Sexual Reproduction in Flowering Plants

The big idea: A flower is a plant's "wedding hall". The male part makes pollen (which carries the male gametes). The female part holds the egg. When pollen reaches the female part, fertilisation happens and the flower turns into a **fruit with seeds**.

Words to know

Word	Simple meaning
Stamen	Male part of the flower (filament + anther)
Pistil / carpel	Female part of the flower (stigma + style + ovary)
Pollen grain	Tiny "packet" that carries the male gametes
Ovule	Structure inside the ovary that becomes the **seed**
Pollination	Pollen reaching the stigma
Fertilisation	Male gamete fusing with the female gamete (egg)

The flower: who's who

Parts of a flower:

- **Androecium** (male) = all the stamens. Each **stamen** = **filament** (stalk) + **anther** (makes pollen).
- **Gynoecium** (female) = all the pistils. Each **pistil** = **stigma** (receives pollen) + **style** (tube) + **ovary** (contains ovules).

Male side: anther and pollen

- A typical anther has **2 lobes**, and each lobe has **2 chambers** (theca), so it is **bilobed and dithecous**.
- So an anther has **4 microsporangia** (pollen sacs).
- **Wall of the microsporangium**, outside to inside: **epidermis** → **endothecium** → **middle layers** → **tapetum**.
- The **tapetum** is the innermost layer. It **feeds** the developing pollen.

Memory trick for the wall layers: "**E**very **E**lephant **M**akes **T**ea" → **E**pidermis, **E**ndothecium, **M**iddle layers, **T**apetum.

How pollen is made (microsporogenesis)

Microspore mother cell (2n) → *meiosis* → microspore tetrad (4 cells, n) → each microspore becomes a pollen grain.

Pollen grain: a tough little packet

- **Exine** is the hard outer wall, made of **sporopollenin**. It is one of the **toughest natural materials**: it survives high heat, strong acids and alkalis, and **no enzyme can break it**. That is why pollen is found preserved as fossils.
- **Germ pores** are gaps in the exine where there is no sporopollenin. The pollen tube comes out through them.
- **Intine** is the thin inner wall, made of **cellulose and pectin**.

- Inside a mature pollen grain there are **2 cells**:
  - **Vegetative cell**: big, has food, and forms the pollen tube.
  - **Generative cell**: small, divides to make **2 male gametes**.
- About **60%** of flowering plants shed pollen at this **2-celled stage**.

> **Did you know?** Pollen of rice and wheat stays alive for only about **30 minutes**. Pollen of the rose, pea and tobacco families stays alive for **months**. Scientists store pollen for years in **liquid nitrogen (−196 °C)** in "pollen banks".

> **Pollen allergy:** Pollen of ***Parthenium*** (carrot grass) causes asthma and allergies.

Female side: ovule and embryo sac

- The ovary contains **ovules**, attached to a cushion called the **placenta**.
- **Parts of an ovule:** funicle (stalk), hilum, integuments (coverings), **micropyle** (small opening), chalaza (base) and **nucellus** (food tissue).

How the embryo sac is made

Megaspore mother cell (2n) → *meiosis* → 4 megaspores (n) → 3 degenerate, 1 stays functional → *3 rounds of free-nuclear mitosis* → embryo sac with **8 nuclei in 7 cells**.

- Only **one** megaspore survives, so this is called **monosporic development**.

> **Memory trick: "7 cells, 8 nuclei" → "3 + 1 + 3"**
> - **3** at the bottom (micropylar end) = **egg apparatus** (1 egg + 2 synergids)
> - **1** big one in the middle = **central cell** (it has **2** polar nuclei, which is the extra nucleus)
> - **3** at the top (chalazal end) = **antipodals**

- **Synergids** have a **filiform apparatus**, which works like a "landing guide" that attracts and guides the pollen tube.

Pollination: getting pollen to the stigma

Type	Where the pollen goes	Simple way to remember
Autogamy	Same flower	"Auto" = self
Geitonogamy	Another flower on the **same plant**	Like a neighbour, but genetically the same as selfing
Xenogamy	A flower on a **different plant**	"Xeno" = stranger. The only type that brings **new genes**

- **Chasmogamous** flowers open normally.
- **Cleistogamous** flowers **never open**, so they always self-pollinate (e.g. *Viola*, *Oxalis*, *Commelina*). They give an assured seed set, even without pollinators.

Who carries the pollen?

- **Abiotic (non-living) agents:**
  - **Wind:** light, non-sticky pollen and feathery stigmas (grasses, maize).

- **Water:** rare; *Vallisneria*, *Hydrilla* and *Zostera*.
- **Biotic (living) agents:** mostly insects (especially bees), also birds and bats. Their flowers are large, colourful, fragrant and rich in nectar.

> **Did you know?** *Amorphophallus* has one of the **tallest flowers** (about 6 feet)! The **yucca plant and its moth** can't survive without each other. The moth lays eggs in the flower and pollinates it at the same time.

> **Common mistake:** Most water plants (like the **water lily** and **water hyacinth**) are **not** pollinated by water. They are pollinated by insects or wind. Water pollination is found in only about 30 genera, mostly monocots.

Outbreeding devices: stopping self-pollination

Plants want variety, so many have tricks to avoid selfing:

1. Pollen release and stigma readiness happen at **different times**.
2. Anther and stigma are at **different positions**.
3. **Self-incompatibility**: the pistil rejects its own pollen (a genetic lock).
4. **Unisexual flowers**:
   - **Monoecious** plants (castor, maize) have male and female flowers on the same plant. This stops autogamy but **not geitonogamy**.
   - **Dioecious** plants (papaya) have male and female flowers on **different plants**. This stops **both**.

Artificial hybridisation (plant breeding)

- **Emasculation** means removing the anthers from a flower before they release pollen.
- **Bagging** means covering the flower with a butter-paper bag so no unwanted pollen gets in.
- The breeder then dusts the chosen pollen on the stigma and bags the flower again.

Double fertilisation (a favourite exam topic)

The pollen tube brings **2 male gametes**. **Both** of them fuse with something, so it's called **double** fertilisation. This happens only in flowering plants (angiosperms).

- **Syngamy:** male gamete 1 + egg (n) → **zygote (2n)** → becomes the **embryo**.
- **Triple fusion:** male gamete 2 + 2 polar nuclei (n + n) → **primary endosperm nucleus, PEN (3n)** → becomes the **endosperm** (food).

> **Memory trick:** **Syn**gamy = **sin**gle fusion (2 nuclei → **2n**). **Tri**ple fusion = **three** nuclei → **3n**.

After fertilisation: what becomes what

Before	After
Ovary	**Fruit**
Ovary wall	**Pericarp** (fruit wall)

Before	After
Ovule	**Seed**
Integuments	**Seed coat** (testa and tegmen)
Zygote	**Embryo**
Primary endosperm nucleus	**Endosperm**

> **Memory trick:** "**O**vary → fruit, **O**vule → seed". The bigger word (ovary) makes the bigger thing (fruit).

Endosperm: the baby's lunch box

- Endosperm forms **before** the embryo, because the baby needs food first!
- Most common type: **free-nuclear** (many nuclei, no walls yet).
- **Coconut:** the **water** is free-nuclear endosperm and the **white kernel** is cellular endosperm.
- **Non-albuminous seeds** use up all the endosperm (pea, groundnut).
- **Albuminous seeds** keep some endosperm (wheat, maize, castor).
- **Perisperm** is leftover nucellus (black pepper, beet).

The embryo

- The zygote grows: **proembryo** → **globular** → **heart-shaped** → **mature embryo**.
- A **monocot** embryo (like grass) has 1 cotyledon called the **scutellum**. The shoot tip is covered by the **coleoptile** and the root tip by the **coleorhiza**.

Fruits and seeds: fun facts

- **False fruits** grow from the thalamus as well as the ovary (apple, strawberry, cashew).
- **Parthenocarpic fruits** grow **without fertilisation**, so they have **no seeds** (banana).
- **Oldest seeds:** a *Lupinus arcticus* seed germinated after about **10,000 years**, and a date palm (*Phoenix dactylifera*) seed after about **2,000 years**.

Apomixis and polyembryony

- **Apomixis** means forming seeds **without fertilisation** (some grasses, Asteraceae). It is useful for farmers because hybrid seeds made this way stay the same every year, so farmers don't need to buy new hybrid seed every season.
- **Polyembryony** means **more than one embryo** in one seed (citrus, mango).

30-second revision

- Anther = 4 microsporangia; tapetum feeds the pollen.
- Exine = sporopollenin (the toughest material). Germ pores have no sporopollenin.
- Embryo sac = **7 cells, 8 nuclei** (monosporic).
- Xenogamy = the only pollination type that brings new genes.
- Double fertilisation = **syngamy (2n zygote) + triple fusion (3n PEN)**.
- Ovary → fruit, ovule → seed, integuments → seed coat.

Human Reproduction

> **The big idea:** Humans reproduce sexually. The father makes **sperms** in the testes and the mother makes **eggs (ova)** in the ovaries. A sperm and an egg join (**fertilisation**) to form a **zygote**. The zygote grows into a baby inside the mother's **uterus** for about **9 months**.

The whole story in 7 steps

1. **Gametogenesis:** making sperms and eggs.
2. **Insemination:** sperms are transferred into the female.
3. **Fertilisation:** sperm + egg → zygote.
4. **Cleavage and implantation:** the embryo attaches to the uterus wall.
5. **Gestation (pregnancy):** the baby grows for about 9 months.
6. **Parturition:** birth of the baby.
7. **Lactation:** the mother feeds milk.

Male reproductive system

- **Testes** (2) are the sperm factories. They sit **outside** the body in a skin pouch called the **scrotum**.
- The scrotum keeps the testes **2–2.5 °C cooler** than the body, because sperms need a cooler temperature to form.
- Each testis has about **250 compartments** called **testicular lobules**. Each lobule has **1–3 seminiferous tubules**, where the sperms are made.

Cell	Where	Job
Spermatogonia	Inside the seminiferous tubules	Divide to form sperms
Sertoli cells	Inside the seminiferous tubules	**Nurse cells**: feed the developing sperms
Leydig cells (interstitial cells)	**Outside** the tubules	Make the male hormone **testosterone (androgens)**

The sperm's journey out

Seminiferous tubules → rete testis → vasa efferentia → epididymis (sperms stored and mature) → vas deferens → ejaculatory duct → urethra → outside.

> **Memory trick for the duct path:** "**S**ita **R**ides **V**ery **E**asy **V**ans **E**very **U**tsav" → **S**eminiferous tubules → **R**ete testis → **V**asa efferentia → **E**pididymis → **V**as deferens → **E**jaculatory duct → **U**rethra.

- **Accessory glands:** 2 **seminal vesicles**, 1 **prostate** and 2 **bulbourethral** glands.
- Their fluid is **seminal plasma**. It is rich in **fructose** (energy for sperms), calcium and enzymes.
- **Semen** = sperms + seminal plasma.

Female reproductive system

- **Ovaries** (2) make the **eggs** and the hormones **estrogen** and **progesterone**.

- **Oviduct (fallopian tube)** has 3 parts: **infundibulum** (funnel with finger-like **fimbriae** that catch the egg) → **ampulla** (wide part) → **isthmus** (narrow part).
- **Fertilisation happens at the ampullary–isthmic junction.**
- **Uterus (womb):** where the baby grows. Its wall has 3 layers:

Layer	Simple description
Perimetrium	Thin outer covering
Myometrium	Thick **muscle** layer that **squeezes during birth**
Endometrium	Inner lining that thickens every month and **sheds during menstruation**

- **Mammary glands** (breasts) make milk. Each has **15–20 lobes** full of milk-making cells (alveoli).

Making gametes (gametogenesis)

Spermatogenesis: making sperms

Spermatogonium (2n) → *grows* → primary spermatocyte (2n) → *meiosis I* → 2 secondary spermatocytes (n) → *meiosis II* → 4 spermatids (n) → *spermiogenesis* → 4 sperms (n).

- **Spermiogenesis** means spermatids changing into sperms (they get a tail).
- **Spermiation** means the release of sperms from the seminiferous tubules.

Hormones control it all

- The **hypothalamus** releases **GnRH**, which acts on the **anterior pituitary**.
- The anterior pituitary releases:
  - **LH** → acts on **Leydig cells** → they make testosterone.
  - **FSH** → acts on **Sertoli cells** → they help spermiogenesis.

> **Memory trick:** **L**H → **L**eydig cells. **F**SH → the "**F**eeder" cells (Sertoli).

Parts of a sperm

Part	Contains	Job
Head	Nucleus + **acrosome** (cap)	Acrosome has enzymes to **break into the egg**
Neck	—	Joins head and middle piece
Middle piece	Lots of **mitochondria**	Makes **energy** for swimming
Tail	—	Swims

- One ejaculation releases **200–300 million sperms**. For normal fertility, at least **60%** must have normal shape and at least **40%** must swim strongly.

Oogenesis: making eggs

- It starts **before birth**. Millions of egg mother cells (**oogonia**) form in each ovary of the unborn baby girl, and **no new ones are made after birth**.

- Many follicles die between birth and puberty. At puberty, only **60,000–80,000** primary follicles are left in each ovary.
- Follicles grow: **primary** → **secondary** → **tertiary** (with a fluid space called the **antrum**) → **Graafian follicle** (mature).
- The **secondary oocyte** is released at **ovulation**. It is covered by the **zona pellucida** layer.

Spermatogenesis	Oogenesis
Starts at **puberty**	Starts **before birth** (oogonia)
1 cell → **4 sperms**	1 cell → **1 egg** + polar bodies
Goes on all the time	Happens in a **monthly cycle**

> **Common mistake:** The egg released at ovulation is **not** a finished ovum. It is a **secondary oocyte**. It finishes meiosis II **only after a sperm enters it**.

The menstrual cycle (about 28 days)

Phase	Days	What happens
Menstrual	1–5	The endometrium breaks down and bleeding happens
Follicular (proliferative)	6–13	A follicle grows. **FSH** and **estrogen** rise. The endometrium grows again
Ovulation	~14	**LH surge** → the Graafian follicle bursts and releases the egg
Luteal (secretory)	15–28	The empty follicle becomes the **corpus luteum**, which makes **progesterone** to keep the endometrium ready for a baby

- **If no fertilisation:** the corpus luteum dies → progesterone falls → the endometrium breaks down → the next period starts.
- **Menarche** is the **first** period (at puberty). **Menopause** is when periods **stop**, around **50 years**.

> **Memory trick:** "**L**H = **L**et the egg go". The **LH surge** causes ovulation on day 14. **Corpus luteum** makes **progesterone** = "**pro-gestation**", the hormone that supports pregnancy.

