Cell and nuclear division

D2.1 · SL and HL

Different division problems require different nuclear outcomes

Follow the cell boundary and the chromosome sets

Shared D2.1: new cells, cytokinesis, replication, mitosis, meiosis, variation and non-disjunction. Retained extension: mitotic-index evidence.

AHL: proliferation, cell cycle, cyclins and tumour behaviour. State whether a count refers to the whole cell or one product.

All diagrams and numerical samples are invented teaching models; named human biology is identified explicitly.

Separate cell production from distribution of nuclei

Process	Outcome and purpose
Cell division	Existing parent cell gives daughter cells
Nuclear division	Distributes chromosomes before daughter cells separate
Mitosis	Maintains chromosome number in normal daughter nuclei
Meiosis	Reduces chromosome sets and generates combinations
Cytokinesis	Separates cytoplasm; nuclear division alone can leave several nuclei in one cell

A rigid wall changes the mechanism of cytokinesis

Cell type	Mechanism
Animal	Actin–myosin ring contracts; cleavage furrow deepens
Plant	Vesicles contribute to a central cell plate; it expands to the existing boundary
Plant product	New separating membranes and wall; no animal-style pinching through a rigid wall

Equal nuclear sets need not mean equal cytoplasmic shares

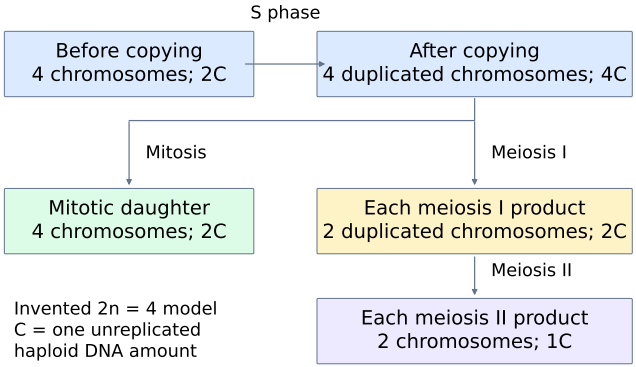
Explain what each daughter must inherit

Human oogenesis retains most cytoplasm in the egg lineage and much less in polar bodies.

Budding yeast gives a smaller bud a daughter nucleus and cytoplasm; products differ in size.

Daughters need inherited mitochondria and other required organelles that arise from existing organelles. Nuclear DNA alone is not a physical organelle.

Follow chromosome count and DNA amount through the two routes



Copy DNA first; distinguish chromosome sets from DNA amount.

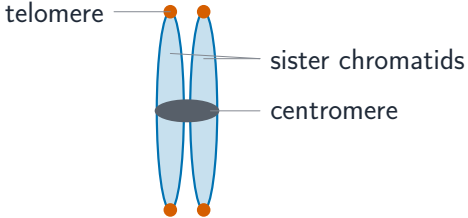
Count a duplicated chromosome before counting its DNA

1. **Invented model.** Diploid $2n = 4$ before copying: four chromosomes, four DNA molecules, 2C.
2. **After replication.** Four duplicated chromosomes, eight sister chromatids / DNA molecules, 4C.
3. **Convention.** Attached sisters count as one chromosome. C is DNA amount in one unreplicated haploid set, not chromosome count.

The whole anaphase cell and one daughter have different counts

1. **Before separation.** Four duplicated chromosomes at metaphase.
2. **Sisters separate.** Eight daughter chromosomes in the undivided anaphase cell; four towards each pole.
3. **After cytokinesis.** Each normal daughter has four chromosomes and 2C DNA. Mitosis has maintained its chromosome number.

