-essential (children).
- **Limiting amino acids**: cereals – **lysine** (also threonine); pulses – **methionine** (S-amino acids) and tryptophan → cereal + pulse diet is complementary. **QPM** (quality protein maize) – **opaque-2** gene, more lysine & tryptophan.
- **Peptide bond** (–CO–NH–): amide bond formed by condensation (loss of H_2O) between α-COOH and α-NH_2; **planar, partial double-bond character, trans**.

Structure level	Description	Bonds / example
Primary	Amino-acid **sequence**	Peptide bonds; **Sanger** sequenced **insulin** (51 aa: A 21 + B 30)
Secondary	Local folding	H-bonds of backbone: **α-helix** (Pauling & Corey; **3.6 residues/turn**, keratin) and **β-pleated sheet** (silk fibroin)
Tertiary	3-D folding of one chain	Disulphide, ionic, H-bonds, hydrophobic interactions; myoglobin (Kendrew, first 3-D structure)
Quaternary	Association of subunits	**Haemoglobin – 4 subunits (2α + 2β)**

- **Denaturation**: loss of secondary/tertiary (biological activity) by heat, pH, urea, alcohol, heavy metals – **primary structure stays intact**; e.g. **boiling egg** (albumin coagulates), **curdling of milk**.
- Fibrous (insoluble; **keratin**, **collagen** – most abundant animal protein, myosin, fibroin) vs globular (soluble; albumin, insulin, haemoglobin, enzymes). **RuBisCO** = most abundant protein on earth.
- Conjugated proteins: glycoproteins, lipoproteins, nucleoproteins, **phosphoprotein – casein** (milk), chromoprotein – haemoglobin.
- **Osborne fractions** of seed proteins: albumins (water-soluble), globulins (salt – main **pulse** protein: legumin, vicilin), **prolamins** (70% alcohol – **gliadin** wheat, **zein** maize, hordein barley, kafirin sorghum), **glutelins** (dilute acid/alkali – **glutenin** wheat, **oryzenin** – major rice protein).
- Protein estimation – **Kjeldahl** (N × factor); general factor **6.25** (protein ≈ 16% N); wheat **5.7**, rice 5.95, milk 6.38. Biuret test – peptide bonds (violet); **ninhydrin** – free amino acids (Ruhemann's purple; proline yellow); xanthoproteic – aromatic amino acids (yellow); Millon's – tyrosine.
- Approximate protein %: rice ~7, wheat ~11–12, maize ~9–10, pulses 20–25, groundnut ~25, **soybean ~40**.

Enzymes

- Biocatalysts, almost all **proteins**; exceptions – **ribozymes** (catalytic RNA; Cech & Altman, Nobel 1989; peptidyl transferase is rRNA). Term "enzyme" – **Kühne (1878)**; cell-free fermentation (zymase) – **Buchner (1897)**; first enzyme crystallised – **urease** by **Sumner (1926)** from jack bean.
- Lower **activation energy**; do not alter equilibrium; highly specific. Models: **lock-and-key – Emil Fischer (1894)**; **induced fit – Koshland (1958)**.
- Optimum: most animal enzymes ~37 °C; **pepsin pH ~2**, salivary amylase ~6.8, **trypsin ~8**. Temperature coefficient Q_{10} ≈ 2. Units: katal (mol s^{-1}); IU = 1 µmol min^{-1}.
- **Holoenzyme = apoenzyme (protein) + cofactor**. Cofactors: **prosthetic group** (tightly bound, e.g. haem in catalase/peroxidase), **coenzyme** (loosely bound organic, mostly vitamin-derived), **metal ions** (Zn^{2+} – carbonic anhydrase, carboxypeptidase; Mg^{2+} – kinases; Mo – nitrogenase).

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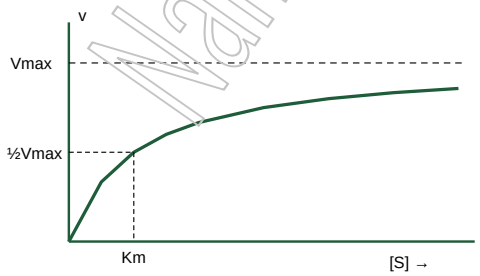
- **Isoenzymes** – different forms catalysing the same reaction (LDH has 5). **Zymogens** – inactive precursors (pepsinogen, trypsinogen).

EC class (IUBMB)	Reaction catalysed	Example
1 Oxidoreductases	Oxidation–reduction	Dehydrogenases, oxidases, catalase, peroxidase
2 Transferases	Group transfer (not H)	Transaminases, kinases (hexokinase)
3 Hydrolases	Hydrolysis	**Amylase, lipase, protease, invertase, urease**
4 Lyases	Removal/addition of groups forming double bonds (non-hydrolytic)	Aldolase, decarboxylases, fumarase
5 Isomerases	Intramolecular rearrangement	Phosphohexose isomerase, mutases, epimerases
6 Ligases (synthetases)	Joining two molecules using **ATP**	DNA ligase, pyruvate carboxylase
7 Translocases (added **2018**)	Movement of ions/molecules across membranes	ATP synthase-type transporters, Na^+/K^+-ATPase

Vitamin	Coenzyme form	Role
B_1 thiamine	**TPP**	Oxidative decarboxylation (PDH)
B_2 riboflavin	**FAD, FMN**	H/electron carriers
B_3 niacin	**NAD^+, $NADP^+$**	H/electron carriers
B_5 pantothenic acid	**Coenzyme A**	Acyl transfer (acetyl-CoA)
B_6 pyridoxine	**PLP**	**Transamination**
B_7 biotin	Biocytin	**Carboxylation**
B_9 folic acid	THF	One-carbon transfer
B_{12} cobalamin	Methylcobalamin, deoxyadenosylcobalamin	Methyl transfer, isomerisation

KEY FORMULAE

- Michaelis–Menten (1913): $v = V_{max}[S] / (K_m + [S])$.
- $K_m = [S]$ at which $v = ½ V_{max}$; low K_m = high affinity.
- Lineweaver–Burk: $1/v = (K_m/V_{max})(1/[S]) + 1/V_{max}$; y-intercept = $1/V_{max}$, x-intercept = $-1/K_m$.



Michaelis–Menten curve: rate (v) approaches V_{max}; K_m is the substrate concentration giving ½V_{max}

Inhibition	Binds	K_m	V_{max}	Example
Competitive	Active site (substrate analogue); overcome by excess substrate	**Increases**	**Unchanged**	**Malonate → succ dehydrogenase**; s drugs vs PABA; methotrexate
Non-competitive	Site other than active site	Unchanged	**Decreases**	Heavy metals (Hg **cyanide → cytoch oxidase**
Uncompetitive	ES complex only	Decreases	Decreases	Rare
Irreversible	Covalent bond to active site	—	—	**Organophosphat → AChE** (serine)
Allosteric / feedback	Regulatory site by end-product	—	—	Phosphofructokin ATP/citrate

Lipids

- **Triglycerides (triacylglycerols)** = glycerol + 3 fatty acids (ester bonds); fats (solid, mainly saturated) vs oils (liquid, mainly unsaturated). Energy: **fat 9 kcal/g** vs carbohydrate and protein **4 kcal/g**.
- **Saturated**: lauric C12:0 (coconut ~45–50%), palmitic C16:0 (palm oil), stearic C18:0. **Unsaturated**: **oleic C18:1 (ω-9)** – olive, groundnut; **linoleic C18:2 (ω-6)** – safflower (~75%), sunflower; **α-linolenic C18:3 (ω-3)** – **linseed** (richest), mustard, soybean; arachidonic C20:4 (ω-6); EPA & DHA – fish oils; **erucic acid C22:1** – mustard/rapeseed (canola = < 2% erucic acid, low glucosinolates).
- **Essential fatty acids**: **linoleic and α-linolenic** (arachidonic is conditionally essential, made from linoleic). Natural unsaturated fatty acids are **cis**; **trans fats** arise from partial hydrogenation (vanaspati). FSSAI limit: **trans fat ≤ 2%** of total fat in oils/fats (from 1 January 2022).
- **Phospholipids** (lecithin = phosphatidylcholine, cephalin) – membranes, emulsifiers. **Sterols**: **cholesterol** (animals only; precursor of steroid hormones, bile acids, vitamin D_3); **ergosterol** (fungi; provitamin D_2); phytosterols (sitosterol). **Waxes** = long-chain fatty acid + long-chain monohydric alcohol.

Constant	Definition	Indicates
Saponification value	mg KOH to saponify **1 g** fat	**Inversely ∝ mean molecular weight**; high for short chains – coconut ~250–260; most oils ~185–195
Iodine value	g I_2 absorbed by **100 g** fat	**Degree of unsaturation**: drying oils > 130 (**linseed ~170–200**), semi-drying 100–130 (sunflower, soybean ~120–140 overlap), non-drying < 100 (groundnut ~85–100, olive ~80–88, **coconut ~8–10**)
Acid value	mg KOH to neutralise **free fatty acids** in 1 g fat	Hydrolytic rancidity / freshness; FFA % (as oleic) ≈ acid value ÷ 2
Peroxide value	meq active O_2 per kg	**Oxidative rancidity** (early stage)
Reichert–Meissl value	mL 0.1 N alkali for volatile **water-soluble** FA from 5 g fat	**Butyric acid** – butter/ghee purity (ghee high; vegetable oils < 1)

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Polenske value	Volatile **insoluble** FA	Coconut-oil adulteration of butter
Acetyl value	Free –OH groups	High in **castor oil** (ricinoleic acid)

- **Rancidity**: (1) **hydrolytic** – lipase/moisture split triglycerides → **free fatty acids** (butyric acid smell of rancid butter; rapid in **rice bran**); (2) **oxidative (autoxidation)** – O_2 attacks double bonds of unsaturated FA → peroxides → aldehydes/ketones (off-flavour); accelerated by light, heat, Cu/Fe traces; prevented by **antioxidants (BHA, BHT, TBHQ, tocopherols)**, nitrogen flushing, dark packing; (3) ketonic – by moulds.
- **Hydrogenation** of oils with **Ni catalyst** → vanaspati (raises m.p., lowers iodine value, creates trans fats).
- Oil content (approx.): groundnut 45–50%, sesame ~50%, sunflower ~40%, mustard ~38–42%, **soybean ~18–20%** (but ~40% protein), cottonseed ~18–20% (gossypol – toxic pigment), rice bran 15–20%.

Nucleic acids

- Discovered as "**nuclein**" by **Friedrich Miescher (1869)**. **Nucleoside** = base + pentose (N-glycosidic bond); **nucleotide** = nucleoside + phosphate. Nucleotides join by **3′–5′ phosphodiester bonds**.
- **Purines** (double ring): adenine, guanine. **Pyrimidines** (single ring): cytosine, **thymine (DNA only)**, **uracil (RNA only)**.
- **Chargaff's rule**: A = T, G = C; purines = pyrimidines. **A=T – 2 H-bonds; G≡C – 3 H-bonds** (GC-rich DNA has higher melting temperature).
- **Double helix – Watson & Crick (1953)**, using X-ray data of Rosalind Franklin and Maurice Wilkins. **B-DNA**: right-handed, antiparallel, **~10 bp/turn**, pitch **3.4 nm**, rise **0.34 nm** per bp, diameter **2 nm**. Z-DNA is left-handed.
- **ATP** = adenine + ribose + 3 phosphates – "energy currency"; hydrolysis of terminal phosphate ≈ −30.5 kJ mol^{-1} (−7.3 kcal).

Feature	DNA	RNA
Sugar	**2′-Deoxyribose**	**Ribose** (2′-OH makes it less stable, catalytic)
Bases	A, G, C, **T**	A, G, C, **U**
Strands	Usually double-stranded	Usually single-stranded
Chargaff's rule	Obeyed	Not obeyed
Location	Nucleus (also mitochondria, chloroplast)	Nucleus & cytoplasm (ribosomes)
Function	Genetic material of most organisms	Protein synthesis; genetic material of some viruses (**TMV**, HIV, influenza); first genetic material
Types	A, B, Z forms	**mRNA** (template), **tRNA** (adaptor, clover-leaf, smallest), **rRNA** (most abundant, ~80%)
Alkali	Stable	Hydrolysed (2′-OH)

Vitamins & minerals

- Term "vitamine" – **Casimir Funk (1912)** (isolated from rice bran). **Fat-soluble: A, D, E, K** – stored in liver/fat, excess can be toxic. **Water-soluble: B-complex and C** – not stored (except B_{12} in liver), excreted in urine.

Vitamin	Chemical name	Deficiency	Rich source / note
A	**Retinol** (provitamin β-carotene)	**Night blindness**, xerophthalmia, Bitot's spots, keratomalacia	Liver, carrot, yellow/green vegetables; retinal in rhodopsin
D	**Calciferol** (D_2 ergo-, D_3 chole-)	**Rickets** (children), **osteomalacia** (adults)	Made in skin by **UV-B** from 7-dehydrocholesterol; active form calcitriol acts as hormone
E	**Tocopherol**	Sterility (rats), RBC haemolysis	**Antioxidant**; wheat-germ oil, vegetable oils
K	**Phylloquinone** (K_1), menaquinone (K_2, gut bacteria), menadione (K_3)	Delayed **blood clotting**, haemorrhage	Green leafy vegetables; antagonised by dicoumarol/warfarin
B_1	**Thiamine**	**Beriberi** (wet/dry), Wernicke–Korsakoff	Bran/aleurone – lost by **polishing rice**; retained by parboiling
B_2	**Riboflavin**	Cheilosis, angular stomatitis, glossitis	Milk; light-sensitive
B_3	**Niacin** (nicotinic acid)	**Pellagra** – 3 Ds: dermatitis, diarrhoea, dementia (4th death)	Made from **tryptophan** (60 mg → 1 mg); maize/jowar diets
B_5	Pantothenic acid	"Burning feet" syndrome	Widespread
B_6	Pyridoxine	Convulsions, anaemia, peripheral neuritis	Cereals, pulses
B_7	**Biotin** (vitamin H)	Dermatitis, hair loss	Raw egg white **avidin** binds biotin
B_9	**Folic acid** (folate)	**Megaloblastic anaemia**; **neural tube defects**	Green leaves; supplement in pregnancy
B_{12}	**Cyanocobalamin** (contains **Co**)	**Pernicious anaemia** (needs intrinsic factor)	Only animal foods/microbes – vegans at risk
C	**Ascorbic acid**	**Scurvy** (bleeding gums, poor wound healing)	**Amla (~600 mg/100 g)**, guava, citrus; needed for collagen; destroyed by heat/oxidation; humans, primates, guinea pigs cannot synthesise

Mineral	Role	Deficiency / excess
Calcium, phosphorus	Bones, teeth; Ca^{2+} in clotting, muscle contraction	Rickets, osteoporosis
Iron	Haemoglobin, myoglobin, cytochromes	**Anaemia** (most common nutritional deficiency)
Iodine	**Thyroxine**	**Goitre**, cretinism; iodised salt ≥ 15 ppm at consumer level

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Fluorine	Tooth enamel (fluorapatite)	Dental caries (low); **fluorosis** (> 1.5 mg/L)
Zinc	Cofactor of > 300 enzymes; insulin storage	Growth retardation, hypogonadism, acrodermatitis enteropathica
Selenium	Glutathione peroxidase	**Keshan disease** (cardiomyopathy)
Copper	Cytochrome oxidase, tyrosinase	Menkes disease (deficiency); **Wilson's disease** (accumulation)
Cobalt	Part of **vitamin B_{12}**	Pernicious anaemia
Chromium / molybdenum	Glucose tolerance factor / xanthine oxidase	Impaired glucose tolerance
Sodium, potassium	Osmotic balance, nerve impulse	Hypo-/hyper-natraemia, hypokalaemia

Metabolism overview (respiration details – see ch7)

Pathway	Site	Key output
Glycolysis (EMP)	Cytoplasm	Glucose → **2 pyruvate**; net **2 ATP + 2 NADH**; no O_2 needed
Link reaction (PDH complex)	Mitochondrial matrix	Pyruvate → **acetyl-CoA** + CO_2 + NADH
Krebs / TCA / citric acid cycle	**Matrix**	Per acetyl-CoA: **3 NADH, 1 $FADH_2$, 1 GTP/ATP, 2 CO_2** (first product citrate, 6C)
ETS + oxidative phosphorylation	**Inner mitochondrial membrane**	O_2 = final e^- acceptor → H_2O; chemiosmosis (**Peter Mitchell**)
Fermentation	Cytoplasm	Yeast → ethanol + CO_2; muscle/*Lactobacillus* → lactic acid; only 2 ATP
β-Oxidation	Mitochondria	Fatty acids → acetyl-CoA (2C units)
Gluconeogenesis	Liver (cytoplasm + mitochondria)	Glucose from lactate, glycerol, amino acids
Urea (ornithine) cycle	Liver	NH_3 → urea (Krebs–Henseleit)

- ATP per glucose (aerobic): **38 (NCERT, theoretical)**; modern estimate 30–32. Anaerobic: 2.
- **Respiratory quotient** (CO_2/O_2): carbohydrate **1.0**, protein ~0.9, fat ~**0.7**, organic acids > 1, anaerobic = ∞.
- Glycogenesis (glucose → glycogen), glycogenolysis (glycogen → glucose), lipogenesis; **transamination** (PLP) links amino-acid and carbohydrate metabolism.

Grain quality biochemistry (storage link)

- **Moisture** is the master factor in storage. Typical maximum limits in FCI/Government procurement specifications: **wheat 12%**, **rice 14%** (raw/parboiled), **paddy 17%**, coarse grains (maize, jowar, bajra, ragi) **14%** (relaxations are sometimes allowed in a given season).
- Moisture content: **wet basis** = water ÷ total weight × 100 (trade standard); **dry basis** = water ÷ dry matter × 100; **db = wb × 100/(100 − wb)**. Reference method – **hot-air oven (~130 °C)**; quick methods – capacitance/resistance moisture meters; Karl Fischer titration for very low moisture.
- **Equilibrium moisture content (EMC)**: grain neither gains nor loses water at a given RH and temperature. Cereals at ~65–70% RH reach ~13–14% moisture. Storage moulds need **water activity $a_w \gtrsim$ 0.65–0.70**; yeasts ~0.88; bacteria ~0.90.
- **Grain respiration**: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + heat (≈ 2800 kJ mol^{-1}). Respiration rises sharply with moisture and temperature → heat + water → **hot spots**, dry-matter loss, mould growth, "sweating".
- Rules of thumb: **Harrington** – seed storage life roughly **doubles for each 1% fall in moisture** (5–14% range) and for each **5 °C fall in temperature** (0–50 °C range); also safe if **RH (%) + temperature (°F) < 100**.
- Storage fungi: ***Aspergillus*** and ***Penicillium*** (field fungi – *Fusarium*, *Alternaria*, *Cladosporium*, *Helminthosporium*).