Fertilisation and implantation

1. The sperm meets the egg at the ampullary–isthmic junction.
2. The sperm enters; changes in the zona pellucida block other sperms.
3. The egg (secondary oocyte) finishes meiosis II.
4. The **zygote (2n)** forms.
5. **Cleavage** (mitosis) → **morula** (8–16 cells) → **blastocyst**.
6. **Implantation:** the blastocyst embeds in the endometrium.

- **Blastocyst** has 2 parts:
  - **Trophoblast** (outer layer): sticks to the uterus and helps form the placenta.
  - **Inner cell mass**: becomes the **baby**. It has **stem cells** that can form any tissue.

Boy or girl?

- The mother's eggs all carry **X**.
- The father's sperms are **50% X and 50% Y**.
- X egg + X sperm = **XX** → **girl**. X egg + Y sperm = **XY** → **boy**.

> **Exam focus:** The **father's sperm decides** the sex of the baby, because only the father can give a Y chromosome. The chance of a boy or girl is **50 : 50** every time.

Pregnancy: the baby grows

- **Placenta** is the link between mother and baby. It gives food and oxygen and removes waste. It is joined to the baby by the **umbilical cord**.
- **Placenta also makes hormones: hCG, hPL**, estrogens, progestogens and **relaxin**.

> **Memory trick: hCG** (human chorionic gonadotropin) is the "I'm pregnant" hormone. Home pregnancy test kits detect it in urine.

Three germ layers

Layer	Forms
Ectoderm (outer)	Skin, brain and nerves
Mesoderm (middle)	Muscles, bones, blood, heart
Endoderm (inner)	Lining of the gut, lungs, liver

> **Memory trick: Ecto = Exterior** (skin, nerves). **Endo = Entrails** (gut). **Meso = Middle** (muscles, bones, blood).

Month-by-month milestones

When	What develops
End of month 1	**Heart** forms and starts beating
End of month 2	Limbs and fingers/toes
End of month 3 (1st trimester)	Most organs are formed
Month 5	First **movements** felt, hair on head
End of month 6 (2nd trimester)	Eyelids separate, eyelashes form
End of month 9	Baby is ready to be born

Birth and breastfeeding

- **Parturition** (birth) is started by signals from the fully grown baby and the placenta. This is called the **foetal ejection reflex**.
- It causes the release of **oxytocin**, which makes the uterus muscles squeeze. Squeezing causes more oxytocin, and so on, until the baby is born.

- **Colostrum** is the first milk after birth. It is full of **IgA antibodies**, which protect the newborn.

30-second revision

- Testes are in the scrotum, 2–2.5 °C cooler than the body.
- Sertoli = nurse cells; Leydig = testosterone.
- Fertilisation happens at the **ampullary–isthmic junction**.
- **LH surge → ovulation (day 14)**; corpus luteum → progesterone.
- Zygote → morula → blastocyst → implantation.
- The **father decides the baby's sex** (X or Y sperm).
- Oxytocin → birth; colostrum → IgA antibodies.

Reproductive Health

The big idea: Reproductive health means a person is **healthy in body, mind, behaviour and social life** in everything related to reproduction (WHO definition). This chapter covers **family planning** (birth control), **safe abortion** rules, **sexually transmitted infections** and **help for couples who can't have children**.

India's efforts

- India was one of the **first countries** to start a nationwide family planning programme, in **1951**.
- Today it is part of the **RCH (Reproductive and Child Health Care)** programme.
- Schools teach **sex education** to remove myths and give correct information.

Exam focus: amniocentesis. A doctor takes some amniotic fluid (the fluid around the baby) to check for **genetic disorders**. In India it is **banned for finding out the baby's sex**, to stop **female foeticide**.

Population explosion

Year	India's population
1947 (Independence)	about **350 million**
2000 (May)	crossed **1 billion**

- **Why it grew:** fewer deaths, fewer mothers and babies dying (lower **MMR** and **IMR**), and more people reaching reproductive age.
- **Ways to control it:** encourage small families, use contraceptives, and raise the marriage age. The legal marriage age is **18 for girls and 21 for boys**.

Contraception (birth control)

In simple words: Contraceptives are methods that stop a pregnancy from happening. A good contraceptive is **safe, easy to use, easy to get, effective, reversible** and has **few side effects**.

There are 5 groups of methods: **natural**, **barrier**, **IUDs**, **oral pills, injections and implants**, and **surgical** (permanent).

How each method works

Method	How it works	Remember
Periodic abstinence	Avoid sex on **days 10–17** of the cycle, when ovulation is likely	"Avoid the fertile window"
Withdrawal (coitus interruptus)	Male withdraws before ejaculation	Not very reliable
Lactational amenorrhea	No periods (and no ovulation) while **fully breastfeeding**, up to **6 months** after birth	Works only while fully breastfeeding

Method	How it works	Remember
Condoms	Stop sperms from reaching the egg	**Also protect against STIs and AIDS**
Copper IUDs	Cu ions **reduce sperm movement** and ability to fertilise	"Copper cuts sperm power"
Hormonal IUDs	Make the uterus **unsuitable for implantation** and the cervix **hostile to sperms**	
Pills	**Stop ovulation** and implantation, and thicken cervical mucus	Taken daily for 21 days
Saheli	A **non-steroidal**, **once-a-week** pill made by **CDRI, Lucknow**	Made in India
Emergency contraception	Pills or an IUD within **72 hours** of unprotected sex	"Within 3 days"
Vasectomy	**Vas deferens** is cut and tied, so sperms can't come out	**V**asectomy = **V**as (male)
Tubectomy	**Fallopian tube** is cut and tied, so the egg can't reach the uterus	**T**ubectomy = **T**ube (female)

> **Common mistake:** Surgical methods (vasectomy and tubectomy) are **permanent**. They are **very poorly reversible**, so they are not a "try and undo" method.

Medical Termination of Pregnancy (MTP)

- MTP means ending a pregnancy on purpose, before the baby is fully grown.
- **Legal in India since 1971** (MTP Act), with an amendment in **2017** to reduce illegal abortions.
- It is **relatively safe during the first trimester** (up to **12 weeks**).
- Big risk: **illegal abortions by untrained people** are dangerous and can kill.

Sexually Transmitted Infections (STIs)

Infections that spread through sexual contact. They are also called **VD** (venereal diseases) or **RTI** (reproductive tract infections).

STI	Caused by	Curable?
Gonorrhoea	Bacterium	Yes, if treated early
Syphilis	Bacterium	Yes, if treated early
Chlamydiasis	Bacterium	Yes, if treated early
Trichomoniasis	Protozoan	Yes, if treated early
Genital warts	Virus	Treatable
Genital herpes	Virus	**Not completely curable**
Hepatitis B	Virus	**Not completely curable**
HIV / AIDS	Virus	**Not curable**

> **Memory trick for the 3 incurable STIs:** "**H**, **H**, **H**" → **H**erpes, **H**epatitis B and **H**IV.

- **Hepatitis B and HIV** can also spread by **sharing needles** and **blood transfusion**, and from **mother to baby**.

- **If not treated**, STIs can cause **PID** (pelvic inflammatory disease), abortions, stillbirths, **ectopic pregnancy** (the baby grows outside the uterus), **infertility** and even **cancer** of the reproductive tract.
- **Prevention:** avoid sex with unknown or multiple partners, **always use condoms**, and see a doctor early if in doubt.

Infertility and ART (Assisted Reproductive Technologies)

Some couples can't have children. Science can help using **ART**, techniques that help the sperm and egg meet.

- **Low sperm count → AI / IUI**: semen is placed in the vagina or uterus.
- **Sperm can't enter the egg → ICSI**: a sperm is injected straight into the egg.
- **Female can't make eggs → GIFT**: a donor egg is placed in her fallopian tube.
- **IVF + ET** ("test tube baby"): the egg and sperm meet in the lab, then the embryo is transferred:
  - embryo with **up to 8 cells → ZIFT** (into the fallopian tube)
  - embryo with **more than 8 cells → IUT** (into the uterus)

Short name	Full form	In simple words
IVF	In Vitro Fertilisation	Egg and sperm meet in a **lab dish** ("test tube baby")
ET	Embryo Transfer	The embryo is put back into the mother
ZIFT	Zygote Intra Fallopian Transfer	Zygote or embryo with **up to 8 cells → fallopian tube**
IUT	Intra Uterine Transfer	Embryo with **more than 8 cells → uterus**
GIFT	Gamete Intra Fallopian Transfer	**Donor egg** → fallopian tube of a woman who **can't make eggs**
ICSI	Intra Cytoplasmic Sperm Injection	One sperm is **injected** straight into the egg
AI / IUI	Artificial Insemination / Intra Uterine Insemination	Semen from the husband or a donor is placed in the vagina or uterus

> **Memory trick:** **Z**IFT = **Z**ygote goes to the tube. **I**UT = **I**nto the **U**terus (bigger embryo). **G**IFT = a **G**ift of an egg (from a donor).

30-second revision

- Family planning started in India in **1951**; now under RCH.
- Amniocentesis for sex determination is **banned**.
- CuT reduces sperm motility; Saheli = weekly, non-steroidal (CDRI Lucknow).
- Emergency contraception: within **72 hours**.
- MTP is legal since **1971** and safest in the first **12 weeks**.
- Incurable STIs: **Herpes, Hepatitis B, HIV**.
- ZIFT (≤ 8 cells, tube), IUT (> 8 cells, uterus), GIFT (donor egg), ICSI (injected sperm).

Principles of Inheritance and Variation

> **The big idea:** Why do you look like your parents, but not exactly like them? **Inheritance** is how traits pass from parents to children. **Variation** is how children differ from their parents. **Gregor Mendel**, the "Father of Genetics", worked out the basic rules using **pea plants**.

Words to know

Word	Simple meaning	Example
Gene	A unit of heredity that controls a trait	Gene for plant height
Allele	Different forms of the same gene	**T** (tall) and **t** (dwarf)
Dominant	The allele that shows up when paired with another allele	**T**
Recessive	The allele that is hidden when paired with a dominant allele	**t**
Homozygous	Both alleles are the same	**TT** or **tt**
Heterozygous	The two alleles are different	**Tt**
Genotype	The genes an organism has	TT, Tt, tt
Phenotype	How it looks	Tall or dwarf

> **Memory trick: Geno**type = **gene** letters (Tt). **Pheno**type = what you can **see** ("pheno" sounds like "phone camera").

Why did Mendel choose peas?

- Pea plants are easy to grow and have a **short life cycle**.
- They have many **clear, opposite traits** (tall/dwarf, green/yellow).
- They **self-pollinate** naturally but can also be **cross-pollinated** by hand.
- Mendel studied **7 pairs of contrasting traits** from **1856 to 1863**.

Monohybrid cross: one trait at a time

Mendel crossed a pure **tall (TT)** plant with a pure **dwarf (tt)** plant.

Parents TT (tall) × tt (dwarf) → **F1:** all Tt (all tall) → *self-pollinate Tt × Tt* → **F2:** TT, Tt, Tt, tt → **3 tall : 1 dwarf** (genotype 1 TT : 2 Tt : 1 tt).

Punnett square for F1 × F1 (Tt × Tt):

♀ \ ♂	**T**	**t**
T	TT (tall)	Tt (tall)
t	Tt (tall)	tt (dwarf)

> **Exam focus: learn these ratios by heart.**
>
> - Monohybrid F2 **phenotype 3 : 1**, **genotype 1 : 2 : 1**
> - Dihybrid F2 **phenotype 9 : 3 : 3 : 1**
> - **Test cross** (monohybrid) **1 : 1**; dihybrid test cross **1 : 1 : 1 : 1**

Test cross: find the hidden genotype

A tall plant could be **TT or Tt**. To find out, cross it with a **dwarf (tt)** plant:

- If **all** the offspring are tall → the plant was **TT**.
- If **half** are tall and half dwarf (**1 : 1**) → the plant was **Tt**.

Mendel's 3 laws

Law	In simple words
1. Law of Dominance	In a **Tt** plant, only the dominant trait (**T**, tall) shows
2. Law of Segregation	The two alleles **separate** when gametes form, so each gamete gets **only one** allele. Also called the "law of purity of gametes"
3. Law of Independent Assortment	Genes for **different traits** are passed on **independently** of each other

> **Memory trick: "DSI"** → **D**ominance, **S**egregation, **I**ndependent assortment. Think "**D**on't **S**kip **I**nheritance".

Dihybrid cross: two traits together

Mendel crossed **round yellow (RRYY)** seeds with **wrinkled green (rryy)** seeds. The F1 were all **RrYy** (round yellow). In the F2:

Round yellow	Round green	Wrinkled yellow	Wrinkled green
9	3	3	1

- 4 types of gametes from each parent: **RY, Ry, rY, ry**. That gives a **4 × 4 = 16** box Punnett square.
- This cross proved the **Law of Independent Assortment**.

When Mendel's rules bend: exceptions

1. Incomplete dominance: blending

- In the **snapdragon (dog flower, *Antirrhinum*)**: **red (RR) × white (rr)** → **pink (Rr)** in F1.
- F2 = **1 red : 2 pink : 1 white**. Here the **phenotype ratio is the same as the genotype ratio (1:2:1)**.

2. Co-dominance: both show

- **ABO blood groups** in humans are controlled by the gene **I**, which has **3 alleles**: **I^A, I^B and i**.
- **I^A and I^B are co-dominant** (both show together as AB). **i is recessive**.

- This also shows **multiple alleles** (more than 2 alleles for one gene in a population).

Genotype	Blood group
I^AI^A or I^Ai	**A**
I^BI^B or I^Bi	**B**
I^AI^B	**AB** (co-dominance!)
ii	**O**

> **Memory trick: 3 alleles → 6 genotypes → 4 blood groups** ("**3-6-4**").

3. Pleiotropy and polygenic inheritance

	Pleiotropy	Polygenic inheritance
Meaning	**One gene → many effects**	**Many genes → one trait**
Example	**Phenylketonuria**	**Human skin colour**, height

> **Memory trick: Pleio**tropy = **Plenty** of effects from 1 gene. **Poly**genic = **Po**lice team: many genes work together on 1 trait.

Chromosomal theory of inheritance

- **Sutton and Boveri** said genes are on **chromosomes**, and chromosomes move in pairs like Mendel's factors.
- **Thomas Hunt Morgan** proved it using **fruit flies (*Drosophila*)**.

> **Did you know?** *Drosophila* was perfect for genetics: it grows on simple food, completes its life cycle in about **2 weeks**, one mating gives **hundreds of flies**, and males and females are easy to tell apart.

- **Linkage:** genes on the **same chromosome** tend to be inherited **together**.
- **Recombination:** new combinations appear when linked genes separate (by crossing over).
- **Tight linkage** gives few recombinants; **loose linkage** gives more.
- **Alfred Sturtevant** used recombination frequency to make the first **gene maps**.