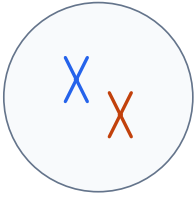
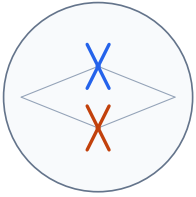
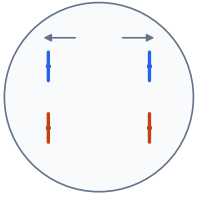
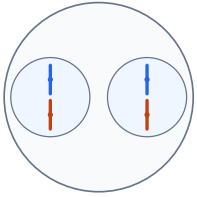
A replicated chromosome



one chromosome = two identical copies after DNA replication

Telomeres cap the ends

Use chromosome arrangement to identify a mitotic phase

Prophase	Metaphase	Anaphase	Telophase
			
2 duplicated	2 duplicated	4 in whole cell	2 in each nucleus

Mitosis separates sisters into equivalent daughter nuclei.

Connect the phase name to visible evidence

Phase	Evidence
Prophase	Condensation and spindle development; nuclear-envelope breakdown
Metaphase	Duplicated chromosomes individually aligned at equator
Anaphase	Sisters separate; daughter chromosomes move to opposite poles
Telophase	Chromosomes reach poles; nuclear envelopes form; chromosomes decondense

Condensation and movement do not create new DNA copies

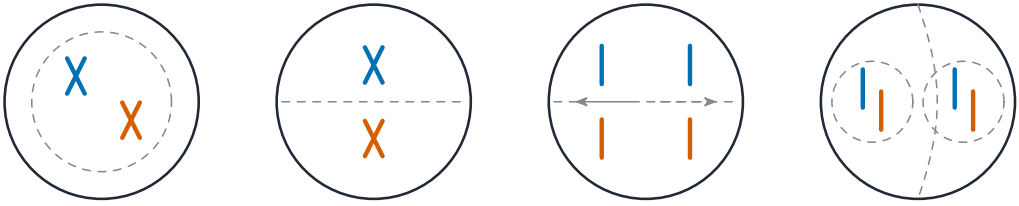
Use structures to explain distribution

Histone-associated packaging helps condense long DNA into visible chromosomes. An X represents attached sisters, not two homologues.

Microtubules and motor proteins help position and move chromosomes. Chromosomes do not swim to poles.

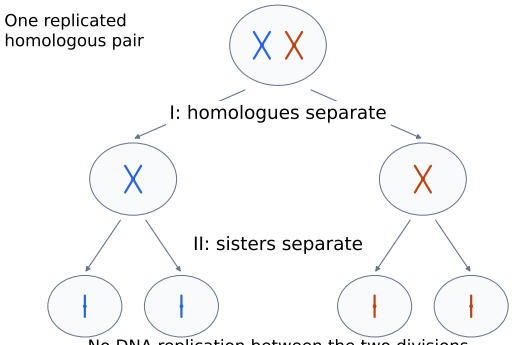
Use arrangement rather than cell shape to identify a phase. Interphase is not a mitotic phase; normal equivalence does not rule out mutation or segregation errors.

The stages of mitosis



Telophase: two new nuclei form

Track one homologous pair through the two divisions



Meiosis I separates homologues; meiosis II separates sisters.

Specify what separates and what each product contains

Stage	Chromosome and DNA outcome
Before I, after replication	Diploid; each chromosome has two sisters
Meiosis I	Homologues separate; haploid products still have duplicated chromosomes
Between I and II	No second DNA replication
Meiosis II	Sisters separate; four haploid nuclei result
Fertilization	Haploid contributions join to restore two chromosome sets

Apply the count to the invented 2n = 4 species

1. **Parent after copying.** Four duplicated chromosomes, 4C DNA.
2. **Each of two products after I.** Two duplicated chromosomes, 2C DNA; one member of each pair.
3. **Each of four products after II.** Two unduplicated chromosomes, 1C DNA. Four nuclei need not become four equal functional gametes in oogenesis.