Mycotoxin	Fungus	Commodity / note
Aflatoxin B_1 (most potent; liver carcinogen)	***Aspergillus flavus*, *A. parasiticus***	Groundnut, maize, cotton seed; fluoresces under UV (B – blue, G – green); **M_1** appears in milk. FSSAI total aflatoxin limit in cereals ≈ **15 µg/kg**
Ochratoxin A	*A. ochraceus*, *Penicillium verrucosum*	Stored cereals, coffee; kidney toxin
Deoxynivalenol (DON, vomitoxin)	*Fusarium graminearum*	Wheat (head blight), maize
Zearalenone / fumonisins	*Fusarium* spp.	Maize; oestrogenic / oesophageal cancer link
Patulin	*Penicillium expansum*	Apple juice
Ergot alkaloids	*Claviceps purpurea*	Rye, bajra (ergotism)

- **Free fatty acids (FFA)**: grain and fungal **lipases** hydrolyse lipids during storage → FFA (fat acidity) rises; it is one of the **most sensitive early indicators of grain deterioration**, especially in damp or mouldy grain. Fat acidity is expressed as mg KOH per 100 g dry grain.
- **Rice bran**: lipase becomes active immediately after milling → FFA rises very fast; bran must be **stabilised by heat** (or the oil extracted) within hours for edible rice-bran oil. Parboiling inactivates lipase.
- Other storage changes: reducing sugars first rise (amylase) then fall (respiration); **non-reducing sugars decrease**; protein solubility and **available lysine** fall (**Maillard reaction** – reducing sugar + free amino group → brown melanoidins); **thiamine** is lost; viability/germination declines. "**Ageing**" of rice (3–6 months) improves cooking quality – more volume expansion, less stickiness.
- **Wheat quality**: protein (bread wheat ~12–14%, biscuit wheat ~8–10%); **gluten** = **gliadin** (prolamin; viscosity/extensibility) + **glutenin** (glutelin; elasticity/strength) – forms when flour is kneaded with water; dry gluten ≈ ⅓ of wet gluten. Tests: **Zeleny sedimentation** (gluten quality), **falling number** (Hagberg) – low value (≲ 200 s) = high α-amylase = **sprout damage**; hectolitre (test) weight. Gluten causes **coeliac disease** in sensitive people. Durum wheat – semolina/pasta.
- **Rice quality**: **amylose content** decides cooking texture – waxy (0–2%, sticky), low (10–20%, soft), intermediate (20–25%, preferred in India), high (> 25%, dry, fluffy, hardens on cooling); gelatinisation temperature (alkali spreading value); gel consistency; head-rice recovery; basmati aroma = **2-acetyl-1-pyrroline (2-AP)**. **Parboiling** gelatinises starch, drives B-vitamins

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from bran into the endosperm, reduces breakage and stabilises bran oil.

- **Anti-nutritional factors**: trypsin inhibitors (soybean – heat-labile), **phytic acid** (chelates Ca, Fe, Zn; main P store of seeds), tannins (sorghum), **β-ODAP** in *Lathyrus sativus* (khesari) → **neurolathyrism**, **gossypol** (cottonseed), glucosinolates and erucic acid (mustard), **HCN glycosides** (linamarin – cassava; dhurrin – young sorghum), solanine (green potato), vicine/convicine (faba bean – favism), lectins (raw beans), raffinose/stachyose (flatulence).

MEMORY TRICK

Essential amino acids: **"PVT TIM HaLL"** – Phe, Val, Thr, Trp, Ile, Met, His, (Arg), Leu, Lys. EC classes in order: **"Over The Hill, Lie In Long Trousers"** – Oxidoreductase, Transferase, Hydrolase, Lyase, Isomerase, Ligase, Translocase. Fat-soluble vitamins: **"ADEK"**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Which of these is a non-reducing sugar: glucose, maltose, lactose, sucrose? → **Sucrose**.
- Linkage in cellulose? → **β-1,4 glycosidic**.
- K_m of an enzyme is? → **Substrate concentration at half V_{max}**.
- In competitive inhibition V_{max} and K_m? → **V_{max} unchanged, K_m increases**.
- Iodine value of an oil measures? → **Degree of unsaturation**.
- Deficiency of niacin causes? → **Pellagra**; vitamin containing cobalt? → **B_{12}**.

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12. Physics

NOTE

General-science physics is asked at NCERT Class 9–12 level: SI units & dimensions, instruments, laws (Newton, Archimedes, Bernoulli, Ohm, Faraday), standard values (g, c, speed of sound, escape velocity, latent heats), optical/electrical applications and "why does it happen" questions (blue sky, mirage, twinkling). Expect 1–3 MCQs, often with a one-step numerical. Storage-linked items: humidity & dew point, evaporation/condensation in godowns, Co-60 irradiation of grain.

12.1 Measurement, Units & Dimensions ★★★

- **Physical quantity** = numerical value × unit. Fundamental (base) quantities are independent; derived quantities are expressed through them.
- **SI** (Système International) adopted by the **11th CGPM, 1960**; has **7 base units**. Radian and steradian (earlier "supplementary units") are now **dimensionless derived units**.
- **2019 redefinition** (decided by 26th CGPM, Nov 2018; in force **20 May 2019**, World Metrology Day): all 7 base units are now defined by fixing exact values of **defining constants**. The **kilogram** is defined through the **Planck constant h = 6.626 070 15 × 10^{-34} J s** (measured with the Kibble/watt balance); the platinum–iridium cylinder (International Prototype Kilogram, 1889) was retired.
- The **ampere** is now defined by fixing **e**, the **kelvin** by fixing **Boltzmann constant k**, the **mole** by fixing **Avogadro number N_A**.

Base quantity	Unit (symbol)	Defined by fixing (2019)
Length	**metre (m)**	Speed of light **c = 299 792 458 m/s** (metre = distance light travels in 1/299 792 458 s)
Mass	**kilogram (kg)**	**Planck constant h**
Time	**second (s)**	Caesium-133 hyperfine frequency **9 192 631 770 Hz** (atomic clock)
Electric current	**ampere (A)**	Elementary charge **e = 1.602 176 634 × 10^{-19} C**
Thermodynamic temperature	**kelvin (K)**	Boltzmann constant **k = 1.380 649 × 10^{-23} J/K**
Amount of substance	**mole (mol)**	**N_A = 6.022 140 76 × 10^{23} mol^{-1}**
Luminous intensity	**candela (cd)**	Luminous efficacy **683 lm/W** of 540 × 10^{12} Hz radiation

- **Systems of units**: **CGS** (cm, g, s – French); **FPS** (foot, pound, second – British); **MKS** (m, kg, s) → extended to SI. CGS force = **dyne** (1 N = **10^5 dyne**); CGS work = **erg** (1 J = **10^7 erg**).

Derived quantity	SI unit	In base units
Force	newton (N)	kg m s^{-2}
Work / energy	joule (J)	N m = kg m^2 s^{-2}
Power	watt (W)	J s^{-1}
Pressure / stress	pascal (Pa)	N m^{-2}
Frequency	hertz (Hz)	s^{-1}
Charge	coulomb (C)	A s
Potential difference	volt (V)	W A^{-1} = J C^{-1}
Resistance / conductance	ohm (Ω) / siemens (S)	V A^{-1} / A V^{-1}
Radioactivity / absorbed dose / dose equivalent	becquerel / gray / sievert	s^{-1} / J kg^{-1} / J kg^{-1}

Prefix	Factor	Prefix	Factor
hecto (h)	10^2	centi (c)	10^{-2}
kilo (k)	10^3	milli (m)	10^{-3}
mega (M)	10^6	micro (μ)	10^{-6}
giga (G)	10^9	nano (n)	10^{-9}
tera (T)	10^{12}	pico (p)	10^{-12}
exa (E)	10^{18}	atto (a)	10^{-18}
ronna (R) / quetta (Q)	10^{27} / 10^{30}	**ronto (r) / quecto (q)**	10^{-27} / 10^{-30}

CODE UPDATE

The 27th CGPM (November 2022) added four prefixes – **ronna (10^{27}), quetta (10^{30}), ronto (10^{-27}), quecto (10^{-30})** – the first additions since 1991.

Practical / non-SI unit	Value
Light year (distance)	**9.46 × 10^{15} m**
Astronomical unit (Sun–Earth mean distance)	**1.496 × 10^{11} m**
Parsec	**3.26 light years** ≈ 3.08 × 10^{16} m (largest practical unit of distance)
1 atm	**1.013 × 10^5 Pa** = 76 cm Hg = 760 torr; 1 bar = 10^5 Pa
1 calorie	**4.186 J** (≈ 4.2 J)
1 electron volt	**1.6 × 10^{-19} J**
1 kWh (Board of Trade unit)	**3.6 × 10^6 J**
1 horsepower	**746 W** (metric hp ≈ 735.5 W)

Dimensions

- **Dimensions** = powers to which base quantities (M, L, T, A, K…) are raised to represent a quantity. **Dimensional formula** of force = **[MLT^{-2}]**.
- **Dimensionless**: strain, refractive index, relative density, angle, Poisson's ratio, coefficient of friction, dielectric constant, Reynolds number, mechanical advantage.

Quantity	Dimensional formula	Same dimensions as
Force, weight	**[MLT^{-2}]**	thrust
Momentum, impulse	**[MLT^{-1}]**	impulse = momentum
Work, energy, torque	**[ML^2T^{-2}]**	torque = work (but torque is not measured in J)
Power	**[ML^2T^{-3}]**	—
Pressure, stress, Young's/bulk modulus	**[$ML^{-1}T^{-2}$]**	energy per unit volume
Gravitational constant G	**[$M^{-1}L^3T^{-2}$]**	—
Planck constant h	**[ML^2T^{-1}]**	**angular momentum**
Coefficient of viscosity η	**[$ML^{-1}T^{-1}$]**	—

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Surface tension	$[MT^{-2}]$	spring constant, surface energy

- **Uses of dimensional analysis**: (i) checking correctness of an equation (**principle of homogeneity** – every term must have the same dimensions), (ii) converting units between systems ($n_1u_1 = n_2u_2$), (iii) deriving relations (e.g. pendulum $T \propto \sqrt{(l/g)}$).
- **Limitations**: cannot find **dimensionless constants** (2π, ½); fails for trigonometric, exponential, log functions; cannot derive relations with sums/differences; cannot distinguish quantities with same dimensions (work vs torque); fails if quantity depends on more than 3 base quantities (in mechanics).
- A dimensionally correct equation **may still be wrong**; a dimensionally wrong equation is **certainly wrong**.

Significant figures & errors

- All non-zero digits are significant; zeros between non-zero digits are significant; **leading zeros are not** (0.0052 → **2** s.f.); trailing zeros after a decimal point are significant (2.500 → **4** s.f.); 4.700×10^3 → 4 s.f. Powers of 10 do not count.
- Multiplication/division: result has as many s.f. as the **least precise** number. Addition/subtraction: as many **decimal places** as the least.
- **Errors**: **systematic** (instrumental e.g. zero error, personal, environmental – can be corrected); **random** (reduced by taking many readings); **gross** (blunders).
- Absolute error Δa; relative error = $\Delta a/a$; percentage error = $(\Delta a/a) \times 100$.

KEY FORMULAE

- $Z = A \pm B \rightarrow \Delta Z = \Delta A + \Delta B$ (absolute errors add).
- $Z = AB$ or $A/B \rightarrow \Delta Z/Z = \Delta A/A + \Delta B/B$ (relative errors add).
- $Z = A^n \rightarrow \Delta Z/Z = n(\Delta A/A)$. E.g. 2% error in radius → **6%** error in volume ($V \propto r^3$).
- Vernier least count = 1 MSD − 1 VSD = **MSD/n** (1 mm/10 = **0.1 mm = 0.01 cm**).
- Screw gauge least count = **pitch ÷ no. of circular scale divisions** (0.5 mm/50 = **0.01 mm**).
- Correct reading = observed reading − (zero error, with sign). Positive zero error is subtracted.

Instrument	Measures / used for
Vernier caliper	Internal/external diameter, depth (LC 0.1 mm) – Pierre Vernier
Screw gauge (micrometer)	Thickness of wire/sheet (LC 0.01 mm)
Clinical thermometer	Body temperature, range **35–42 °C** (94–108 °F); has a kink (constriction)
Mercury thermometer	−39 °C to ~357 °C (Hg freezes −38.8 °C, boils 356.7 °C)
Alcohol thermometer	Very low temperatures (ethanol freezes ≈ −114 °C) – polar regions
Pyrometer	Very high temperatures (furnaces, Sun) – by radiation
Hygrometer / psychrometer	**Relative humidity** (wet & dry bulb)
Barometer	Atmospheric pressure (Torricelli, 1643; Fortin's, aneroid). Sudden fall → **storm**; gradual fall → rain; steady rise → fair weather
Hydrometer	**Relative density of liquids** (Archimedes' principle; floats deeper in lighter liquid)
Lactometer	**Purity of milk** by specific gravity (cow milk ≈ 1.028–1.030; added water lowers it)
Anemometer	**Wind speed** (wind vane – direction)
Manometer	Pressure of gases (U-tube)
Sphygmomanometer	Blood pressure (normal ≈ 120/80 mm Hg)
Odometer / speedometer / tachometer	**Distance travelled** by vehicle / speed / rpm
Seismograph	Earthquake waves (Richter scale – logarithmic)
Potentiometer	EMF accurately (draws no current at balance)

Physical constant	Value
Speed of light in vacuum c	**2.998×10^8 m/s** ($\approx 3 \times 10^8$)
Gravitational constant G	**6.67×10^{-11} N m^2 kg^{-2}**
Planck constant h	**6.626×10^{-34} J s**
Elementary charge e	**1.602×10^{-19} C**
Electron / proton / neutron mass	9.11×10^{-31} kg / 1.673×10^{-27} kg / 1.675×10^{-27} kg ($m_p \approx$ **1836 m_e**)
Avogadro number N_A	**6.022×10^{23} mol^{-1}**
Universal gas constant R	**8.314 J mol^{-1} K^{-1}**
Coulomb constant $1/4\pi\varepsilon_0$	**9×10^9 N m^2 C^{-2}**
1 atomic mass unit (u)	1.66×10^{-27} kg ≡ **931.5 MeV**
Standard g	**9.8 m/s^2** (9.80665)
Molar volume of ideal gas at STP (0 °C, 1 atm)	**22.4 L** (22.7 L at IUPAC STP, 1 bar)

MEMORY TRICK

Seven base units: **"Kids Must Study And Know More Chemistry"** → Kilogram, Metre, Second, Ampere, Kelvin, Mole, Candela.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Since 2019 the kilogram is defined using which constant? → **Planck constant**.
- Planck constant has the same dimensions as? → **Angular momentum**.
- Which pair has identical dimensions? → **Work and torque** (also pressure and stress).
- Instrument to check purity of milk? → **Lactometer**.
- Number of significant figures in 0.00340? → **3**.
- Parsec is a unit of? → **Distance** (light year too – not time).

12.2 Motion & Laws of Motion ★★★

- **Scalars** (magnitude only): mass, distance, speed, time, work, energy, power, temperature, pressure, electric current (has direction but adds as scalar), charge, potential.
- **Vectors** (magnitude + direction, obey vector addition): displacement, velocity, acceleration, force, momentum, impulse, torque, weight, electric & magnetic field.
- **Distance** = actual path length (scalar, always +ve); **displacement** = shortest straight-line distance from initial to final position (vector, can be zero). |displacement| ≤ distance. One full round of a circle → displacement **zero**.

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- **Speed** = distance/time; **velocity** = displacement/time. Average velocity can be zero while average speed is not. Speedometer shows **instantaneous speed**.
- **Acceleration** = rate of change of velocity (m/s^2); negative acceleration = retardation. **Uniform circular motion** is accelerated motion (direction changes) though speed is constant.
- Slope of x–t graph = velocity; slope of v–t graph = acceleration; **area under v–t graph = displacement**.
- 1 km/h = **5/18 m/s** (72 km/h = 20 m/s).

KEY FORMULAE

- $v = u + at$; $s = ut + \frac{1}{2}at^2$; $v^2 = u^2 + 2as$; s_n (n-th second) $= u + a(2n - 1)/2$.
- Free fall from rest: $v = gt$, $h = \frac{1}{2}gt^2$, $v = \sqrt{(2gh)}$, $t = \sqrt{(2h/g)}$. Body thrown up with u: max height $= u^2/2g$, time to top $= u/g$.
- Projectile: range $R = u^2 \sin 2\theta / g$; max height $H = u^2 \sin^2\theta / 2g$; time of flight $T = 2u \sin \theta / g$.
- Circular motion: $v = \omega r$; centripetal acceleration $a = v^2/r = \omega^2 r$; $F = mv^2/r$.
- Momentum $p = mv$; $F = dp/dt = ma$; impulse $J = F\Delta t = \Delta p$.
- Gravitation $F = Gm_1m_2/r^2$; $g = GM/R^2$; $v_{escape} = \sqrt{(2gR)}$; $v_{orbital} = \sqrt{(gR)}$ (near surface).

- In vacuum all bodies fall with the **same acceleration** regardless of mass (Galileo; feather & coin experiment). $g \approx$ **9.8 m/s²** (take 10 for quick sums).
- **Projectile**: path is a **parabola**; horizontal velocity stays constant (no air resistance), vertical acceleration = g downward. At the highest point velocity is horizontal ($u \cos \theta$) and acceleration = g. **Maximum range at θ = 45°** ($R_{max} = u^2/g$, then $H = R/4$). Complementary angles (θ and 90° − θ, e.g. 30° & 60°) give the **same range**.
- **Centripetal force** acts towards centre (provided by tension, friction, gravity). **Centrifugal force** is a pseudo force in the rotating frame (cream separator, washing-machine dryer, centrifuge). Banking of roads provides centripetal force; cyclist leans inward.

Newton's law (Principia, 1687)	Statement	Examples
First (law of inertia)	A body continues in rest or uniform motion unless acted on by an external force. Defines force; **mass is the measure of inertia**	Passengers jerk forward when bus stops; dust removed by beating carpet; leaves fall when branch shaken
Second	Rate of change of momentum ∝ applied force: **F = ma**. Measures force; 1 N = force giving 1 kg an acceleration of 1 m/s^2	Cricketer pulls hands back while catching (increase time → reduce force); cushions, shock absorbers, sand pits
Third	Every action has an **equal and opposite reaction**, acting on **different bodies**	Rocket/jet propulsion, recoil of gun, swimming, walking, rowing

- **Law of conservation of linear momentum**: if net external force is zero, total momentum is constant (follows from 2nd and 3rd laws). **Recoil**: $m_{bullet}v_{bullet} = -M_{gun}V_{gun}$ → gun moves back with much smaller speed. **Rocket** works on conservation of momentum, works even in vacuum.
- **Apparent weight in a lift**: moving up with acceleration a → m(g + a) (heavier); down → m(g − a); **free fall (cable breaks) → zero**; uniform velocity → mg.
- **Friction** opposes relative motion; independent of area of contact (ideally); ∝ normal reaction ($F = \mu N$). Order: **static (limiting) > kinetic (sliding) > rolling**. Hence wheels, ball bearings reduce friction; lubricants, streamlining too. Friction is necessary for walking, writing, braking. Angle of repose: $\tan \theta = \mu_s$.

Gravitation

- $G = 6.67 \times 10^{-11}$ **N m² kg⁻²** – universal, first measured by **Henry Cavendish (1798)**. g varies from place to place; G does not.
- Mass of Earth ≈ 6×10^{24} **kg**, mean radius ≈ **6371 km** (≈ 6400 km in sums). g on Moon ≈ **1/6** of Earth (mass remains same; weight becomes 1/6).
- **With height**: $g_h \approx g(1 - 2h/R)$ for $h \ll R$ – decreases. **With depth**: $g_d = g(1 - d/R)$ – decreases; **zero at the centre**. g is maximum at the surface.
- **With latitude**: g is **maximum at the poles (≈ 9.83)**, **minimum at the equator (≈ 9.78 m/s²)** – due to Earth's rotation and polar flattening. If Earth stopped rotating, g at the equator would increase (no change at poles); if it spun ~17 times faster, bodies at the equator would be weightless.
- **Escape velocity** (Earth) = **11.2 km/s**; independent of mass of body and angle of projection. Moon ≈ **2.4 km/s** – too low to hold an atmosphere.
- **Orbital velocity** near Earth's surface ≈ **7.9 km/s** (≈ 8 km/s); $v_e = \sqrt{2} \times v_o$. Orbital speed is independent of satellite mass; decreases with height.
- **Geostationary satellite**: height ≈ **35,786 km (~36,000 km)** above the equator, period **24 h** (one sidereal day ≈ 23 h 56 min), moves **west → east** in the equatorial plane; used for communication, weather (INSAT/GSAT). Polar/sun-synchronous satellites orbit at ~500–800 km for remote sensing.
- **Weightlessness**: in a freely falling body/orbiting satellite, normal reaction = 0 (gravity still acts). Astronauts feel weightless; a pendulum clock stops in a satellite.