Sex determination: boy or girl?

System	Example	Female	Male
XX–XO	Grasshopper	XX	**XO** (one X only)
XX–XY	Humans, *Drosophila*	XX	**XY**
ZW–ZZ	Birds	**ZW**	ZZ
Haplodiploidy	Honey bee	**Diploid** (32 chromosomes), from a fertilised egg	**Haploid** (16 chromosomes), from an **unfertilised egg**

> **Common mistake:** In **birds**, the **female (ZW)** decides the sex of the chick, not the male. In humans it's the male (XY) who decides.

> **Did you know?** A male honey bee (drone) has **no father** and **cannot have sons**, but he has a **grandfather** and can have **grandsons**!

Mutation

- A **mutation** is a change in DNA.
- **Point mutation:** one base changes. Example: **sickle-cell anaemia**.
- **Frameshift mutation:** a base is added or deleted, which shifts the whole reading frame.
- **Mutagens:** things that cause mutation, such as **UV rays** and some chemicals.

Pedigree analysis

A **pedigree** is a family tree that shows how a trait is passed down. It helps track genetic diseases.

Symbol	Meaning
Square	Male
Circle	Female
Shaded (filled) square or circle	Affected person
Horizontal line joining a square and a circle	Mating (marriage)
Double line	Consanguineous mating (between relatives)

Genetic disorders

A. Mendelian disorders (a single gene change)

Disorder	Type	Key fact
Haemophilia	**X-linked recessive**	Blood doesn't clot. Mostly affects **males**; carrier mothers pass it to sons. Famous in **Queen Victoria's** family
Colour blindness	**X-linked recessive**	Can't tell **red from green**. About **8% of males** and **0.4% of females**
Sickle-cell anaemia	**Autosomal recessive**	**Glutamic acid → valine** at the **6th position** of the β-globin chain (**GAG → GUG**). RBCs become sickle-shaped
Phenylketonuria	**Autosomal recessive**	Can't convert **phenylalanine → tyrosine**, which leads to **mental retardation**
Thalassemia	**Autosomal recessive**	**Less globin** is made (a **quantity** problem). Sickle-cell makes the **wrong** globin (a **quality** problem)

> **Memory trick:** In sickle-cell, the "**Glu**e" (glutamic acid) is replaced by "**Val**entine" (valine) at position **6 → Glu6Val**.

B. Chromosomal disorders (whole chromosome changes)

- **Aneuploidy:** one chromosome extra or missing, caused by failed separation during cell division.
- **Polyploidy:** whole extra **sets** of chromosomes. Common in plants.

Disorder	Chromosomes	Features
Down's syndrome	**Trisomy 21** (47 chromosomes)	Short, small round head, furrowed tongue, partly open mouth, palm crease, slow mental development
Klinefelter's syndrome	**47, XXY**	**Male** with some female features (breast growth); **sterile**
Turner's syndrome	**45, XO**	**Female** with underdeveloped ovaries; **sterile**

> **Memory trick: K**linefelter = **K**ing with an extra X (**XXY**, male). **T**urner = **T**oo few, just one X (**XO**, female).

30-second revision

- Monohybrid 3:1 (phenotype), 1:2:1 (genotype); dihybrid 9:3:3:1; test cross 1:1.
- Incomplete dominance: snapdragon → pink (1:2:1).
- ABO blood groups = co-dominance + multiple alleles (3-6-4).
- Morgan → *Drosophila* → linkage; Sturtevant → gene maps.
- Birds: female ZW. Honey bee male: haploid (16).
- Haemophilia and colour blindness: X-linked recessive. Sickle-cell: Glu6Val.
- Down's = 21 trisomy; Klinefelter = XXY; Turner = XO.

Molecular Basis of Inheritance

> **The big idea: DNA** is the "recipe book" of life. Its instructions are copied (**replication**), rewritten as RNA (**transcription**) and then used to build proteins (**translation**). Proteins do almost all the work in our bodies.

The central dogma: DNA → RNA → Protein

DNA → *transcription* → **mRNA** → *translation* → **protein**. DNA also copies itself by **replication**.

> **Memory trick: Tran-S-cription** = making a **S**cript (RNA) from DNA. **Tran-SL-ation** = trans**L**ating that script into the **L**anguage of proteins (amino acids). It's like DNA is a **master recipe book in a library**, mRNA is a **photocopy** of one recipe, and the ribosome is the **chef** who cooks the protein.

Structure of DNA

Building block: the nucleotide

- **Nucleotide** = **nitrogen base + sugar + phosphate**.
- **Nucleoside** = nitrogen base + sugar (no phosphate).
- **Purines** (2 rings): **A**denine, **G**uanine.
- **Pyrimidines** (1 ring): **C**ytosine, **T**hymine (in DNA), **U**racil (in RNA instead of T).

> **Memory trick:** "**Pure As Gold**" → **Pur**ines = **A** and **G**. The rest (C, T, U) are pyrimidines: "**CUT** the **Py**e".

The double helix (Watson and Crick, 1953)

- DNA is a **twisted ladder**: the **sides** are sugar–phosphate and the **steps** are base pairs.
- The two strands run in **opposite directions** (**antiparallel**): one 5'→3', the other 3'→5'.
- **A = T** (2 hydrogen bonds) and **G ≡ C** (3 hydrogen bonds).
- **Pitch** (one full turn) = **3.4 nm**, with **10 base pairs** per turn, so the distance between two base pairs = **0.34 nm**.
- **Chargaff's rule:** in DNA, **A = T** and **G = C**, so purines = pyrimidines.
- Watson and Crick built their model using **X-ray pictures** by **Maurice Wilkins and Rosalind Franklin**.

> **Exam focus: calculating DNA length.** Human DNA has **6.6×10^9 bp**. Length = $6.6 \times 10^9 \times 0.34 \times 10^{-9}$ m ≈ **2.2 metres**! And it all fits into a tiny nucleus. *E. coli* has **4.6×10^6 bp**.

How 2 metres of DNA fits in a nucleus: packaging

DNA double helix → wraps around a **histone octamer** (8 histones) → **nucleosome** (~200 bp) → "beads on a string" → **chromatin fibre** → **chromosome** (seen during cell division).

- **Histones** are **positively charged** (rich in **lysine and arginine**), so they hold **negatively charged** DNA like a magnet.
- **Euchromatin:** loosely packed and **active** (genes are read).
- **Heterochromatin:** tightly packed and **inactive**.

> **Memory trick: Eu**chromatin = "**Eu-**phoria", open and active. **Hetero**chromatin = tightly **h**eld, **h**idden and inactive.

Proving DNA is the genetic material

Scientist(s)	Year	Experiment	Result
Frederick Griffith	1928	Mixed **heat-killed smooth (S)** bacteria with **live rough (R)** bacteria and injected mice → mice **died**	Something "**transformed**" R into S (**transformation**)
Avery, MacLeod, McCarty	1944	Found which chemical did the transforming	It was **DNA**
Hershey and Chase	1952	Grew viruses with radioactive **^{32}P (DNA)** or **^{35}S (protein)**	Only **^{32}P** entered the bacteria → **DNA is the genetic material**

- Viruses with **radioactive DNA (^{32}P)** infected bacteria → radioactivity was found **inside** the bacteria.
- Viruses with **radioactive protein (^{35}S)** infected bacteria → radioactivity stayed **outside** the bacteria.
- **Conclusion:** DNA, not protein, enters the bacteria and carries the genetic information.

> **Memory trick: P** for **P**hosphorus → **P**resent in DNA. **S** for **S**ulphur → found in proteins (in some amino acids), not in DNA.

Why DNA is better than RNA as genetic material

- RNA has an extra **2'-OH group**, which makes it **reactive and unstable**.
- RNA **mutates faster**.
- DNA is **double-stranded** and stable. That's why DNA stores information, while RNA mostly carries messages.
- **RNA was probably the first genetic material** ("RNA world"), and some RNAs work as enzymes (**ribozymes**).

DNA replication: making a copy

- DNA copies itself in a **semi-conservative** way: each new DNA has **1 old strand + 1 new strand**.
- **Proved by Meselson and Stahl (1958)** using heavy nitrogen (^{15}N) and normal nitrogen (^{14}N) in *E. coli*.

1. **Start:** all DNA has heavy ^{15}N (band at the bottom of the tube).
2. **After 1 generation in ^{14}N:** all DNA is hybrid ^{15}N/^{14}N (one middle band).
3. **After 2 generations in ^{14}N:** half is hybrid and half is light ^{14}N (a middle band and a top band).

The replication team (enzymes)

Enzyme	Job
Helicase	Unzips the DNA
DNA polymerase	Adds new nucleotides, **only in the 5'→3' direction**
DNA ligase	Joins the short pieces ("glue")

- **Leading strand:** made **continuously**.
- **Lagging strand:** made in short pieces called **Okazaki fragments**, which ligase joins.

- Replication starts at a point called the **origin of replication (ori)**, and happens in the **S phase** of the cell cycle.

Transcription: DNA → RNA

- Only **one strand** of DNA is used as a template.
  - **Template strand** (3'→5'): read to make RNA.
  - **Coding strand** (5'→3'): **same sequence as the RNA**, with T in place of U.
- A **transcription unit** has 3 parts: **promoter** (start signal) → **structural gene** → **terminator** (stop signal).

In bacteria	In eukaryotes (like us)
One RNA polymerase makes all RNAs	**Three** RNA polymerases
σ (sigma) factor helps start; **ρ (rho) factor** helps stop	**Pol I** → rRNAs, **Pol II** → mRNA (hnRNA), **Pol III** → tRNA, 5S rRNA, snRNA
Transcription and translation happen **together**	Transcription in the **nucleus**, translation in the **cytoplasm**

> **Memory trick: "R-M-T" = 1-2-3.** Pol **I** → **R**RNA, Pol **II** → **M**RNA, Pol **III** → **T**RNA.

RNA processing in eukaryotes

The first copy (**hnRNA**) is edited before it leaves the nucleus:

hnRNA (exons + introns) → **splicing** (remove introns, join exons) → **capping** (add a methyl guanosine cap at the 5' end) → **tailing** (add a poly-A tail at the 3' end) → **mRNA**.

> **Memory trick: Ex**ons = **Ex**pressed (kept). **In**trons = **In**terrupting (thrown out). The mRNA wears a **cap** on its head (5') and has a **tail** at the back (3').

The genetic code

- Worked out by **George Gamow**, **Har Gobind Khorana** and **Marshall Nirenberg**.
- **Severo Ochoa's enzyme** (polynucleotide phosphorylase) helped make RNA for the experiments.

Property	Meaning
Triplet	3 bases = 1 codon → **64 codons**
61 code for amino acids	**3 are stop codons: UAA, UAG, UGA**
Unambiguous	One codon → only **one** amino acid
Degenerate	One amino acid can have **many codons**
Comma-less	Read continuously, with no gaps
Nearly universal	Same in almost all living things
AUG	The **start codon**; also codes for **methionine**

> **Memory trick for the stop codons: UAA** = "**U A**re **A**way", **UAG** = "**U A**re **G**one", **UGA** = "**U G**o **A**way".

Translation: RNA → protein

- **tRNA** is the "**adapter**". One end has the **anticodon** (it reads the mRNA codon); the other end carries the matching **amino acid**. Its 2D shape is a **clover leaf** and its 3D shape is an **inverted L**.
- **Ribosome** is the protein factory. In bacteria, its **23S rRNA** works as an enzyme (a **ribozyme**) that makes the peptide bonds.

1. **Charging:** each tRNA picks up its amino acid (uses ATP).
2. **Initiation:** the ribosome binds the mRNA at the start codon AUG.
3. **Elongation:** amino acids join one by one by peptide bonds.
4. **Termination:** at a stop codon, the protein is released.

- **UTRs** (untranslated regions) are extra parts at both ends of mRNA that are not translated.

Gene regulation: the *lac* operon

> **In simple words:** Bacteria don't waste energy. They make the enzymes for digesting lactose (milk sugar) **only when lactose is present**. It's like a **motion-sensor light** that switches on only when someone walks in.

- Proposed by **Jacob and Monod** in *E. coli*.
- **Regulator gene (i)** makes a **repressor** protein.
- **Structural genes:**
  - **z** → **β-galactosidase** (breaks lactose)
  - **y** → **permease** (lets lactose into the cell)
  - **a** → **transacetylase**
- **Lactose is the inducer.** It switches the operon **on**.
- This is **negative regulation**, because the repressor switches it off.

> **Memory trick: "Z-Y-A → Big Party Tonight"** → **z** = **B**eta-galactosidase, **y** = **P**ermease, **a** = **T**ransacetylase.

Human Genome Project (HGP)

- A huge international project from **1990 to 2003** to read all human DNA.
- **Methods: ESTs** (Expressed Sequence Tags) to find genes that are expressed, and **sequence annotation** (read everything, then find what each part does). Vectors used: **BAC** and **YAC**. Sequencing method by **Frederick Sanger**.

Salient feature	Value
Total bases	**3164.7 million bp**
Average gene size	**3000 bases**
Largest known gene	**Dystrophin** (**2.4 million bases**)
Number of genes	about **30,000**
Same in all humans	**99.9%** of bases
Protein-coding part	**less than 2%**

Salient feature	Value
Most genes	**Chromosome 1** (2968 genes)
Fewest genes	**Y chromosome** (231 genes)
SNPs found	about **1.4 million**
Genes of unknown function	**more than 50%**

> **Did you know?** You are **99.9% identical** in DNA to every other person on Earth. All our differences come from just 0.1%!

DNA fingerprinting

- Developed by **Alec Jeffreys**.
- Uses **VNTRs** (Variable Number of Tandem Repeats): short DNA sequences that repeat a **different number of times in different people**, so everyone's pattern is unique (except identical twins).

1. **Isolate DNA** (from blood, hair, skin).
2. **Cut** it with restriction enzymes.
3. **Separate** the pieces by gel electrophoresis.
4. **Transfer** them to a nylon membrane (**Southern blotting**).
5. **Hybridise** with a labelled VNTR probe.
6. **Autoradiography** shows the band pattern.

- **Uses:** solving crimes (**forensics**), **paternity disputes**, and studying population diversity and evolution.

30-second revision

- DNA: antiparallel; A=T (2 bonds), G≡C (3 bonds); 10 bp per turn, 3.4 nm pitch.
- Human DNA ≈ 2.2 m long; nucleosome = histone octamer + ~200 bp.
- Griffith → transformation; Avery → DNA; Hershey–Chase (^{32}P) → DNA is the genetic material.
- Meselson–Stahl → semi-conservative replication.
- Pol I rRNA, Pol II mRNA, Pol III tRNA. Splicing, capping, tailing.
- Stop codons: UAA, UAG, UGA; start: AUG (Met).
- *lac* operon: z, y, a; lactose = inducer; negative regulation.
- HGP: ~30,000 genes, 99.9% same; DNA fingerprinting uses VNTRs.

