DP IB Biology: SL

Your notes

1.4 Cells: Division

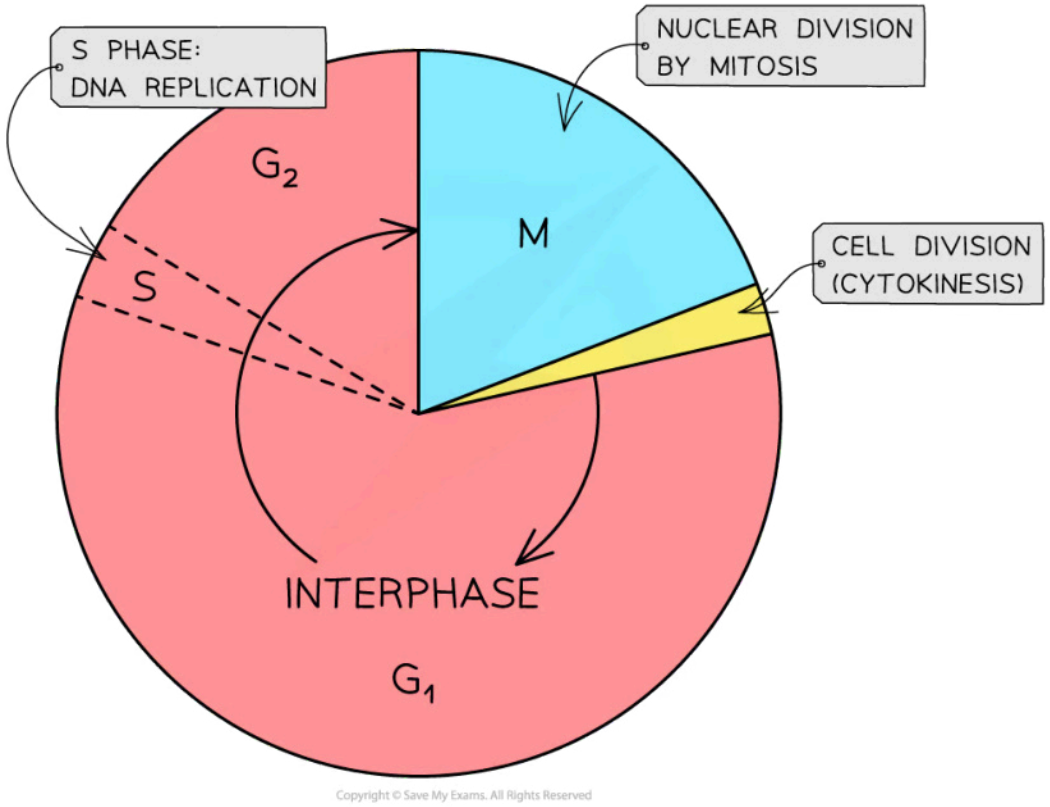
Contents

1.4.1 Cell Cycle

Your notes

Interphase

- **Mitosis** is part of a **precisely controlled process** known as the **cell cycle**
- The cell cycle is the **regulated sequence of events** that occurs **between one cell division and the next**
- The cell cycle has three phases:
  - **interphase**
  - **nuclear division (mitosis)**
  - **cell division (cytokinesis)**
- The length of the cell cycle varies depending on:
  - The environmental conditions, the cell type and the organism
  - For example, onion root tip cells divide once every 20 hours (roughly) but human intestine epithelial cells divide once every 10 hours (roughly)
- The movement from one phase to another is triggered by chemical signals called **cyclins**



The cell cycle

S = synthesis (of DNA); G = growth; M = mitosis

Your notes

Interphase

- **Interphase** is the **longest** and **most active phase** of the **cell cycle**
- During interphase, the cell:
  - **Increases** in **mass** and **size**
  - Carries out many cellular functions in the nucleus and cytoplasm eg. **synthesising proteins** and **replicating its DNA** ready for mitosis (these only occur during interphase)
  - **Increases** the number of **mitochondria**
  - **Increases** the number of **chloroplasts** (if they are a plant or algae cell)

The phases of interphase

- Interphase consists of **three** phases:
  - **G_1 phase**
  - **S phase**
  - **G_2 phase**
- The gap between the previous cell division and the S phase is called the **G_1 phase** – **G** stands for **growth**
  - Cells make the **RNA, enzymes and other proteins required for growth** during the G_1 phase
- It is at some point during the G_1 phase a **signal** is received telling the cell to **divide** again (although some cells do not receive this signal and will **never divide;** they enter the **G_0 phase**)
- After the G_1 phase of interphase the cell enters the next phase of the cell cycle, the **S phase** – **S** stands for **synthesis** (of DNA)
  - The S phase is relatively short
  - The **DNA in the nucleus replicates,** resulting in each chromosome consisting of two identical sister chromatids
- Between the S phase and next cell division event the **G_2 phase** occurs
  - During the G_2 phase, the **cell continues to grow and the new DNA that has been synthesised is checked** and any errors are usually repaired
  - Other preparations for cell division are made (eg. production of tubulin protein, which is used to make microtubules for the mitotic spindle)
- **Interphase = G_1 + S + G_2**