Kepler's law	Statement	Consequence
1st – Law of orbits	Planets move in **elliptical orbits** with Sun at one focus	Perihelion (nearest), aphelion (farthest)
2nd – Law of areas	Radius vector sweeps **equal areas in equal times**	Planet is **fastest at perihelion**; follows from conservation of **angular momentum**
3rd – Law of periods	$T^2 \propto a^3$ (a = semi-major axis)	Outer planets have longer years

QUICK NUMERICALS

- Car goes 0 → 20 m/s in 5 s: $a = 20/5 =$ **4 m/s²**; distance $= \frac{1}{2} \times 4 \times 25 =$ **50 m**.
- Stone dropped from 20 m ($g = 10$): $t = \sqrt{(2 \times 20/10)} =$ **2 s**; $v =$ **20 m/s**.
- Ball projected at 20 m/s at 45° ($g = 10$): $R = 400/10 =$ **40 m**; $H = 10$ m.
- 5 kg gun fires 50 g bullet at 400 m/s: recoil $= 0.05 \times 400 / 5 =$ **4 m/s**.

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PREVIOUSLY ASKED / LIKELY QUESTIONS

- Area under velocity–time graph gives? → **Displacement**.
- Rocket propulsion is based on? → **Newton's 3rd law / conservation of momentum**.
- Escape velocity from Earth's surface? → **11.2 km/s**.
- Where is g maximum on Earth's surface? → **Poles**.
- Kepler's 2nd law is a consequence of conservation of? → **Angular momentum**.
- Angle of projection for maximum range? → **45°**.

12.3 Work, Energy, Power & Properties of Matter ★★★

- **Work** W = F s cos θ (scalar, joule). Zero work when displacement is zero (pushing a wall) or force ⊥ displacement (coolie carrying load on a level road, centripetal force, Earth's gravity on a satellite in circular orbit). Negative work: friction, gravity on a body thrown up.
- **Kinetic energy** KE = ½mv^2; doubling velocity → KE **×4**. **p = √(2m·KE)**; if KE becomes 4 times, momentum doubles. For equal KE, the heavier body has more momentum.
- **Potential energy** PE = mgh (gravitational); elastic PE of spring = ½kx^2. Water stored in a dam = PE; wound spring of a watch = elastic PE.
- **Work–energy theorem**: net work = change in KE. **Law of conservation of energy**: energy can neither be created nor destroyed. Freely falling body: KE + PE = constant (at half height KE = PE).
- **Power** = work/time = **F·v**; SI unit watt; **1 hp = 746 W**. kWh is a unit of **energy**, not power.
- **Collisions**: momentum is conserved in all; KE conserved only in **elastic** collisions. Coefficient of restitution e = 1 (perfectly elastic), 0 (perfectly inelastic – bodies stick). Equal masses in 1-D elastic collision **exchange velocities**.

Lever class	Middle element	MA	Examples
Class I	**Fulcrum**	>, = or < 1	See-saw, scissors, pliers, crowbar, beam balance, hand pump
Class II	**Load**	**Always > 1**	Nutcracker, wheelbarrow, bottle opener, lemon squeezer, door
Class III	**Effort**	**Always < 1** (gains speed)	Forceps, tweezers, fishing rod, human forearm, broom, sugar tongs

- Mechanical advantage MA = load/effort; velocity ratio VR = distance moved by effort/distance moved by load; **efficiency = MA/VR** (always < 100% due to friction). Principle of lever: load × load arm = effort × effort arm. Inclined plane, pulley, wheel & axle, screw, wedge are other simple machines.

Elasticity

- **Hooke's law**: within elastic limit, **stress ∝ strain**. Stress = force/area (N/m^2); strain = change in dimension/original (no unit).
- **Young's modulus** Y = longitudinal stress/strain; **bulk modulus** K = volume stress/strain (reciprocal = compressibility); **shear (rigidity) modulus** η. Liquids and gases have only bulk modulus.
- **Steel is more elastic than rubber** (larger Y; needs more stress for same strain). Y of steel ≈ 2 × 10^{11} N/m^2. Y depends on material, not on dimensions. Poisson's ratio: theoretical −1 to 0.5; practical 0–0.5.

Fluids – pressure & buoyancy

- **Pressure** = thrust/area (pascal). Sharp knife, nails, narrow heels → small area, high pressure; wide straps on bags, broad tyres on tractors, foundations of buildings → large area, low pressure.
- Liquid pressure P = **hρg** – depends on depth and density, **not on shape/area of vessel**. Dams are thicker at the bottom.
- **Atmospheric pressure** at sea level = **1.013 × 10^5 Pa ≈ 76 cm of Hg ≈ 10.3 m of water**; decreases with altitude (nose bleeding at heights; fountain pens leak in aircraft).
- **Pascal's law**: pressure applied to an enclosed fluid is transmitted **equally and undiminished** in all directions. Applications: **hydraulic lift**, hydraulic press, hydraulic brakes. $F_1/A_1 = F_2/A_2$.
- **Archimedes' principle**: a body immersed in a fluid experiences an **upthrust = weight of fluid displaced**. Apparent loss of weight = buoyant force.
- **Law of floatation**: a body floats when weight of liquid displaced = weight of body (density of body ≤ density of liquid). Fraction submerged = $\rho_{body}/\rho_{liquid}$. **Ice (0.917 g/cm^3) floats with ~90% (≈ 9/10) submerged**.
- Ship floats higher in **sea water** (denser) than in river water; easier to swim in sea; man floats easily in Dead Sea. Iron needle sinks but iron ship floats (hollow shape displaces more water). **Plimsoll line** marks safe loading of ships.
- Density of water is **maximum at 4 °C (1000 kg/m^3)**. Relative density = density of substance/density of water at 4 °C (no unit).
- **Equation of continuity**: $A_1v_1 = A_2v_2$ – liquid flows faster in narrow parts (water from a pipe goes farther when nozzle is pressed; deep rivers flow slowly).

Surface tension & viscosity

- **Surface tension** = force per unit length on the liquid surface (N/m) = surface energy per unit area (J/m^2). Due to **cohesive forces**. Water ≈ 0.072 N/m at 25 °C.
- Surface tension **decreases with rise of temperature** (zero at critical temperature) and with soap/detergent (hot soapy water cleans better).
- Effects: **raindrops and mercury droplets are spherical** (minimum surface area); insects walk on water; needle floats; oil spread on sea calms waves.
- **Angle of contact**: water–clean glass ≈ 0° (wets glass, concave meniscus, rises); mercury–glass ≈ 140° (does not wet, convex meniscus, **depressed**).
- **Capillarity**: rise h = 2T cos θ/(rρg) – **h ∝ 1/r** (narrower tube, higher rise; Jurin's law). Examples: oil in a lamp wick, ink in blotting paper, towel absorbing water, **rise of soil water** – farmers plough/hoe the surface (breaking capillaries) to **conserve soil moisture**.
- **Viscosity** = internal friction of fluids. Coefficient η, SI unit **Pa s (poiseuille)**; CGS **poise** (1 poise = 0.1 Pa s). Honey, glycerine highly viscous.
- Viscosity of **liquids decreases with rise in temperature**; of **gases increases** with temperature.
- **Stokes' law**: viscous drag on a sphere F = **6πηrv**. **Terminal velocity** $v_t = 2r^2(\rho - \sigma)g / 9\eta$ – **∝ r^2**. Explains slow fall of raindrops, parachute descent, fog droplets floating, sedimentation of soil particles (basis of **pipette method** of soil texture analysis).

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- **Bernoulli's theorem** (conservation of energy in flowing ideal fluid): **$P + \frac{1}{2}\rho v^2 + \rho gh$ = constant** – where speed is high, pressure is low. Applications: **lift on aircraft wing (aerofoil)**, roofs blown off in storms, atomiser/sprayer, Bunsen burner, venturimeter, carburettor, two boats moving side by side are pulled together, swing of spinning ball (**Magnus effect**).

QUICK NUMERICALS

- KE of 2 kg body at 3 m/s = ½ × 2 × 9 = **9 J**.
- PE of 1 kg raised 10 m (g = 10) = **100 J**.
- Hydraulic lift: small piston 10 cm^2, large 1000 cm^2; 100 N effort lifts **10,000 N**.

MEMORY TRICK

Levers "**F-L-E = 1-2-3**": the thing in the middle – Fulcrum (I), Load (II), Effort (III). Friction order "**S-K-R** – Static King, Rolling Runs easiest".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Lift of an aeroplane is explained by? → **Bernoulli's principle**.
- Hydraulic brakes work on? → **Pascal's law**.
- Raindrops are spherical due to? → **Surface tension**.
- Viscosity of a liquid with rise in temperature? → **Decreases** (gases: increases).
- Nutcracker is which class of lever? → **Class II**.
- Why is it easier to swim in sea water? → **Higher density → greater buoyancy**.

12.4 Heat & Thermodynamics ★★★

- **Heat** = energy in transit due to temperature difference (joule; calorie). **Temperature** = degree of hotness; decides direction of heat flow; measured by thermometer.
- Absolute zero = **0 K = −273.15 °C = −459.67 °F**; molecular KE is minimum (not exactly zero). Kelvin scale has no negative values; written "K", not "°K".
- Normal human body temperature = **37 °C = 98.6 °F = 310 K**. Water: freezes 0 °C/32 °F/273.15 K; boils 100 °C/212 °F/373.15 K.
- **−40° is the same on Celsius and Fahrenheit**. Fahrenheit and Kelvin read the same at **574.59** (≈ 575).

KEY FORMULAE

- **$C/5 = (F - 32)/9 = (K - 273.15)/5$**; $F = 9C/5 + 32$; $K = C + 273.15$. A change of 1 °C = 1 K = 1.8 °F.
- Linear/areal/volume expansion: $\Delta L = \alpha L \Delta T$; **$\alpha : \beta : \gamma = 1 : 2 : 3$**.
- Heat absorbed $Q = mc\Delta T$; phase change $Q = mL$.
- Stefan–Boltzmann: $E = \sigma T^4$ ($\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}) – doubling absolute T → radiation ×16.
- Wien's displacement law: $\lambda_{max} T = b = 2.9 \times 10^{-3}$ m K.
- Newton's law of cooling: rate of cooling $\propto (T - T_0)$ (for small excess temperature).
- First law: $\Delta Q = \Delta U + \Delta W$; ideal gas $PV = nRT$.
- Carnot efficiency $\eta = 1 - T_2/T_1$ (Kelvin); refrigerator COP = $T_2/(T_1 - T_2)$.

- **Thermal expansion**: gaps in railway tracks and bridges; telephone wires sag in summer; hot riveting; glass stopper loosened by warming the neck. **Bimetallic strip** (brass + iron/invar) bends on heating – used in **thermostats**, fire alarms, MCB overload trips. **Invar** (Fe–Ni) has very low α – pendulums, measuring tapes.
- **Anomalous expansion of water**: water contracts from 0 °C to **4 °C** and expands above 4 °C → max density at 4 °C. Lakes freeze from the top; aquatic life survives below; water pipes burst in winter. Ice is lighter than water (expands ~9% on freezing).
- **Specific heat capacity** = heat to raise 1 kg by 1 K. Water **4186 J kg^{-1} K^{-1} (1 cal g^{-1} $°C^{-1}$)** – highest among common substances (exceptions: hydrogen gas ≈ 14,300, liquid ammonia ≈ 4700). Hence water used as coolant in radiators and hot-water bags; land heats and cools faster than sea (sea/land breezes); coastal climate moderate.

Substance	Specific heat (J kg^{-1} K^{-1})
Water	**4186**
Ice	≈ 2100
Aluminium	≈ 900
Iron	≈ 450
Copper	≈ 385
Mercury / lead	≈ 140 / 130 (low – mercury heats quickly, suitable for thermometers)

- **Latent heat** – absorbed/released at constant temperature during change of state. **Latent heat of fusion of ice = 336 kJ/kg (80 cal/g)** (precise value ≈ 334 kJ/kg). **Latent heat of vaporisation of water = 2260 kJ/kg (540 cal/g)**.
- **Steam at 100 °C burns more severely than water at 100 °C** (extra 2260 kJ/kg). Ice at 0 °C cools better than water at 0 °C.
- Boiling point **increases with pressure** → **pressure cooker** (~120 °C); falls at high altitude (cooking difficult in hills; ~70 °C on Everest). Melting point of ice **decreases with pressure** → **regelation** (skating, glacier flow). Impurities raise b.p. and lower f.p. (salt on icy roads).
- **Sublimation**: solid → vapour directly (camphor, naphthalene, dry ice, iodine, ammonium chloride). **Aluminium phosphide** fumigant releases phosphine on reacting with moisture.

Mode of heat transfer	Medium	Key facts / examples
Conduction	Mainly solids; molecules vibrate in place	Metals good conductors (**silver best**, then copper, gold, aluminium); wood, air, wool, glass wool, thermocol poor (insulators). Cooking pots have wooden handles; double walls, woollen clothes trap air
Convection	Liquids & gases; actual movement of molecules	Sea and land breezes, monsoon, trade winds, ventilators near ceiling, heating water from below; does not occur in solids or in zero gravity
Radiation	**No medium**; electromagnetic (mainly infrared)	Sun's heat reaches Earth; travels at speed of light; dark rough surfaces are good absorbers & emitters (Kirchhoff); white/shiny surfaces reflect – white clothes in summer, white-painted godown roofs

- **Thermos (Dewar) flask** reduces all three: vacuum between double walls (conduction & convection), silvered surfaces (radiation), cork stopper.
- **Black body** absorbs all radiation; good absorbers are good emitters (**Kirchhoff's law**).

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- **Wien's law**: hotter body emits peak at shorter wavelength – red hot → white hot → bluish; Sun (~5800 K) peaks at ~500 nm (visible); Earth (~288 K) peaks at ~10 µm (infrared) → greenhouse effect.

Law of thermodynamics	Statement	Gives concept of
Zeroth	If A and B are each in thermal equilibrium with C, they are in equilibrium with each other	**Temperature** (basis of thermometers)
First	$\Delta Q = \Delta U + \Delta W$ – heat supplied = increase in internal energy + work done	**Internal energy**; conservation of energy; no perpetual motion machine of 1st kind
Second	Kelvin–Planck: no engine converts heat **wholly** into work. Clausius: heat cannot flow from cold to hot by itself (without external work)	**Entropy** (entropy of an isolated system never decreases); no 100% efficient engine
Third	Entropy of a perfect crystal → 0 as T → 0 K; absolute zero cannot be reached in finite steps	Unattainability of 0 K

- **Heat engine**: takes heat Q_1 from source at T_1, rejects Q_2 to sink at T_2; $\eta = W/Q_1$. **Carnot engine** (ideal, reversible) has maximum efficiency between two temperatures; depends only on temperatures, not on working substance. $\eta = 100\%$ only if $T_2 = 0$ K (impossible). Diesel engines (higher compression, no spark plug) are more efficient than petrol engines.
- **Refrigerator/heat pump**: reverse heat engine; transfers heat from cold to hot using work. Refrigerant absorbs latent heat by evaporating inside (evaporator) and releases it in the condenser at the back. Cold storages commonly use **ammonia**; domestic units moved from CFCs to HFC-134a and now isobutane (R-600a).

Humidity, dew point & evaporation (storage link)

- **Absolute humidity** = mass of water vapour per unit volume of air (g/m^3). **Relative humidity (RH)** = (actual vapour pressure ÷ saturation vapour pressure at that temperature) × 100.
- Warm air holds more vapour; on cooling the **same air**, RH rises. **Dew point** = temperature at which air becomes saturated (**RH = 100%**) and vapour condenses. Dew, fog, mist, frost (dew point below 0 °C) form this way.
- **Wet & dry bulb hygrometer**: larger difference between readings → **drier air (lower RH)**; equal readings → RH 100%.
- **Godown relevance**: when warm, moist air meets cold surfaces (walls, roof, grain at the periphery) below its dew point → **condensation** → wetting, caking, mould and hot spots. **Moisture migration** occurs from warm to cool zones in a grain mass. Grain is in equilibrium with air RH (equilibrium moisture content); mould growth is favoured above ≈ **70% RH** and insects multiply faster in warm humid conditions. Hence aeration/ventilation only when outside air is cool and dry, dunnage, and tarpaulin covers.
- **Evaporation** (surface phenomenon, at all temperatures) **causes cooling** – takes latent heat from surroundings. Faster with ↑ temperature, ↑ surface area, ↑ wind speed, ↓ **humidity**. Examples: earthen pot (matka) cools water, sweating, desert coolers (less effective in humid monsoon weather), feeling cold after acetone/spirit on skin, dogs panting.

QUICK NUMERICALS

- 1 kg ice at 0 °C → steam at 100 °C: 336 + 418.6 + 2260 ≈ **3015 kJ**.
- Carnot engine between 500 K and 300 K: $\eta = 1 - 300/500 =$ **40%**.

MEMORY TRICK

Latent heats of water: **"80 to melt, 540 to fly"** (cal/g) = 336 and 2260 kJ/kg. Laws of thermodynamics: "**0 – Temperature, 1 – Energy, 2 – Entropy, 3 – Zero (absolute)**".

PREVIOUSLY ASKED / LIKELY QUESTIONS

- At what temperature are Celsius and Fahrenheit readings equal? → **−40°**.
- Why does steam cause more severe burns than boiling water? → **Latent heat of vaporisation**.
- Water has maximum density at? → **4 °C**.
- Heat from the Sun reaches Earth by? → **Radiation**.
- Concept of entropy comes from? → **Second law of thermodynamics**.
- At dew point, relative humidity is? → **100%**.

12.5 Electricity ★★★

- **Charge** is quantised: q = ne; **e = 1.6 × 10^{-19} C**; 1 C = **6.25 × 10^{18}** electrons. Charge is conserved and additive; like charges repel. Charging by friction transfers electrons (glass rubbed with silk → positive; ebonite with fur → negative).
- **Coulomb's law**: $F = k\, q_1 q_2 / r^2$, k = **9 × 10^9 N m^2 C^{-2}**. In a medium, force reduces by the **dielectric constant K** (water K ≈ 80 – hence water dissolves ionic salts).
- **Electric field** E = F/q (N/C = V/m); field lines start on +ve and end on −ve charges, never intersect. **Inside a conductor E = 0** (charge resides on outer surface) → **electrostatic shielding**: safer to sit inside a car/bus during lightning. Lightning conductors use sharp points (charge density highest at points).
- **Electric potential** V = W/q; **1 volt = 1 J/C**. Current flows from higher to lower potential. Earth's potential taken as zero.
- **Capacitance** C = Q/V, unit **farad** (practical µF, pF). Parallel-plate $C = K\varepsilon_0 A/d$ – inserting a dielectric increases C. Energy stored = $\frac{1}{2}CV^2$. Capacitors in **series**: $1/C = \Sigma 1/C_i$; **parallel**: $C = \Sigma C_i$ (opposite of resistors). Capacitor blocks DC, passes AC.
- **Current** I = Q/t; 1 ampere = 1 C/s. Conventional current flows opposite to electron flow.
- **Ohm's law** (Georg Ohm, 1827): at constant temperature **V = IR**; V–I graph is a straight line for ohmic conductors. Non-ohmic: diodes, transistors, electrolytes, filament lamp at varying temperature.
- **Resistance** $R = \rho L/A$; ρ = **resistivity** (Ω m) depends only on material and temperature. Stretching a wire to n times its length makes R **n^2** times (volume constant). Conductance = 1/R (siemens).
- Resistivity order: **silver < copper < gold < aluminium** < tungsten < iron < nichrome. Copper/aluminium used in wires (Al in overhead transmission – light, cheap). **Nichrome** (Ni–Cr) – heater elements (high ρ, high melting point, does not oxidise). **Tungsten** – bulb filament (melting point **3422 °C**); bulbs filled with inert gas (argon/nitrogen). **Manganin/constantan** – standard resistances (very low temperature coefficient).

