Unit 3 · Cell Division

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Biomolecules and Cell Biology (Units 1–3 together): 9 of 75 marks; with Biology, Microbiology, Biota and Environment and Conservation a combined 21, at least 3 MCQs, 2 short and 1 long from them
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** long (8): two successive stages of meiosis drawn; what changes between them by **disjunction** (4); what if it didn't happen (chromosome number not kept) (1); draw the next stage with two features (3)
- **MCQ (1 mark)**
  - cytokinesis; S phase (two chromatids); G_0
  - metaphase plate; acrocentric → J
  - cell plate grows center → out
  - crossing over: non-sister chromatids; anaphase I: homologs part; DNA copied once
- **Short and long (in parts)**
  - define cell cycle, mitosis, meiosis; name the phases
  - phases and sub-phases in detail
  - mitosis vs meiosis: daughter cells, genetic make-up, roles
  - significance of mitosis; of meiosis
  - identifying stages under the microscope; use in cancer, medicine, genetics, reproduction
  - role of both in a sexual life cycle

Key terms

Cell division: one parent (mother) cell → two or more daughter cells.

Karyokinesis (*karyon*, nucleus): division of the nucleus.

Cytokinesis (*kytos*, cell): division of the cytoplasm → two cells.

Cell cycle: events from one division to the next: growth, copying of DNA, division.

Interphase: between two divisions; $G_1 + S + G_2$; once called the "resting stage".

G_0 (quiescent stage): cell has left the cycle from G_1; works, doesn't prepare to divide.

Mitogens: signals (growth factors) telling a cell to divide.

Mitotic index: % of cells counted that are dividing.

Homologous chromosomes: a matching pair, one from each parent.

Synapsis: side-by-side pairing of homologs (zygotene), held by the **synaptonemal complex**.

Bivalent (tetrad): a paired homolog couple; 4 chromatids.

Crossing over: swap of matching pieces between **non-sister chromatids** (pachytene).

Chiasma (pl. chiasmata): X-shaped join where crossing over happened (diplotene).

Terminalization: chiasmata slide to chromosome ends (diakinesis).

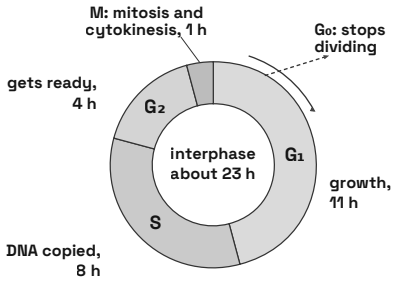
Disjunction: separation of homologs at anaphase I.

Interkinesis: pause between meiosis I and II; **no DNA copying**.

Congression: movement of chromosomes to the equator (metaphase).

Cell cycle

- **three cycles together**
  - **chromosome**: DNA copied → sister chromatids → shared out
  - **cytoplasmic**: cell grows → cytoplasm divides
  - **centrosome**: copied → two move to poles (animal cells)



Cell cycle of a human cell in a dish (~24 h): G_1, S, G_2 (interphase, ~23 h), M (~1 h); G_0 off G_1.

Stage	Events
G_1 (first gap)	grows fast; RNA, proteins, enzymes, carbohydrates, lipids, organelles; nucleotides, ATP stored; DNA unchanged; checkpoint at end
S (synthesis)	**DNA replicated**; histones, kinetochore proteins made; each chromosome → **two sister chromatids**; number same, DNA doubled; centrioles copied
G_2 (second gap)	proteins for division, **tubulin**; ATP; mitochondria, plastids done; centrioles mature; DNA checked, repaired
M: karyokinesis	prophase, metaphase, anaphase, telophase
M: cytokinesis	furrow (animals), cell plate (plants)

- interphase "resting" only in looks: chromosomes uncoiled, unseen; the **most active** stage
- G_0: no mitogens or cell specialized; **differentiation**
  - for life: most **nerve cells**, **heart muscle**
  - can return: **liver** cells, cells round a **wound**

