

The mitotic cell cycle: summary notes

These revision notes cover the **mitotic cell cycle** topic of the Cambridge International AS & A Level Biology syllabus (9700). They cover the structure of a chromosome and the stages of the cell cycle (interphase, mitosis and cytokinesis). For each stage of mitosis they show what happens to the chromosomes, the nuclear envelope, the cell surface membrane and the spindle. They also explain why mitosis matters, the roles of stem cells and telomeres, and how uncontrolled division can lead to a tumour. There are worked examples on counting chromosomes and DNA and on calculating the mitotic index, a glossary, and quick-check questions with answers. Parts marked "Beyond the syllabus" are useful background only and are not required.

Syllabus reference: 9700 Topic 5, Cell and nuclear division (5.1 Replication and division of nuclei and cells; 5.2 Chromosome behaviour in mitosis).

1. Chromosome structure

A **chromosome** is one very long DNA molecule together with proteins. In a eukaryotic nucleus the DNA is packed with proteins called **histones**. DNA and protein together are called **chromatin**.

- **DNA** carries the genes. Each chromosome contains one DNA molecule until the DNA is replicated.
- **Histones** are small, positively charged (basic) proteins. DNA is negatively charged because of its phosphate groups, so the two attract each other. The DNA wraps around groups of eight histone molecules to form bead-like units called **nucleosomes**, which are then coiled and folded further. This packing lets about 2 m of DNA fit into a human nucleus only a few μm across. It also helps control which genes can be transcribed.
- During interphase the chromatin is loosely packed, so genes can be transcribed and DNA can be replicated. At the start of mitosis the chromatin **condenses** (supercoils), so the chromosomes become short, thick and visible with a light microscope.

After DNA replication, each chromosome is made of two identical **sister chromatids**. Each chromatid contains one DNA molecule. The two chromatids are held together at the **centromere**. During mitosis, spindle microtubules attach to the centromere region at protein structures called kinetochores.

At each end of every chromosome is a **telomere**: a long run of a short, repeated, non-coding base sequence (in humans the repeat is TTAGGG). Section 6 covers telomeres.

Learn these definitions

Chromosome: a structure made of one DNA molecule (or, after replication, two identical DNA molecules as sister chromatids) associated with histone proteins, carrying a linear sequence of genes.

Chromatid: one of the two identical copies of a replicated chromosome. Each contains one DNA molecule and is joined to its sister chromatid at the centromere.

Centromere: the region of a chromosome that holds the two sister chromatids together and to which spindle microtubules attach during nuclear division.

Telomere: a repetitive, non-coding DNA sequence at each end of a chromosome that protects the

genes near the ends from being lost during DNA replication.

Diagram described in words: a replicated chromosome in metaphase looks like an X or a pair of parallel rods. Each arm of the X is part of one chromatid. The two chromatids are joined at a narrow point (the centromere). The tips of each chromatid are the telomeres.

Counting chromosomes and chromatids

Count **chromosomes by counting centromeres**. A replicated chromosome (two chromatids, one centromere) counts as **one** chromosome. When the centromere splits in anaphase, each separated chromatid counts as a chromosome in its own right.

Body cells of most animals and many plants are **diploid (2n)**. They contain two sets of chromosomes, arranged in **homologous pairs**: one chromosome of each pair comes from each parent, and the two carry the same genes at the same loci but may have different alleles. Do not confuse homologous chromosomes (a matching pair from two parents) with sister chromatids (two identical copies made by replication).

2. The cell cycle

The **cell cycle** is the sequence of events from the formation of a new cell until that cell divides into two. It has three main parts: **interphase**, **mitosis** (nuclear division) and **cytokinesis** (division of the cytoplasm).

Learn this definition

Mitosis: division of one nucleus into two daughter nuclei that have the same chromosome number as the parent nucleus and are genetically identical to it and to each other.

Interphase

Interphase is usually by far the longest part of the cycle. It is not a "resting" stage, because the cell is metabolically very active. It has three phases.