Evolution

> **The big idea:** Life on Earth has been **changing slowly over millions of years**. Simple life forms gave rise to the huge variety we see today, including us. **Evolution** explains **how** this happened: mainly through **variation** and **natural selection**.

Earth's history in one timeline

Time ago	Event
~20 billion years	Big Bang: the universe begins
~4.5 billion years	Earth forms
~4 billion years	First life appears
~2000 million years	First cellular life forms
~500 million years	Invertebrates
~350 million years	Jawless fish; lobefins lead to amphibians
~200 million years	Reptiles and dinosaurs
~65 million years	Dinosaurs disappear; mammals spread
~75,000–10,000 years	Modern humans (*Homo sapiens*) spread

Origin of life

- **Spontaneous generation** (life from rotting matter) was an old idea. **Louis Pasteur** disproved it: life comes only from **pre-existing life**.
- **Oparin and Haldane** said the first life came from **non-living organic molecules** (like RNA and proteins) through **chemical evolution**.

Miller's experiment (1953)

Flask with CH_4, H_2, NH_3 and water vapour → heated to 800 °C with electric sparks → **amino acids** formed.

> **In simple words:** Miller **recreated early Earth's atmosphere** in a flask. Sparks acted like **lightning**. Building blocks of life (**amino acids**) formed on their own, which supported the idea of chemical evolution.

> **Memory trick for Miller's gases: "MAHW"** → **M**ethane (CH_4), **A**mmonia (NH_3), **H**ydrogen (H_2), **W**ater vapour. Think "**Ma**ke **H**istory **W**ith gases".

Evidence for evolution

1. Fossils (palaeontology)

- **Fossils** are remains of old organisms preserved in rocks. Different rock layers have different life forms, showing how life **changed over time**.

2. Comparative anatomy

	Homologous organs	**Analogous organs**
Origin / structure	**Same**	**Different**
Function	**Different**	**Same**
Type of evolution	**Divergent** (one ancestor → different uses)	**Convergent** (different ancestors → same use)
Examples	Forelimbs of **whale, bat, cheetah, human**; thorn of *Bougainvillea* and tendril of *Cucurbita*; vertebrate hearts and brains	Wings of **butterfly and bird**; eyes of **octopus and mammals**; flippers of **penguin and dolphin**; **sweet potato (root) and potato (stem)**

> **Memory trick: HOMO**logous = **HOME** is the **same** (same origin), jobs are different. **ANA**logous = **ANA**ther origin, **same** job.

3. Natural selection seen in action

- **Industrial melanism (England):** before factories, **light (white-winged) moths** were more common on light, lichen-covered trees. After industrialisation, smoke **killed the lichens and darkened the tree trunks**, so **dark moths** were better hidden from birds and became more common.
- **Resistance:** use of **herbicides, pesticides and antibiotics** has selected **resistant** weeds, insects and bacteria within a short time.

> **Exam focus:** In industrial melanism, **no moth "turned" dark**. The dark moths were **already there**; they simply **survived better**, so their numbers went up. That is natural selection.

Adaptive radiation

> **In simple words:** One ancestor species spreads into **different habitats** and evolves into **many different species**, each suited to its own place.

- **Darwin's finches** on the **Galápagos Islands**: from **seed-eating** ancestors, finches evolved **different beaks** to eat seeds, insects and more.
- **Australian marsupials** (kangaroo, koala, Tasmanian wolf and more) evolved from **one ancestor** on the same continent.
- When adaptive radiation happens in **different places** and gives similar-looking animals (e.g. **placental wolf** and **Tasmanian wolf**, a marsupial), it is **convergent evolution**.

Theories of evolution

Lamarck	**Darwin**	**Hugo de Vries**
Use and disuse of organs; **acquired characters are inherited**	**Natural selection**: "survival of the fittest"	**Mutation theory**

Lamarck	Darwin	Hugo de Vries
Giraffes stretched their necks to reach leaves, and **passed on** long necks	Giraffes with longer necks **survived better** and had more babies	Big, sudden changes (**saltation**) create new species
Rejected	Accepted (with modern genetics)	Worked on **evening primrose** (*Oenothera lamarckiana*)

Darwin's natural selection, step by step

1. **Overproduction:** organisms produce many offspring.
2. **Limited resources → struggle for existence**.
3. **Variation:** no two individuals are the same.
4. **Survival of the fittest:** better-suited individuals survive.
5. They **reproduce more** and pass on useful traits.
6. Over many generations → **new species**.

- **Fitness** in Darwin's sense means **reproductive fitness**: leaving **more offspring**, not being the strongest!
- **Alfred Wallace**, working in the **Malay Archipelago**, reached the same conclusion.

> **Common mistake:** Darwin's variations are **small and directional**; de Vries' mutations are **large, sudden and random**. Don't mix them up!

Hardy–Weinberg principle

> **In simple words:** In a population, **allele frequencies stay the same generation after generation**, unless something disturbs them. This balance is called **genetic equilibrium**.

- If **p** = frequency of allele A and **q** = frequency of allele a:
  - $\mathbf{p + q = 1}$
  - $\mathbf{p^2 + 2pq + q^2 = 1}$ (p^2 = AA, $2pq$ = Aa, q^2 = aa)

5 factors that disturb the balance:

1. Gene migration (gene flow)
2. Genetic drift (chance changes)
3. Mutation
4. Genetic recombination
5. Natural selection

> **Memory trick: "My Great Man Ran Now"** → **M**igration, **G**enetic drift, **M**utation, **R**ecombination, **N**atural selection.

- **Founder effect:** a small group moves to a new place. By chance, its allele frequencies are different from the original population, so the new group can become a new species.

Three types of natural selection

Type	Which individuals win?	Result
Stabilising	The **average** ones	More individuals near the average
Directional	**One extreme**	The average **shifts** to one side
Disruptive	**Both extremes**	**Two peaks** form

A quick story of plant and animal evolution

- **Plants:** early land plants (like *Zosterophyllum*, *Psilophyton*) → **ferns** and **seed ferns** → **gymnosperms** → **angiosperms** (flowering plants).
- **Animals: jawless fish** (~350 mya) → **lobefins** (like the **coelacanth**, the ancestor of amphibians) → **amphibians** → **reptiles** → **dinosaurs**, **birds** and **mammals**.

> **Did you know?** The **coelacanth** was thought to have died out long ago, until fishermen caught a **living one in South Africa in 1938**!

Human evolution

Hominid	Time	Key features
Dryopithecus and *Ramapithecus*	~15 mya	Hairy, walked like gorillas; *Ramapithecus* was more man-like
Australopithecus	~2 mya	East African grasslands; stone weapons; ate fruit
Homo habilis	~2 mya	First human-like being; brain **650–800 cc**; probably did not eat meat
Homo erectus	~1.5 mya	Brain **~900 cc**; probably ate meat
Neanderthal man	1,00,000–40,000 years ago	Brain **~1400 cc**; buried the dead
Homo sapiens	Arose in Africa	Cave art ~18,000 years ago; farming ~10,000 years ago

> **Memory trick for brain size: "650 → 900 → 1400"**. The brain **grows** as we go from *Homo habilis* → *Homo erectus* → Neanderthal.

> **Common mistake:** *Homo habilis* **probably did not eat meat**; *Homo erectus* **probably ate meat**. Read the question carefully!

30-second revision

- Miller: CH_4, H_2, NH_3, water vapour + sparks → amino acids.
- Homologous = same origin, divergent; analogous = same function, convergent.
- Industrial melanism: dark moths survived better after pollution.
- Darwin's finches and Australian marsupials = adaptive radiation.

- Fitness = reproductive fitness.
- Hardy–Weinberg: $p^2 + 2pq + q^2 = 1$; 5 disturbing factors (MGMRN).
- Brain size: habilis 650–800 → erectus 900 → Neanderthal 1400 cc.

Human Health and Disease

The big idea: Health means being well in **body, mind and social life**, not just "not being sick". This chapter covers the **germs that make us sick**, how our **immune system** fights them, and serious problems like **AIDS, cancer and drug abuse**.

Common diseases in humans

How to study this table: for each disease, remember **4 things**: the **germ**, **how it spreads**, the **main symptom** and one **special fact**.

Disease	Germ (pathogen)	How it spreads	Main symptoms and special facts
Typhoid	*Salmonella typhi* (bacterium)	Contaminated **food and water**	High fever (39–40 °C), weakness, stomach pain. **Widal test** confirms it. Famous carrier: "**Typhoid Mary**"
Pneumonia	*Streptococcus pneumoniae*, *Haemophilus influenzae* (bacteria)	**Droplets** from coughs and sneezes; sharing glasses	**Alveoli fill with fluid**, so breathing is hard. In severe cases, **lips and fingernails turn grey to bluish**
Common cold	**Rhinoviruses**	Droplets; touching contaminated things	Blocked nose, sore throat, cough. Lasts **3–7 days**. Affects the nose and airways, **not the lungs**
Malaria	*Plasmodium* (protozoan): *P. vivax*, *P. malariae*, ***P. falciparum*** (most dangerous)	Bite of the **female *Anopheles*** mosquito	**Chills and high fever every 3–4 days**
Amoebiasis	*Entamoeba histolytica* (protozoan)	**Houseflies** carry it to food and water	Constipation, cramps, stools with **mucus and blood**
Ascariasis	*Ascaris* (roundworm)	Eggs in **soil, water, vegetables**	Internal bleeding, anaemia, **blocked intestine**
Filariasis (elephantiasis)	*Wuchereria bancrofti*, *W. malayi* (worms)	Bite of the **female *Culex*** mosquito	**Swelling of the legs** (and genital organs)
Ringworm	*Microsporum*, *Trichophyton*, *Epidermophyton* (**fungi**)	Towels, combs, soil	**Dry, scaly, itchy patches** on skin, nails, scalp. Grows in warm, **moist** body folds

Common mistake: Ringworm is not caused by a worm! It is caused by a **fungus**. And the **common cold** is a virus, so antibiotics don't cure it.

Memory trick for mosquitoes:

- **A**nopheles → m**A**laria
- **C**ulex → filariasis (think "**C**urved, swollen legs")
- Aedes → dengue and chikungunya

The malaria parasite's life cycle

1. An infected female *Anopheles* bites → **sporozoites** enter the blood.
2. Sporozoites reach the **liver** and multiply.
3. They then attack **red blood cells** and multiply there.
4. RBCs burst and release **haemozoin** → chills and high fever.
5. Some parasites become **gametocytes** (male and female).
6. A mosquito bites the patient and sucks up the gametocytes.
7. **Fertilisation** happens in the mosquito's stomach.
8. New sporozoites form and move to the mosquito's **salivary glands**, ready to infect the next person.

- **Humans** are the **intermediate host** (asexual reproduction happens in us).
- The **mosquito** is the **definitive host** (sexual reproduction happens there).

> **Exam focus:** The toxin that causes the chills and fever in malaria is **haemozoin**. The **infective stage** for humans is the **sporozoite**.

Preventing infectious diseases

- **Personal hygiene:** clean body, clean drinking water, clean food.
- **Public hygiene:** proper disposal of waste and sewage.
- **Control mosquitoes:** no **stagnant water**; spray insecticides; use **mosquito nets** and screens.
- Put the fish ***Gambusia*** in ponds. It **eats mosquito larvae**.
- **Vaccines** and **antibiotics**.

Immunity: the body's army

- **Innate immunity** (inborn, non-specific):
  - Physical barrier: skin, mucus
  - Physiological barrier: stomach acid, saliva, tears
  - Cellular barrier: neutrophils, monocytes, natural killer cells, macrophages
  - Cytokine barrier: interferons
- **Acquired immunity** (specific, has memory):
  - Humoral: **B cells** make antibodies
  - Cell-mediated: **T cells** attack directly

Innate immunity: 4 barriers

> **Memory trick: "PPCC"** → **P**hysical, **P**hysiological, **C**ellular, **C**ytokine.

- **Physical barrier:** skin, and the **mucus** lining of the nose, gut and airways, which traps germs.
- **Physiological barrier: stomach acid**, saliva and **tears** kill germs.
- **Cellular barrier:** white blood cells like **PMNL-neutrophils**, **monocytes**, **natural killer cells** and **macrophages** eat or kill germs.
- **Cytokine barrier:** virus-infected cells release **interferons**, which **protect nearby cells** from the virus.

Acquired immunity

- It is **specific** (one germ at a time) and has **memory**.
- **Primary response:** the first time we meet a germ, the response is **slow and weak**.
- **Secondary response:** the next time, the response is **fast and strong**, thanks to memory cells. This is also called the **anamnestic response**.

B-lymphocytes	T-lymphocytes
Make **antibodies** that float in the blood	**Don't** make antibodies; they help B cells and kill infected cells
Humoral immunity	**Cell-mediated immunity (CMI)**
	Responsible for **graft (organ transplant) rejection**

Structure of an antibody

- Each antibody has **4 chains**: **2 heavy + 2 light**, written as H_2L_2.
- Types of antibodies: **IgA, IgM, IgE, IgG** (and IgD).

Active vs passive immunity

Active immunity	Passive immunity
Your body **makes its own** antibodies	**Ready-made** antibodies are given
After an infection or a **vaccine**	**Colostrum** (mother's first milk), antibodies from mother to baby through the placenta, **anti-tetanus** injection, **snake anti-venom**
Slow to start, **long-lasting**	**Fast**, but **short-lived**

> **In simple words: vaccination.** A vaccine contains a **weak or dead germ** (or part of it). The body "practises" on it and makes **memory cells**. When the real germ comes, the body is **ready**. **Hepatitis B vaccine** is made in **yeast** using **recombinant DNA technology**.

When immunity goes wrong

- **Allergy:** the body **over-reacts** to harmless things (**allergens**) like dust, pollen or animal hair.
  - Involves **IgE** antibodies and chemicals like **histamine** and **serotonin** from **mast cells**.
  - Treated with **antihistamines, adrenaline and steroids**.
- **Autoimmunity:** the body **attacks its own cells**. Example: **rheumatoid arthritis**.

Lymphoid organs

Primary lymphoid organs	Secondary lymphoid organs
Where lymphocytes are **made and mature**	Where lymphocytes **meet germs** and multiply
Bone marrow and **thymus**	**Spleen, lymph nodes, tonsils, Peyer's patches** (in the small intestine) and **appendix**

- **MALT** (mucosa-associated lymphoid tissue) makes up about **50%** of all lymphoid tissue in the body.