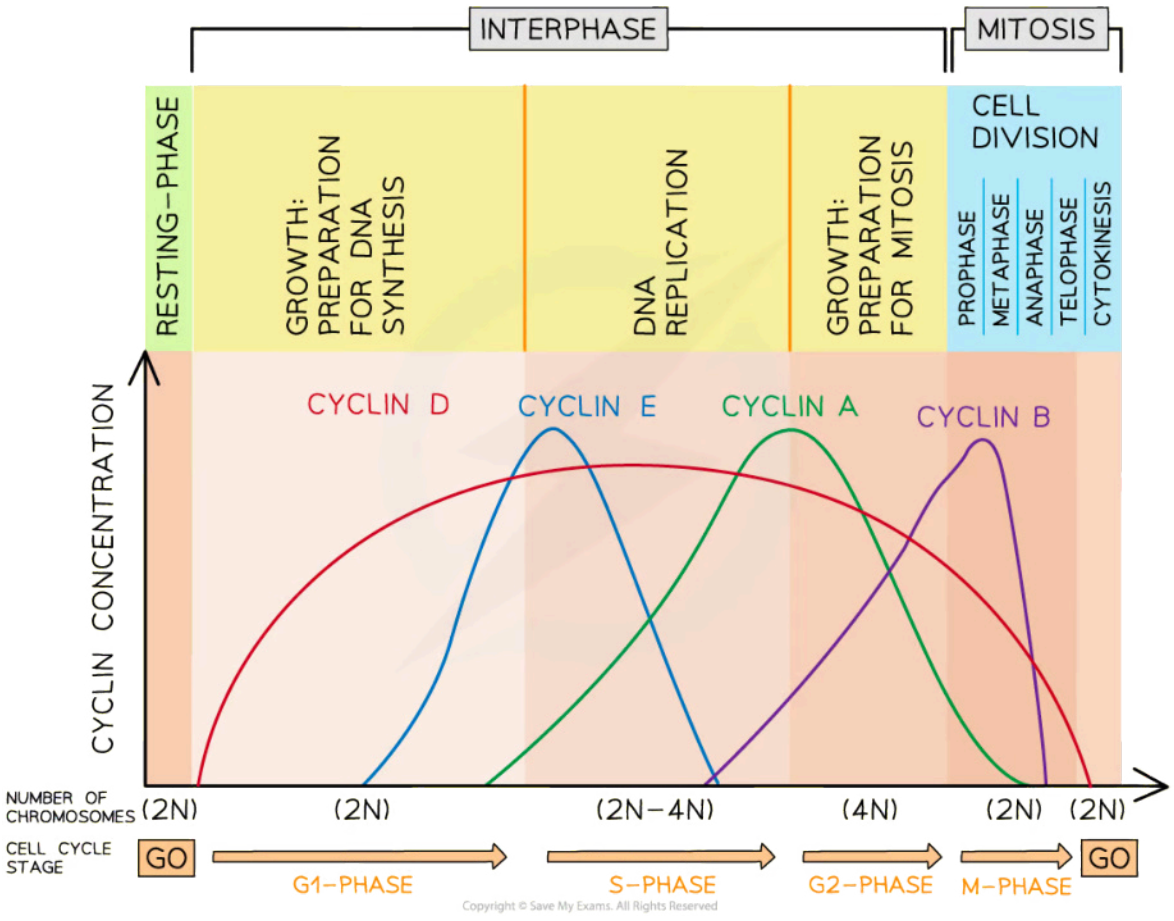
Examiner Tip

Make sure you know the order of the phases of the cell cycle but also what specifically occurs during the different phases. Don't forget, interphase is itself made up of three distinct stages (G_1, S and G_2) and you need to know what happens during each of these.For example, an exam question might ask you to identify the stage of the cell cycle during which a cell would be producing the most mRNA molecules and explain why. The correct answer would be the G_1 phase, as this is when protein synthesis is occurring and the production of mRNA occurs during transcription (the first part of protein synthesis).