Phase	Main events
G₁ (first gap / growth phase)	The cell grows, makes proteins (including the enzymes needed for DNA replication) and new organelles, and carries out its normal functions. Each chromosome is a single chromatid (one DNA molecule).
S (synthesis phase)	DNA is replicated (semi-conservatively), so each chromosome now has two identical sister chromatids joined at the centromere. Histones are also made. The mass of DNA in the nucleus doubles. In animal cells the centrosome (a pair of centrioles) is also duplicated.
G₂ (second gap / growth phase)	The cell keeps growing. Respiration supplies the ATP needed for division. Proteins needed for division are made, such as tubulin for the spindle. The newly replicated DNA is checked for errors, which are repaired before mitosis begins.

Beyond the syllabus (useful background, not required): the cycle has checkpoints, for example near the end of G₁ and G₂, where the cell is checked before it goes on. Cells that stop dividing, such as most mature nerve cells, leave the cycle from G₁ (after dividing) and enter a non-dividing state called **G₀**.

Mitosis and cytokinesis

Mitosis divides the nucleus into two genetically identical nuclei. It is a continuous process, but it is described in four stages: **prophase, metaphase, anaphase and telophase** (Section 3). **Cytokinesis** divides the cytoplasm to produce two separate daughter cells. It usually starts in late anaphase or telophase.

How the DNA content changes during the cycle

Stage	DNA mass per nucleus (G_1 value = x)	Chromatids per chromosome	Chromosomes in the cell (counted by centromeres)
G_1	x	1	$2n$
S	rises steadily from x to $2x$	$1 \rightarrow 2$	$2n$
G_2	$2x$	2	$2n$
Prophase and metaphase	$2x$	2	$2n$
Anaphase	$2x$ in the cell, being separated into two sets of x	1 (chromatids separated)	$4n$ ($2n$ moving to each pole)
After telophase / cytokinesis	x in each daughter nucleus	1	$2n$ in each daughter cell

On a graph of DNA mass per cell against time, the line is flat in G_1 , slopes upwards during S, stays flat at double the value through G_2 and early mitosis, and drops back to the original value when the cell divides. The chromosome number per nucleus ($2n$) is the same in the parent and daughter nuclei. Counted by centromeres, the cell has $2n$ chromosomes from G_1 to metaphase and briefly $4n$ in anaphase, when the chromatids separate and become chromosomes ($2n$ moving to each pole). The amount of DNA per chromosome doubles in S phase and halves when the chromatids separate in anaphase.

3. The stages of mitosis

Syllabus 5.2.1 asks you to describe what happens to the **chromosomes** at each stage, together with the **nuclear envelope**, the **cell surface membrane** and the **spindle**, in both animal and plant cells.

Stage	Chromosomes	Nuclear envelope and nucleolus	Spindle
Prophase	Chromatin condenses (coils up). Chromosomes become shorter, thicker and visible, each seen as two sister chromatids joined at the centromere.	The nucleolus disappears. The nuclear envelope breaks down into small vesicles at the end of prophase.	In animal cells the two centrosomes (each with a pair of centrioles) move to opposite poles of the cell. A spindle of microtubules forms between the poles. Once the envelope has broken down, spindle microtubules attach to the centromeres.

Metaphase	Chromosomes line up one by one on the equator (metaphase plate) of the spindle, each attached by its centromere.	No nuclear envelope.	The spindle is fully formed. Microtubules from opposite poles are attached to the centromere of each chromosome (one to each sister chromatid).
Anaphase	Centromeres divide, so the sister chromatids separate. The chromatids (now called chromosomes) are pulled towards opposite poles, centromere first , so the arms trail behind in a V shape.	No nuclear envelope.	Spindle microtubules attached to the centromeres shorten and pull the chromatids apart. This uses energy from ATP.
Telophase	A complete set of chromosomes arrives at each pole. The chromosomes uncoil (decondense) and become long and thin again, so they can no longer be seen.	A new nuclear envelope forms around each set of chromosomes and nucleoli reappear. There are now two nuclei.	The spindle breaks down (the microtubules depolymerise).

Cell surface membrane: it does not change from prophase to anaphase. In animal cells it starts to pull in at the equator (the cleavage furrow) in late anaphase or telophase. In plant cells, new cell surface membranes form from the fused vesicles of the cell plate (see Cytokinesis below).