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- Resistance of metals **increases with temperature**; of semiconductors and insulators **decreases**.

KEY FORMULAE

- Series: $R = R_1 + R_2 + \ldots$ (same current; R > largest). Parallel: $1/R = 1/R_1 + 1/R_2 + \ldots$ (same voltage; R < smallest). n equal resistors R: series nR, parallel R/n → ratio n^2.
- Cell: $I = E/(R + r)$; terminal voltage $V = E - Ir$ (V < E while delivering current; V = E on open circuit).
- Power $P = VI = I^2R = V^2/R$; Joule's law of heating $H = I^2Rt$.
- Electrical energy = P × t ; **1 kWh (1 unit) = 3.6 × 10^6 J**.
- Wheatstone bridge balanced: P/Q = R/S.

- **EMF** = work done per unit charge by the source in moving charge round the full circuit (not a force); measured exactly with a **potentiometer**. **Internal resistance** r of cell rises with age.
- **Kirchhoff's laws**: **junction law** (ΣI = 0) – **conservation of charge**; **loop law** (ΣIR = ΣE) – **conservation of energy**.
- **Ammeter** – in series, very low resistance (galvanometer + low **shunt** in parallel). **Voltmeter** – in parallel, very high resistance (galvanometer + high resistance in series). Ideal ammeter R = 0; ideal voltmeter R = ∞.
- Two bulbs in **series**: **lower-wattage bulb glows brighter** (higher R, same I). In **parallel**: higher-wattage bulb glows brighter. Rated 100 W–220 V bulb: $R = V^2/P$ = **484 Ω**, I ≈ 0.45 A.
- **Heating effect applications**: electric iron, heater, geyser, toaster, bulb, **fuse**. Electric bulb converts most energy to heat (~90%); LEDs are far more efficient.

Household supply / device	Facts
Supply in India	**230 V (often quoted 220 V) AC, 50 Hz**; peak = 230 × √2 ≈ **325 V**; USA 120 V, 60 Hz
Wiring	All appliances in **parallel** (each gets full voltage, independent switching). Switches and fuse on the **live** wire
Wire colours	Old Indian: live **red**, neutral **black**, earth **green**. Current IS/IEC: live **brown**, neutral **blue**, earth **green-yellow**
Fuse	Safety device in **series**; wire of **low melting point** (tin–lead alloy), melts on excess current. Rating slightly above normal current
MCB	Miniature circuit breaker – trips automatically on overload (bimetallic, thermal) and short circuit (electromagnetic); can be reset
RCCB / ELCB	Trips on **earth leakage** (current imbalance; 30 mA for human safety) – protects against shock
Earthing	Metal body of appliance connected to earth (low-resistance path); prevents shock if live wire touches body. Three-pin plug: earth pin is **thicker and longer**
Short circuit vs overload	Short circuit – live and neutral touch (R ≈ 0, huge current). Overload – too many appliances on one socket / voltage surge

Cell / battery	EMF	Key facts
Daniell cell	1.1 V	$Zn/ZnSO_4 \parallel CuSO_4/Cu$
Dry cell (Leclanché)	**1.5 V**	**Primary** (non-rechargeable); zinc can = anode (–), carbon rod = cathode (+), MnO_2 + NH_4Cl paste
Lead–acid	**2 V per cell**	Secondary; car battery = 6 cells = 12 V; electrolyte **dilute H_2SO_4** (sp. gr. ~1.28 when fully charged)
Lithium-ion	~3.6–3.7 V	Mobiles, EVs; Nobel Chemistry 2019

- **Superconductivity**: zero resistance below a critical temperature – discovered by **H. Kamerlingh Onnes (1911)** in **mercury at 4.2 K**. Superconductors expel magnetic field (**Meissner effect** – perfect diamagnets). High-T_c ceramic (cuprate) YBCO ≈ 92 K – above liquid nitrogen (77 K). Uses: MRI magnets, maglev trains, particle accelerators, lossless transmission.

Semiconductors (basics)

- Conductors: overlapping bands; insulators: wide band gap (diamond ≈ 5.5 eV); **semiconductors**: small gap – **Si ≈ 1.1 eV, Ge ≈ 0.7 eV**. At 0 K a pure semiconductor behaves as an insulator.
- **Intrinsic** = pure; **extrinsic** = doped. **n-type**: pentavalent dopant (**P, As, Sb**) – donor, majority carriers **electrons**. **p-type**: trivalent dopant (**B, Al, Ga, In**) – acceptor, majority carriers **holes**. Doped crystal remains **electrically neutral**.
- **p–n junction diode**: conducts in **forward bias** (p to +), blocks in reverse bias → used as **rectifier** (AC → DC; half-wave/full-wave). Depletion layer barrier ≈ 0.7 V (Si), 0.3 V (Ge).
- Special diodes: **Zener** – voltage regulator (reverse breakdown); **LED** – light emission (GaAs, GaP; blue LED Nobel 2014); **photodiode** – light detection; **solar cell** – photovoltaic (light → electricity, no bias).
- **Transistor** (npn/pnp; emitter, base, collector) – **amplifier** and **switch**; invented **1947** at Bell Labs by Bardeen, Brattain & Shockley. Base is thin and lightly doped.

QUICK NUMERICALS

- Three 6 Ω resistors: series **18 Ω**; parallel **2 Ω**.
- Cell E = 2 V, r = 0.5 Ω, external R = 3.5 Ω: I = 2/4 = **0.5 A**; terminal V = 2 – 0.25 = **1.75 V**.
- 1 kW heater used 5 h/day for 30 days = **150 kWh (units)**; at ₹6/unit = ₹900.

MEMORY TRICK

"Ammeter = Along (series), Voltmeter = Versus (across/parallel)." Doping: "**P**enta gives **N**egatives, **T**ri gives **P**ositive holes" – n-type from group 15, p-type from group 13.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Fuse wire should have? → **Low melting point** (high resistance), connected in series in live wire.
- 1 kWh equals? → **3.6 × 10^6 J**.
- Filament of electric bulb is made of? → **Tungsten**.
- Household appliances are connected in? → **Parallel**.
- Majority carriers in n-type semiconductor? → **Electrons**.
- Kirchhoff's junction law is based on conservation of? → **Charge**.

12.6 Magnetism & Electromagnetism ★★☆

- **Magnetic field B**: SI unit **tesla (T)** = Wb/m^2; CGS **gauss** (1 T = **10^4 G**). Earth's field at surface ≈ **25–65 μT (≈ 0.3–0.6 G)**.
- Field lines go **N → S outside** the magnet and S → N inside; they are **closed loops** and never intersect. Poles always occur in pairs –

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isolated monopoles do not exist; breaking a magnet gives two complete magnets.

- Freely suspended magnet points **N–S**; repulsion is the **sure test** of magnetism (attraction can occur with unmagnetised iron).

Property	Diamagnetic	Paramagnetic	Ferromagnetic
Behaviour in field	Weakly **repelled** (move to weaker field)	Weakly attracted	**Strongly attracted**
Susceptibility χ	Small, **negative**	Small, positive	Very large, positive
Effect of temperature	Independent	$\chi \propto 1/T$ (**Curie's law**)	Becomes paramagnetic above **Curie temperature**
Examples	Bi, Cu, Ag, Au, water, NaCl, N_2, superconductors (perfect)	Al, Na, Pt, Mn, Cr, O_2, $CuSO_4$	**Fe, Co, Ni, Gd**, alnico (domains)

- **Curie temperature**: iron ≈ **770 °C (1043 K)**, nickel ≈ 358 °C, cobalt ≈ 1115 °C. Heating/hammering destroys magnetism.
- **Soft iron**: high permeability, **low retentivity and low coercivity** (narrow hysteresis loop) → **electromagnets, transformer cores**, relays. **Steel/alnico**: high retentivity and coercivity → **permanent magnets**. Magnetic shielding by soft-iron rings.
- **Earth's magnetism**: Earth behaves as if a bar magnet lies inside with its **S-pole near geographic north**. Origin – dynamo effect in the liquid outer core.
- **Elements of Earth's magnetism** (3): (i) **Declination** – angle between geographic and magnetic meridian; (ii) **Dip/inclination** – angle of total field with horizontal (measured by **dip circle**) – **90° at magnetic poles, 0° at magnetic equator**; (iii) horizontal component B_H (zero at poles).
- **Oersted (1820)**: a current-carrying wire deflects a compass needle – **electricity produces magnetism**. Direction by **right-hand thumb rule** / Maxwell's corkscrew rule. Field of a long straight wire $B = \mu_0 I/2\pi r$ (concentric circles).
- **Solenoid** carrying current behaves like a bar magnet; with soft-iron core = **electromagnet** (electric bell, cranes, relays, MRI, loudspeakers). Field inside a long solenoid is uniform: $B = \mu_0 nI$.
- **Force on a current-carrying conductor** $F = BIL \sin\theta$ – maximum when conductor ⊥ field, zero when parallel. Direction by **Fleming's left-hand rule** → **motor**. **Lorentz force** on moving charge $F = qvB \sin\theta$ (no work done; path circular in uniform B). Parallel currents in the same direction **attract**.
- **Electromagnetic induction – Michael Faraday (1831)** (independently Joseph Henry): changing magnetic flux induces EMF. **Faraday's law**: $e = -d\Phi/dt$ (flux Φ in weber). **Lenz's law**: induced current opposes the change causing it – consequence of **conservation of energy** (gives the minus sign). Direction in a generator by **Fleming's right-hand rule**.

Feature	AC	DC
Direction	Reverses periodically; India **50 Hz** → reverses **100 times/s**	Constant direction
Source	AC generator (alternator), power stations	Cells, batteries, solar panels, rectifiers, DC dynamo
Transformation	**Can be stepped up/down by transformer** – cheap transmission	Cannot be transformed directly
Needs DC	—	**Electroplating, electrolysis**, battery charging

- **Transformer**: works on **mutual induction**; **only on AC** (DC gives no changing flux – coil may burn). Ideal: $V_s/V_p = N_s/N_p = I_p/I_s$. Step-up: $N_s > N_p$ (voltage ↑, current ↓); step-down: $N_s < N_p$. Does not change **frequency** or (ideally) **power**.
- Transformer losses: copper (I^2R), iron (**eddy current** – laminated core; **hysteresis** – soft iron core), flux leakage, humming. Efficiency of large transformers ~95–99%.
- Power is transmitted at **high voltage** (e.g. 220/400/765 kV) and low current to reduce **I^2R line loss**, stepped down near consumers to 11 kV and then 230/415 V. HVDC is used for very long distances.
- **Electric motor**: electrical → mechanical; based on force on current-carrying coil in a magnetic field; DC motor uses **split-ring commutator** to reverse current every half rotation. Used in fans, pumps, mixers, conveyors.
- **Generator (dynamo)**: mechanical → electrical; based on electromagnetic induction. AC generator uses **slip rings**; DC generator uses split rings (commutator).
- **Electromagnetic waves**: predicted by **Maxwell (1864)**, produced by **Hertz (1887)**; produced by **accelerated charges**; transverse; need **no medium**; all travel at $c = 1/\sqrt{(\mu_0\varepsilon_0)} = 3 \times 10^8$ **m/s** in vacuum.

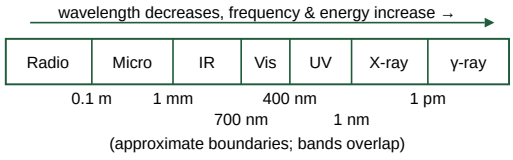

Fig. 12.1 Electromagnetic spectrum (not to scale).

Region (λ, approx.)	Source / discovered	Uses
Radio (> 0.1 m)	Oscillating circuits; Hertz	Radio/TV broadcast (AM 530–1710 kHz; FM 88–108 MHz), communication
Microwave (0.1 m – 1 mm)	Klystron, magnetron	**RADAR**, **microwave oven (2.45 GHz – heats water molecules)**, mobile/satellite links, Wi-Fi, microwave disinfestation research
Infrared (1 mm – 700 nm)	Hot bodies; W. Herschel (1800)	Heat radiation, **TV remote**, night vision, thermal imaging, physiotherapy, **greenhouse effect**, remote sensing of crop health
Visible (700 – 400 nm)	Sun, lamps	Vision, **photosynthesis (PAR 400–700 nm)**
Ultraviolet (400 nm – 1 nm)	Sun, arc lamps; Ritter (1801)	**Sterilising** water/surfaces, vitamin D synthesis, detecting forged notes; absorbed by **ozone layer**; causes skin cancer, cataract
X-rays (1 nm – 10^{-3} nm)	**Röntgen (1895)**, X-ray tube	Medical diagnosis (bone fracture), CT, crystal structure, airport security, detecting hidden infestation in grain kernels

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Gamma rays ($< 10^{-3}$ nm)	Radioactive nuclei (Villard, 1900)	**Cancer radiotherapy**, sterilisation of medical equipment, **food irradiation**

QUICK NUMERICALS

- Transformer $N_p = 100$, $N_s = 2000$, $V_p = 220$ V → V_s = **4400 V** (step-up).
- Step-down 230 V → 11.5 V needs turns ratio $N_p : N_s$ = **20 : 1**; if I_s = 2 A, I_p = **0.1 A**.

MEMORY TRICK

Left for Motor, Right for geneRator ("MoLe" and "GeRi"). Fingers: **F**orefinger = **F**ield, se**C**ond finger = **C**urrent, thu**M**b = **M**otion. Spectrum (long → short λ): **"Raging Martians Invaded Venus Using X-ray Guns"**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Transformer works on the principle of? → **Mutual induction**; works only on **AC**.
- Electric motor converts? → **Electrical energy into mechanical energy**.
- Angle of dip at magnetic poles? → **90°**.
- Above Curie temperature a ferromagnet becomes? → **Paramagnetic**.
- Which EM radiation is used in TV remote controls? → **Infrared**.
- Which has the shortest wavelength: radio, UV, X-ray, γ? → **Gamma rays**.

12.7 Light ★★★

- Light is an electromagnetic wave (transverse); speed in vacuum **c ≈ 3 × 10^8 m/s** – maximum possible speed. First measured by **Ole Rømer (1676)** using Jupiter's moons. Sunlight takes ≈ **8 min 20 s** to reach Earth; moonlight ≈ 1.3 s.
- Theories: corpuscular (**Newton**), wave (**Huygens**), electromagnetic (**Maxwell**), quantum/photon (**Planck, Einstein**) → dual nature.
- **Laws of reflection**: (i) angle of incidence = angle of reflection; (ii) incident ray, reflected ray and normal lie in the same plane.
- **Plane mirror** image: virtual, erect, same size, **laterally inverted**, as far behind as object is in front (focal length infinite, power zero). Mirror moved by x → image shifts **2x**; mirror rotated by θ → reflected ray turns **2θ**. To see full image, mirror height ≥ **half the person's height**. Number of images between two mirrors at angle θ: n = 360/θ − 1 (when 360/θ is even; 90° → **3**, 60° → 5); parallel mirrors → infinite.
- **Spherical mirrors**: **f = R/2**. New Cartesian sign convention: distances measured from the pole; along incident light +ve, against −ve; heights above axis +ve.

Mirror	Image nature	Uses
Concave (converging)	Real & inverted for object beyond F; at F → image at infinity; **between P and F → virtual, erect, enlarged**	**Shaving/make-up mirror**, dentist's mirror, **headlights, torches, searchlights** (bulb at focus gives parallel beam), solar cookers/furnaces, ophthalmoscope
Convex (diverging)	**Always virtual, erect, diminished**, between P and F	**Rear-view mirrors** of vehicles (wide field of view), street-light reflectors, shop security mirrors, blind turns
Plane	Virtual, erect, same size	Looking glass, periscope

KEY FORMULAE

- Mirror formula: **1/f = 1/v + 1/u** ; magnification m = −v/u = h′/h ; f = R/2.
- Snell's law: **n_1 sin i = n_2 sin r** ; refractive index n = c/v = sin i / sin r.
- Real depth / apparent depth = n (water: object looks at ≈ 3/4 of real depth).
- Critical angle: **sin C = 1/n** (n of denser medium w.r.t. rarer).
- Lens formula: **1/f = 1/v − 1/u** ; m = v/u ; lens-maker: $1/f = (n - 1)(1/R_1 - 1/R_2)$.
- Power **P = 1/f (f in metres)**, unit **dioptre (D)**; lenses in contact $P = P_1 + P_2$.
- Simple microscope M = 1 + D/f (D = 25 cm); compound microscope $M = m_o \times m_e$, astronomical telescope $M = f_o/f_e$, tube length $f_o + f_e$.
- Young's double slit fringe width β = λD/d.

- **Refraction**: bending of light when it passes obliquely from one medium to another due to **change in speed**. **Frequency remains unchanged**; speed and wavelength change. Rarer → denser: bends **towards the normal**.
- Refractive index depends on medium and **wavelength** (n larger for violet than red) and temperature.

Medium	n (approx.)	Critical angle
Air	1.0003	—
Ice	1.31	≈ 50°
Water	**1.33**	**≈ 48.6°**
Kerosene	1.44	≈ 44°
Crown glass	**1.5** (1.52)	**≈ 42°**
Diamond	**2.42** (highest common)	**≈ 24.4°**

- Effects of refraction: pool/tank appears **shallower**; pencil in water appears bent; lemon in glass of water looks bigger; **twinkling of stars** (atmospheric refraction – point sources; planets don't twinkle); **advance sunrise and delayed sunset** (~2 min each, Sun visible ~4 min longer); flattened Sun at horizon.
- **Total internal reflection (TIR)**: light goes from **denser to rarer** medium and angle of incidence **exceeds the critical angle**. Examples: **sparkling of diamond** (small C ≈ 24°), **optical fibre** (endoscopy, telecom – core of higher n than cladding), **mirage** in deserts/hot roads (hot air near ground is rarer), looming (in cold regions), shining of air bubble/test tube in water, totally reflecting prisms in binoculars and periscopes.
- Convex lens (converging, +ve f, P +ve); concave lens (diverging, −ve f, P −ve). Convex lens gives virtual, erect, magnified image when object is within F (**magnifying glass**); concave lens always gives virtual, erect, diminished image. An air bubble in water acts as a **diverging lens**.

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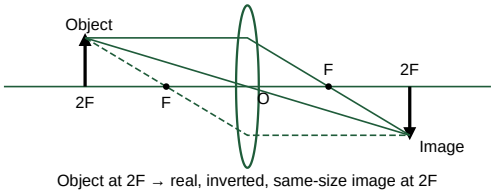

Fig. 12.2 Convex lens: ray parallel to axis passes through F; ray through optical centre O goes undeviated; ray through F emerges parallel (dashed).