Cyclins

Your notes

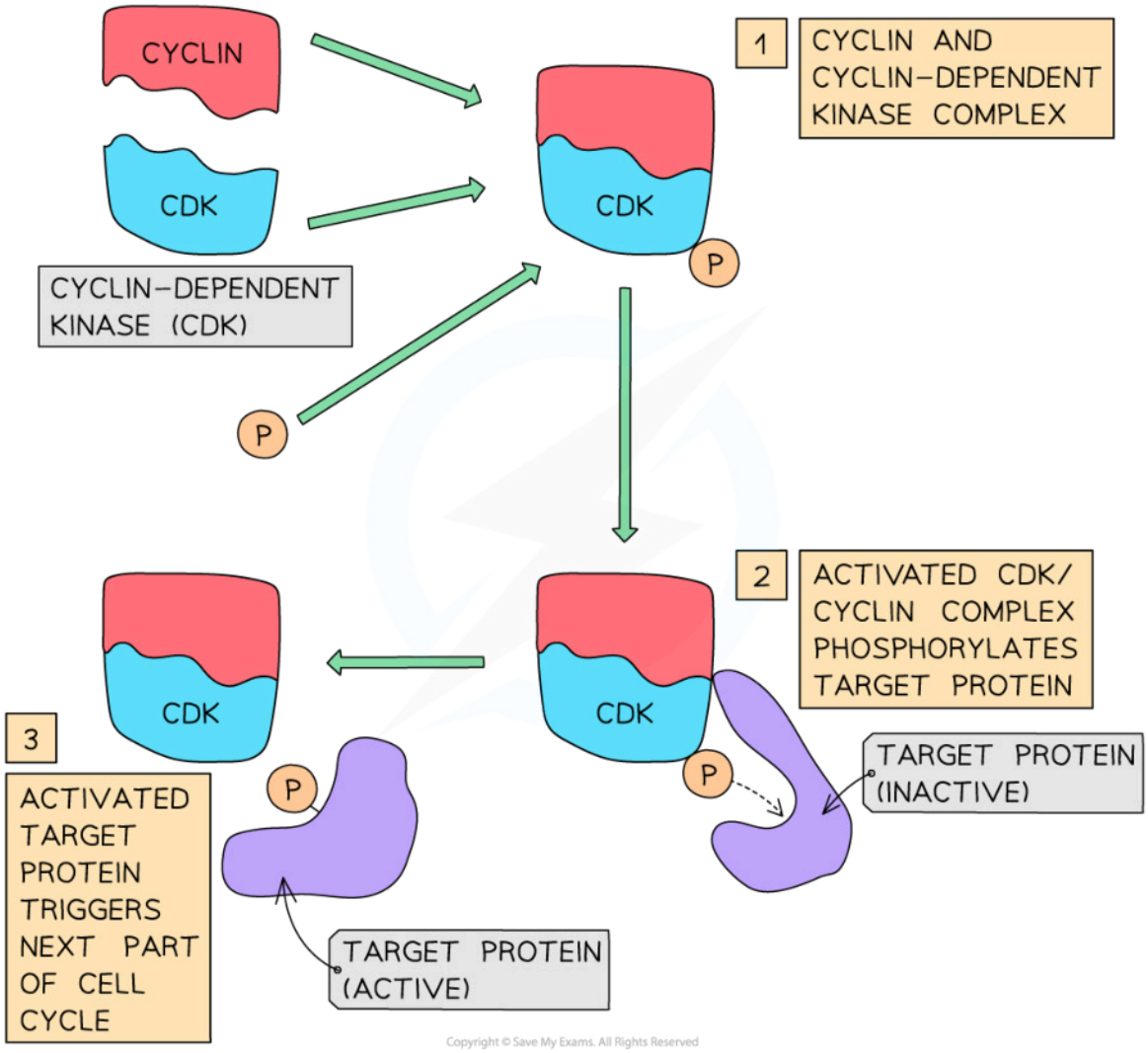
- The **cell cycle** is a sequence of stages including **interphase** (G_1, S & G), **mitosis** and **cytokinesis**
- The cycle is **controlled** by **cyclins** (a group of proteins) and **kinases** (enzymes)
- There are **four different cyclins** (**D, E, A & B**) whose concentrations rise and fall over the cycle:
  - D – **present first**, triggers cells to **move** from **G_1 to S phase**
  - E – **highest** concentration at the start of **S phase**, **prepares** the cell for **DNA replication** during S phase
  - A – **highest** concentration in **G_2 phase** but activates two different kinases that trigger two processes:
    - In the **S phase**, it **activates DNA replication**
    - In **G_2 phase**, it **prepares** the cell for **mitosis**
  - B - **highest** concentration at the **beginning** of **mitosis**, **promotes** the **formation** of the **mitotic spindle**



Cyclins control the cell cycle. The presence of certain cyclins triggers a specific stage of the cell cycle.

Your notes

- When each of the different **cyclins** reach a **certain concentration** they **trigger the next stage** of the cell cycle
- This ensures **key processes** (e.g. DNA replication, organelle multiplication and protein synthesis) **occur** at the **correct time**
- When a specific cyclin has reached a certain concentration it will **bind** with another group of proteins (**cyclin-dependent kinases**) forming a **complex** which is **activated**
- This complex **phosphorylates** (attaches a phosphate) a **target protein** which **activates it,** causing it to trigger **specific functions** (e.g. DNA replication)
- Once the specific function is complete the phosphate is released, the cyclin breaks down and the cyclin-dependent kinases become inactive



The mechanism for cell cycle control by cyclins

NOS: Serendipity and scientific discoveries; the discovery of cyclins was accidental

- Some scientific discoveries occur by accident, meaning that the scientist might not necessarily have been deliberately searching for information about the particular mechanism, process, molecule or structure that they ended up discovering
- The discovery of the cyclins was **serendipitous** (occurred by chance)
- Tim Hunt and his team were researching protein synthesis in sea urchin eggs, however, whilst doing this research they noticed a protein (later named by Hunt as **cyclin**) that repeatedly increased and decreased in concentration and that these coincided with the phases of the cell cycle
- This discovery led to new research which found the presence of other cyclins and their function as a key factor in the regulation of the cell cycle

Examiner Tip

It is important to know the order of the cyclins (DEAB - think dead but with a B of course). When answering questions on which cyclins trigger which stage of the cell cycle it may be easier to sketch a graph. In Biology a well-annotated diagram can get you as many marks as a written answer.