How long

- human cell in a dish 24 h: G_1 ~46 %, S ~33 %, G_2 ~17 %, M ~4 %
- many cells: G_1 30–40 %, S 30–50 %, G_2 10–20 %, M 5–10 %
- *E. coli* **20 min**; intestinal epithelium every 8–10 h (CDC's book); onion root tip **~20 h**; frog embryo ~30 min (skips G_1, G_2)
- controls (Nobel 2001): **Hartwell** (checkpoint genes, yeast), **Nurse** (**CDK**), **Hunt** (**cyclins**, sea urchin eggs); brakes fail → **cancer**

Mitotic index

$$\text{mitotic index} = \frac{\text{cells in P + M + A + T}}{\text{total cells counted}} \times 100\,\%$$

$$\text{time in a stage} = \frac{\text{cells in that stage}}{\text{total cells}} \times \text{length of cycle}$$

- a longer stage catches more cells
- e.g. 60 of 500 dividing → 12 %; prophase longest, **anaphase shortest**

Three types of division

1. **direct** (amitosis)
2. **indirect** (mitosis)
3. **reductional** (meiosis)

Amitosis

- *a* without + *mitos* thread; **no visible chromosomes, no spindle**
- nucleus lengthens → groove in middle → splits; cytoplasm furrows → two halves
- genes **not shared exactly**
- examples: **macronucleus of** *Paramecium*, cartilage cells, mammalian liver, old or damaged tissue
- **binary fission** (bacteria, archaea): copy circular chromosome, copies move apart, cell pinches; often treated with amitosis
- *Amoeba*: binary fission, but its nucleus divides by **mitosis**

Mitosis

- *mitos* thread; **two** daughter cells, **same number and kind** of chromosomes (46 → 46; onion 16 → 16)
- **equational**, **indirect** division
- where: **somatic** cells, **meristems** (root, shoot tips, cambium), **embryo**, germ cells multiplying

Interphase

- long thin **chromatin**; nucleolus, envelope seen
- DNA copied (S); proteins, RNA made; organelles, centrioles copied

a. Prophase (*pro* first): longest stage of mitosis

- nucleus rounder, cytoplasm more viscous
- chromatin **coils, condenses** (**condensins**) → shorter, thicker
- each chromosome: **two sister chromatids** at the **centromere**
- centrosomes → **poles**; **astral rays** → **asters**; spindle starts
- end: **nucleolus**, **nuclear envelope** disappear

b. Metaphase (*meta* after)

- spindle fibers attach at **kinetochores** (one a chromatid, to opposite poles)
- **congression** → **equatorial (metaphase) plate**; centromeres on it
- small chromosomes in middle, large round edge
- shortest, thickest → **counted, photographed now**

c. Anaphase (*ana* up, back): **shortest**; migration

- **centromere splits** → sister chromatids → **daughter chromosomes**
- move to **opposite poles**, centromere first; kinetochore fibers shorten, fibers between lengthen, push poles apart
- shapes: **V** metacentric · **L** submetacentric · **J** acrocentric · **I** telocentric

d. Telophase (*telos* end): reorganization, prophase in reverse

- chromosomes at poles; take up water, **uncoil**
- spindle disappears
- **nuclear envelope**, **nucleolus** re-form
- **two daughter nuclei**

Counting

- count by **centromeres**
- human metaphase: 46 chromosomes, 92 chromatids
- anaphase: 92 chromosomes (46 to each pole)

Cytokinesis (late anaphase or telophase)

Plant cell	Animal cell
cell plate; wall stops pinching	**furrowing**
spindle remnants → **phragmoplast**	ring of **actin** and **myosin** under membrane
Golgi (and ER) vesicles of pectin fuse at equator	ring tightens → **cleavage furrow**
grows **center** → **outward**	deepens **outside** → **in**
plate → **middle lamella**; each cell lays a primary wall	cell pinched in two