Object position (convex lens)	Image	Application
At infinity	At F; real, inverted, point-sized	Burning glass, telescope objective
Beyond 2F	Between F and 2F; real, inverted, diminished	**Camera**, human eye
At 2F	At 2F; real, inverted, same size	Photocopier
Between F and 2F	Beyond 2F; real, inverted, magnified	**Projector**, microscope objective
At F	At infinity	Spotlight, collimator
Between F and O	Same side; **virtual, erect, magnified**	**Magnifying glass**, eyepiece

Human eye

- Light enters through **cornea** (does most of the refraction), passes through pupil (size controlled by **iris**), crystalline lens, and forms a **real, inverted** image on the **retina**. Retina has **rods** (dim light, black-and-white; rhodopsin needs vitamin A) and **cones** (bright light, colour). **Blind spot** – where optic nerve leaves (no rods/cones); **yellow spot (fovea)** – sharpest vision.
- **Accommodation**: ability to change focal length by **ciliary muscles**. **Near point** (least distance of distinct vision) = **25 cm** for normal eye; **far point = infinity**. **Persistence of vision ≈ 1/16 s** (basis of cinema).

Defect	Can see clearly	Cause	Correction
Myopia (short-sightedness)	Near objects	Eyeball elongated / lens too convergent; image in front of retina	**Concave (diverging) lens**
Hypermetropia (long-sightedness)	Distant objects	Eyeball short / lens less convergent; image behind retina; near point > 25 cm	**Convex (converging) lens**
Presbyopia	Distant (near vision poor; age-related)	Weakening of ciliary muscles, loss of lens flexibility with age	**Bifocal** / progressive lens
Astigmatism	Lines in one direction blurred	Unequal curvature of cornea	**Cylindrical lens**
Cataract	Blurred, cloudy vision	Opacity of eye lens	Surgery (intraocular lens)
Colour blindness	—	Defective cones (genetic, X-linked)	No cure

Dispersion, scattering & wave optics

- **Dispersion**: splitting of white light into seven colours **VIBGYOR** by a prism – **Newton (1666)**. Cause: n differs for different wavelengths. **Red deviates least** (longest λ ≈ 700 nm, lowest n, fastest in glass); **violet deviates most** (shortest λ ≈ 400 nm). A second inverted prism recombines the colours.
- **Rainbow**: dispersion + refraction + **internal reflection** in raindrops (often loosely called TIR, but the reflection is partial – angle is below the critical angle); seen with **Sun behind the observer**. Primary rainbow: red on the outside (~42°), violet inside (~40°); secondary rainbow (two internal reflections) has reversed colours and is fainter.
- **Rayleigh scattering**: intensity $\propto 1/\lambda^4$ by particles much smaller than λ. **Sky is blue** (blue scattered most); **Sun appears red at sunrise/sunset** (light travels longer path; blue scattered away); **danger signals are red** (least scattered, seen farthest); **sky looks black to astronauts** (no atmosphere). Clouds are white – large droplets scatter all colours equally.
- **Tyndall effect**: scattering of light by colloidal particles (beam visible in a dusty room or forest canopy).
- **Raman effect**: change in wavelength of light scattered by molecules – **C.V. Raman**, discovered **28 February 1928** (celebrated as **National Science Day**), **Nobel Prize 1930**.
- **Interference**: superposition of light from **coherent sources** (same frequency, constant phase difference) – constructive (bright) and destructive (dark) fringes; **Thomas Young (1801)** double slit. Colours of **soap bubbles and oil films** on water are due to **thin-film interference**.
- **Diffraction**: bending of light around obstacles/apertures comparable to its wavelength. Sound diffracts easily (heard around corners). Colours on a **CD/DVD** (grating). Limits resolving power of microscopes/telescopes.
- **Polarisation**: restriction of vibrations to one plane – proves light is a **transverse wave**; **sound cannot be polarised** (longitudinal in air). **Polaroid sunglasses** cut glare, 3-D movies, LCD screens. Brewster's law $\tan i_p = n$.
- **Optical instruments**: **compound microscope** – objective of **short focal length and small aperture**, eyepiece of larger f. **Astronomical telescope** – objective of **large focal length and large aperture** (more light-gathering), eyepiece of short f; final image inverted. **Reflecting telescopes** use concave mirrors (no chromatic aberration).

QUICK NUMERICALS

- Concave mirror f = 15 cm, object at 30 cm (u = −30, f = −15): 1/v = −1/15 + 1/30 → v = **−30 cm** (real, inverted, same size – object at C).
- Convex lens f = 50 cm → P = 1/0.5 = **+2 D**. Lens of power −2.5 D → f = **−40 cm** (concave).
- Myopic eye with far point 2 m needs lens f = −2 m → P = **−0.5 D**.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Rear-view mirror of a vehicle is? → **Convex mirror**.
- Sparkling of diamond / working of optical fibre is due to? → **Total internal reflection**.
- Blue colour of sky is due to? → **Rayleigh scattering** ($\propto 1/\lambda^4$).
- Myopia is corrected by? → **Concave lens**; astigmatism by **cylindrical lens**.
- National Science Day (28 Feb) commemorates? → **Discovery of Raman effect (1928)**.
- Which colour deviates most in a prism? → **Violet**.

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12.8 Sound & Waves ★★★

- **Wave** = disturbance that transfers **energy, not matter**. **Mechanical waves** need a medium (sound, water waves, seismic); **electromagnetic waves** need none.
- **Transverse**: particles vibrate **perpendicular** to wave direction – crests & troughs (waves on a string, EM waves, S-waves of earthquakes). Cannot travel through liquids/gases as bulk (no rigidity) except at the surface.
- **Longitudinal**: particles vibrate **parallel** to propagation – **compressions & rarefactions** (**sound in air**, P-waves, spring pushed and pulled). Can travel in solids, liquids and gases.
- Characteristics: **amplitude** (maximum displacement), **wavelength λ** (distance between consecutive crests/compressions), **frequency f** (vibrations/s, Hz), **time period T = 1/f**. **v = fλ**. Frequency is set by the source and **does not change** with medium.
- **Sound cannot travel through vacuum** (bell-jar experiment; astronauts on the Moon talk by radio).

Medium	Speed of sound (approx.)
Air at 0 °C	**331–332 m/s**
Air at 20 °C	**343 m/s**
Water	**≈ 1480–1500 m/s** (sea water ~1530)
Steel / iron	**≈ 5000–5960 m/s**

- Order: **solids > liquids > gases** (elasticity dominates over density). Ear on the rail hears an approaching train earlier.
- Speed in gas **∝ √T** (absolute temperature): increases ≈ **0.6 m/s per °C** rise. **Increases with humidity** (moist air is less dense) – sound travels faster on a rainy day. **Independent of pressure** at constant temperature (P/ρ constant). Inversely ∝ √(density) – faster in hydrogen than oxygen (4 times).
- Light is much faster than sound → **lightning seen before thunder** is heard.

Range	Frequency	Examples / uses
Infrasonic	**< 20 Hz**	Earthquakes, volcanic eruptions, **elephants, whales**, rhinoceros; pendulum; some animals sense quakes early
Audible	**20 Hz – 20 kHz**	Human hearing (upper limit falls with age); children hear up to ~20 kHz
Ultrasonic	**> 20 kHz**	**Bats** (echolocation), **dolphins**, porpoises; dogs hear up to ~45 kHz (dog whistle); moths can hear bats

- **Uses of ultrasound**: **SONAR** (Sound Navigation And Ranging) – depth of sea, submarines, shoals of fish; **ultrasonography** (foetus, organs), **echocardiography**; breaking kidney stones (lithotripsy); cleaning delicate/odd-shaped parts; detecting cracks/flaws in metal blocks; homogenisation of milk; ultrasonic humidifiers.
- **Echo**: reflected sound heard distinctly. Persistence of hearing ≈ **0.1 s** → minimum distance to obstacle = (343 × 0.1)/2 ≈ **17.2 m** (total path 34.4 m). Bats and SONAR use echoes; depth d = vt/2.
- **Reverberation**: persistence of sound due to **repeated reflections** in a hall. Reduced by sound-absorbing materials – fibreboard, curtains, rough plaster, carpets, perforated panels. **Multiple reflection** used in **stethoscope**, megaphone, ear trumpet, soundboards, curved ceilings of auditoria.

Characteristic	Depends on	Key facts
Pitch (shrillness)	**Frequency**	Women's and children's voices have higher pitch; mosquito buzz high pitch, lion's roar low pitch but loud
Loudness	**Amplitude** (intensity ∝ A^2)	Measured in **decibel (dB)**; also depends on ear's sensitivity
Quality / timbre	**Waveform** (overtones/harmonics)	Distinguishes two sounds of same pitch and loudness (identifying a person's voice, instruments)

- **Decibel**: sound level $\beta = 10 \log_{10}(I/I_0)$, $I_0 = \mathbf{10^{-12}\ W/m^2}$ (threshold of hearing = 0 dB). **+10 dB = 10 × intensity**; +20 dB = 100 ×. Whisper ≈ 20–30 dB; normal conversation ≈ **60 dB**; heavy traffic ≈ 80–90 dB; prolonged exposure above ~**85 dB** damages hearing; threshold of pain ≈ **120–130 dB**.
- **Doppler effect** (C. Doppler, 1842): apparent change in frequency due to relative motion of source and observer – approaching → **higher pitch**; receding → lower (whistle of passing train/ambulance). Uses: police **radar speed guns**, Doppler radar (weather), **Doppler ultrasound** (blood flow), satellite tracking; for light – **red shift** of receding galaxies (expanding universe, Hubble).
- **Natural vibration** = at natural frequency; **forced vibration** = at frequency of external force; **resonance** = forced frequency equals natural frequency → **maximum amplitude**. Examples: soldiers **break step** while crossing a bridge; Tacoma Narrows bridge collapse (1940, wind-induced); tuning a radio (electrical resonance); glass shattered by a singer's note; resonance tube to find speed of sound.
- **Beats**: periodic waxing and waning of loudness when two sounds of **slightly different frequencies** superpose. **Beat frequency = $|f_1 - f_2|$**; ear detects up to ~10 beats/s. Used to **tune musical instruments** and find unknown frequency.

QUICK NUMERICALS

- SONAR echo received after 2 s, v_{water} = 1500 m/s → depth = 1500 × 2/2 = **1500 m**.
- Thunder heard 3 s after flash (v = 343 m/s) → distance ≈ **1.03 km**.
- Tuning forks of 256 Hz and 260 Hz → **4 beats/s**.

MEMORY TRICK

"P-F, L-A, Q-W" → **P**itch–**F**requency, **L**oudness–**A**mplitude, **Q**uality–**W**aveform. Speed of sound: "**Solid Leads, Gas Lags**"; rises with Temperature and Humidity, Pressure has no say.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Audible frequency range for humans? → **20 Hz – 20 kHz**.
- Bats navigate using? → **Ultrasonic waves (echolocation)**.
- Speed of sound is independent of? → **Pressure** (at constant temperature).
- Minimum distance for a distinct echo? → **≈ 17.2 m**.
- Pitch of sound depends on? → **Frequency**.
- Change in pitch of a passing train's whistle is due to? → **Doppler effect**.

12.9 Modern Physics Basics ★☆☆

- **Photoelectric effect**: emission of electrons from a metal surface when light of suitable frequency falls on it – observed by **Hertz**

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(1887), explained by **Einstein (1905)** using Planck's quantum idea (**Nobel Prize 1921** – for this, not relativity).

- Key facts: emission occurs only if frequency ≥ **threshold frequency** ν_0; it is **instantaneous**; **max KE depends on frequency, not intensity**; **number of photoelectrons (photocurrent) ∝ intensity**. Proves **particle (photon) nature** of light.
- Uses: photocell (automatic doors, burglar alarms, light meters, street-light switches), solar cells (photovoltaic effect – related), CCD camera sensors.

KEY FORMULAE

- Photon energy **$E = h\nu = hc/\lambda$** ; E (eV) ≈ 1240/λ (nm) → 620 nm photon ≈ 2 eV.
- Einstein's equation: **$KE_{max} = h\nu - \varphi$** (φ = work function = $h\nu_0$).
- Bohr: hydrogen energy E_n = **$-13.6/n^2$ eV**; angular momentum = nh/2π. Ionisation energy of H = 13.6 eV.
- Radioactive decay: $N = N_0(½)^{t/T½}$; $T_{½} = 0.693/\lambda$; mean life $\tau = 1/\lambda = 1.44\ T_{½}$.
- Mass–energy: **$E = mc^2$** ; 1 u = **931.5 MeV** ; 1 g mass ≡ 9×10^{13} J.

Atomic model / discovery	Scientist (year)	Key point
Electron (cathode rays, e/m)	**J.J. Thomson (1897)**	"Plum pudding" model (1904) – positive sphere with embedded electrons
Nucleus	**Rutherford (1911)**	**α-particle scattering by gold foil**: most passed through → atom mostly empty; positive charge & mass in tiny nucleus ($\sim10^{-15}$ m vs atom $\sim10^{-10}$ m). Failed to explain stability & line spectra
Neutron	**James Chadwick (1932)**	Neutral; mass slightly greater than proton

- **Radioactivity**: spontaneous disintegration of unstable nuclei – discovered by **Henri Becquerel (1896)** in uranium; **Marie & Pierre Curie** discovered polonium and radium (1898). Unaffected by temperature, pressure or chemical state; a nuclear phenomenon.

Property	Alpha (α)	Beta (β^-)	Gamma (γ)
Nature	Helium nucleus (^4_2He)	Fast electron (from nucleus: n → p + e + antineutrino)	High-energy EM photon
Charge	+2e	−e	**None** (not deflected by fields)
Penetrating power	**Least** – stopped by paper/skin	Medium – few mm aluminium	**Highest** – several cm of lead/concrete
Ionising power	**Highest**	Medium	Least
Change in nucleus	A − 4, **Z − 2**	A same, **Z + 1**	No change in A or Z

- **Half-life** = time for half the nuclei to decay; constant for a given isotope. After n half-lives, fraction left = **$1/2^n$**. Examples: **C-14 ≈ 5730 years** (carbon dating of fossils/wood up to ~50,000 years – W. Libby), **U-238 ≈ 4.5×10^9 years** (age of rocks/Earth), Ra-226 ≈ 1600 y, **Co-60 ≈ 5.27 y**, Cs-137 ≈ 30 y, **I-131 ≈ 8 days**, P-32 ≈ 14.3 days, tritium ≈ 12.3 y, Rn-222 ≈ 3.8 days.
- **Nuclear fission**: heavy nucleus splits into two medium nuclei on absorbing a **slow (thermal) neutron** – Hahn & Strassmann (1938). $^{235}U + n \rightarrow {}^{141}Ba + {}^{92}Kr +$ **3n** + **~200 MeV**. Released neutrons cause a **chain reaction**; needs **critical mass**. Uncontrolled → atom bomb; controlled → nuclear reactor.

Reactor component	Function	Materials
Fuel	Fissile material	**U-235** (natural U has only ~0.7%), Pu-239, U-233 (from thorium)
Moderator	**Slows down fast neutrons**	**Heavy water (D_2O)**, graphite, ordinary water
Control rods	**Absorb neutrons**, control rate	**Cadmium, boron**, hafnium
Coolant	Removes heat to produce steam	Water, heavy water, liquid sodium (fast breeders), CO_2
Shield	Stops radiation	Thick concrete, lead

- India: first reactor **Apsara (1956, Trombay)**; first nuclear power station **Tarapur (1969)**; Indian **PHWRs use natural uranium + heavy water**; **three-stage programme** (Homi J. Bhabha) to use India's large **thorium** reserves; Prototype Fast Breeder Reactor (500 MWe) at **Kalpakkam**.
- **Nuclear fusion**: light nuclei combine to form heavier nucleus – needs very high temperature (~10^7 K; "thermonuclear"). **Source of energy of the Sun and stars** (hydrogen → helium, proton–proton chain); hydrogen bomb. Fusion releases more energy **per unit mass** than fission. ITER (France) – international fusion project; India is a member.
- **Mass defect** = mass of separate nucleons − mass of nucleus; converted into **binding energy** (Einstein's $E = mc^2$, 1905). Binding energy per nucleon is maximum (~8.8 MeV) for **Fe-56** – most stable nucleus.

Radiation quantity	SI unit	Old unit
Activity (disintegrations per second)	**becquerel (Bq)** = 1 decay/s	**curie (Ci) = 3.7×10^{10} Bq**; rutherford = 10^6 Bq
Absorbed dose (energy per kg)	**gray (Gy)** = 1 J/kg	rad = 0.01 Gy
Equivalent / effective dose (biological effect)	**sievert (Sv)**	rem = 0.01 Sv

- Dose limits (ICRP, followed by **AERB**): radiation workers **20 mSv/year** averaged over 5 years (max 50 mSv in any one year); general public **1 mSv/year**. Detected by **Geiger–Müller counter**.

Radioisotope	Use
Cobalt-60 (γ, 1.17 & 1.33 MeV)	**Cancer radiotherapy** (cobalt unit), sterilisation of medical products, **food irradiation** – grain/pulse disinfestation, sprout inhibition
Iodine-131	**Thyroid** diagnosis & treatment (goitre, hyperthyroidism)
Carbon-14	**Carbon dating**; tracer in photosynthesis studies (Calvin cycle)
Phosphorus-32	**Tracer for fertiliser uptake by plants**; treatment of leukaemia/polycythaemia
Technetium-99m	Most widely used **diagnostic imaging** isotope (6 h half-life)

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Food irradiation (storage link)

- Exposure of food to ionising radiation – **γ-rays from Co-60 / Cs-137**, or electron beams/X-rays (≤ 10 MeV / 5 MeV). Food **does not become radioactive**. Codex/WHO consider foods irradiated up to **10 kGy** safe and wholesome.
- Typical dose ranges: **sprout inhibition** (onion, potato, garlic) ≈ **0.02–0.2 kGy**; **insect disinfestation** of cereals, pulses and their products ≈ **0.25–1.0 kGy**; delay of ripening ≈ 0.2–1 kGy; reduction of pathogens/microbial load (spices, meat) ≈ 1–10 kGy.
- Advantages for grain storage: **no chemical residue** (alternative to fumigants such as methyl bromide), kills all life stages including hidden infestation; limitation: **no residual protection** – re-infestation possible, so needs insect-proof packaging.
- India: regulated by the **Atomic Energy (Radiation Processing of Food and Allied Products) Rules, 2012** (AERB licensing) and FSSAI; developed by **BARC**. **KRUSHAK** facility at **Lasalgaon (Nashik)** for onions (commissioned 2002). Irradiated food carries the **Radura** logo.

QUICK NUMERICALS

- Isotope with $T_{½}$ = 5 days: after 20 days (4 half-lives), fraction left = **1/16**.
- Energy from 1 mg mass: $E = 10^{-6} \times (3 \times 10^{8})^{2} = \mathbf{9 \times 10^{10}}$ **J**.
- $^{238}_{92}U$ emits one α → $^{\mathbf{234}}_{\mathbf{90}}\mathbf{Th}$; then one β → $^{234}_{91}Pa$.

MEMORY TRICK

Penetration "**α – Paper, β – Aluminium, γ – Lead**" (P-A-L). Reactor: "**Moderator Slows, Control rods Catch**" – heavy water slows, cadmium/boron catch neutrons.