Your notes

Cytokinesis

Cytokinesis

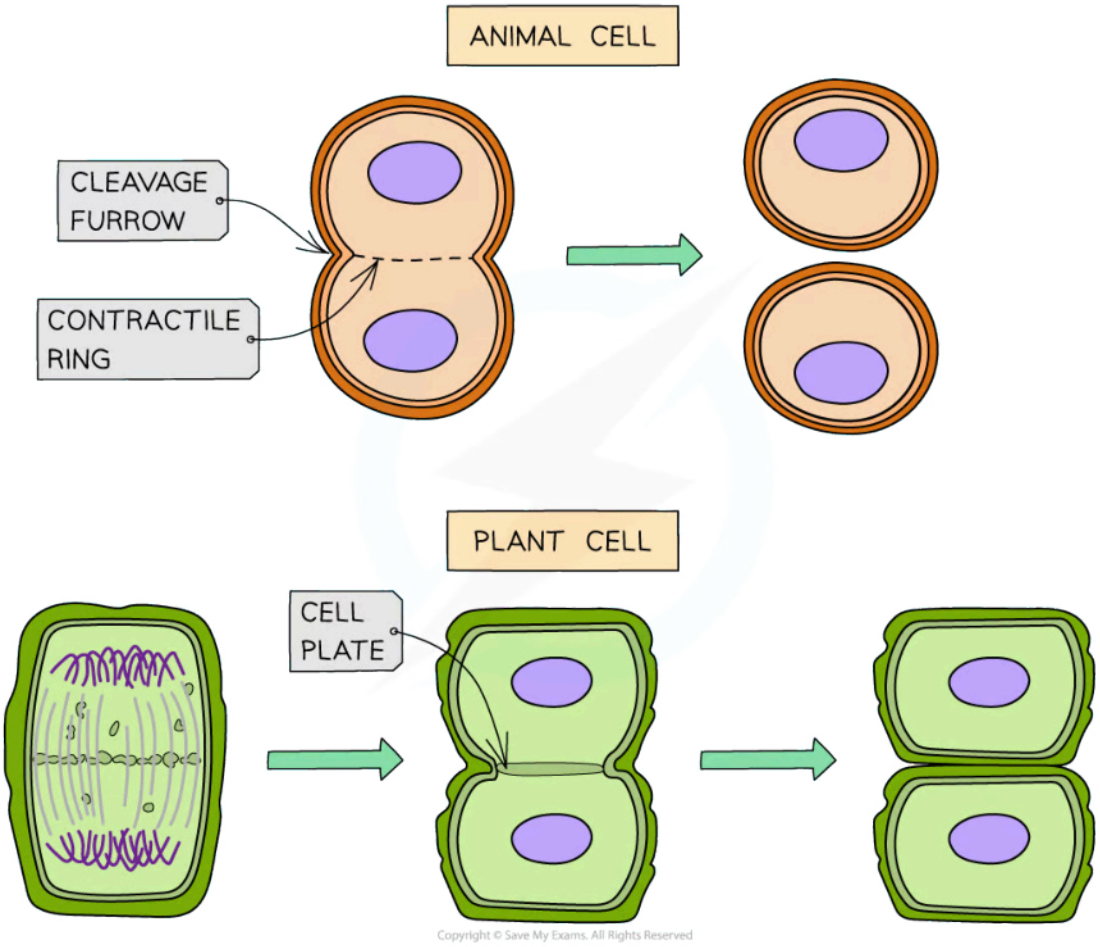
- Follows the nuclear division (**mitosis**) phase
- Once the nucleus has divided into two genetically identical nuclei, the **cell divides in two** with one nucleus moving into each cell to **create two genetically identical daughter cells**

Mitosis in animal and plant cells

- The process differs slightly in animal and plant cells
- In **animal** cells:
  - A '**cleavage furrow**' forms and separates the daughter cells
  - The cleavage furrow forms when actin and myosin proteins form a contractile ring just under the plasma membrane
  - This ring is formed at the equator (centre) of the cell
  - As the proteins contract, they pull the plasma membrane towards the centre eventually separating the cell into two daughter cells
- In **plants** cells:
  - A '**cell plate**' (the precursor to a new cell wall) forms at the equator. Once the cell plate reaches the cell walls of the parent cell, new cell walls are produced, separating the new daughter cells
  - The cell plate is formed from vesicles carrying carbohydrates, lipids and proteins fusing together to create the two plasma membranes
  - After this other vesicles, carrying pectin and cellulose, deposit these substances by exocytosis in the gap between the two new membranes leading to the formation of new cell walls


Your notes

Your notes



Cytokinesis in an animal cell and a plant cell

Examiner Tip

Remember that cytokinesis is **not** a stage in mitosis, it is the last stage of the **cell cycle**.