AIDS

- **AIDS** = **A**cquired **I**mmuno **D**eficiency **S**yndrome. It is caused by **HIV**, a **retrovirus** (it has **RNA** as its genetic material).
- **Spreads through:** unsafe sex, **infected blood**, **sharing needles**, and from an **infected mother to her baby**.
- **Does NOT spread by:** touching, hugging, sharing food or mosquito bites.

How HIV destroys the immune system

1. HIV enters the body and gets into a **macrophage**.
2. **Reverse transcriptase** makes viral DNA from the viral RNA.
3. The viral DNA joins the host DNA; the macrophage keeps making new viruses (an "HIV factory").
4. The new viruses attack **helper T-cells**.
5. The number of helper T-cells keeps falling.
6. The immune system fails → infections such as TB (*Mycobacterium*) and *Toxoplasma*.

- **Test: ELISA** (enzyme-linked immunosorbent assay).
- **Treatment: anti-retroviral drugs** only **slow down** the disease; they **don't cure** it.
- **Awareness: NACO** (National AIDS Control Organisation) and NGOs educate people. **World AIDS Day is 1 December**.

Cancer

> **In simple words:** Normally, cells stop dividing when they touch other cells (**contact inhibition**). Cancer cells **lose this control** and keep dividing, forming a lump called a **tumour**.

Benign tumour	**Malignant tumour**
Stays in **one place**	**Spreads** to other body parts (**metastasis**)
Usually less harmful	**Dangerous**: this is what we call cancer

- **Causes (carcinogens):**
  - **Physical: X-rays, gamma rays** (ionising radiation) and **UV rays** (non-ionising)
  - **Chemical: tobacco smoke** and other chemicals
  - **Biological: oncogenic viruses**. Genes called **proto-oncogenes** (c-onc) in normal cells can also turn into cancer genes.
- **Detection: biopsy**, blood tests, **X-ray, CT scan, MRI**, and antibodies against cancer antigens.
- **Treatment:** surgery, **radiation therapy**, **chemotherapy** and **immunotherapy** (e.g. **α-interferon**, which boosts the immune system).

Drugs and alcohol abuse

Drug type	**Examples**	**Source**	**Effect**
Opioids	**Heroin ("smack")** = diacetylmorphine	Latex of the **poppy plant** (*Papaver somniferum*)	**Depressant**: slows body functions

Drug type	Examples	Source	Effect
Cannabinoids	Marijuana, **hashish, charas, ganja**	***Cannabis sativa***	Affect the **heart and blood vessels**
Coca alkaloid	**Cocaine** ("coke", "crack")	***Erythroxylum coca***	Interferes with **dopamine**; causes excitement, then **hallucinations**
Hallucinogens	—	***Datura*, *Atropa belladonna***	Hallucinations

- **Barbiturates, amphetamines, benzodiazepines** and **LSD** are sometimes used as medicines, but are often **misused**.
- **Tobacco:** contains **nicotine**, which makes the adrenal gland release **adrenaline**, raising **blood pressure and heart rate**. Smoking increases **carbon monoxide** in the blood, so less oxygen reaches the body.

Why teens are at risk, and how to stay safe

- **Adolescence** (about **12–18 years**) is a time of curiosity, stress and **peer pressure**.
- **Warning signs:** falling grades, skipping school, losing interest in hobbies, mood swings, changes in sleep and eating.
- **How to prevent it:**
    1. Avoid **undue peer pressure**. It's OK to say **NO**.
    2. **Education and counselling**.
    3. Talk to **parents and friends**.
    4. Watch for **danger signs**.
    5. Get **professional and medical help**.

30-second revision

- Typhoid → *Salmonella typhi*, Widal test. Malaria → *Plasmodium*, female *Anopheles*, haemozoin.
- Filariasis → *Wuchereria*, *Culex*. Ringworm → **fungi**.
- *Gambusia* fish eats mosquito larvae.
- Innate barriers: physical, physiological, cellular, cytokine (PPCC).
- Antibody = H_2L_2. B cells → antibodies; T cells → CMI and graft rejection.
- HIV → macrophage → helper T cells ↓. ELISA test. 1 December.
- Cancer: contact inhibition lost; malignant tumours spread (metastasis).

Microbes in Human Welfare

The big idea: Not all microbes are "bad germs"! Many microbes are our **helpers**: they make **curd, bread, cheese, medicines and fuel**, clean up **sewage**, and act as natural **pesticides and fertilisers**.

Where microbes help us

Useful microbes help us in six areas: **household products**, **industrial products**, **sewage treatment**, **biogas production**, **biocontrol** and **biofertilisers**.

1. Microbes in household products

Product	Microbe	What it does
Curd	***Lactobacillus*** and other **lactic acid bacteria (LAB)**	Make **lactic acid**, which **curdles milk**. Also increase **vitamin B_{12}** and kill harmful germs in the stomach
Idli / dosa batter	**Bacteria**	Fermentation makes **CO_2**, so the batter becomes **puffy**
Bread	**Baker's yeast** (*Saccharomyces cerevisiae*)	Fermentation makes CO_2, so the dough **rises**
Toddy	Microbes	A traditional drink from southern India, made by **fermenting palm sap**
Swiss cheese	***Propionibacterium sharmanii***	Makes lots of **CO_2**, which creates the **big holes**
Roquefort cheese	**Fungi**	Ripen the cheese and give it flavour

Memory trick: "**Swiss** cheese has **S**o many holes" → **P**ropionibacterium **sh**armanii = "**P**uts **sh**apes (holes)".

2. Microbes in industry

Fermented drinks

- **Brewer's yeast** (*Saccharomyces cerevisiae*) ferments fruit juices and grains.
- **Without distillation: wine and beer**.
- **With distillation: whisky, brandy and rum** (they have more alcohol).

Antibiotics

Did you know? Penicillin, the **first antibiotic**, was discovered **by accident**! **Alexander Fleming** noticed that a mould (***Penicillium notatum***) growing in his dish **stopped *Staphylococcus* bacteria** from growing. Later, **Ernest Chain and Howard Florey** showed how powerful it was, and it saved many soldiers in **World War II**. All three won the **Nobel Prize in 1945**.

- **Antibiotic** means "against life". Antibiotics are chemicals made by microbes that **kill or stop** disease-causing microbes.

Chemicals, enzymes and medicines

Product	Microbe	Type	Use
Citric acid	***Aspergillus niger***	Fungus	Food flavour
Acetic acid (vinegar)	***Acetobacter aceti***	Bacterium	Vinegar
Butyric acid	***Clostridium butylicum***	Bacterium	—
Lactic acid	***Lactobacillus***	Bacterium	—
Ethanol	***Saccharomyces cerevisiae***	Yeast	Alcohol, fuel
Lipases	Microbes	Enzyme	In **detergents**: remove **oily stains**
Pectinases, proteases	Microbes	Enzyme	Make bottled **fruit juices clear**
Streptokinase	***Streptococcus***	Bacterium	**"Clot buster"**: removes **blood clots** in heart-attack patients
Cyclosporin A	***Trichoderma polysporum***	Fungus	**Immunosuppressant** in **organ transplants**
Statins	***Monascus purpureus***	Yeast	**Lower blood cholesterol**

Memory tricks:

- **A**spergillus → **A**cid (citric)
- **Ace**tobacter → **Ace**tic acid
- **Butyl**icum → **Butyr**ic acid
- **Strepto**kinase → breaks clots like a "**stroke** saver"
- **S**tatins → **S**lash cholesterol (from **M**onascus → "**M**inus fat")

3. Microbes in sewage treatment

In simple words: Sewage (dirty water from homes and cities) is full of **organic waste** and germs. **Sewage treatment plants (STPs)** use **microbes** to eat up this waste and make the water safe to release into rivers.

1. **Primary treatment (physical):** filtering and settling remove grit, soil and pebbles. The settled solids form **primary sludge**; the liquid on top is the **primary effluent**.
2. **Secondary treatment (biological):** the effluent is aerated. Aerobic microbes grow as **flocs** and eat the organic matter, so the **BOD falls**.
3. The flocs settle as **activated sludge**:
   - a small part goes back into the aeration tank as **inoculum**;
   - most goes to **anaerobic sludge digesters**, where bacteria produce **biogas**.
4. The treated water is released into rivers.

- **Flocs** are clumps of **bacteria + fungal threads**, like tiny "cleaning teams".
- **BOD (Biochemical Oxygen Demand):** the amount of **oxygen** that microbes would use to break down all the organic matter in **one litre** of water.

> **Exam focus: High BOD = more pollution.** Dirty water has lots of organic matter, so microbes need lots of oxygen to break it down. Secondary treatment continues until BOD is low.

- The Ministry of Environment and Forests started the **Ganga Action Plan** and the **Yamuna Action Plan** to save these rivers from pollution.

4. Microbes in biogas production

- **Biogas** is mostly **methane (CH_4)**, with some CO_2 and H_2S. It burns well and is used for **cooking and lighting**.
- It is made by **methanogens** (e.g. ***Methanobacterium***). These bacteria live **without oxygen** (anaerobic).
- They are found in **cow dung (gobar)** and in the **rumen** (stomach) of cattle, where they help **digest cellulose**.

Cow dung slurry → digester tank (no oxygen) → methanogens act → **biogas** (mainly CH_4) for cooking. The spent slurry is used as **fertiliser**.

- The biogas technology in India was developed mainly by **IARI** (Indian Agricultural Research Institute) and **KVIC** (Khadi and Village Industries Commission).

> **Memory trick: Methano**bacterium makes **methane**. Cow dung is **gobar**, so a biogas plant is also called a **gobar gas** plant.

5. Microbes as biocontrol agents

> **In simple words:** Instead of spraying harmful chemicals, we use **living things to control pests**. This is safer for the environment.

Biocontrol agent	Controls
Ladybird beetle	**Aphids**
Dragonflies	**Mosquitoes**
***Bacillus thuringiensis* (Bt)**	**Caterpillars** (butterfly larvae). Its toxin kills them in their gut
Trichoderma (fungus)	**Plant disease germs** (pathogens) in the soil
Baculoviruses (*Nucleopolyhedrovirus*)	**Insects** and other arthropods. **Species-specific**, so they don't harm useful insects

- **IPM (Integrated Pest Management):** using many **eco-friendly** methods together instead of only chemicals.

6. Microbes as biofertilisers

Group	Examples	How they help
Symbiotic bacteria	***Rhizobium*** (in **root nodules** of **legumes** like peas and beans)	**Fix nitrogen** from the air
Free-living bacteria	***Azospirillum***, ***Azotobacter*** (in soil)	**Fix nitrogen**
Fungi (mycorrhiza)	***Glomus***	Absorb **phosphorus** for the plant; protect roots from germs; help survive **drought and salt**

Group	Examples	How they help
Cyanobacteria (blue-green algae)	***Anabaena, Nostoc, Oscillatoria***	**Fix nitrogen**, very important in **rice (paddy) fields**

> **Memory trick:** "**Rhizo**bium" = **root** (rhizo means root) → lives in **root** nodules. **Azo**tobacter and **Azo**spirillum → "**Azo**te" is the old French name for **nitrogen**!

30-second revision

- Curd → *Lactobacillus* (LAB), vitamin B_{12} ↑. Swiss cheese holes → *Propionibacterium sharmanii*.
- Penicillin → Fleming (*Penicillium notatum*); Chain and Florey.
- Citric acid → *Aspergillus niger*; statins → *Monascus*; cyclosporin A → *Trichoderma*; streptokinase → clot buster.
- Sewage: primary (physical) → secondary (biological, flocs) → activated sludge → biogas. High BOD = high pollution.
- Biogas = methane, made by methanogens (*Methanobacterium*); IARI and KVIC.
- Biocontrol: Bt, *Trichoderma*, baculoviruses, ladybird. Biofertilisers: *Rhizobium*, *Azotobacter*, *Glomus*, *Anabaena*.

Biotechnology: Principles and Processes

> **The big idea: Biotechnology** uses living things (or their parts) to make useful products. The star technique is **genetic engineering**: we **cut** a useful gene out of one organism and **paste** it into another, like **cut-copy-paste on a computer**. For example, the human insulin gene is put into bacteria, which then make insulin for diabetic patients.

Two core techniques

Technique	In simple words
1. Genetic engineering	**Changing DNA/RNA**: putting new genes into an organism
2. Bioprocess engineering	Growing **huge numbers of microbes/cells** in **sterile** (germ-free) conditions to make the product

- **EFB (European Federation of Biotechnology)** definition: "the integration of natural science and organisms, cells, parts thereof, and molecular analogues for products and services."

> **Did you know?** The **first recombinant DNA** was made in **1972** by **Stanley Cohen and Herbert Boyer**. They joined an **antibiotic-resistance gene** to a **plasmid of *Salmonella typhimurium***.

The 3 basic steps of genetic modification

1. Identify the DNA with the useful gene.
2. Introduce it into a host organism.
3. Keep the new DNA in the host and pass it on to the host's offspring.

The toolkit

- **Restriction enzymes:** "molecular scissors"
- **DNA ligase:** "molecular glue"
- **Vectors:** carriers such as plasmids and bacteriophages
- **Competent host:** e.g. *E. coli*

1. Restriction enzymes: molecular scissors

- They **cut DNA at specific sequences**.
- The first one discovered was **Hind II**. It always cuts at a particular **6 base-pair** sequence.
- **Exonucleases** cut nucleotides from the **ends** of DNA. **Endonucleases** cut **inside** the DNA at specific points.

How they are named: EcoRI

Letter	Meaning
E	Genus: ***E**scherichia*
co	Species: ***co**li*
R	Strain: **R**Y13

Letter	Meaning
I	The **1st** enzyme found in that strain (Roman numeral)

Palindromes: restriction enzymes recognise **palindromic** sequences. These read the **same on both strands** in the 5'→3' direction (like the words "MADAM" or "RACECAR").

```
EcoRI site:   5' — G ↓A A T T C — 3'
              3' — C T T A A↑ G — 5'

After cutting:
              5' — G          A A T T C — 3'
              3' — C T T A A          G — 5'
                   └── sticky ends ──┘
```

- EcoRI cuts **between G and A** on each strand, leaving short single-stranded overhangs called **sticky ends**.
- Sticky ends easily **stick** to matching ends from the same enzyme. **DNA ligase** then seals them.

> **Memory trick:** A **palindrome** reads the same both ways: "**MALAYALAM**". The EcoRI site **GAATTC** read 5'→3' on the other strand is also **GAATTC**!