PREVIOUSLY ASKED / LIKELY QUESTIONS

- Einstein got the Nobel Prize for? → **Photoelectric effect**.
- Energy of the Sun is due to? → **Nuclear fusion** (hydrogen → helium).
- SI unit of radioactivity? → **Becquerel**; of equivalent dose → **sievert**.
- Radioisotope used for irradiation/disinfestation of foodgrains? → **Cobalt-60**.
- Function of moderator in a nuclear reactor? → **Slow down neutrons**.
- Most penetrating radiation? → **Gamma rays**.

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13. Last-Day Revision (Value & Fact Sheet)

Topic	Must-remember facts
Agronomy	Liebig – law of minimum; cropping intensity = GCA/NSA × 100; LER > 1 → intercropping advantageous; 17 essential nutrients (Ni the 17th); wheat CRI stage 21 DAS most critical for irrigation; Khaira disease of rice = Zn deficiency
Fertilisers & seeds	Urea 46% N; DAP 18-46-0; SSP 16% P_2O_5 (+ ~12% S); MOP 60% K_2O; seed tags: breeder golden yellow, foundation white, certified azure blue, truthfully labelled opal green
Horticulture	Ethylene – ripening hormone; climacteric: mango, banana, apple, tomato, papaya, guava; non-climacteric: citrus, grapes, pomegranate, strawberry, pineapple; calcium carbide banned for ripening; jam needs ≈ 65–70% TSS; irradiation symbol = Radura
Animal husbandry	Gestation: cow ≈ 280 d, buffalo ≈ 310 d, sheep/goat ≈ 150 d, pig ≈ 114 d; chicken egg incubation 21 d; HTST pasteurisation 72 °C/15 s, LTLT 63 °C/30 min; Sahiwal – best milch cattle; Murrah – best buffalo; Operation Flood – Verghese Kurien (NDDB)
Plant protection	Bordeaux mixture 1:1:100 ($CuSO_4$: lime : water) – Millardet; Irish famine – Phytophthora infestans (late blight); Bengal famine 1943 – brown spot of rice; IPM uses ETL; Trichogramma – egg parasitoid; neem – azadirachtin
Extension & economics	Adopter categories 2.5 / 13.5 / 34 / 34 / 16%; first KVK Puducherry 1974; MSP ≥ 1.5 × (A2 + FL); e-NAM 2016; Agmark Act 1937; FCI 1965; NFSA 2013 – 5 kg/person/month
Warehousing	CWC set up 1957 (Agricultural Produce (Development & Warehousing) Corporations Act 1956; now Warehousing Corporations Act 1962), Navratna, under Ministry of Consumer Affairs, Food & PD; WDRA under Warehousing (Development & Regulation) Act 2007; negotiable warehouse receipts / e-NWR for pledge finance; CAP = cover and plinth storage; FIFO issue
Cell biology	Cell theory – Schleiden & Schwann; cell discovered by Robert Hooke (1665); nucleus – Robert Brown; fluid mosaic model – Singer & Nicolson (1972); ribosomes 70S (prokaryote) / 80S (eukaryote); crossing over at pachytene; chiasmata seen at diplotene
Genetics	Monohybrid F_2 3:1; dihybrid 9:3:3:1; test cross 1:1; incomplete dominance 1:2:1; epistasis 12:3:1, 9:7, 9:3:4, 15:1, 13:3; DNA double helix – Watson & Crick 1953; semi-conservative replication – Meselson & Stahl; start codon AUG; stop codons UAA, UAG, UGA; Down syndrome trisomy 21
Plant physiology	Photosynthesis O_2 comes from water; PS I – P700, PS II – P680; RuBisCO most abundant protein; C4 – maize, sugarcane (Kranz anatomy, PEP carboxylase); CAM – pineapple; glycolysis in cytoplasm; Krebs cycle in mitochondrial matrix; RQ: carbohydrate 1, fat ≈ 0.7; ABA closes stomata; gibberellin – bolting, seedless grapes; cytokinin delays senescence
Ecology & diversity	Five-kingdom classification – Whittaker 1969; binomial nomenclature – Linnaeus; 10% law – Lindeman; pyramid of energy always upright; bryophytes – amphibians of plant kingdom; pteridophytes – first vascular plants; biomagnification – DDT
Insects	Insects – 3 body regions, 3 pairs of legs, 1 pair of antennae; excretion by Malpighian tubules (uric acid); moulting hormone ecdysone, juvenile hormone from corpora allata; Coleoptera – largest order; mouthparts: housefly sponging, butterfly siphoning, mosquito piercing-sucking, honeybee chewing-lapping
Stored grain pests	Primary/internal feeders: rice weevil Sitophilus oryzae, lesser grain borer Rhyzopertha dominica, Angoumois grain moth Sitotroga cerealella, pulse beetle Callosobruchus; Khapra beetle Trogoderma granarium – only the larva damages; secondary: red flour beetle Tribolium castaneum, saw-toothed grain beetle Oryzaephilus, rice moth Corcyra cephalonica
Rodents	Lesser bandicoot Bandicota bengalensis – most destructive in India; house rat Rattus rattus; Norway rat R. norvegicus (burrowing); acute rodenticide zinc phosphide (pre-baiting needed; bait shyness); anticoagulants warfarin (multi-dose), bromadiolone (single-dose); antidote vitamin K_1
Fumigation	Aluminium phosphide (3 g tablet releases 1 g PH_3) – phosphine; exposure ≈ 5–7 days under gas-proof covers; phosphine smells of garlic/carbide (impurities); methyl bromide – ozone depleter, Montreal Protocol (allowed only for quarantine & pre-shipment); ideal fumigant – toxic to insects, non-inflammable, non-residual
Insecticides & toxicity	DDT – Paul Müller; organophosphates & carbamates inhibit acetylcholinesterase; pyrethroids act on Na^+ channels; neonicotinoids on nicotinic receptors; LD_{50} lower = more toxic; label colours: red (extremely toxic) → yellow → blue → green (slightly toxic); OP poisoning antidote atropine + pralidoxime (2-PAM); Insecticides Act 1968; Bhopal 1984 – methyl isocyanate
Microbiology	Pasteur – pasteurisation, germ theory; Koch – postulates; Fleming – penicillin 1928; Gram-positive stains purple; autoclave 121 °C, 15 psi, 15–20 min; TMV – first virus discovered; aflatoxin – Aspergillus flavus (B1 most toxic, liver carcinogen); ergot – Claviceps purpurea
Public health	Malaria – female Anopheles (Plasmodium); dengue, chikungunya, Zika – Aedes; plague – rat flea Xenopsylla cheopis; leptospirosis – rodent urine; typhoid – Salmonella Typhi; FSS Act 2006 (FSSAI); HACCP – 7 principles; World Food Safety Day 7 June
Chemical bonding	Shapes: CH_4 tetrahedral 109.5°, NH_3 pyramidal 107°, H_2O bent 104.5°, BF_3 trigonal planar, PCl_5 trigonal bipyramidal, SF_6 octahedral; O_2 paramagnetic (bond order 2); fluorine most electronegative; ice less dense than water (hydrogen bonding)
Inorganic & physical	Avogadro 6.022×10^{23}; R = 8.314 J/mol·K; 22.4 L at STP; pH + pOH = 14 (25 °C); Haber process – Fe catalyst; contact process – V_2O_5; washing soda $Na_2CO_3 \cdot 10H_2O$; baking soda $NaHCO_3$; plaster of Paris $CaSO_4 \cdot \frac{1}{2}H_2O$; gypsum $CaSO_4 \cdot 2H_2O$; bauxite – Al ore; haematite – Fe ore
Organic & biochemistry	Markovnikov rule; Tollens/Fehling test – aldehydes; iodoform test – methyl ketones; vulcanisation with sulphur; sucrose non-reducing; cellulose β-1,4 glucose; 20 amino acids; peptide bond; vitamin deficiencies: A – night blindness, B1 – beriberi, B3 – pellagra, C – scurvy, D – rickets, K – poor clotting
Mechanics & units	7 SI base units; 1 hp = 746 W; g = 9.8 m/s²; maximum projectile range at 45°; escape velocity 11.2 km/s; geostationary orbit ≈ 36,000 km; 1 kWh = 3.6×10^6 J; lactometer – milk purity; hygrometer – humidity

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Heat & sound	−40 °C = −40 °F; K = °C + 273.15; specific heat of water ≈ 4186 J/kg·K; latent heat: fusion 336 kJ/kg, vaporisation ≈ 2260 kJ/kg; sound in air ≈ 343 m/s (20 °C), faster in solids; audible range 20 Hz–20 kHz; echo needs ≥ 17.2 m
Light, electricity, magnetism	Mirror/lens formula $1/f = 1/v \pm 1/u$ (sign convention); power P = 1/f (m) in dioptre; myopia – concave lens, hypermetropia – convex lens; blue sky by Rayleigh scattering ($\propto 1/\lambda^4$); Raman effect 1928; Ohm's law V = IR; $P = VI = I^2R$; Fleming's left-hand rule – motor, right-hand rule – generator; transformer works only on AC; household supply 230 V, 50 Hz

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14. 500 Most Expected Questions & Answers

> **NOTE**
> Rapid-fire revision: 500 one-line questions chosen for the CWC JE (Technical) paper, in the same order as the chapters. Cover the answer, attempt, then check. Numericals carry a short working hint.

14.1 Crop Production (Q 1–45)

1. Law of Diminishing Returns (yield law) was given by? → **E.A. Mitscherlich (1909)**
2. Harvest index is the ratio of? → **Economic yield ÷ biological yield × 100**
3. Cropping intensity formula? → **Gross cropped area ÷ net sown area × 100**
4. Sole yields: A 4 t, B 2 t; intercrop: A 3 t, B 1 t. LER? → **1.25 (3/4 + 1/2)**
5. Growing of lentil/lathyrus in standing rice before its harvest is called? → **Relay cropping (paira/utera)**
6. SRI (System of Rice Intensification) was developed in? → **Madagascar (Fr. Henri de Laulanié, 1983)**
7. Number of agro-climatic sub-zones under NARP? → **127**
8. Rainfall range of dryland farming? → **750–1150 mm per year**
9. Broad Bed & Furrow (BBF) system was developed by? → **ICRISAT (for Vertisols)**
10. Photosynthetically active radiation (PAR) wavelength range? → **400–700 nm**
11. Most extensive soil order in India? → **Inceptisols**
12. Particle density of an average mineral soil? → **≈ 2.65 g/cm³**
13. BD 1.33 g/cc, PD 2.66 g/cc. Porosity? → **50% [(1 − 1.33/2.66) × 100]**
14. Factor to convert organic carbon to organic matter? → **1.724 (Van Bemmelen)**
15. Soil with pH > 8.5, EC < 4 dS/m and ESP > 15 is? → **Sodic (alkali) soil**
16. Most deficient micronutrient in Indian soils? → **Zinc**
17. Whiptail of cauliflower is due to deficiency of? → **Molybdenum**
18. Nickel is a constituent of which enzyme? → **Urease**
19. Neutralising value of CaO ($CaCO_3$ = 100)? → **179**
20. Urea needed to supply 92 kg N/ha? → **200 kg (92 ÷ 0.46)**
21. K_2O content of muriate of potash? → **60%**
22. Fertiliser with highest N content? → **Anhydrous ammonia (82% N)**
23. Nutrient content of nano DAP (IFFCO)? → **8% N and 16% P_2O_5**
24. Biofertiliser associated with Azolla? → **Anabaena azollae (cyanobacterium)**
25. Method for available P in neutral/alkaline soils? → **Olsen's method ($NaHCO_3$)**
26. Soil moisture tension at field capacity? → **−1/3 bar (pF 2.54)**
27. Indicator plant used for permanent wilting point? → **Dwarf sunflower**
28. Most critical stage of maize for irrigation? → **Tasselling–silking**
29. Duty 1728 ha/cumec, base period 120 days. Delta? → **0.6 m (8.64 × 120 ÷ 1728)**
30. 1 cumec equals how many cusecs? → **≈ 35.3 cusec**
31. Irrigation water is unsafe when RSC exceeds? → **2.5 meq/L**
32. Herbicide applied pre-plant incorporated due to volatility? → **Fluchloralin**
33. Atrazine inhibits which process? → **Photosystem-II (photosynthetic electron transport)**
34. Biological agent for Parthenium control? → **Zygogramma bicolorata (Mexican beetle)**
35. Epidemic dropsy is caused by seeds of? → **Argemone mexicana (sanguinarine) in mustard oil**
36. Tag colour of truthfully labelled seed? → **Opal green**
37. Minimum germination standard for certified maize seed? → **90%**
38. Harrington's rule: seed life doubles with every fall of? → **1% seed moisture or 5 °C temperature**
39. First semi-dwarf rice variety introduced in India? → **Taichung Native-1 (TN-1)**
40. Names of India's first genome-edited rice varieties (2025)? → **DRR Dhan 100 (Kamala) and Pusa DST Rice 1**
41. Chromosome number of bread wheat (*Triticum aestivum*)? → **2n = 42 (hexaploid)**
42. World's first cotton hybrid H-4 was developed by? → **C.T. Patel (Surat, 1970)**
43. Maturity index of sugarcane (Brix by hand refractometer)? → **≥ 18%**
44. Rice production 2025-26 (3rd Advance Estimates)? → **154.02 million tonnes**
45. Kharif crop with the highest MSP for KMS 2026-27? → **Sesamum (₹10,346/q)**

14.2 Horticulture & Post-Harvest (Q 46–75)

46. India's fruit production in 2025-26 (2nd Advance Estimates)? → **121.48 Mt (+3.25% over 2024-25)**
47. Largest vegetable crop of India by production? → **Potato (59.89 Mt, 2025-26 2nd AE)**
48. India's top fresh-fruit export by value? → **Grapes**
49. Mango hybrid Mallika is a cross of? → **Neelum × Dashehari**
50. Ber and aonla are commercially propagated by? → **Patch budding**
51. Number of plants per hectare at 5 m × 5 m square planting? → **400 (10,000 ÷ 25)**
52. Plants per hectare at 5 m spacing in hexagonal system? → **≈ 462 (400 × 1.155)**

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53. Fruit type of pomegranate? → **Balausta (edible part: juicy testa)**
54. Mango malformation is controlled by spraying? → **NAA 200 ppm in October**
55. Whiptail of cauliflower is due to deficiency of? → **Molybdenum**
56. PGR that increases female flowers in cucurbits? → **Ethrel (ethephon)**
57. Pungency of onion is due to? → **Allyl propyl disulphide**
58. "Kufri" potato varieties are released by? → **CPRI, Shimla**
59. Economic part of clove? → **Unopened (dried) flower bud**
60. Mace is botanically the? → **Aril of the nutmeg seed**
61. India's first GI-tagged product? → **Darjeeling tea (2004-05)**
62. Shade provided by HDPE shade-net houses? → **35–75% (50% most common)**
63. Optimum pH of a hydroponic nutrient solution? → **5.5–6.5**
64. Ethylene concentration used in ripening chambers? → **≈ 100 ppm, at 18–20 °C**
65. Chemical that delays ripening by blocking ethylene receptors? → **1-MCP (1-methylcyclopropene)**
66. Enzyme that converts ACC to ethylene? → **ACC oxidase**
67. Best precooling method for leafy vegetables like lettuce? → **Vacuum cooling**
68. Curing of potato heals wounds by? → **Suberisation (wound periderm formation)**
69. Build-up of reducing sugars in potato stored below ≈ 8–10 °C? → **Cold sweetening**
70. O_2 level in CA storage of apple? → **2–3% O_2 (with 1–5% CO_2) at 0–1 °C**
71. Minimum water activity for growth of most bacteria? → **≈ 0.91**
72. Minimum fruit juice content in an RTS beverage? → **10% (TSS ≥ 10%)**
73. Enzyme used to test adequacy of blanching? → **Peroxidase (most heat-stable)**
74. Processing temperature for canning low-acid foods (pH > 4.6)? → **121 °C (destroys *Clostridium botulinum* spores)**
75. India's first commercial irradiation plant for perishables (KRUSHAK) is at? → **Lasalgaon, Nashik (BARC, 2002)**

14.3 Animal Husbandry, Dairy & Fisheries (Q 76–105)

76. State with the largest cattle population (20th Livestock Census)? → **West Bengal**
77. India's egg production in 2024-25? → **149.11 billion (2nd in world)**
78. The 21st Livestock Census (Oct 2024–Feb 2025) is notable for being? → **First fully digital census (mobile app); 16 species, 219 breeds**
79. Karan Swiss crossbred cattle is a cross of? → **Brown Swiss × Sahiwal (NDRI Karnal)**
80. Heaviest buffalo breed, with heavy drooping horns? → **Jaffarabadi (Gujarat)**
81. Smallest cattle breed of India? → **Vechur (Kerala)**
82. Diploid chromosome number of river buffalo? → **2n = 50 (swamp buffalo 48)**
83. Indian cattle are classified scientifically as? → ***Bos indicus* (humped zebu)**
84. Exotic dairy breed with the highest milk fat (~5%)? → **Jersey**
85. The "Queen of fodders" is? → **Lucerne (*Medicago sativa*)**
86. Crude protein content of a feed with 3% nitrogen? → **18.75% (CP = N × 6.25)**
87. Toxic principle of subabul (*Leucaena*)? → **Mimosine**
88. Rumen VFA that is the main glucose (glucogenic) precursor? → **Propionic acid (propionate)**
89. Gestation period of a mare (horse)? → **≈ 340 days**
90. Length of the oestrous cycle in sheep? → **17 days**
91. Cryoprotectant used in freezing bull semen? → **Glycerol**
92. Sex-sorted semen is produced by which technique? → **Flow cytometry (≈ 90% female calves)**
93. World's first cloned buffalo calf (NDRI Karnal, 2009)? → **Samrupa**
94. Causal organism of haemorrhagic septicaemia (galghotu)? → ***Pasteurella multocida* (B:2)**
95. Indigenous vaccine against lumpy skin disease? → **Lumpi-ProVacInd (ICAR-NRCE Hisar & IVRI)**
96. Rinderpest was declared eradicated from the world in? → **2011 (India free in 2006)**
97. Isoelectric pH at which casein precipitates? → **pH 4.6**
98. Index organism for milk pasteurisation? → ***Coxiella burnetii***
99. UHT treatment of milk uses? → **135–150 °C for 2–4 s, aseptic packaging**
100. Minimum fat and SNF in double-toned milk (FSSAI)? → **1.5% fat, 9.0% SNF**
101. Test used to detect vanaspati in ghee? → **Baudouin test (furfural + HCl; crimson colour)**
102. Rennet enzyme used for cheese making? → **Chymosin (rennin)**
103. Incubation period of Japanese quail eggs? → **17–18 days (shortest)**
104. Bottom feeder among the Indian major carps? → **Mrigal (*Cirrhinus mrigala*)**
105. Induced breeding of carps was first achieved on 10 July 1957 by? → **Dr Hiralal Chaudhuri & Dr K.H. Alikunhi**

14.4 Plant Protection (Q 106–140)

106. Disease triangle + time as the fourth factor gives the? → **Disease tetrahedron (disease pyramid)**
107. Who coined "monocyclic" and "polycyclic" (simple/compound interest) diseases? → **J.E. Van der Plank (1963) – father of epidemiology**

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108. First proof that a microorganism causes plant disease (wheat bunt, 1807) was by? → **B. Prevost**

109. First bacterial plant disease described by T.J. Burrill (1878)? → **Fire blight of pear/apple (*Erwinia amylovora*)**