1.4.2 Phases of Mitosis

Your notes

Phases of Mitosis

- Mitosis is the process of nuclear division by which **two genetically identical daughter nuclei** are produced that are also genetically identical to the parent cell nucleus (they have the same number of chromosomes as the parent cell)
- **Significance of mitosis**: mitosis occurs whenever the production of genetically identical nuclei are required in eukaryotic cells
  - E.g. during embryonic development, growth, tissue repair and asexual reproduction

Embryonic development and growth of multicellular organisms

- **Unicellular zygotes** divide by mitosis in order to **grow in size**
- After a certain amount of growth, they then differentiate **into embryos**
- **Growth** of multicellular organisms occurs as the number of new cells increases due to mitosis
- This growth may occur across the whole body of the organism or be confined to certain regions, such as in the meristems (growing points) of plants

Replacement of cells & repair of tissues

- Damaged tissues can be repaired by mitosis followed by cell division
- As cells are constantly dying they need to be **continually replaced by genetically identical cells**
- In humans, for example, cell replacement occurs particularly rapidly in the skin and the lining of the gut
- Some animals can regenerate body parts, for example, zebrafish can regenerate fins and axolotls regenerate legs and their tail amongst other parts

Asexual reproduction

- Asexual reproduction is the production of new individuals of a species by a **single** parent organism – the offspring are genetically identical to the parent
- For unicellular organisms such as *Amoeba*, cell division results in the reproduction of a **genetically identical offspring**
- For multicellular organisms, new individuals grow from the parent organism (by cell division) and then detach ('bud off') from the parent in different ways
- This type of reproduction can be observed in different plant, fungi and animal species
- Some examples of these are budding in *Hydra* and yeast and runners from strawberries

Phases of Mitosis

- Although mitosis is, in reality, one continuous process, it can be divided into **four main stages or phases**
- These stages are:
  - **Prophase**
  - **Metaphase**

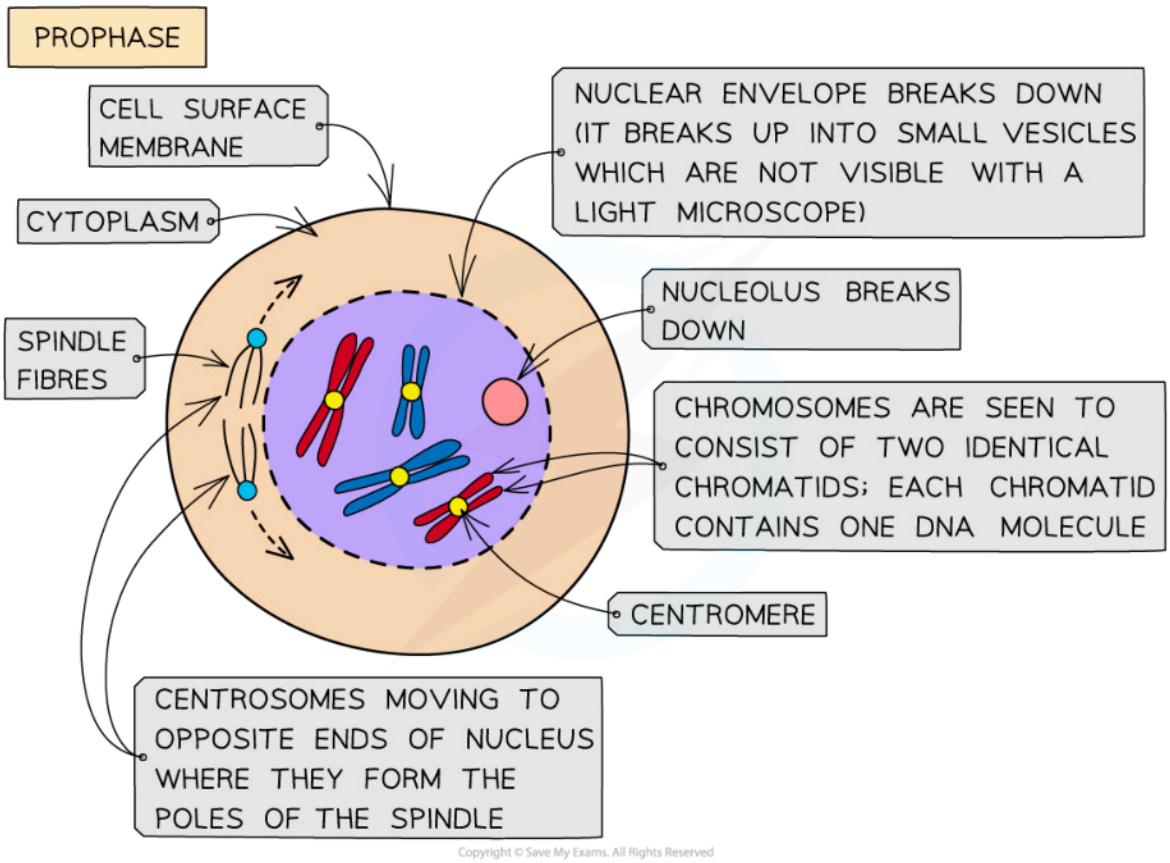
- **Anaphase**
- **Telophase**

- Most organisms contain many chromosomes in the nuclei of their cells (eg. humans have 46) but the diagrams below show mitosis of an animal cell with only four chromosomes, for simplicity
- The different colours of the chromosomes are just to show that half are from the female parent and half from the male parent