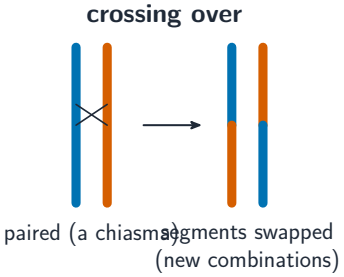
Distinguish two sources of new allele combinations

Mechanism	**What changes?**
Crossing over	Corresponding DNA regions exchanged between non-sister chromatids of homologues in prophase I
Random orientation	Bivalents orient independently at metaphase I, redistributing whole homologues
Mutation	Creates new alleles, rather than merely shuffling them
Fertilization	Combines contributions from two gametes

Possible types across divisions are not products of one division

1. **Assumption.** n $= 3$ independently orienting pairs; ignore crossing over.
2. **Possible combinations.** $2^3 = 8$ whole-chromosome combinations across possible products.
3. **Limit.** One meiosis still produces four nuclei. Crossing over adds within-chromosome combinations; each gamete need not receive exactly half maternal homologues.

Crossing over



New combinations of alleles

Random orientation

independent assortment



the pairs line up in a random order, so each gamete gets a random mix

2^n combinations for n pairs

Connect an abnormal gamete with the full-trisomy model

1. **Error.** A gamete receives two chromosome 21 copies after failure of normal separation.
2. **Fertilization.** Joins a normal gamete carrying one: three chromosome 21 copies, 47 total chromosomes.
3. **Interpretation.** Extra chromosome 21 material causes Down syndrome. Rearrangement and mosaic forms mean not every case is described only by the simple 47-chromosome model.

Name the division in which non-disjunction occurs

Specified error	Four product outcomes
I error, normal II	Two with an extra chromosome; two lacking one
Normal I, error in one II cell	Two normal-number products; one extra; one lacking
Limit	Other segregation steps assumed normal; these are outcomes of specified models, not error probabilities

Include interphase in the denominator

1. **Invented counts.** 160 interphase, 20 prophase, 8 metaphase, 7 anaphase, 5 telophase.
2. **Index.** Mitotic $= 40$; total $= 200$; $40/200 = 0.20 = 20\%$.
3. **Compare.** Another field: $18/120 = 0.15 = 15\%$. Match tissue and sampling before attributing a difference to treatment.

A snapshot fraction is not a direct division rate

Design a representative count and state the population model

Preselect fields, define boundary and ambiguous-cell rules, record exclusions, and use representative fields plus biological replication.

Identify chromosome arrangement, not dark staining alone. All four mitotic phases enter the numerator.

An asynchronous steady population can support a phase-time estimate, but non-cycling cells, synchronization or arrest can break that model.

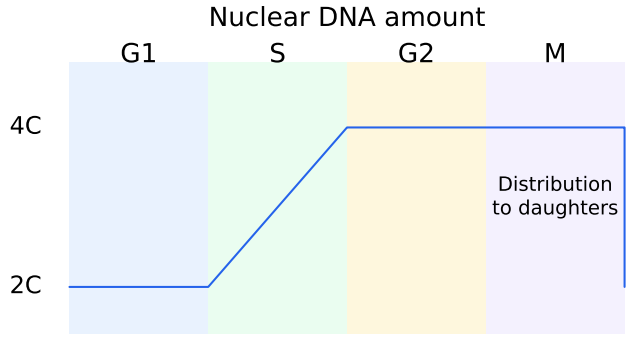
A high mitotic index can reflect slow exit from mitosis

1. **Model estimate.** 20% mitotic and a 15-hour cycle suggest $0.20 \times 15 = 3$ hours in mitosis.
2. **Assumptions.** Representative asynchronous cycling population, steady behaviour and comparable survival.
3. **Alternative.** Metaphase arrest accumulates dividing cells while daughter-cell production can fall. More cells in a phase need not mean faster passage through it.

Distinguish cell number, cell size and tissue context

Example	Interpretation
Plant meristems	Division supplies cells; later expansion/differentiation also contribute
Early animal embryos	Cleavage can partition cytoplasm into more, smaller cells without matching mass growth
Routine skin replacement	Proliferation supplies cells to replace losses
Wound repair	Division works with migration and other tissue processes; enlargement alone is not proliferation

Follow one daughter lineage through DNA copying and distribution



One daughter lineage; phase widths are schematic

DNA amount rises during S, then is distributed to daughters.