110. Phytoplasma (MLO) was first discovered in 1967 by? → **Doi et al. (Japan)**

111. Red rust of tea is caused by? → **Alga *Cephaleuros virescens***

112. Khaira disease of rice is due to deficiency of? → **Zinc**

113. *Orobanche* (broomrape) is what type of parasite? → **Total root parasite**

114. Sexual spore of Ascomycetes? → **Ascospore (borne in an ascus)**

115. Abnormally tall, thin seedlings in bakanae disease of rice are due to excess of? → **Gibberellin (from *Fusarium fujikuroi*)**

116. Wheat disease with a fishy (trimethylamine) smell of infected grains? → **Karnal bunt (*Tilletia indica*)**

117. Vector of rice tungro virus? → **Green leafhopper (*Nephotettix virescens*)**

118. "Green plague" of pigeonpea is? → **Sterility mosaic (vector eriophyid mite *Aceria cajani*)**

119. "Stag-head" (deformed inflorescence) of mustard is caused by? → **White rust (*Albugo candida*)**

120. Late blight forecasting model of ICAR-CPRI, Shimla? → **JHULSACAST**

121. Pathogen of Panama wilt of banana? → ***Fusarium oxysporum* f. sp. *cubense***

122. Vector of citrus greening (Huanglongbing)? → **Psyllid *Diaphorina citri***

123. Ufra disease of deep-water rice is caused by? → **Nematode *Ditylenchus angustus***

124. Golden cyst nematode of potato was first reported in India from? → **Nilgiris, Tamil Nadu (1961)**

125. Ratio of Bordeaux paste used as wound dressing? → **1 : 1 : 10 (10%)**

126. Draft law proposed to replace the Insecticides Act 1968 (released Jan 2026)? → **Pesticides Management Bill, 2025 – still a draft, not introduced**

127. First systemic fungicide? → **Carboxin (Vitavax) – von Schmeling & Kulka, 1966**

128. Melanin-biosynthesis-inhibitor fungicide used against rice blast? → **Tricyclazole**

129. Antibiotic used against sheath blight of rice? → **Validamycin**

130. Streptomycin sulphate : tetracycline HCl ratio in streptocycline? → **9 : 1**

131. Largest order of insects? → **Coleoptera (beetles, weevils)**

132. "Dead heart" at tillering and "white ear" at heading in rice are caused by? → **Yellow stem borer (*Scirpophaga incertulas*)**

133. "Silver shoot" / "onion leaf" in rice is caused by? → **Gall midge (*Orseolia oryzae*)**

134. Identification marks of fall armyworm larva? → **Inverted "Y" on head; four spots in a square on 8th abdominal segment**

135. Sex pheromone used to trap pink bollworm? → **Gossyplure**

136. Para-pheromone lure for oriental fruit fly *Bactrocera dorsalis*? → **Methyl eugenol**

137. Formula for Economic Injury Level (Pedigo)? → **EIL = C ÷ (V × I × D × K)**

138. *Trichogramma* is mass-reared on eggs of? → **Rice moth (*Corcyra cephalonica*)**

139. White muscardine fungus? → ***Beauveria bassiana***

140. Yellow triangle on a pesticide label: category and oral LD_{50}? → **Highly toxic; 51–500 mg/kg**

14.5 Extension, Economics, Marketing & Warehousing (Q 141–175)

141. Percentage of innovators in Rogers' adopter categories? → **2.5%**

142. Demonstration that shows "what can be done" by comparing results? → **Result demonstration (Seaman Knapp)**

143. Communication model that first introduced the concept of "noise"? → **Shannon & Weaver (1949)**

144. Farm business income = gross income minus which cost? → **Cost A1 (A2 for tenant farmers)**

145. Shepherd's formula for marketing efficiency? → **ME = V/I − 1 (V = consumer price value, I = marketing cost)**

146. First regulated market in India? → **Karanja (Berar), 1886 – cotton**

147. e-NAM was launched on? → **14 April 2016 (lead agency SFAC)**

148. Marketed surplus exceeding marketable surplus indicates? → **Distress sale**

149. Quarter with the highest buffer norm for rice + wheat? → **1 July – 411.20 lakh tonnes**

150. Buffer norm (rice + wheat) as on 1 October? → **307.70 lakh tonnes**

151. Buffer norm (rice + wheat) as on 1 January? → **214.10 lakh tonnes**

152. Current foodgrain buffer norms were last revised in? → **January 2015**

153. Mode of FCI sale of surplus grain under OMSS(D)? → **e-auction (to flour mills, processors, traders)**

154. Committee (1951–54) that recommended a national warehouse network? → **All India Rural Credit Survey Committee (A.D. Gorwala)**

155. Board created by the Agricultural Produce (Development & Warehousing) Corporations Act, 1956? → **National Cooperative Development & Warehousing Board**

156. Exact date of establishment of CWC? → **2 March 1957**

157. CWC's share in the equity of a State Warehousing Corporation? → **50% (other 50% by State Govt)**

158. Number of SWCs in which CWC holds equity? → **19**

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159. Authorised share capital of CWC? → **₹100 crore (paid-up ₹68.02 crore)**

160. Section of the Warehousing Corporations Act, 1962 listing CWC's functions? → **Section 11**

161. CWC's status before it styled itself a Navratna CPSE (2024)? → **Schedule 'A' Miniratna Category-I**

162. CWC subsidiary whose business CWC took over on 31 Oct 2022? → **Central Railside Warehouse Company (CRWC)**

163. CWC's Farmers' Extension Service Scheme started in? → **1978-79**

164. Rebate on CWC storage charges for cooperatives and agri start-ups? → **10% (farmers 30%)**

165. WDRA was constituted on? → **26 October 2010**

166. From when must WDRA-registered warehouses issue only e-NWRs? → **1 June 2019 (e-NWR launched 26 Sep 2017)**

167. Two repositories that hold e-NWRs? → **NERL and CCRL**

168. WDRA's digital gateway (2024) for farmer storage and e-NWR loans? → **e-Kisan Upaj Nidhi (e-KUN)**

169. Corpus of the Credit Guarantee Scheme for e-NWR-based Pledge Financing? → **₹1,000 crore (launched 16 Dec 2024)**

170. PSL ceiling for pledge loans against e-NWR/NWR per farmer? → **₹90 lakh**

171. Section of the Customs Act, 1962 for licensing public bonded warehouses? → **Section 57**

172. Guaranteed hiring period by FCI for private investors under PEG (2008)? → **10 years**

173. Locations of the first modern private silos for FCI (Adani, 2007)? → **Moga (Punjab) and Kaithal (Haryana)**

174. FCI hiring assurance for godowns built under the cooperative grain storage plan? → **9 years**

175. AMI subsidy rate for PACS godowns after the Oct 2024 amendment? → **33.33% (margin money cut to 10%)**

14.6 Botany I – Cell Biology, Tissues & Genetics (Q 176–220)

176. Who coined the term "cell" after observing cork? → **Robert Hooke (1665, *Micrographia*)**

177. The nucleus was discovered by? → **Robert Brown (1831, orchid cells)**

178. Smallest known living cell? → ***Mycoplasma* (PPLO), ≈ 0.3 µm**

179. Ribosomes were first observed by? → **George Palade (1953) – "Palade particles"**

180. Type of ribosomes in the cytoplasm of eukaryotic cells? → **80S (60S + 40S)**

181. GM mustard DMH-11 was developed by? → **Prof. Deepak Pental, CGMCP, University of Delhi**

182. Infoldings of the inner mitochondrial membrane are called? → **Cristae**

183. Calvin cycle (dark reaction) takes place in which part of chloroplast? → **Stroma**

184. Leucoplast that stores starch (e.g. potato)? → **Amyloplast**

185. Microtubule arrangement in the axoneme of cilia/flagella? → **9 + 2 (9 doublets + 2 central singlets)**

186. Haplo-diploid sex determination is seen in? → **Honey bee (drone n = 16, female 2n = 32)**

187. Cell wall of fungi is mainly made of? → **Chitin**

188. Change in DNA content during S phase? → **2C → 4C (chromosome number stays 2n)**

189. Genome-edited rice developed from Samba Mahsuri by ICAR-IIRR (2025)? → **DRR Dhan 100 (Kamala)**

190. Colchicine arrests cell division at which stage? → **Metaphase (inhibits spindle formation)**

191. Terminalisation of chiasmata occurs in? → **Diakinesis**

192. Number of mitotic divisions needed to form 64 cells from one cell? → **63 (N − 1)**

193. Meiosis I is also called? → **Reductional division (homologues separate)**

194. Meristem responsible for increase in girth? → **Lateral meristem (vascular & cork cambium)**

195. Gymnosperms lack vessels except in the order? → **Gnetales**

196. Xylem with protoxylem towards periphery, typical of roots, is called? → **Exarch**

197. Vascular bundle with phloem on both sides of xylem, e.g.? → **Bicollateral – *Cucurbita***

198. Vessels of heartwood are plugged by? → **Tyloses**

199. Periderm consists of? → **Phellem + phellogen + phelloderm**

200. Kranz anatomy is characteristic of? → **C_4 plants (maize, sugarcane, sorghum)**

201. Flattened green petiole (phyllode) is found in? → **Australian *Acacia***

202. Hypanthodium inflorescence is found in? → ***Ficus* (fig, banyan)**

203. Edible part of litchi? → **Aril**

204. Monoadelphous stamens are characteristic of which family? → **Malvaceae (China rose, cotton)**

205. Phenotypic ratio of a monohybrid test cross? → **1 : 1**

206. Number of gamete types produced by genotype AaBbCc? → **8 (2^n, n = 3)**

207. F_2 ratio of recessive epistasis (coat colour in mice)? → **9 : 3 : 4**

208. F_2 ratio of duplicate dominant genes (*Capsella* capsule shape)? → **15 : 1**

209. Number of genotypes possible with 4 multiple alleles? → **10 [n(n + 1)/2]**

210. Chromosomal theory of inheritance was proposed by? → **Sutton & Boveri (1902)**

211. 1% recombination frequency equals? → **1 map unit (centiMorgan, cM)**

212. Amino acid change in sickle-cell anaemia? → **Glutamic acid → valine at 6th position of β-globin**

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213. In Hershey–Chase experiment, phage DNA was labelled with? → **^{32}P (protein with ^{35}S)**

214. Number of hydrogen bonds between guanine and cytosine? → **Three (G ≡ C)**

215. Length of a B-DNA of 10,000 bp? → **3.4 µm (10,000 × 0.34 nm)**

216. A dsDNA has 30% adenine; percentage of cytosine? → **20% (A + C = 50%)**

217. Okazaki fragments are joined by? → **DNA ligase**

218. In eukaryotes, tRNA and 5S rRNA are transcribed by? → **RNA polymerase III**

219. Gene of lac operon coding for β-galactosidase? → **z gene**

220. Recognition sequence of EcoRI? → **5'-GAATTC-3' (cuts G↓AATTC, sticky ends)**

14.7 Botany II – Diversity, Ecology & Physiology (Q 221–265)

221. Who coined the term "taxonomy"? → **A.P. de Candolle (1813)**

222. Tautonyms such as *Rattus rattus* are allowed in which nomenclature? → **Zoological only; not allowed in botany**

223. Priority of plant names under the ICN dates from? → **1 May 1753 (Linnaeus, *Species Plantarum*)**

224. The biological species concept was given by? → **Ernst Mayr**

225. Number of families recognised in Bentham & Hooker's *Genera Plantarum*? → **202**

226. Latest version of the Angiosperm Phylogeny Group classification? → **APG IV (2016)**

227. Type specimen chosen later when no holotype was designated? → **Lectotype**

228. Code governing names of cultivated plants (cultivars)? → **ICNCP**

229. Reserve food of red algae (Rhodophyceae)? → **Floridean starch**

230. Characteristic accessory pigment of brown algae? → **Fucoxanthin (with chlorophyll a and c)**

231. Algin is commercially obtained from? → **Brown algae (Phaeophyceae)**

232. Ascospores of sac fungi are formed? → **Endogenously, inside asci**

233. Fungi imperfecti (Deuteromycetes) are so called because they lack? → **A known sexual stage (reproduce only by conidia)**

234. N-fixing cyanobacterium living in the water fern *Azolla*? → ***Anabaena azollae***

235. Ploidy of endosperm in gymnosperms and angiosperms respectively? → **Haploid (n) and triploid (3n)**

236. Smallest flowering plant? → ***Wolffia***

237. Life-cycle pattern of the brown alga *Fucus*? → **Diplontic**

238. The term "ecosystem" was coined by? → **A.G. Tansley (1935)**

239. Photosynthetically active radiation (PAR) is what fraction of incident sunlight? → **Less than 50%**

240. Shape of the pyramid of biomass in the sea? → **Inverted (fish biomass > phytoplankton)**

241. Logistic (Verhulst–Pearl) growth equation? → **$dN/dt = rN (K – N)/K$**

242. Value of Z (species–area slope) for small regions? → **0.1–0.2 (continents 0.6–1.2)**

243. Phosphorus cycle belongs to which type? → **Sedimentary (no significant gaseous phase)**

244. Pioneer species of a hydrosere? → **Phytoplankton**

245. Cattle egret feeding near grazing cattle is an example of? → **Commensalism (+, 0)**

246. Criteria for a biodiversity hotspot (Myers)? → **≥1,500 endemic vascular plants and ≥70% habitat lost**

247. Number of biodiversity hotspots worldwide / in India? → **36 / 4**

248. India's first biosphere reserve? → **Nilgiri (1986)**

249. Number of Ramsar sites in India (October 2026)? → **103 (Sukhna Lake, Sauj Jheel latest)**

250. The term "Evil Quartet" for causes of biodiversity loss was coined by? → **Jared Diamond**

251. Itai-itai disease is caused by? → **Cadmium (Cd) poisoning**

252. ATP and NADPH needed by the Calvin cycle per glucose? → **18 ATP + 12 NADPH (6 turns × 3 ATP, 2 NADPH)**

253. Reaction centre of Photosystem I? → **P700**

254. Copper-containing electron carrier between cyt b_6f and PS I? → **Plastocyanin**

255. Organelles involved in photorespiration? → **Chloroplast, peroxisome, mitochondrion**

256. RQ of malic acid? → **1.33 ($4\ CO_2 \div 3\ O_2$)**

257. Key regulatory enzyme of glycolysis? → **Phosphofructokinase (PFK)**

258. Rotenone blocks which part of the ETS? → **Complex I (NADH dehydrogenase)**

259. Casparian strip of the endodermis is made of? → **Suberin**

260. Micronutrient that is a component of urease? → **Nickel (Ni)**

261. Bacterium oxidising nitrite to nitrate? → ***Nitrobacter***

262. Auxin was isolated from *Avena* coleoptile tips by? → **F.W. Went (1928)**

263. Ethylene is biosynthesised from which amino acid? → **Methionine**

264. Pr form of phytochrome absorbs light of wavelength? → **Red, ~660 nm (converts to Pfr)**

265. Chemical used to prevent sprouting of stored onion and potato? → **Maleic hydrazide (MH)**

14.8 Zoology I – Insects, Organ Systems & Heredity (Q 266–305)

266. Type of antenna of the red flour beetle (*Tribolium*)? → **Capitate (clubbed)**

267. Lamellate antennae are characteristic of which family? → **Scarabaeidae (white grub, rhinoceros beetle)**

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268. Johnston's organ is located in which antennal segment? → **Pedicel (2nd segment)**

269. Number of stylets in the mouthparts of a female mosquito? → **6 (labrum, hypopharynx, 2 mandibles, 2 maxillae)**

270. Pseudotracheae and labellum are features of which mouthparts? → **Sponging type (housefly)**

271. Labium of insects is formed by fusion of? → **Second maxillae**

272. Correct sequence of insect leg segments (base to tip)? → **Coxa → trochanter → femur → tibia → tarsus → pretarsus**

273. Forelegs of the mole cricket are of which type? → **Fossorial (digging)**

274. Hemelytra (half-leathery forewings) are found in? → **Heteroptera (true bugs)**

275. Wing-coupling by hamuli is found in which order? → **Hymenoptera**

276. Waterproof wax layer of insect cuticle lies in? → **Epicuticle**

277. Chitin is a polymer of? → **N-acetyl-D-glucosamine (β-1,4 linked)**

278. Inert dusts (silica aerogel) kill stored-grain insects by? → **Abrading cuticular wax → desiccation**

279. Hormone responsible for tanning of new cuticle after moult? → **Bursicon**

280. Methoprene and pyriproxyfen are analogues of? → **Juvenile hormone**

281. Diflubenzuron acts as an insecticide by? → **Inhibiting chitin synthesis**

282. Chief blood sugar of insects? → **Trehalose**

283. Gastric caeca of the cockroach number? → **6–8 (at foregut–midgut junction)**

284. Rectal location of Malpighian tubule tips to conserve water is called? → **Cryptonephridial system**

285. Maximum number of spiracle pairs in an insect? → **10 (2 thoracic + 8 abdominal)**

286. Number of chambers in the cockroach heart? → **13**

287. Target site of neonicotinoids such as imidacloprid? → **Nicotinic acetylcholine receptor**

288. Diamide insecticides (chlorantraniliprole) act on? → **Ryanodine receptor (muscle Ca^{2+} channel)**

289. Structural and functional unit of the compound eye? → **Ommatidium**

290. Development of drones from unfertilised eggs is called? → **Arrhenotoky (haplodiploidy)**

291. Pupa with appendages free from the body? → **Exarate (beetles)**

292. Sex pheromone (lure) of the pink bollworm? → **Gossyplure**

293. Methyl eugenol is used to trap males of? → **Oriental fruit fly (*Bactrocera dorsalis*)**

294. Rice moth *Corcyra cephalonica* is used to mass-rear? → ***Trichogramma* (egg parasitoid)**

295. Development period of the worker honeybee? → **21 days**

296. Tarsal formula of Tenebrionidae (flour beetles)? → **5-5-4**

297. Vector of kala-azar? → **Sandfly (*Phlebotomus*)**

298. Flame cells are excretory structures of? → **Platyhelminthes (flatworms)**

299. Normal tidal volume of a healthy human? → **About 500 mL**

300. TV 500, IRV 2500, ERV 1000 mL. Vital capacity? → **4000 mL (ERV + TV + IRV)**

301. Stroke volume 70 mL, heart rate 72/min. Cardiac output? → **≈ 5 L/min (70 × 72 = 5040 mL)**

302. Normal GFR in a healthy human? → **≈ 125 mL/min (180 L/day)**

303. Muscle protein to which Ca^{2+} binds to start contraction? → **Troponin**

304. If q^2 (recessive phenotype) = 0.09, frequency of carriers? → **0.42 (q = 0.3, p = 0.7; 2pq)**

305. Sickle-cell anaemia codon change in β-globin gene? → **GAG → GUG (Glu → Val)**

14.9 Microorganisms, Food Safety & Public Health (Q 306–340)

306. Who first saw bacteria and called them "animalcules"? → **Antonie van Leeuwenhoek**

307. Who suggested agar as a solidifying agent for culture media (1882)? → **Fanny Hesse**

308. Spores used as the biological indicator for autoclave efficiency? → ***Geobacillus stearothermophilus***

309. Standard sterilisation condition in a hot air oven? → **160 °C for 2 hours**

310. Phase contrast microscope, used for living unstained cells, was invented by? → **Frits Zernike (Nobel 1953)**

311. Acid-fastness of *Mycobacterium* is due to? → **Mycolic acid in the cell wall**

312. Compound that, with calcium, gives endospores their heat resistance? → **Dipicolinic acid**

313. One bacterium with a generation time of 20 min gives how many cells after 2 h? → **64 cells (6 generations, 2^6)**

314. Griffith's transformation experiment (1928) used which bacterium? → ***Streptococcus pneumoniae* (in mice)**

315. Infectious particles with protein but no nucleic acid? → **Prions (Stanley Prusiner)**

316. Sterol in fungal membranes that is the target of antifungal drugs? → **Ergosterol**

317. Citric acid is produced commercially by? → ***Aspergillus niger***

318. Cholesterol-lowering statins are produced by? → ***Monascus purpureus***

319. Two bacteria used together to make yoghurt? → ***Streptococcus thermophilus* and *Lactobacillus bulgaricus***

320. Endophytic nitrogen-fixing biofertiliser for sugarcane? → ***Gluconacetobacter* (*Acetobacter*) *diazotrophicus***

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321. Metals required by the nitrogenase enzyme? → **Molybdenum (Mo) and iron (Fe)**