Key idea: why the daughter nuclei are genetically identical

DNA is replicated accurately (semi-conservatively) in S phase, so the two sister chromatids of every chromosome carry identical DNA. In metaphase each chromosome is attached to microtubules from both poles. In anaphase the sister chromatids are separated, one going to each pole. Each pole therefore receives exactly one copy of every chromosome, so both daughter nuclei have the same number and type of chromosomes as the parent nucleus.

Common trap: in mitosis, homologous chromosomes do **not** pair up. Each chromosome lines up on the equator on its own. (Homologous pairing happens only in meiosis.)

Cytokinesis

Feature	Animal cell	Plant cell
How the cytoplasm divides	A ring of actin filaments (with myosin) pulls the cell surface membrane inwards around the equator. This forms a cleavage furrow , which deepens until the cell is pinched in two.	Vesicles from the Golgi body gather at the equator and fuse to form a cell plate .
Where the division starts	At the edge of the cell; the furrow moves inwards.	At the centre of the cell; the cell plate grows outwards until it reaches the side walls.

New cell wall	None is formed.	The vesicle membranes become the new cell surface membranes, and their contents build a new cellulose cell wall (with a middle lamella) between the two daughter cells.
Shape change	The cell rounds up and constricts in the middle.	The cell wall is rigid, so there is no furrow and the cell does not pinch in.

Plant v. animal mitosis (spindle formation, not cytokinesis)

Feature	Animal cell	Plant cell
Centrioles / centrosomes	Present; the spindle forms from the centrosomes.	Flowering plant cells have no centrioles. The spindle still forms, organised from microtubule-organising regions near the nuclear envelope.

Recognising stages in photomicrographs and slides

You may be asked to identify stages in photographs of, for example, a squashed and stained root tip. Useful clues:

- **Interphase:** a clear, rounded nucleus with an intact envelope, often with a visible nucleolus; granular stained chromatin but no individual chromosomes.
- **Prophase:** the nucleus is still roughly round, but thread-like chromosomes can be seen inside it; the outline of the nucleus may be fading.
- **Metaphase:** chromosomes in a band across the middle of the cell; no nucleus.
- **Anaphase:** two groups of V-shaped chromosomes moving apart towards opposite ends.
- **Telophase:** two dense groups of chromosomes at opposite ends; new nuclear envelopes forming; in plant cells a faint line (the cell plate) may appear between them.

Worked example 1: counting chromosomes, chromatids and DNA

A diploid body cell of a particular plant species has 14 chromosomes. The mass of DNA in the nucleus of this cell during G_1 is 9.6 arbitrary units (au). State the number of chromosomes, the number of chromatids and the mass of DNA in (a) G_2 , (b) metaphase, (c) anaphase (whole cell), (d) one daughter cell after cytokinesis.

Step 1 – G_1 starting point. 14 chromosomes, each one chromatid (one DNA molecule): 14 chromosomes, 14 chromatids, 9.6 au.

Step 2 – S phase replicates every DNA molecule, so the DNA mass doubles: $9.6 \times 2 = 19.2$ au. Each chromosome now has two chromatids, but there are still 14 centromeres.

(a) **G_2 :** 14 chromosomes; $14 \times 2 = 28$ chromatids; 19.2 au.

(b) **Metaphase:** nothing has separated yet: 14 chromosomes; 28 chromatids; 19.2 au.

(c) **Anaphase:** the centromeres have divided, so each of the 28 chromatids is now an independent chromosome: 28 chromosomes in the cell (14 moving to each pole), each a single chromatid; still 19.2 au in the whole cell.

(d) **Daughter cell:** receives one set of 14 chromosomes, each a single chromatid; DNA mass =

$19.2 \div 2 = 9.6$ au (the same as the parent cell in G_1).

4. The significance of mitosis

Mitosis produces daughter cells that are **genetically identical** to each other and to the parent cell and have the **same chromosome number**. This matters whenever an organism needs new cells that carry exactly the same genetic information.