Interphase is active, with a distinct DNA-copying stage

Stage	Main connection
G1	Growth and biosynthesis
S	DNA replication; nuclear DNA amount doubles
G2	Further biosynthesis and preparation before division
M and cytokinesis	Chromosomes and cytoplasm distributed
Organelle inheritance	Mitochondria / chloroplasts grow and divide from existing organelles

Track the DNA mass without losing the cell boundary

1. **Invented G1 value.** 6 pg nuclear DNA.
2. **After S and in G2.** 12 pg, still in one cell; the whole anaphase cell retains 12 pg.
3. **Normal daughter.** 6 pg per daughter after distribution. Sister separation does not destroy half the DNA.

Cyclin-dependent controls regulate progression at checkpoints

A threshold is part of a control system, not a sufficient verdict

Different cyclin concentrations rise and fall through the cell cycle; suitable levels help regulate passage through checkpoints.

DNA damage or other unsuitable conditions can prevent progression even when a measured cyclin is abundant.

Not all tissue cells continuously cycle. Specific cyclin names are unnecessary here; explain regulated progression and why it matters.

Two gene classes can lose growth control in different ways

Gene class	Mutation consequence
Proto-oncogene	Can become an oncogene with excessive growth-promoting activity
Tumour suppressor	Loss of function can remove restraint or protective control
Interpretation	Accumulated changes matter; not every mutation makes every gene an oncogene

Tumour behaviour needs evidence beyond size

Term	Meaning
Benign	Localized without malignant invasion / metastasis; location can still cause harm
Malignant	Cancerous; can invade surrounding tissue
Primary tumour	Original site
Secondary tumour	Develops after spread from the primary; retains its cancer origin

Attempt the full practice set before revealing the checks

Explain mechanism, counts and evidence separately

Distinguish cytokinesis from nuclear division, identify mitosis and track $2n = 6$ chromosome / DNA counts through both routes.

Explain variation, non-disjunction, organelle inheritance and the 24/160 mitotic index.

AHL: connect proliferation, cell cycle and cyclins; distinguish tumour terms and evaluate a phase-time estimate.

Check the shared chromosome and combination calculations

1. **Replication.** 2n $= 6$ and 6 pg before copying $\rightarrow$ six duplicated chromosomes, twelve DNA molecules, 12 pg after copying.
2. **Distribution.** Whole mitotic anaphase: twelve chromosomes; daughter: six. Meiosis I product: three duplicated / 6 pg; II: three unduplicated / 3 pg.
3. **Other checks.** $2^4 = 16$ possible combinations across divisions, four nuclei from one meiosis; $24/160 = 0.15 = 15\%$ **mitotic index**.

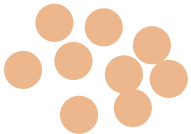
AHL practice: calculate index and evaluate the duration estimate

1. **Counts.** Total $= 270$; mitotic $= 60$; $60/270 = 2/9 \approx 0.222 = 22.2\%$ (rounded).
2. **Time.** $(2/9) \times 20 = 40/9 \approx 4.44$ hours under the stated steady asynchronous population model.
3. **Limits.** Use representative sampling and clear exclusions. Metaphase arrest increases occupancy by slowing exit, not necessarily by producing daughter cells faster.

Uncontrolled cell division



controlled: cells stop dividing



uncontrolled: a tumour grows

The growing mass is a tumour

Check yourself

State what was counted before explaining a consequence

Whole cell, one nucleus and one meiotic product are different boundaries. Chromosome count and DNA amount are different quantities.

Mitosis separates sisters; meiosis I separates homologues; meiosis II separates sisters. Identify phase by arrangement.

AHL: interphase is active; cyclin concentration alone is not the whole checkpoint. Mitotic index and tumour size do not independently establish rate or malignant behaviour.