322. Entomopathogenic fungus that causes white muscardine disease? → ***Beauveria bassiana***

323. Main gas in biogas and its approximate share? → **Methane, about 50–70%**

324. Equilibrium relative humidity (ERH) of grain with a_w = 0.70? → **70% (ERH = a_w × 100)**

325. Minimum water activity for growth of most spoilage bacteria? → **About 0.91**

326. Maximum moisture for paddy in FCI procurement specifications? → **17%**

327. Turkey X disease (England, 1960) was caused by? → **Aflatoxin in contaminated groundnut meal**

328. Aflatoxin that appears in the milk of animals fed contaminated feed? → **Aflatoxin M_1**

329. FSSAI maximum limit for aflatoxins in cereals and cereal products? → **15 µg/kg (ppb)**

330. Main target organ of ochratoxin A? → **Kidney (nephrotoxic)**

331. Ergotism ("St. Anthony's fire") is caused by? → ***Claviceps purpurea* sclerotia in rye and other grains**

332. Neurotoxin in khesari dal that causes lathyrism? → **BOAA (β-ODAP)**

333. Vector of kala-azar in India? → **Sandfly, *Phlebotomus argentipes***

334. Antibody made first in the primary immune response? → **IgM (pentamer)**

335. Food poisoning with 1–6 h incubation and a heat-stable enterotoxin is caused by? → ***Staphylococcus aureus***

336. D-value in thermal processing means? → **Time at a given temperature to kill 90% of microbes**

337. Total number of steps in the Codex HACCP sequence? → **12 (5 preliminary steps + 7 principles)**

338. Annual turnover above which an FBO needs a Central FSSAI licence? → **₹20 crore**

339. Baudouin test detects which adulterant in ghee? → **Vanaspati (contains sesame oil; crimson red colour)**

340. Bacterial indicator of faecal contamination of drinking water? → ***Escherichia coli* (absent in 100 mL)**

14.10 Storage Pests, Fumigation & Toxicology (Q 341–390)

341. Scientific name of the lesser grain borer? → ***Rhyzopertha dominica* (Bostrichidae)**

342. Angoumois grain moth *Sitotroga cerealella* belongs to which family? → **Gelechiidae (Lepidoptera)**

343. Damaging stage of the pulse beetle (*Callosobruchus chinensis*)? → **Grub (larva), developing inside the seed**

344. Khapra beetle belongs to which family? → **Dermestidae**

345. Stored-grain pest that can survive on grain with only ≈ 2% moisture? → **Khapra beetle (*Trogoderma granarium*)**

346. Secretions of *Tribolium* that give flour a pungent odour and pinkish tinge? → **Benzoquinones**

347. Bruchid pest of stored groundnut pods and tamarind? → ***Caryedon serratus***

348. Species of *Sitophilus* that cannot fly? → **Granary weevil, *S. granarius***

349. Dermatitis caused by the flour mite *Acarus siro*? → **Grocer's itch**

350. Crushed grain on ninhydrin paper shows insect infestation as? → **Purple spots (amino acids in insect body fluid)**

351. Principle of the flotation test for hidden infestation? → **Hollow infested kernels have lower density and float**

352. Non-destructive method that shows larvae and pupae inside kernels? → **X-ray radiography**

353. FSSAI maximum limit of uric acid in wheat and other foodgrains? → **100 mg/kg**

354. Uric acid in stored grain is an index of? → **Contamination by insect excreta**

355. FCI uniform specification: maximum moisture in wheat? → **12%**

356. FCI procurement maximum moisture for paddy? → **17%**

357. Grain heating up to ≈ 42 °C caused by insect activity is called? → **Dry grain heating**

358. Harrington's thumb rule for safe seed storage? → **RH (%) + temperature (°F) ≤ 100**

359. Width of the rat-proof projection at plinth level of a godown? → **≈ 15–18 cm**

360. Plinth height of a NABARD-model rural godown? → **≈ 0.8 m (80 cm) above ground**

361. Frequency of stock inspection by warehouse technical staff (WDRA)? → **Fortnightly**

362. Dilution of malathion 50% EC for prophylactic spraying in godowns? → **1 : 100 in water (≈ 0.5% a.i.)**

363. Spray volume for prophylactic treatment of godown surfaces? → **3 L of spray per 100 m^2**

364. Strength and interval of deltamethrin 2.5% WP spray? → **40 g per litre water; every 3 months**

365. Interval of malathion prophylactic spraying? → **Fortnightly**

366. Dichlorvos (DDVP) was banned in India from? → **31 December 2020**

367. AlP dose for a bag stack under gas-proof cover (CWC/FCI)? → **3 tablets (9 g AlP) per tonne**

368. Tablets of 3 g AlP needed for a 200 t stack at 3 tablets/t? → **600 tablets (1.8 kg); 200 × 3**

369. FAO phosphine dose for space fumigation of an empty store? → **≈ 1 g PH_3 per m^3**

370. Phosphine released by one 0.6 g AlP pellet? → **≈ 0.2 g PH_3**

371. Compound in AlP tablets that releases NH_3 and CO_2 to cut fire risk? → **Ammonium carbamate**

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372. Minimum grain temperature for phosphine fumigation (FAO)? → **15 °C**

373. Exposure period for phosphine fumigation above 25 °C (FAO)? → **7 days (≈ 10 days at 15–25 °C)**

374. Odour of pure phosphine? → **Odourless; garlic smell comes from impurities (diphosphine)**

375. TLV (8-h TWA) of phosphine in Indian texts? → **0.3 ppm (STEL 1 ppm)**

376. IDLH value of phosphine (NIOSH)? → **50 ppm**

377. Long sand-filled tubes used to seal fumigation cover edges? → **Sand snakes**

378. Device used to detect methyl bromide leaks? → **Halide leak detector lamp (flame turns blue-green)**

379. Methyl bromide was phased out in India (except QPS) from? → **1 January 2015 (Montreal Protocol)**

380. Biochemical target of phosphine in insects? → **Cytochrome c oxidase (mitochondrial respiration)**

381. Making 0.005% bromadiolone bait from 0.25% CB: ratio? → **1 part CB : 49 parts bait; 0.25 ÷ 50**

382. Composition of 2% zinc phosphide rat bait? → **96 parts cereal : 2 parts oil : 2 parts ZnP**

383. Enzyme inhibited by anticoagulant rodenticides? → **Vitamin K epoxide reductase**

384. Pre-baiting is essential with which type of rodenticide? → **Acute poisons (zinc phosphide), to overcome neophobia**

385. Rat whose tail is longer than head + body and which climbs roofs? → **House/roof rat, *Rattus rattus***

386. Label band colour and signal word for oral LD_{50} above 5000 mg/kg? → **Bright green; "CAUTION" (slightly toxic)**

387. Dermal LD_{50} range for the blue (moderately toxic) label? → **2001–20000 mg/kg**

388. WHO class Ia (extremely hazardous) oral LD_{50} in rats? → **Less than 5 mg/kg**

389. Antidote for carbamate insecticide poisoning? → **Atropine only (2-PAM not recommended)**

390. ADI is derived from NOAEL by dividing by a safety factor of? → **100 (10 inter-species × 10 intra-species)**

14.11 Chemistry & Biochemistry (Q 391–450)

391. Energy of the electron in the second Bohr orbit of hydrogen? → **−3.4 eV (−13.6/2^2)**

392. Radius of the second Bohr orbit of hydrogen? → **2.116 Å (0.529 × n^2, n = 2)**

393. Number of radial nodes in a 3p orbital? → **1 (n − l − 1 = 3 − 1 − 1)**

394. Experiment that measured the charge on the electron? → **Millikan's oil-drop experiment (1.602 × 10^{-19} C)**

395. Mendeleev's "eka-silicon" was later discovered as? → **Germanium (Ge)**

396. First true noble-gas compound and its maker? → **$Xe^+[PtF_6]^-$, Neil Bartlett (1962)**

397. Shape of SF_4 molecule? → **See-saw (sp^3d; 4 bond pairs + 1 lone pair)**

398. Hybridisation and shape of XeF_4? → **sp^3d^2, square planar (H = ½(8 + 4) = 6)**

399. Bond order of N_2^+? → **2.5 (½(9 − 4)); paramagnetic**

400. Spin-only magnetic moment of Fe^{3+}? → **5.92 BM (√35; 5 unpaired electrons)**

401. C–O bond order in the carbonate ion? → **1.33 (4 bonds ÷ 3 resonance positions)**

402. Temperature at which water has maximum density? → **4 °C (1.000 g cm^{-3})**

403. pH of 10^{-8} M HCl? → **≈ 6.98 (add 10^{-7} M H^+ from water; not 8)**

404. pH of 0.001 M NaOH at 25 °C? → **11 (pOH = 3; 14 − 3)**

405. Molarity of 4 g NaOH dissolved to make 500 mL solution? → **0.2 M (0.1 mol ÷ 0.5 L)**

406. Freezing-point depression of 1 molal aqueous NaCl (complete dissociation)? → **3.72 K (i K_f m = 2 × 1.86 × 1)**

407. Osmotic pressure of 0.1 M glucose at 300 K? → **≈ 2.46 atm (CRT = 0.1 × 0.0821 × 300)**

408. Half-life of a first-order reaction with k = 0.0693 min^{-1}? → **10 min (0.693/k)**

409. Time for 75% completion of a first-order reaction? → **Two half-lives (2 t½)**

410. Charge needed to deposit 1 mol Al from Al^{3+}? → **3 F ≈ 2.89 × 10^5 C (3 × 96,485)**

411. Standard ΔG° of the Daniell cell (E° = 1.1 V)? → **≈ −212 kJ mol^{-1} (−nFE°, n = 2)**

412. Chemical name of Calgon used to soften water? → **Sodium hexametaphosphate, $Na_6P_6O_{18}$**

413. Acceptable fluoride limit in drinking water (IS 10500:2012)? → **1.0 mg/L (permissible 1.5 mg/L)**

414. Available chlorine in commercial bleaching powder? → **About 35%**

415. Process refining nickel via volatile $Ni(CO)_4$? → **Mond process (vapour-phase refining)**

416. Bauxite is concentrated by leaching with NaOH in which process? → **Bayer's process**

417. Richest ore of iron? → **Magnetite, Fe_3O_4 (~72% Fe)**

418. Theoretical nitrogen content of pure urea? → **46.7% (28/60 × 100); fertiliser grade 46%**

419. Number of structural isomers of pentane (C_5H_{12})? → **3 (n-, iso-, neo-pentane)**

420. Degree of unsaturation of naphthalene ($C_{10}H_8$)? → **7 (10 − 8/2 + 1)**

421. Alcohol giving immediate turbidity with Lucas reagent? → **Tertiary (3°) alcohol**

422. Acyl chloride + H_2 over Pd–$BaSO_4$ → aldehyde is called? → **Rosenmund reduction**

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423. Product of HBr + propene in presence of peroxide? → **1-Bromopropane (anti-Markovnikov, Kharasch effect)**

424. Monomer of Teflon? → **Tetrafluoroethene, $CF_2=CF_2$**

425. Artificial sweetener stable at cooking temperature? → **Sucralose (~600 × sucrose)**

426. Test giving foul-smelling isocyanide with primary amines? → **Carbylamine test ($CHCl_3$ + alc. KOH)**

427. Specific rotation of glucose at mutarotation equilibrium? → **+52.7°**

428. Invert sugar is dextro- or laevorotatory? → **Laevorotatory (fructose −92° outweighs glucose +52.7°)**

429. Glycosidic linkage at branch points of amylopectin and glycogen? → **α-1,6**

430. Monomer unit of chitin? → **N-Acetylglucosamine (β-1,4 linked)**

431. Seliwanoff's test distinguishes which sugars? → **Ketoses (cherry-red colour) from aldoses**

432. First limiting amino acid in cereal proteins? → **Lysine**

433. Crude protein of a sample with 2% Kjeldahl N (general factor)? → **12.5% (2 × 6.25)**

434. Prolamin protein of maize? → **Zein**

435. First enzyme to be crystallised, and by whom? → **Urease, J.B. Sumner (1926)**

436. EC class 7 enzymes (added 2018)? → **Translocases**

437. Michaelis–Menten rate when [S] = 3 K_m? → **0.75 V_{max} ($3K_m/4K_m$)**

438. Effect of a non-competitive inhibitor on K_m and V_{max}? → **K_m unchanged; V_{max} decreases**

439. Two protein fractions that form wheat gluten? → **Gliadin (extensibility) and glutenin (elasticity)**

440. Neurotoxin in *Lathyrus sativus* (khesari) causing neurolathyrism? → **β-ODAP (β-N-oxalyl-L-α,β-diaminopropionic acid)**

441. Reichert–Meissl value is used to judge? → **Purity of butter/ghee (volatile water-soluble fatty acids, butyric)**

442. FSSAI limit of trans fat in oils and fats (from Jan 2022)? → **≤ 2% of total fat**

443. A DNA has 20% adenine; percentage of cytosine? → **30% (A = T = 20; G = C = 30)**

444. Length of a 1000 bp B-DNA molecule? → **340 nm (0.34 nm per bp)**

445. Vitamin D deficiency in adults causes? → **Osteomalacia**

446. Keshan disease (cardiomyopathy) is due to deficiency of? → **Selenium**

447. Respiratory quotient when fat is respired? → **About 0.7**

448. Grain with 20% moisture (wet basis) has what dry-basis moisture? → **25% (20 × 100/80)**

449. Low Hagberg falling number of wheat indicates? → **High α-amylase – sprout damage**

450. Aflatoxin appearing in milk of animals fed contaminated feed? → **Aflatoxin M_1 (from B_1)**

14.12 Physics (Q 451–500)

451. SI base unit of luminous intensity? → **Candela (cd)**

452. 1 newton is equal to how many dynes? → **10^5 dyne**

453. Dimensional formula of power? → **$[ML^2T^{-3}]$**

454. One light year is approximately? → **9.46×10^{15} m (a unit of distance)**

455. Least count of a common screw gauge? → **0.01 mm (pitch 0.5 mm ÷ 50 divisions)**

456. If the side of a cube is measured with 1% error, percentage error in its volume? → **3% ($V \propto a^3$, errors multiply by 3)**

457. Express 54 km/h in m/s. → **15 m/s (54 × 5/18)**

458. Time taken by a stone dropped from 45 m to reach the ground (g = 10 m/s^2)? → **3 s ($t = \sqrt{(2h/g)} = \sqrt{9}$)**

459. Maximum height reached by a ball thrown up at 30 m/s (g = 10 m/s^2)? → **45 m ($H = u^2/2g = 900/20$)**

460. Apparent weight of a 60 kg man in a lift accelerating upward at 2 m/s^2 (g = 10)? → **720 N (m(g + a) = 60 × 12)**

461. Who first measured the universal gravitational constant G? → **Henry Cavendish (1798)**

462. Height of a geostationary satellite above the equator? → **≈ 35,786 km (~36,000 km); period 24 h**

463. Orbital velocity of a satellite near Earth's surface? → **≈ 7.9 km/s ($v_e = \sqrt{2} \times v_o$)**

464. Forceps and fishing rod belong to which class of lever? → **Class III (effort in the middle; MA < 1)**

465. Power of a motor lifting 100 kg through 10 m in 20 s (g = 10)? → **500 W (mgh/t = 10,000/20)**

466. Pressure due to water alone at a depth of 10 m (ρ = 1000 kg/m^3, g = 10)? → **1×10^5 Pa ($P = h\rho g$)**

467. The Plimsoll line on a ship indicates? → **Safe loading limit (maximum draught)**

468. Capillary rise in a tube varies with tube radius r as? → **$h \propto 1/r$ (Jurin's law)**

469. Terminal velocity of a small sphere falling through a fluid is proportional to? → **Square of its radius (r^2; Stokes' law)**

470. Hoeing the soil surface conserves soil moisture by? → **Breaking capillaries, reducing capillary rise and evaporation**

471. SI unit of coefficient of viscosity? → **Pa s (poiseuille); 1 poise = 0.1 Pa s**

472. 77 °F expressed in Celsius? → **25 °C ($C = 5(F - 32)/9$)**

473. Heat needed to raise 2 kg of water by 10 °C (c = 4186 J kg^{-1} K^{-1})? → **83,720 J ≈ 83.7 kJ ($Q = mc\Delta T$)**

474. Latent heat of fusion of ice? → **336 kJ/kg (80 cal/g)**

475. Food cooks faster in a pressure cooker because? → **Boiling point of water rises with pressure (~120 °C)**

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476. Bimetallic strip is used in? → **Thermostats (also fire alarms, MCB overload trips)**

477. Dry and wet bulb thermometers show the same reading; relative humidity is? → **100% (air saturated)**

478. Current drawn by an 1100 W heater on a 220 V supply? → **5 A (I = P/V)**

479. Two 4 Ω resistors in parallel are connected in series with a 3 Ω resistor; total resistance? → **5 Ω (2 Ω + 3 Ω)**

480. Energy consumed by a 2 kW geyser in 30 minutes? → **1 kWh = 1 unit (P × t = 2 × 0.5)**

481. Peak value of 230 V (rms) household AC supply? → **≈ 325 V (230 × √2)**

482. Alloy used for heating elements of electric heaters and irons? → **Nichrome (Ni–Cr)**

483. Band gap of silicon? → **≈ 1.1 eV (germanium ≈ 0.7 eV)**

484. Diode used as a voltage regulator? → **Zener diode**

485. Superconductivity was discovered by? → **H. Kamerlingh Onnes (1911), in mercury at 4.2 K**

486. 1 tesla equals how many gauss? → **10^4 gauss**

487. Curie temperature of iron? → **≈ 770 °C (1043 K)**

488. Why is a transformer core laminated? → **To reduce eddy-current losses**

489. Lenz's law is a consequence of conservation of? → **Energy**

490. Wavelength range of photosynthetically active radiation (PAR)? → **400–700 nm**

491. Focal length of a lens of power +4 D? → **+25 cm, convex (f = 1/P = 0.25 m)**

492. Mirage in deserts is caused by? → **Total internal reflection (hot air near ground is rarer)**

493. Hypermetropia (long-sightedness) is corrected using? → **Convex (converging) lens**

494. Colours seen in soap bubbles and oil films are due to? → **Thin-film interference**

495. Wavelength of a 340 Hz sound in air (v = 340 m/s)? → **1 m (λ = v/f)**

496. Echo from a cliff is heard 2 s after a shout (v = 340 m/s); distance of cliff? → **340 m (d = vt/2)**

497. Soldiers break step while crossing a bridge to avoid? → **Resonance**

498. Maximum kinetic energy of photoelectrons depends on? → **Frequency of incident light (not intensity)**

499. A 32 g sample has half-life 2 h; mass left after 8 h? → **2 g (4 half-lives: $32/2^4$)**

500. Radiation dose range used for insect disinfestation of cereals and pulses? → **0.25–1.0 kGy**

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