- bacteria: ring of **FtsZ** + septum; many fungi: cross-wall

Significance

1. **growth**: zygote → adult
2. **asexual reproduction**: yeast budding, *Hydra* buds, fragments, runners, tubers, cuttings
3. **genetic stability**: same chromosome number
4. **repair, regeneration**: skin over a cut, ~2 million red blood cells a second, lizard's tail
5. **workable size**: surface : volume, nucleus : cytoplasm
6. **genetic consistency**: same quantity and quality of genes
7. **cancer**: controls fail → **tumor**

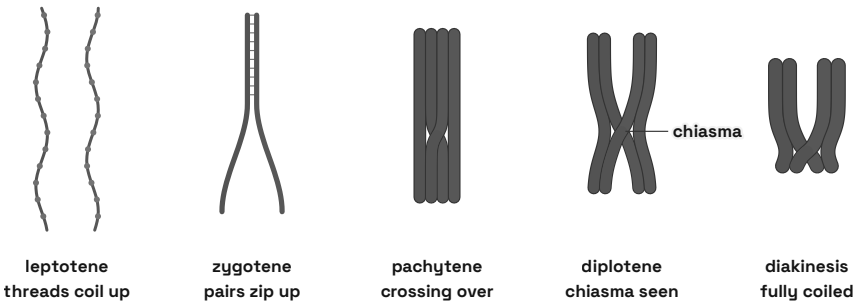
- **vincristine**, **vinblastine** (Madagascar periwinkle, *Catharanthus roseus*, बाह्रमासे फूल): bind **tubulin**, stop the spindle → cell stuck before anaphase; childhood leukemia

Onion root tip (Activity 1.3.1)

- grow roots 5 days on water; cut 1–2 cm tips late morning
- **stain** (acetocarmine, acetic orcein) + **1 M HCl**, warm: acid dissolves **middle lamella**; stain colors chromosomes
- keep 2–3 mm tip; **squash** under cover slip; 10× then 40×
- most cells in **interphase**; anaphase hardest to find (shortest); **no centrioles, asters** in onion

Meiosis

- *meioun*, make smaller; **diploid (2n)** → **four haploid (n)** cells; **reductional division**
- halving needed: two gametes join at fertilization
- **Hertwig** 1876 (sea urchin eggs); **Van Beneden** 1883 (*Ascaris*, 4 chromosomes); named by **Farmer and Moore** 1905
- in **meiocytes**: spermatocytes, oocytes; pollen (microspore) mother cells, megaspore mother cells
- interphase copies DNA (G_2 short); then **meiosis I + meiosis II**, **no DNA copying between**



Prophase I on one homologous pair: leptotene, zygotene, pachytene, diplotene, diakinesis.

Prophase I (longest phase of meiosis)

Sub-phase	Meaning	Events
leptotene	thin thread	nucleus enlarges; long thin single-looking threads; **chromomeres**; **bouquet stage**; envelope, nucleolus remain
zygotene	yoke	homologs pair: **synapsis**; **synaptonemal complex**; **bivalents** (23 in humans)
pachytene	thick	4 chromatids seen: **tetrad**; sister and non-sister chromatids; **crossing over**; longest of these
diplotene	double	synaptonemal complex goes; homologs separate except at **chiasmata**; nucleolus smaller; human oocytes pause here for years
diakinesis	across	most condensed; bivalents to edge; **terminalization**; nucleolus, envelope disappear; spindle forms

- crossing over: breaks fixed gene packages → Ab, aB besides AB, ab → **variation**

Metaphase I

- **bivalents** line up: **two rows** (two plates), homologs either side of equator
- each centromere to **one pole only**; sister chromatids act as one
- which homolog faces which pole: **chance**, each pair independent

Anaphase I

- **centromeres do not split**
- **homologs** separate to opposite poles = **disjunction**
- each pole: mix of maternal and paternal; **half the number**, each still 2 chromatids

Telophase I

- chromosomes uncoil a little; spindle goes
- envelope, nucleolus may form → **two haploid nuclei**; may be skipped

Cytokinesis I: furrow or cell plate; in most dicot pollen mother cells only once, after meiosis II