Role	Explanation and example
Growth	A multicellular organism grows by increasing its number of cells. Every new cell needs the full set of genes so that it can later differentiate correctly. Examples: a zygote grows into an embryo; plant shoot and root tips lengthen by division in meristems.
Replacement of damaged or dead cells	Cells that wear out or die are replaced by identical cells that can do the same job. Examples: cells lining the small intestine and the outer layer of the skin are constantly lost and replaced; red blood cells are replaced from stem cells in bone marrow.
Repair of tissues	Nearby cells divide to produce identical replacement cells, which repair the damaged tissue. Examples: healing of a cut in the skin; mending of a broken bone.
Asexual reproduction	A single parent produces offspring that are genetically identical to itself (clones). Examples: budding in yeast, runners of strawberry plants, potato tubers. This lets an organism quickly exploit a favourable environment.
Immune response (<i>link to Topic 11; not listed under 5.1.2</i>)	When a B- or T-lymphocyte with a receptor specific to an antigen is activated, it divides repeatedly by mitosis (clonal expansion). This produces a large clone of identical cells that all recognise the same antigen.

Exam tip: when asked to "explain the importance of mitosis", always link the role to the fact that the cells are genetically identical, not just to "making more cells".

5. Stem cells

Learn this definition

Stem cell: an unspecialised cell that keeps its ability to divide by mitosis indefinitely. Its daughter cells can either stay as stem cells or differentiate into specialised cells.

When a stem cell divides, one daughter cell often stays as a stem cell, keeping up the supply, while the other goes on to differentiate.

Role in cell replacement and tissue repair (the part to learn): adult stem cells are found in tissues such as bone marrow, the skin and the lining of the gut. They divide by mitosis throughout life to replace cells that are lost or damaged. For example, bone marrow stem cells produce millions of new red blood cells every second in a human. This is needed because red blood cells have no nucleus, cannot divide and survive only about four months. In plants, **meristem** cells in root and shoot tips (and in the cambium) act as stem cells.

Beyond the syllabus (useful background, not required): stem cells differ in how many cell types they can produce (their potency).

Type (potency)	Can become	Example
Totipotent	Any cell type, including cells of the placenta; can form a whole organism.	The zygote and the cells of the very early embryo (first few divisions).
Pluripotent	Almost any cell type of the body, but not a whole organism.	Cells of the inner cell mass of an early embryo (blastocyst): embryonic stem cells.
Multipotent	A limited range of related cell types.	Stem cells in adult bone marrow, which produce red blood cells, white blood cells and platelets.

6. Telomeres

DNA polymerase cannot fully replicate the very end of a linear DNA molecule, so a short stretch at the end is not copied. As a result, the DNA molecule gets a little **shorter every time it is replicated**.

Beyond the syllabus (useful background, not required): the lagging strand is built in short sections, each starting from a short primer. When the last primer at the end of the strand is removed, DNA polymerase has nothing to build from, so that stretch is not copied.

Telomeres solve this problem:

- They are long stretches of repeated, non-coding sequence at the ends of chromosomes, so the section lost at each replication is part of the telomere, not a gene.
- They therefore **prevent the loss of genes** from the ends of chromosomes during DNA replication.
- They also stop chromosome ends from being treated as broken DNA and from joining to other chromosomes.

In most body cells, telomeres get shorter with each division. When they become too short, the cell stops dividing (or dies). This limits how many times such cells can divide and is linked to ageing. Cells that must divide many times, such as **stem cells** and the cells that give rise to gametes, contain the enzyme **telomerase**. Telomerase adds repeats back onto the ends of chromosomes, so the telomeres stay long enough for many more divisions. Many **cancer cells** also have active telomerase, which is one reason they can keep dividing indefinitely.

7. Uncontrolled cell division and tumours

The cell cycle is normally tightly controlled. Proteins coded for by particular genes stimulate division when new cells are needed. Other proteins stop the cycle if the DNA is damaged or the cell is not ready. Cells normally stop dividing when they touch neighbouring cells, and damaged cells can be made to self-destruct (apoptosis).