Your notes

Prophase

- Chromosomes **condense** and are now visible when stained
- The chromosomes consist of **two identical chromatids** called **sister chromatids** (each containing one DNA molecule) that are joined together at the centromere
- The two centrosomes (replicated in the G_2 phase just before prophase) move towards **opposite poles** (opposite ends of the nucleus)
- **Spindle fibres** (protein **microtubules**) begin to emerge from the centrosomes (consists of two centrioles in animal cells)
- The **nuclear envelope** (nuclear membrane) **breaks down** into small vesicles
- The nucleolus disappears

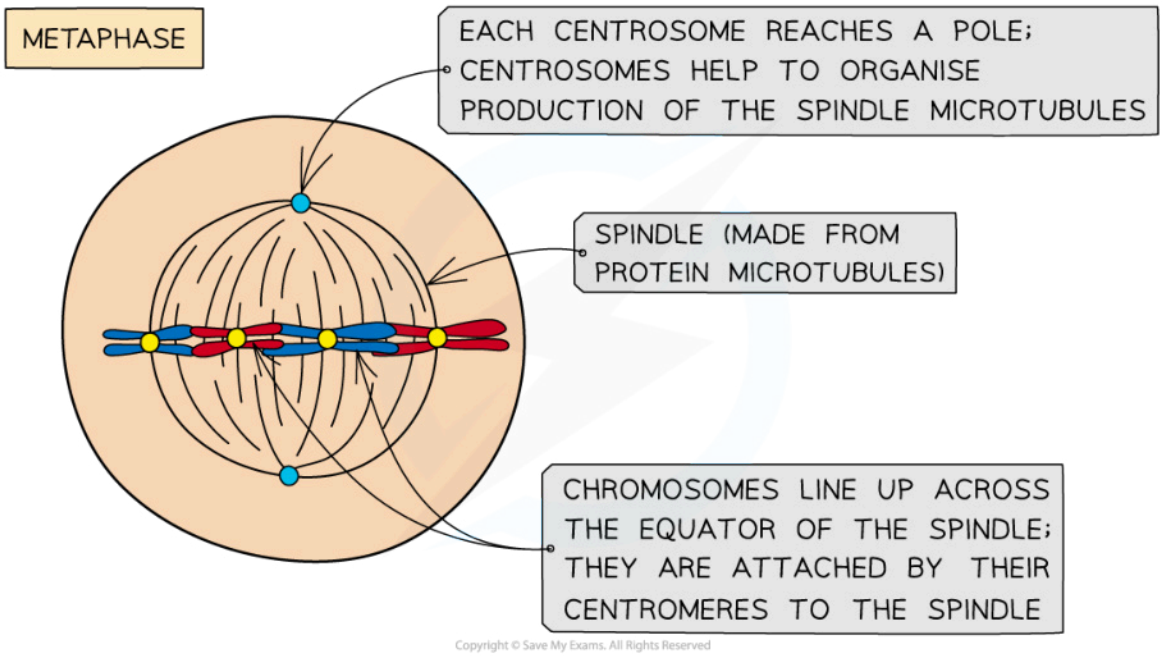


Prophase

Your notes

Metaphase

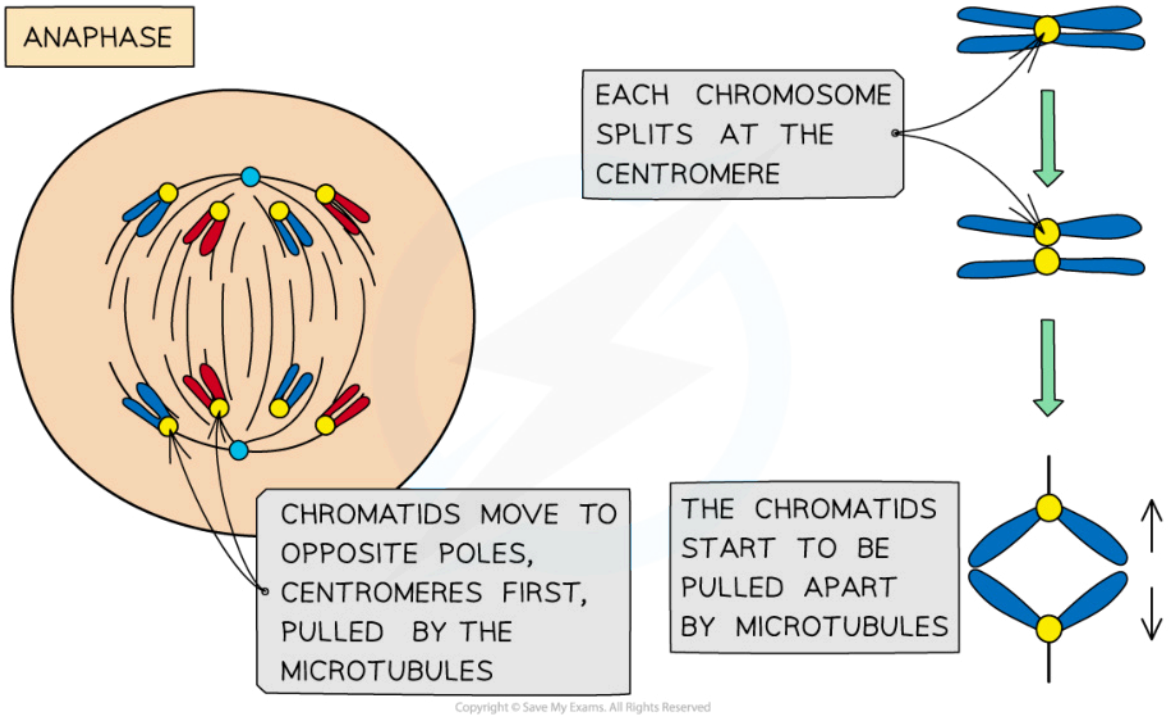
- **Centrosomes** reach **opposite poles**
- **Spindle fibres** (protein microtubules) continue to **extend from centrosomes**
- Chromosomes **line up at the equator** of the spindle (also known as the metaphase plate) so they are equidistant to the two centrosome poles
- Spindle fibres (protein microtubules) reach the chromosomes and **attach to the centromeres**
  - This attachment involves specific proteins called **kinetochores**
- Each **sister chromatid** is attached to a spindle fibre originating from **opposite poles**