2. Gel electrophoresis: sorting DNA pieces by size

1. DNA pieces are placed in wells of an **agarose gel**.
2. An electric current is switched on. DNA (negative) moves towards the **anode** (+).
3. **Small pieces move fast and far**; big pieces move slowly.
4. The gel is stained with **ethidium bromide** and viewed under UV light → orange bands.
5. The band is cut out (**elution**) to get the pure DNA piece.

- **Agarose** comes from **seaweed**.
- DNA is **negatively charged** (because of the phosphate groups), so it moves towards the **positive electrode (anode)**.

> **Memory trick:** "**Small** is **speedy**": smaller DNA pieces travel **farther** through the gel. And "**DNA** is **N**egative, runs to **A**node" (the letters **N** and **A** are both in DNA).

3. Cloning vectors: the delivery trucks

A **vector** carries the foreign gene into the host. Usually a **plasmid** (small circular DNA in bacteria) or a **bacteriophage** (a virus that infects bacteria).

What a good vector needs:

Feature	Why
Origin of replication (ori)	Where copying starts. Controls the **copy number**
Selectable marker	Usually an **antibiotic-resistance gene** (ampicillin, tetracycline, kanamycin, chloramphenicol), to find the cells that took the vector

Feature	Why
Cloning sites	**One** recognition site for common restriction enzymes, so the vector is cut in only one place
Small size	Easier to handle and transfer

Finding the right cells: insertional inactivation

1. The foreign gene is inserted into the vector's ***lacZ*** gene, which breaks it (**insertional inactivation**).
2. Bacteria are grown on a plate with a chromogenic substrate.
3. **White (colourless) colonies** = recombinants (lacZ broken, no colour).
4. **Blue colonies** = non-recombinants (lacZ works and makes the blue colour).

> **Memory trick:** "**White = Winner**". The white colonies have the new gene.

> **Common mistake:** In pBR322, inserting a gene into the **tetracycline** gene (at BamHI) makes cells **lose tetracycline resistance**, but they **keep ampicillin resistance**. The recombinants **grow on ampicillin but not on tetracycline**.

Vectors for plants and animals

- ***Agrobacterium tumefaciens*** causes crown gall disease in plants. Its **Ti plasmid** is **disarmed** (made harmless) and used to carry useful genes **into plants**.
- **Retroviruses** can be **disarmed** and used to carry genes into **animal cells**.

4. Competent host: getting DNA into cells

DNA can't cross cell membranes on its own (it is **hydrophilic**), so we make cells "**competent**":

Method	How
Heat shock	Treat bacteria with **calcium (Ca^{2+})** → put on **ice** → **42 °C** for a moment → back on **ice**
Microinjection	Inject DNA directly into the **nucleus** of an animal cell with a tiny needle
Biolistics (gene gun)	Shoot **gold or tungsten** particles coated with DNA into **plant** cells
Disarmed pathogens	Let *Agrobacterium* or a retrovirus deliver the gene

The complete process of recombinant DNA technology

1. **Isolate DNA:** break the cells with enzymes, remove RNA and protein, add chilled ethanol → DNA threads appear.
2. **Cut DNA** with restriction enzymes; check by gel electrophoresis.
3. **Amplify** the gene with PCR (make millions of copies).
4. **Ligate:** join the gene into a vector with DNA ligase.
5. **Insert** the recombinant DNA into a host; select the transformants.
6. **Grow** the host on a large scale in bioreactors → product.
7. **Downstream processing:** purify, add preservatives, test.

Step 1 detail: breaking open cells

Cell type	Enzyme to break the wall
Bacteria	**Lysozyme**
Plants	**Cellulase**
Fungi	**Chitinase**

- Then **RNA** is removed with **ribonuclease** and **proteins** with **protease**.
- **Chilled ethanol** makes the pure DNA come out as fine **threads**, which can be lifted out (**spooling**).

> **Memory trick:** "**B**acteria **L**ove **L**ysozyme, **P**lants **C**hoose **C**ellulase, **F**ungi **C**hoose **Ch**itinase".

Step 3 detail: PCR, the DNA photocopier

PCR = Polymerase Chain Reaction. It makes **millions of copies** of a gene in a few hours. Each cycle has 3 steps:

1. **Denaturation:** heating (~94 °C) separates the DNA strands.
2. **Annealing:** on cooling, the primers bind.
3. **Extension:** Taq polymerase builds the new strands.
4. The cycle is repeated about 30 times.

- **Taq polymerase** comes from the bacterium ***Thermus aquaticus***, which lives in **hot springs**. The enzyme **doesn't get destroyed by heat**.
- **Primers** are short DNA pieces that mark **where to start** copying.
- **Copies double every cycle**: after *n* cycles there are about $\mathbf{2^n}$ copies. About 30 cycles give about **1 billion** copies!

Cycle	0	1	2	3	4	5	10	30
Copies	1	2	4	8	16	32	1,024	~1 billion

> **Memory trick: "Heat–Stick–Build"** → **D**enaturation, **A**nnealing, **E**xtension (**DAE**).

Step 6 detail: bioreactors

- **Bioreactors** are large tanks (**100–1000 litres**) where the host cells grow and make the product.
- The most common type is the **stirred-tank bioreactor**. It has:
  - an **agitator** (stirrer) to mix,
  - an **oxygen delivery system** (**sparger**, which bubbles air),
  - a **foam control** system,
  - **temperature and pH control**,
  - a **sampling port**.
- **Continuous culture:** used medium is drained out and fresh medium added, which keeps the cells in their most active **log (exponential) phase**.

Step 7: downstream processing

- **Separation and purification** of the product.

- **Formulation** with preservatives.
- **Clinical trials** (for medicines) and **quality control** testing.

30-second revision

- First rDNA: Cohen and Boyer (1972), *Salmonella typhimurium* plasmid.
- EcoRI = *E. coli* RY13, first enzyme. Palindrome GAATTC, sticky ends.
- DNA runs to the **anode**; small pieces go farther; ethidium bromide + UV; elution.
- Vector needs ori, selectable marker, cloning sites. pBR322: ampR, tetR.
- Blue–white selection: **white = recombinant** (lacZ broken).
- Ti plasmid of *Agrobacterium* for plants; Ca^{2+} + heat shock for bacteria.
- PCR: denature → anneal → extend (Taq polymerase); 2^n copies.
- Stirred-tank bioreactor; downstream processing.

Biotechnology and its Applications

The big idea: In Chapter 9 we learnt **how** to cut and paste genes. This chapter shows **what we do with it**: **pest-proof crops**, **human insulin**, **gene therapy**, early **disease detection** and **transgenic animals**, plus the **ethical questions** it raises.

Biotechnology in agriculture

Three ways to grow more food:

1. **Agrochemical-based agriculture** (fertilisers and pesticides)
2. **Organic agriculture**
3. **Genetically engineered crop-based agriculture** (GM crops)

What are GMOs?

In simple words: A **GMO** (Genetically Modified Organism) is a plant, animal or microbe whose **genes have been changed** by genetic engineering. Plants, bacteria, fungi and animals can all be GMOs.

Benefits of GM plants:

- They tolerate stresses such as cold, drought, salt and heat.
- They need fewer chemical pesticides.
- They reduce losses after harvest.
- They use soil minerals more efficiently.
- They can give more nutritious food, e.g. **Golden Rice** (rich in vitamin A).

Did you know? Golden Rice is **yellow-golden** because it is rich in **β-carotene**, which our body turns into **vitamin A**. It was made to fight vitamin A deficiency, which causes night blindness.

Bt cotton: a plant that protects itself

- **Bt** = ***Bacillus thuringiensis***, a soil bacterium that makes a protein **toxic to certain insects**.
- The Bt gene was put into cotton, so the plant makes the toxin itself and **kills pests** that eat it.

How the Bt toxin kills insects

1. The bacterium makes the toxin as an inactive **protoxin** (crystal protein).
2. An insect eats the plant.
3. The **alkaline pH** of the insect gut dissolves the crystals.
4. The protoxin becomes an **active toxin**.
5. The toxin binds the midgut lining and makes **pores**.
6. The cells swell and burst → the insect dies.

> **Exam focus: why doesn't the toxin kill the bacterium itself?** Because the bacterium stores it as an **inactive protoxin**. It only becomes active in the **alkaline gut of the insect**.

Bt genes (called *cry* genes):

Gene	Kills
cryIAc and ***cryIIAb***	**Cotton bollworms**
cryIAb	**Corn borer**

> **Memory trick:** "***cry*** genes make pests **cry**". **Ab** → **A**ttack **b**orer (corn borer).

Pest-resistant plants using RNA interference (RNAi)

- **Problem:** the nematode (roundworm) ***Meloidogyne incognita*** attacks **tobacco roots** and reduces the crop.
- **Solution: RNA interference (RNAi)**, a natural defence method found in all eukaryotes.

1. Nematode-specific genes are put into tobacco using *Agrobacterium*.
2. The plant makes both **sense and antisense RNA**.
3. These pair up to form **double-stranded RNA (dsRNA)**.
4. When the nematode feeds, the dsRNA **silences** its matching mRNA.
5. The needed protein is not made → the nematode dies.

> **In simple words:** RNAi is like **putting "mute" on one specific gene**. The dsRNA finds the matching mRNA and stops it from being used.

Biotechnology in medicine

1. Genetically engineered insulin

- **Insulin** controls blood sugar. Diabetic patients need insulin injections.
- Earlier, insulin came from the **pancreas of slaughtered cattle and pigs**, which caused **allergies** in some patients.
- **Insulin structure:** 2 short chains, **A and B**, joined by **disulphide bridges**.
- In the body it is first made as **pro-insulin**, which has an extra piece called the **C-peptide**. The C-peptide is removed to make mature insulin.

1. DNA sequences for **chain A and chain B** are made separately.
2. Each is put into an *E. coli* plasmid.
3. *E. coli* makes chain A and chain B.
4. The chains are extracted and joined by **disulphide (S–S) bonds**.
5. Result: human insulin (**Humulin**).

- Made in **1983** by the US company **Eli Lilly**.

> **Exam focus:** Eli Lilly made chains **A and B separately** so there was **no C-peptide** to remove later.

2. Gene therapy

> **In simple words:** Gene therapy **fixes a faulty gene** by putting a **correct gene** into a person's cells. It's like **replacing a broken part**.

- **First used in 1990** on a **4-year-old girl** with **ADA (adenosine deaminase) deficiency**. ADA is an enzyme needed for the **immune system** to work.

1. Lymphocytes are taken from the patient's blood.
2. They are grown in the lab.
3. A working **ADA gene** is inserted using a **retrovirus vector**.
4. The cells are put back into the patient.
5. This is **not permanent**: lymphocytes die, so the treatment must be repeated.

- **Permanent cure:** put the ADA gene into **bone marrow cells at an early embryonic stage**.
- Other treatments for ADA deficiency: **bone marrow transplant** and **enzyme replacement therapy**.

3. Molecular diagnosis

- Normal tests find a disease only **after symptoms** appear, when there are many germs.
- **New techniques detect it early**, when there are very few germs or small changes:
    - **PCR:** copies tiny amounts of germ DNA until it can be detected (e.g. HIV in suspected AIDS patients, cancer gene mutations).
    - **ELISA:** based on **antigen–antibody** reactions (e.g. HIV test).
    - **Probes + autoradiography:** a **radioactive single-stranded DNA/RNA probe** sticks to the matching DNA. A **mutated gene won't show up** on the photographic film because the probe can't bind to it.

Transgenic animals

Transgenic animals have a **foreign gene** added to their DNA. More than **95%** of all transgenic animals are **mice**.

Use	Example
Study normal physiology and development	How genes control growth (e.g. insulin-like growth factor)
Study disease	Models for cancer, cystic fibrosis, rheumatoid arthritis, Alzheimer's
Make biological products	**α-1-antitrypsin** to treat **emphysema** (a lung disease)
Test vaccine safety	**Transgenic mice** test the **polio vaccine**
Test chemical safety	Toxicity testing

> **Did you know? Rosie**, the **first transgenic cow** (**1997**), gave milk with **human α-lactalbumin** protein (**2.4 g per litre**). This milk is **more balanced for human babies** than normal cow's milk!

Ethical issues

- **GEAC (Genetic Engineering Approval Committee):** an Indian government body that checks whether **GM research is valid** and whether **GM organisms are safe** for public use.

Biopiracy

> **In simple words: Biopiracy** is when big companies from rich countries use a poor country's **plants and traditional knowledge** for profit, **without permission or payment**.

- **Basmati rice:** India has **27 documented varieties** of Basmati. In **1997**, an American company (**RiceTec**) got a **patent** on Basmati rice and grain in the USA.
- **Turmeric** and **neem** were also patented abroad, even though Indians had used them for centuries.
- India has about **2,00,000 varieties of rice** alone.
- India's Parliament passed the **second amendment of the Indian Patents Bill** to stop this.

> **Memory trick for biopiracy examples: "BTN"** → **B**asmati, **T**urmeric, **N**eem. Think "**B**ig **T**heft of **N**ature".

30-second revision

- GM crops: stress-tolerant, fewer pesticides, Golden Rice (vitamin A).
- Bt toxin: inactive protoxin → alkaline gut → pores → death. *cryIAc*/*cryIIAb* → bollworm; *cryIAb* → corn borer.
- RNAi: dsRNA silences *Meloidogyne incognita* mRNA in tobacco.
- Insulin: chains A and B made separately in *E. coli* (Eli Lilly, 1983).
- Gene therapy: ADA deficiency (1990), lymphocytes + retrovirus.
- Molecular diagnosis: PCR, ELISA, probes. Rosie (1997): human α-lactalbumin.
- GEAC checks GM safety; biopiracy: Basmati, turmeric, neem.

Organisms and Populations

The big idea: Ecology is the study of how living things interact with **each other** and with their **surroundings**. This chapter looks at how single organisms **cope with their environment**, how **populations grow**, and how different species **help or harm each other**.

Levels of ecology

Organism (one tiger) → **population** (all tigers in a forest) → **community** (all species in the forest) → **biome** (a large region, e.g. tropical forest).

Organism and its environment

Major abiotic (non-living) factors

Factor	Key points
Temperature	**Eurythermal** organisms tolerate a **wide** range; **stenothermal** ones tolerate only a **narrow** range
Water	**Euryhaline** organisms tolerate a **wide** range of **salt** concentration; **stenohaline** ones a **narrow** range
Light	Needed for photosynthesis. Controls **flowering** (photoperiodism). **Red algae** live deepest in the sea
Soil	Its type, grain size and drainage decide which plants grow

Memory trick: Eury = **wide** (like "**Eur**ope is wide"). **Steno** = **narrow** (like a **steno**grapher's **narrow** notebook). **Therm** = temperature, **haline** = salt.