Key idea: the chain to learn (5.1.6)

A **mutation** occurs in a gene that controls cell division → the protein it codes for no longer works normally, so division is no longer controlled → the cell divides repeatedly by mitosis → mitosis copies the mutated DNA into every daughter cell, so all of them divide uncontrollably too → a

mass of cells, a **tumour**, forms. Usually several mutations must build up in the same cell.

Carcinogens are factors that increase the chance of mutation and so of cancer. Examples: ultraviolet light, ionising radiation (such as X-rays and gamma rays), chemicals in tobacco smoke, and some viruses. Many anticancer drugs and radiotherapy work by damaging DNA or stopping spindle formation, which affects rapidly dividing cells most.

Beyond the syllabus (useful background, not required): the genes involved, and the two kinds of tumour.

- **Proto-oncogenes** normally stimulate cell division. A mutation can turn one into an **oncogene**, which is permanently "switched on", so division is stimulated all the time.
- **Tumour suppressor genes** normally slow or stop the cycle, for example if DNA is damaged. A mutation that inactivates one removes this brake.

Benign tumour	Malignant tumour (cancer)
Usually grows slowly.	Often grows rapidly.
Cells stay together, often inside a capsule; does not invade surrounding tissue.	Invades neighbouring tissues.
Does not spread to other parts of the body.	Cells can break off and travel in blood or lymph to form secondary tumours elsewhere (metastasis).
Can still be harmful if it presses on organs.	Much more dangerous; harder to treat once it has spread.

8. The mitotic index

The mitotic index is not a named learning outcome in Topic 5, but it often appears in practical and data-analysis questions. It uses the skills from 5.2.2 (interpreting photomicrographs and slides) and from the practical papers.

The **mitotic index** is the proportion of cells in a sample that are dividing by mitosis. It measures how quickly a tissue is growing or replacing cells. A high mitotic index shows rapid division, for example in a root tip meristem or in a tumour.

Learn this formula

mitotic index = number of cells in mitosis ÷ total number of cells counted

It can be given as a decimal or as a percentage (multiply by 100). Cells in mitosis are those in prophase, metaphase, anaphase or telophase. Interphase cells are **not** included in the top line, but they **are** included in the total.

The cells in a sample are dividing at random times, so the fraction of cells in a stage is proportional to how long that stage lasts. If the length of the whole cell cycle is known:

time spent in a stage = (number of cells in that stage ÷ total number of cells) × length of cell cycle

Worked example 2: calculating a mitotic index

A student made a squash of a stained onion root tip and counted the cells in five fields of view. The results were:

Stage	Number of cells
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Interphase	350
Prophase	28
Metaphase	9
Anaphase	6
Telophase	7

(a) Calculate the mitotic index as a percentage. (b) The cell cycle in these cells takes 24 hours. Calculate the time spent in metaphase, in minutes.

Step 1 – cells in mitosis: $28 + 9 + 6 + 7 = 50$

Step 2 – total cells counted: $350 + 50 = 400$

Step 3 – mitotic index: $50 \div 400 = 0.125$

Step 4 – as a percentage: $0.125 \times 100 = 12.5\%$

Step 5 – fraction in metaphase: $9 \div 400 = 0.0225$

Step 6 – time in metaphase: $0.0225 \times 24 \text{ h} = 0.54 \text{ h}$

Step 7 – convert to minutes: $0.54 \times 60 = 32.4 \text{ minutes}$ (about 32 minutes)

Check: prophase has the most mitotic cells (28), so it is the longest stage of mitosis in this sample. Anaphase has the fewest (6), so it is the shortest. Interphase (350 of 400 cells) takes $350 \div 400 \times 24 = 21 \text{ h}$, most of the cycle.

Worked example 3: comparing two regions

In a second root, the student counted 250 cells in a region 1 mm behind the tip and found 40 in mitosis. In a region 10 mm behind the tip, 3 of 300 cells were in mitosis. Compare the two regions and explain the difference.

Step 1 – region near tip: $40 \div 250 = 0.16$ (16%)

Step 2 – region further back: $3 \div 300 = 0.01$ (1%)

Step 3 – compare: $16 \div 1 = 16$, so the mitotic index close to the tip is 16 times higher.