Metaphase

Anaphase

- The sister chromatids **separate at the centromere** (the centromere divides in two)
- Spindle fibres (protein microtubules) begin to **shorten**
- The separated sister chromatids (**now called chromosomes**) are **pulled to opposite poles** by the spindle fibres (protein microtubules)

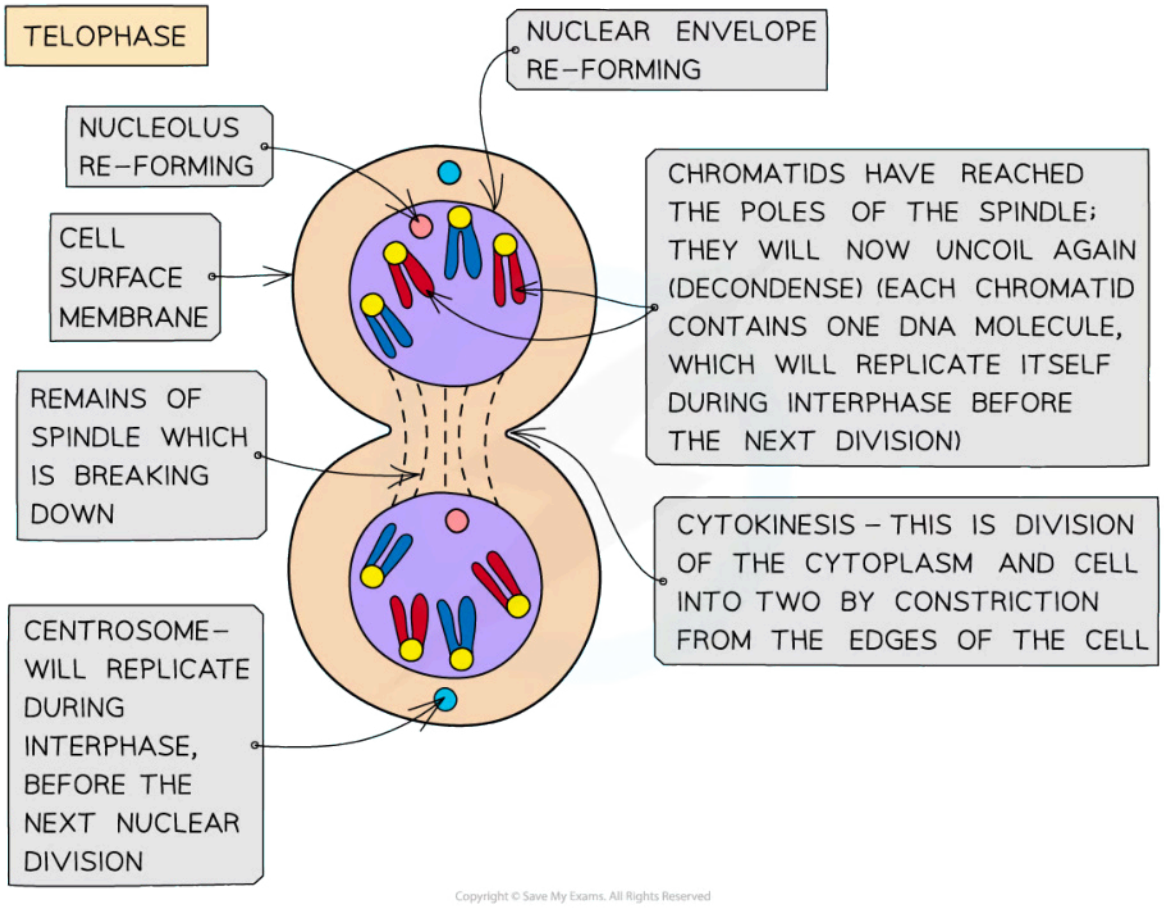


Anaphase

Telophase

- Chromosomes arrive at opposite poles and begin to **decondense**
- **Nuclear envelopes** (nuclear membranes) begin to **reform** around each set of chromosomes
- The **spindle fibres break down**
- New **nucleoli form** within each nucleus

Your notes



Telophase

Examiner Tip

Make sure you learn the four stages of mitosis and what is happening to the DNA molecules (one chromatid contains one DNA molecule) at each stage – learn **'PMAT'** (prophase, metaphase, anaphase, telophase) to help you remember the order of the stages!After interphase but before the parent cell undergoes mitosis, the human parent cell nucleus actually contains 92 DNA molecules! This is because during interphase (S phase), the 46 DNA molecules in the parent cell have replicated to form sister chromatids. As human cells have a diploid number of 46 this replication results in 92 molecules. This ensures the two daughter cells will be diploid (have 46 chromosomes each) when mitosis occurs.Remember to read the questions carefully as **only** human diploid cells have 46 chromosomes so if the question refers to another organism, its diploid number will be different.