Interkinesis: no S phase; **one copying, two divisions** → half the DNA

Meiosis II (like mitosis; **equational**, n → n)

1. **prophase II**: chromosomes (2 chromatids) condense; envelope goes; new spindle at **right angles** to the first
2. **metaphase II**: chromosomes **singly** on the equator; centromere to **both** poles
3. **anaphase II**: **centromeres split**; sister chromatids to opposite poles
4. **telophase II**: uncoil; envelope, nucleolus → **four haploid nuclei**

- cytokinesis II → **four haploid cells**, half the DNA of a G_1 cell, no two alike
- human female: egg starts meiosis before birth, waits at **diplotene** (up to 40+ years); meiosis I before ovulation, II only if a sperm enters; one egg + **polar bodies**
- independent assortment: $\mathbf{2^{23}} \approx 8.4$ million kinds of gamete; two parents ≈ 70 trillion children

Importance of meiosis

1. makes **gametes** (animals), **spores** (plants)
2. keeps **chromosome number constant**: n + n = 2n
3. **variation**: **crossing over + independent assortment**
4. **segregates genes**: Mendel's laws of segregation and independent assortment
5. **polyploids** by non-disjunction: bread wheat 6 sets (2n = 42), potato 4 sets (2n = 48)
6. variation for **breeders**
7. same in all sexual organisms → **common ancestor**
8. **alternation of generations** (2n → n)
9. regular reproductive cycle

Mitosis vs meiosis

Feature	Mitosis	Meiosis
where	somatic cells, meristems, multiplying germ cells	meiocytes: gonads; anthers, ovules
divisions	one	two, after one DNA copying
prophase	short, no sub-phases	prophase I long, five sub-phases
pairing	none; no crossing over, no chiasmata	synapsis, bivalents, crossing over, chiasmata
metaphase	single chromosomes, one plate	metaphase I: bivalents (tetrads), two rows
anaphase	centromeres split; sister chromatids part	anaphase I: whole homologs (no split); anaphase II: chromatids
telophase	always	telophase I short or missed
interkinesis	none	short, no DNA copying
daughter cells	**two, diploid (2n)**, same DNA as G_1 mother	**four, haploid (n)**, half the DNA
genes	identical to mother and each other	different from mother and each other
role	growth, repair, regeneration, asexual reproduction	gametes, spores; variation

Applying it (higher-ability questions)

- **identifying a stage**: chromosomes seen or not; on one plate (metaphase) or two rows (metaphase I); moving apart (anaphase); groups at poles + plate (telophase); pairs, chiasmata (prophase I)
- **cancer**: high mitotic index, many cells dividing; drugs that stop the spindle (vincristine) hit fast-dividing cells
- **genetics**: crossing over, assortment explain Mendel's laws and variation; non-disjunction → wrong chromosome number
- **reproduction**: meiosis halves, fertilization restores; mitosis then grows the zygote
- **disjunction fails** → gametes with an extra or a missing chromosome; chromosome number not kept

COMMON MISTAKES

✗ Interphase is a resting stage
✓ the **most active** stage; only the chromosomes look at rest.

✗ Bacteria, *Amoeba* divide by amitosis
✓ bacteria: **binary fission**; *Amoeba*'s nucleus: **mitosis**; amitosis: *Paramecium* macronucleus, cartilage.

✗ Centromeres split at anaphase I
✓ homologs part, centromeres split only at **anaphase II** (and in mitosis).

✗ DNA copied again in interkinesis
✓ **no S phase**: one copying, two divisions.

✗ Crossing over between sister chromatids
✓ between **non-sister** chromatids.

✗ Metaphase cell has 92 chromosomes
✓ 46 chromosomes, **92 chromatids**; 92 chromosomes only at anaphase.

✗ Cell plate grows from the wall inward
✓ **center** → **outward**; the furrow goes outside → in.

✗ Meiosis II halves the number
✓ meiosis **I** halves it; II is equational.