How organisms respond to stress

1. **Regulate:** keep the body constant (homeostasis). Birds and mammals (thermoregulation).
2. **Conform:** the body changes with the surroundings. 99% of animals and almost all plants.
3. **Migrate:** move away for a while. Siberian birds visit Keoladeo National Park, Bharatpur.
4. **Suspend:** slow down and wait. Hibernation (winter), aestivation (summer), diapause (zooplankton), spores and seed dormancy.

Memory trick: Hibernation = "**Hi**, **Bear**!" sleeping in **winter**. **Aestivation** = "**A**ugust" (**summer**) sleep.

Common mistake: Small animals are rarely found in polar regions. They have a **large surface area compared to their volume**, so they **lose heat quickly** and must spend lots of energy to stay warm.

Adaptations: cool survival tricks

Organism	Adaptation
Kangaroo rat (desert)	**Never drinks water!** It gets water from **breaking down fat** in its body (internal fat oxidation), and makes very **concentrated urine**
Desert plants	**Thick cuticle**, **sunken stomata**, **CAM photosynthesis** (stomata open at **night**), leaves reduced to **spines**; *Opuntia* photosynthesises with its **flat stem**
Mammals of cold places	**Shorter ears and limbs** to lose less heat (**Allen's Rule**)
Seals	Thick layer of fat called **blubber** under the skin
Humans at high altitude	**Altitude sickness** (nausea, tiredness) at places like **Rohtang Pass**. The body adjusts by making **more RBCs**, lowering haemoglobin's binding affinity and **breathing faster**
Archaebacteria	Live in **hot springs** and deep-sea vents, where the temperature is **above 100 °C**

Populations

A **population** is a group of **individuals of the same species** living in an area.

Population attributes

- **Birth rate (natality)** and **death rate (mortality)**: per capita births and deaths.
- **Sex ratio**: e.g. 60% females, 40% males.
- **Population density (N)**: how many live in an area. It can be measured by counting, **per cent cover**, **biomass**, or **indirectly** (e.g. tiger **pug marks** and **faecal pellets**).

Age pyramids

Shape	Meaning
Triangle (wide base)	**Expanding**: many young, growing fast
Bell	**Stable**: not changing much
Urn (narrow base)	**Declining**: few young, shrinking

What changes population size?

- **Increase** the population: **natality** (births) and **immigration** (coming in).
- **Decrease** the population: **mortality** (deaths) and **emigration** (going out).

> $$\mathbf{N(t+1) = Nt + [(B + I) - (D + E)]}$$

> **Memory trick:** **I**mmigration = coming **I**n. **E**migration = **E**xiting.

Population growth models

	Exponential growth	Logistic growth
Resources	**Unlimited**	**Limited**
Curve shape	**J-shaped**	**S-shaped (sigmoid)**
Equation	**$dN/dt = rN$; $N_t = N_0 e^{rt}$**	**$dN/dt = rN\,(K - N)/K$**
Realistic?	Rare in nature	More realistic
Proposed by	—	**Verhulst and Pearl**

- **r** = **intrinsic rate of natural increase**. Examples: **Norway rat 0.015**, **flour beetle 0.12**; for India's human population in 1981, r = **0.0205**.
- **K** = **carrying capacity**: the **maximum population** the environment can support.

> **Memory trick:** **J** = "**J**ust keeps going up" (exponential). **S** = "**S**tops at the limit" (logistic, levels off at K).

Life history variation

- Some species **breed only once** in their life (**Pacific salmon**, **bamboo**). Most **breed many times** (birds, mammals).
- Some make **many small offspring** (**oysters**, pelagic fishes). Others make **few large offspring** (birds, mammals).

Population interactions

Interaction	Species A	Species B	Examples
Mutualism	+	+	**Lichens** (fungus + alga), **mycorrhiza** (fungus + plant roots), **fig and wasp**, **orchid *Ophrys* and bee**
Competition	−	−	**Goats vs Abingdon tortoise** (Galápagos), **flamingos vs fish** for zooplankton
Predation	+	−	**Tiger and deer**, **sparrow eating seeds**
Parasitism	+	−	**Liver fluke**, ***Cuscuta*** on hedge plants, **cuckoo** (brood parasite)
Commensalism	+	0	**Orchid on a mango branch**, **barnacles on a whale**, **cattle egret with cattle**, **clownfish and sea anemone**
Amensalism	−	0	*Penicillium* stopping bacterial growth

> **Memory trick:**
> - **Mutualism** = **M**utual **benefit** (+,+)
> - **Commensalism** = one **comm**utes for free (+,0)
> - **Amensalism** = "**A-men**, I'm hurt and you don't care" (−,0)
> - **Parasitism** = a **para**site takes and harms (+,−)

Predation

- Predators **control prey populations** and keep **species diversity** high.

- **Prickly pear cactus** spread wildly in **Australia** until a **cactus-eating moth** was brought in to control it.
- When the starfish ***Pisaster*** was removed from a coast in America, **more than 10 species** of invertebrates **died out** within a year.
- **How prey defend themselves:**
  - **Camouflage**: insects and frogs blend in.
  - **Poison**: the **monarch butterfly** is distasteful to birds because of chemicals it gets by eating a **poisonous weed** as a caterpillar.
  - **Thorns**: *Acacia* and cactus.
  - **Toxic chemicals**: ***Calotropis*** makes **cardiac glycosides**, so cattle don't eat it.

Competition

- **Gause's Competitive Exclusion Principle:** two **closely related** species competing for the **same resource** can't live together forever. The weaker one is **eliminated**.
- **Resource partitioning:** species avoid competition by **sharing differently**. **MacArthur** showed that **5 species of warblers** live on the **same tree** by feeding at **different heights and times**.

Parasitism: tricky parasites

- **Brood parasitism:** the **cuckoo (koel)** lays its eggs in a **crow's nest**. Its eggs **look like** the crow's eggs, so the crow raises the cuckoo chicks!
- **Ectoparasites** live **outside** the host (lice on humans, ticks on dogs, *Cuscuta* on plants). **Endoparasites** live **inside** (liver fluke, tapeworm).
- The **human liver fluke** needs **two intermediate hosts** (a **snail** and a **fish**) to complete its life cycle.

Mutualism: best friends

- **Fig and wasp:** the female wasp **pollinates** the fig flower while laying eggs in it. The fig feeds the wasp's larvae.
- ***Ophrys*** **orchid (sexual deceit):** one petal **looks like a female bee**. Male bees try to mate with it and **carry pollen** to the next flower.

> **Did you know?** Almost every fig species has its **own partner wasp species** that can pollinate it. They can't survive without each other!

30-second revision

- Eury = wide, steno = narrow tolerance.
- Responses: regulate, conform, migrate, suspend (hibernation, aestivation, diapause).
- Kangaroo rat: internal fat oxidation. Allen's rule: short ears and limbs in the cold.
- Age pyramids: triangle = expanding, bell = stable, urn = declining.
- Exponential = J ($dN/dt = rN$); logistic = S ($dN/dt = rN(K-N)/K$), K = carrying capacity.
- Mutualism (+,+), competition (−,−), predation and parasitism (+,−), commensalism (+,0), amensalism (−,0).
- Gause's principle; MacArthur's warblers; *Ophrys* (sexual deceit); cuckoo (brood parasite).

Ecosystem

> **The big idea:** An **ecosystem** is a place where **living things** (plants, animals, microbes) and **non-living things** (sunlight, water, soil, air) **work together as one unit**. Energy **flows** through it, and nutrients go **round and round**.

Structure of an ecosystem

- **Biotic (living) components:**
  - **Producers:** green plants
  - **Consumers:** animals
  - **Decomposers:** fungi and bacteria
- **Abiotic (non-living) components:** sunlight, water, soil, temperature and air.
- **Stratification:** plants grow in **vertical layers**. In a forest: **tall trees** (top) → **shrubs** → **herbs and grasses** (bottom).
- Ecosystems can be **terrestrial** (forest, grassland, desert) or **aquatic** (pond, lake, sea). They can also be **man-made**, like a crop field or an aquarium.

Productivity: how much food plants make

Term	Meaning
Primary production	Organic matter (**biomass**) made by plants through photosynthesis, per unit area over a time period
GPP (Gross Primary Productivity)	**Total** food made by photosynthesis
NPP (Net Primary Productivity)	Food **left over** after the plants use some for respiration: **NPP = GPP − R**
Secondary productivity	New organic matter made by **consumers**

> **Memory trick:** Think of your **salary**. **GPP** = your **gross** salary. **R** (respiration) = your **expenses**. **NPP** = what's **left** for others (the consumers) to use.

Yearly NPP (organic matter, dry weight):

Region	NPP (billion tons per year)
Land	~115
Oceans	~55
Whole Earth	**~170**

> **Did you know?** Oceans cover about **70%** of Earth but make **less than one-third** of its primary production. Their productivity is limited by **light** (deep water is dark) and **nutrients** (especially nitrogen).

Decomposition: nature's recycling

> **In simple words:** Decomposers break down **dead plants and animals** (called **detritus**) into simple things like **CO_2, water and nutrients**, which plants can use again.

1. **Fragmentation:** detritivores (earthworms) break detritus into small pieces.
2. **Leaching:** water-soluble nutrients sink into the soil.
3. **Catabolism:** bacterial and fungal enzymes break it down chemically.
4. **Humification:** dark, spongy **humus** forms (it decays very slowly).
5. **Mineralisation:** humus slowly releases inorganic nutrients.

> **Memory trick: "Frogs Love Catching Happy Mosquitoes"** → **F**ragmentation, **L**eaching, **C**atabolism, **H**umification, **M**ineralisation.

Decomposition is FAST when...	Decomposition is SLOW when...
Detritus is rich in **nitrogen** and **sugars** (water-soluble substances)	Detritus is rich in **lignin** and **chitin**
Warm and moist	**Cold**
Oxygen is available (aerobic)	**No oxygen** (anaerobic)

Energy flow

- The **Sun** is the **only source of energy** for almost all ecosystems (except deep-sea hydrothermal vent ecosystems).
- Less than **50%** of sunlight is **PAR** (photosynthetically active radiation, the light plants can use).
- Plants capture only **2–10% of PAR**. But this small amount runs the whole living world!
- **Energy flow is one-way (unidirectional):** Sun → producers → herbivores → carnivores. It never flows backwards.

The 10% law (Lindeman)

Only about **10%** of energy passes to the next level. The rest is **lost as heat** (respiration) at each step.

Trophic level	Energy (example)
Producers	10,000 J
Herbivores	1,000 J
Primary carnivores	100 J
Secondary carnivores	10 J

> **Exam focus:** This is why **food chains are short** (usually 3–4 levels). By the 4th or 5th level, **too little energy** is left to support another level.

Food chains and food webs

Grazing food chain (GFC)	Detritus food chain (DFC)
Starts with **living plants**	Starts with **dead organic matter**

Grazing food chain (GFC)	Detritus food chain (DFC)
Grass → goat → man	Dead leaves → earthworms → birds
	In land ecosystems, **more energy flows through the DFC** than the GFC

- A **food web** is many food chains **linked together**, which is more realistic.
- **Standing crop** = the mass of living material at each level at a given time.

Trophic levels:

1. **1st level:** producers
2. **2nd level:** primary consumers (herbivores)
3. **3rd level:** secondary consumers (carnivores)
4. **4th level:** tertiary consumers (top carnivores)

Ecological pyramids

Pyramid of	Usually	Exception
Energy	**Always upright**	**Never inverted**
Number	Upright	**Inverted in a tree ecosystem** (1 tree → many insects → fewer birds)
Biomass	Upright	**Inverted in the sea** (small biomass of **phytoplankton** supports a large biomass of **fish**)

> **Memory trick:** "**Energy is never upside down**". Energy always **decreases** going up, so its pyramid **can never be inverted**.

Limitations of ecological pyramids:

- They don't show a species that belongs to **2 or more** trophic levels.
- They assume a **simple food chain**, not a food web.
- They **don't include saprophytes** (decomposers), even though decomposers are very important.

Ecological succession

> **In simple words:** Succession is the **slow, step-by-step change** in the plants and animals of an area over time. It ends in a stable **climax community** that is in balance with the environment. Think of it as nature **"building" a forest** step by step.

- **Sere** = the whole sequence of communities. Each stage is a **seral stage** (seral community).

Primary succession	Secondary succession
Starts where **no life existed before**: bare rock, a new pond, cooled lava	Starts where life was **destroyed**: abandoned farmland, a burnt or cut forest, a flooded area
No soil at the start	**Soil already present**
Very slow (hundreds to thousands of years)	**Faster**

Succession on land (xerarch) vs in water (hydrarch)

- **Xerarch (on bare rock):** lichens (pioneers; they secrete acids that break the rock) → mosses (bryophytes) → herbs → shrubs → forest (climax).
- **Hydrarch (in water):** phytoplankton (pioneers) → rooted submerged plants → floating plants → reed swamp → marsh meadow → scrub → forest (climax).

> **Exam focus:** Both kinds of succession end in a **mesic** (medium-moisture) climax. **Xerarch** goes from **dry** → **mesic** and **hydrarch** goes from **wet** → **mesic**. The first organisms are called **pioneer species**: **lichens** on rock and **phytoplankton** in water.

30-second revision

- NPP = GPP − R. Earth's NPP ≈ 170 billion tons; oceans ≈ 55 billion tons.
- Decomposition: fragmentation → leaching → catabolism → humification → mineralisation.
- Only 2–10% of PAR is captured; energy flow is **unidirectional**; 10% law.
- GFC starts with living plants; DFC with detritus.
- Energy pyramid is **always upright**. Biomass pyramid is inverted in the sea; number pyramid is inverted for a tree.
- Primary succession: no soil, slow; secondary: soil present, faster.
- Pioneers: lichens (xerarch), phytoplankton (hydrarch). Both end in a mesic climax.

Biodiversity and Conservation

> **The big idea: Biodiversity** is the **variety of life** on Earth: from tiny genes to huge forests. We are **losing species very fast** because of humans. This chapter explains **why biodiversity matters** and **how we can protect it**.

Three levels of biodiversity

The word "biodiversity" was made popular by the biologist **Edward Wilson**.

- **Genetic diversity** (variety *within* a species): *Rauwolfia vomitoria* in the Himalayas makes different amounts of reserpine; India has more than 50,000 rice and 1,000 mango varieties.
- **Species diversity** (variety *of* species): the Western Ghats have more amphibian species than the Eastern Ghats.
- **Ecological diversity** (variety of ecosystems): India has deserts, rainforests, mangroves, coral reefs, wetlands, estuaries and alpine meadows.

How many species are there?