Step 4 – explain: the region just behind the tip is the meristem, where unspecialised cells divide rapidly by mitosis to produce new cells for growth. Further from the tip, cells have stopped dividing and are elongating and differentiating into specialised cells such as xylem, so few are in mitosis.

Practical points for reliable counts: count cells in several fields of view (and several root tips) and calculate a mean; decide beforehand how to treat cells at the edge of the field of view; only score cells in which the stage can be seen clearly; take samples from the same region of the root each time. The stain (for example acetic orcein or toluidine blue) binds to the chromosomes so they can be seen. The tissue is treated with warm acid to separate the cells so they can be squashed into a single layer.

Key terms

Term	Definition
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Anaphase	Stage of mitosis in which centromeres divide and sister chromatids are pulled to opposite poles by shortening spindle microtubules.
Cell cycle	The sequence of events from the formation of a cell until it divides into two: interphase, mitosis and cytokinesis.
Cell plate	Structure formed at the equator of a dividing plant cell from fused Golgi vesicles; develops into new membranes and a new cell wall.
Centromere	Region of a chromosome that holds sister chromatids together, where spindle microtubules attach.
Centrosome	Microtubule-organising centre in animal cells containing a pair of centrioles; forms the poles of the spindle.
Chromatid	One of two identical copies of a replicated chromosome, each containing one DNA molecule.
Chromatin	The complex of DNA and histone proteins that makes up chromosomes.
Clonal expansion	Repeated mitosis of an activated lymphocyte to produce many identical cells specific to one antigen (Topic 11).
Cytokinesis	Division of the cytoplasm to form two daughter cells after nuclear division.
Histones	Positively charged proteins around which DNA is wound to form nucleosomes.
Interphase	The part of the cell cycle between divisions (G_1 , S, G_2), in which the cell grows and replicates its DNA.
Metaphase	Stage of mitosis in which chromosomes are lined up on the equator of the spindle, attached by their centromeres.
Metastasis	Spread of cancer cells from a primary tumour to form secondary tumours elsewhere in the body (background).
Mitosis	Nuclear division producing two genetically identical nuclei with the same chromosome number as the parent nucleus.
Mitotic index	The number of cells in mitosis divided by the total number of cells counted.
Oncogene	A mutated proto-oncogene that stimulates cell division continuously (background).
Prophase	First stage of mitosis: chromosomes condense, the nucleolus disappears, the spindle forms and the nuclear envelope breaks down.
Spindle	Array of microtubules that attaches to centromeres and moves chromosomes during nuclear division.
Stem cell	Unspecialised cell that can keep dividing by mitosis; its daughter cells can stay as stem cells or differentiate into specialised cells.
Telomerase	Enzyme that adds repeat sequences to telomeres; active in stem cells, gamete-producing cells and many cancer cells.
Telomere	Repetitive non-coding DNA at chromosome ends that prevents loss of genes during DNA replication.
Telophase	Final stage of mitosis: chromosomes reach the poles and uncoil, nuclear envelopes re-form and the spindle breaks down.

Tumour	A mass of cells produced by uncontrolled mitosis.
Tumour suppressor gene	A gene whose product slows or stops the cell cycle; inactivation by mutation can lead to uncontrolled division (background).

Quick check

1. State the name of the region that holds two sister chromatids together. [1]
2. State the phase of the cell cycle during which DNA is replicated. [1]
3. State **two** structures or molecules, other than DNA, found in a chromosome during metaphase. [2]
4. Describe what happens to the nuclear envelope and the nucleolus during mitosis. [3]
5. Describe the behaviour of the chromosomes during metaphase and anaphase. [4]
6. Outline **three** differences between cytokinesis in an animal cell and in a plant cell. [3]
7. A body cell of a species of fish has 46 chromosomes. State the number of chromatids in the cell in G₂, and the number of chromosomes moving to each pole in anaphase. [2]
8. Explain the importance of mitosis in the repair of a damaged tissue. [3]
9. In a count of cells from a root tip, 612 cells were in interphase, 45 in prophase, 12 in metaphase, 8 in anaphase and 15 in telophase. Calculate the mitotic index as a percentage. Give your answer to one decimal place. [2]
10. Using the data in question 9, and given that the cell cycle lasts 18 hours, calculate the time spent in anaphase in minutes. Show your working. [2]
11. Outline the role of telomeres and explain why stem cells can divide many more times than most body cells. [4]
12. Explain how a mutation in a gene that controls cell division can lead to the formation of a tumour. [4]
13. A cell in a root tip squash shows two groups of V-shaped chromosomes moving towards opposite ends of the cell. There is no nuclear envelope. Identify the stage of mitosis and give **two** reasons for your answer. [3]
14. Outline the role of stem cells in the replacement of red blood cells. [3]