- **IUCN (2004):** a little more than **1.5 million** species have been **described** so far.
- **Robert May's** estimate of the **total** number of species on Earth: about **7 million**.
- More than **70%** of all recorded species are **animals**. Plants (including algae, fungi, bryophytes, gymnosperms and angiosperms) make up **no more than 22%**.
- Among animals, **insects** are the biggest group, about **70% of all animals**. That means **7 out of every 10 animals are insects**!

> **Did you know?** India has only **2.4%** of the world's land area, but **8.1%** of the world's species! That makes India one of the **12 mega-diversity countries**. India has about **45,000 plant species** and **twice as many animal species**.

Patterns of biodiversity

1. Latitudinal gradient: more life near the equator

Diversity **decreases** as we go from the **equator towards the poles**.

Place	Bird species
Colombia (near the equator)	~1,400
India (tropics)	more than 1,200
New York (41° N)	105
Greenland (71° N)	56

Why are the tropics so rich?

1. **Long, undisturbed history:** the tropics were not frozen by ice ages, so species had **millions of years** to evolve.
2. **Stable climate:** the tropics are **less seasonal** and more **constant and predictable**, so species can **specialise**.
3. **More solar energy:** more sunlight → **more productivity** → more food for more species.

> **Memory trick: "Tropics have TSE"** → **T**ime (long history), **S**table climate, **E**nergy (more sunlight).

> **Did you know?** The **Amazon rainforest** in South America has the **greatest biodiversity on Earth**: more than **40,000 plant species**, **3,000 fishes**, **1,300 birds**, **427 mammals**, **427 amphibians**, **378 reptiles** and more than **1,25,000 invertebrates**!

2. Species–area relationship

- **Alexander von Humboldt** found that as the **area increases**, the **number of species increases**, but only up to a limit.
- On a **log scale** the relationship is a **straight line**: **$\log S = \log C + Z \log A$**
  - **S** = species richness, **A** = area, **Z** = slope (regression coefficient), **C** = Y-intercept.
- **Z** is usually **0.1 to 0.2** for small regions, whatever the group or area.
- For **very large areas** (like whole continents), **Z** is much steeper: **0.6 to 1.2**.

Why is biodiversity important?

Stability of ecosystems

- **David Tilman's** experiments on outdoor plots: plots with **more species** had **less year-to-year change** in total biomass, and **higher productivity**.

The rivet popper hypothesis

> **In simple words:** Biologist **Paul Ehrlich** compared an ecosystem to an **aeroplane** and each **species** to a **rivet** (a metal pin holding it together).
> - Passengers popping out a few rivets from the seats may **not** cause an immediate problem.
> - But as **more rivets** go, the plane becomes **dangerous**.
> - And losing rivets from **key places** like the **wings** (key species) can make the plane **crash** at once!

Loss of biodiversity

- The **IUCN Red List (2004)** records **784 extinctions** in the last **500 years**, including 338 vertebrates, 359 invertebrates and 87 plants.
- **Recent extinctions:**
  - **Dodo** (Mauritius)
  - **Quagga** (Africa)
  - **Thylacine** (Australia)
  - **Steller's sea cow** (Russia)
  - **3 subspecies of tiger** (Bali, Javan and Caspian)
- We are now in the **sixth mass extinction**. It is happening **100 to 1,000 times faster** than before humans, and **humans are the cause**.

What happens when biodiversity is lost?

- **Plant production decreases.**
- The ecosystem becomes **less stable** during disturbances like drought.
- **Some processes change**: water use, pest and disease cycles.

Causes: the "Evil Quartet"

Cause	Examples
1. Habitat loss and fragmentation	**Tropical rainforests** once covered **14%** of Earth's land but now cover only **6%**. The **Amazon** ("**lungs of the planet**") is being cleared for **soybeans** and **cattle grazing**
2. Over-exploitation (taking too much)	**Steller's sea cow** and the **passenger pigeon** were hunted to extinction. Many **marine fish** are over-harvested
3. Alien species invasions	**Nile perch** put into **Lake Victoria** (East Africa) wiped out **more than 200 species of cichlid fish**. Weeds like ***Parthenium*** (carrot grass), ***Lantana*** and **water hyacinth** (*Eichhornia*). The **African catfish** (*Clarias gariepinus*) threatens native catfish in India
4. Co-extinctions	When a species dies out, species that **depend on it** also die out. When a **host fish** goes extinct, its **unique parasites** go too. A plant and its pollinator can also die out together

> **Memory trick for the Evil Quartet: "HOAC" → H**abitat loss, **O**ver-exploitation, **A**lien species, **C**o-extinction. Think "**HOAX** is evil".

Why should we conserve biodiversity?

Reason	In simple words	Example
Narrowly utilitarian	**Direct benefits** we can use or sell	Food, firewood, fibre, **medicines** (more than **25%** of drugs come from plants), industrial products
Broadly utilitarian	**Free services** from nature	The **Amazon produces about 20% of Earth's oxygen**; **pollination** by bees, birds and bats; **aesthetic pleasure** (bird-watching, walking in a forest)
Ethical	Every species has a **right to live**	We share the planet with millions of species

> **Bioprospecting:** searching nature for **useful products** (like new medicines) that have **economic value**. Countries rich in biodiversity can earn a lot from it.

How do we conserve biodiversity?

- **In-situ** (protect it in its natural home): biodiversity hotspots; biosphere reserves, national parks and wildlife sanctuaries; sacred groves.
- **Ex-situ** (protect it outside its natural home): zoos, botanical gardens and wildlife safari parks; cryopreservation of gametes, seed banks and tissue culture.

> **Memory trick: In**-situ = **In** its home. **Ex-**situ = **Ex**ited its home (moved to a zoo or lab).

In-situ conservation

- **Biodiversity hotspots** are regions with **very high species richness** and many **endemic** species (found nowhere else), which are under threat.
  - There are **34 hotspots** in the world.
  - **India has 3 hotspots:** the **Western Ghats and Sri Lanka**, **Indo-Burma**, and the **Himalaya**.
  - Hotspots cover **less than 2%** of Earth's land, but protecting them could reduce mass extinctions by up to **30%**.
- **Protected areas in India: 14 biosphere reserves**, **90 national parks** and **448 wildlife sanctuaries** (as given in NCERT).
- **Sacred groves**: forests protected by local people for **religious and cultural** reasons. Some rare plants survive only here.

State	Sacred groves in
Meghalaya	**Khasi and Jaintia Hills**
Rajasthan	**Aravalli Hills**
Karnataka and Maharashtra	**Western Ghats**
Madhya Pradesh	**Sarguja, Chanda and Bastar** areas

Ex-situ conservation

- **Zoological parks, botanical gardens and wildlife safari parks**.
- **Cryopreservation:** gametes of threatened species are frozen and kept alive for a long time using **liquid nitrogen at −196 °C**.
- **In vitro fertilisation** and **tissue culture** to grow plants in labs.
- **Seed banks** store seeds of many plant varieties.

International efforts

Event	Year	What happened
Earth Summit, Rio de Janeiro	**1992**	All nations were asked to protect biodiversity and use it **sustainably**. This gave the **Convention on Biological Diversity**
World Summit on Sustainable Development, Johannesburg	**2002**	**190 countries** pledged to **significantly reduce** the rate of biodiversity loss by **2010**

30-second revision

- 3 levels: genetic, species, ecological (Edward Wilson).
- ~1.5 million described (IUCN 2004); ~7 million estimated (Robert May). Insects are about 70% of animals.
- India: 2.4% of land, 8.1% of species; one of 12 mega-diversity countries.
- Diversity falls from equator to poles (time, stability, energy).
- $\log S = \log C + Z \log A$; $Z = 0.1–0.2$ (small areas), $0.6–1.2$ (continents).
- Rivet popper (Ehrlich); stability (Tilman).
- Evil Quartet: habitat loss (biggest), over-exploitation, alien species (Nile perch), co-extinctions.
- India's 3 hotspots: Western Ghats–Sri Lanka, Indo-Burma, Himalaya. Earth Summit 1992; WSSD 2002.

REVISION

Quick Revision

> **How to use this page:** Read it the **night before the exam**. It collects the most-asked **scientists, abbreviations, numbers and memory tricks** from all 13 chapters.

Important scientists

Scientist	Famous for	Chapter
Gregor Mendel	Laws of inheritance (pea plants)	4
Sutton and Boveri	Chromosomal theory of inheritance	4
T.H. Morgan	Linkage, using *Drosophila*	4
Alfred Sturtevant	First gene maps	4
Frederick Griffith	Transformation experiment	5
Avery, MacLeod and McCarty	DNA is the transforming principle	5
Hershey and Chase	DNA is the genetic material (^{32}P, ^{35}S)	5
Watson and Crick	Double helix model of DNA (1953)	5
Erwin Chargaff	A = T and G = C	5
Meselson and Stahl	Semi-conservative replication (^{15}N)	5
Jacob and Monod	*lac* operon	5
Alec Jeffreys	DNA fingerprinting	5
Oparin and Haldane	Chemical evolution	6
Stanley Miller	Amino acids from simple gases	6
Charles Darwin	Natural selection	6
Hugo de Vries	Mutation theory (evening primrose)	6
Alexander Fleming	Penicillin	8
Stanley Cohen and Herbert Boyer	First recombinant DNA (1972)	9
Verhulst and Pearl	Logistic growth	11
Gause	Competitive exclusion principle	11
MacArthur	Resource partitioning (warblers)	11
Lindeman	10% law of energy transfer	12
Edward Wilson	Popularised the term "biodiversity"	13
Alexander von Humboldt	Species–area relationship	13
David Tilman	More species = more stable ecosystem	13
Paul Ehrlich	Rivet popper hypothesis	13
Robert May	Estimated ~7 million species on Earth	13

Important abbreviations

Short	Full form
ART	Assisted Reproductive Technologies
IVF	In Vitro Fertilisation
GIFT	Gamete Intra Fallopian Transfer
ZIFT	Zygote Intra Fallopian Transfer
IUT	Intra Uterine Transfer
ICSI	Intra Cytoplasmic Sperm Injection
IUI	Intra Uterine Insemination
IUD	Intra Uterine Device
MTP	Medical Termination of Pregnancy
STI	Sexually Transmitted Infection
RCH	Reproductive and Child Health Care
hCG	Human Chorionic Gonadotropin
VNTR	Variable Number of Tandem Repeats
SNP	Single Nucleotide Polymorphism
EST	Expressed Sequence Tag
BAC / YAC	Bacterial / Yeast Artificial Chromosome
HGP	Human Genome Project
PCR	Polymerase Chain Reaction
ELISA	Enzyme-Linked Immunosorbent Assay
AIDS	Acquired Immuno Deficiency Syndrome
HIV	Human Immunodeficiency Virus
MALT	Mucosa-Associated Lymphoid Tissue
CMI	Cell-Mediated Immunity
NACO	National AIDS Control Organisation
LAB	Lactic Acid Bacteria
BOD	Biochemical Oxygen Demand
STP	Sewage Treatment Plant
IARI	Indian Agricultural Research Institute
KVIC	Khadi and Village Industries Commission
IPM	Integrated Pest Management
GMO	Genetically Modified Organism
GEAC	Genetic Engineering Approval Committee
ADA	Adenosine Deaminase

Short	Full form
EFB	European Federation of Biotechnology
GPP / NPP	Gross / Net Primary Productivity
PAR	Photosynthetically Active Radiation
IUCN	International Union for Conservation of Nature

Numbers you must remember

Fact	Number
Embryo sac	**7 cells, 8 nuclei**
Scrotum is cooler than the body by	**2–2.5 °C**
Sperms per ejaculation	**200–300 million**
Primary follicles left per ovary at puberty	**60,000–80,000**
Emergency contraception works within	**72 hours**
MTP is safest up to	**12 weeks**
Monohybrid / dihybrid F2 ratio	**3 : 1** / **9 : 3 : 3 : 1**
DNA: bp per turn, pitch, gap	**10 bp**, **3.4 nm**, **0.34 nm**
Human DNA length	**~2.2 m**
Human genome	**3164.7 million bp**, ~**30,000 genes**
Codons	**64** (61 amino acids + 3 stop)
Energy passed to the next trophic level	**~10%**
Earth's NPP / oceans' NPP	**170** / **55 billion tons** per year
India's share of land / species	**2.4%** / **8.1%**
Biodiversity hotspots (world / India)	**34 / 3**

Top memory tricks

Topic	Trick
Microsporangium wall layers	"**E**very **E**lephant **M**akes **T**ea" → Epidermis, Endothecium, Middle layers, Tapetum
Male duct path	"**S**ita **R**ides **V**ery **E**asy **V**ans **E**very **U**tsav"
Embryo sac	**3 + 1 + 3** (egg apparatus + central cell + antipodals)
Incurable STIs	"**H, H, H**" → Herpes, Hepatitis B, HIV
Mendel's laws	**DSI** → Dominance, Segregation, Independent assortment
ABO blood groups	**3-6-4** → 3 alleles, 6 genotypes, 4 blood groups
Purines	"**Pure As Gold**" → A and G
RNA polymerases	**R-M-T = 1-2-3**
lac operon genes	"**Z-Y-A → Big Party Tonight**" → β-galactosidase, permease, transacetylase

Topic	Trick
Hardy–Weinberg factors	"**My Great Man Ran Now**"
Innate immunity barriers	**PPCC** → physical, physiological, cellular, cytokine
PCR steps	"**Heat–Stick–Build**" → denaturation, annealing, extension
Decomposition steps	"**Frogs Love Catching Happy Mosquitoes**"
Evil Quartet	**HOAC** → Habitat loss, Over-exploitation, Alien species, Co-extinction

Diagrams to practise

Board exams often ask you to **draw and label** these. Practise each one from your **NCERT textbook** at least **3 times**:

1. T.S. of an anther and the structure of a pollen grain
2. Embryo sac (7 cells, 8 nuclei)
3. L.S. of a flower showing pollen tube growth
4. Human male and female reproductive systems
5. Sperm and ovum
6. Menstrual cycle hormone graph
7. Seminiferous tubule and Graafian follicle
8. DNA double helix and the replication fork
9. *lac* operon (with and without lactose)
10. Antibody structure (H_2L_2)
11. pBR322 vector
12. Growth curves (J and S) and age pyramids
13. Ecological pyramids

Exam tips

- **Use NCERT words.** Examiners look for key terms like "semi-conservative", "contact inhibition" and "reproductive fitness".
- **Draw neat, labelled diagrams** with a pencil. A good diagram can earn full marks even if your answer is short.
- **Underline key words** in long answers.
- For **"differentiate"** questions, always use a **table** with at least 3–4 points.
- Read the **NCERT summary** at the end of each chapter. Many 1-mark questions come directly from there.

Best way to remember: After reading a chapter, **close the book** and try to **teach it** to someone (or even to your wall!). If you can explain it simply, you truly understand it.