Answers

1. Centromere. [1]
2. S phase (synthesis phase) of interphase. [1]
3. Any two: histone proteins; centromere; telomeres; (sister) chromatids. [2]
4. The nucleolus disappears during prophase; the nuclear envelope breaks down (into vesicles) at the end of prophase; a new nuclear envelope re-forms around each set of chromosomes in telophase and nucleoli reappear. [3]
5. Metaphase: chromosomes line up (singly, not in homologous pairs) on the equator of the spindle; each is attached by its centromere to microtubules from both poles. Anaphase: centromeres divide / sister chromatids separate; chromatids are pulled to opposite poles by shortening microtubules, centromere first (arms trailing, V-shaped). [4]

6. Any three; each must be a comparison: animal forms a cleavage furrow / plant forms a cell plate; animal furrow starts at the edge and moves inwards / plant cell plate forms in the centre and grows outwards to the side walls; animal uses a contractile ring of actin (and myosin) to pull the membrane in / plant uses Golgi vesicles that fuse at the equator; plant lays down a new cellulose cell wall (middle lamella) / animal forms no wall. (max 3) [3]

Do not credit points about centrioles or the spindle: these are differences in mitosis, not cytokinesis.

7. G_2 : $46 \times 2 = 92$ chromatids. Anaphase: 46 chromosomes move to each pole. [2]

8. Mitosis produces new cells to replace those damaged or killed; daughter cells are genetically identical to the parent cells (same number of chromosomes, same genes); so they can carry out the same functions / differentiate into the same cell type as the cells they replace; e.g. cells at the edge of a skin wound divide to close it. (max 3) [3]

9. Cells in mitosis = $45 + 12 + 8 + 15 = 80$. Total = $612 + 80 = 692$. Mitotic index = $80 \div 692 = 0.1156... \times 100 = 11.6\%$. [2]

10. Fraction in anaphase = $8 \div 692 = 0.01156...$; time = $0.01156 \times 18 \text{ h} = 0.2081 \text{ h}$; $0.2081 \times 60 = 12.5$ minutes (accept 12 to 12.5 min). Alternative: $8 \div 692 \times 1080 \text{ min} = 12.5 \text{ min}$. [2]

11. Telomeres are repeated, non-coding sequences at the ends of chromosomes; DNA polymerase cannot replicate the very end of the DNA (the lagging strand), so the DNA shortens at each replication; the part lost is telomere rather than genes, so telomeres prevent loss of genes; in most body cells telomeres shorten with each division until the cell stops dividing; stem cells contain (active) telomerase; which adds repeats back onto the telomeres, so they stay long enough for many more divisions. (max 4) [4]

12. The gene codes for a protein that controls the cell cycle (stimulates or stops division); the mutation changes the base sequence, so the protein is non-functional or overactive; cell division is no longer controlled / the cell keeps dividing when it should stop; the cell divides repeatedly by mitosis; the mutation is copied into all daughter cells because mitosis produces genetically identical cells; a mass of cells (tumour) forms; usually several mutations are needed. (max 4) [4]

13. Anaphase [1]. Reasons, any two: chromatids / chromosomes are moving to opposite poles; V shape because each is pulled by its centromere with the arms trailing; no nuclear envelope, so it is not interphase or prophase; not yet telophase, because the new nuclear envelopes have not formed. (max 2 for reasons) [3]

14. Stem cells in the bone marrow; divide by mitosis (throughout life); one daughter cell stays as a stem cell, keeping up the supply; the other differentiates into red blood cells; needed because red blood cells have no nucleus and cannot divide / only live about four months. (max 3) [3]