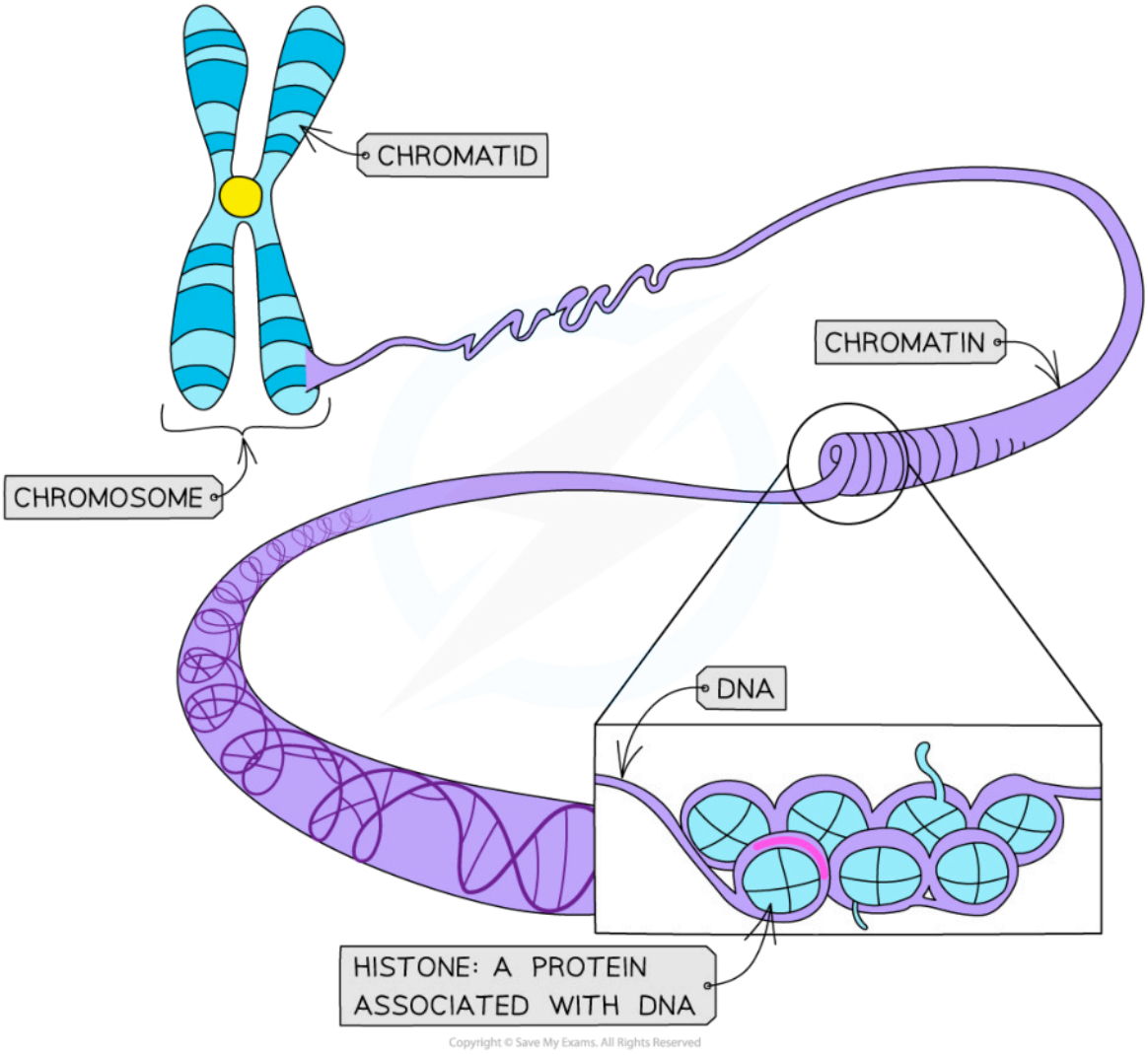
Your notes

Chromosomes Condense

Your notes

Condensation of chromosomes

- DNA molecules are **very long molecules** (human DNA can be more than 50,000 μm) that need to fit within much smaller nuclei (human nuclei average less than 5 μm)
- Prior to mitosis, the DNA molecules are loosely coiled (around histones in eukaryotic cells) to form a complex called **chromatin**
- During **prophase**, the chromatin gets **condensed** by **supercoiling** to form **chromosomes**
- Condensation occurs by the repeated coiling of the DNA molecule (supercoiling)
- This supercoiling is aided in eukaryotic cells by the presence of histone proteins and enzymes



DNA is coiled around histone proteins to make chromatin

1.4.3 Cancer

Your notes

Tumour Formation

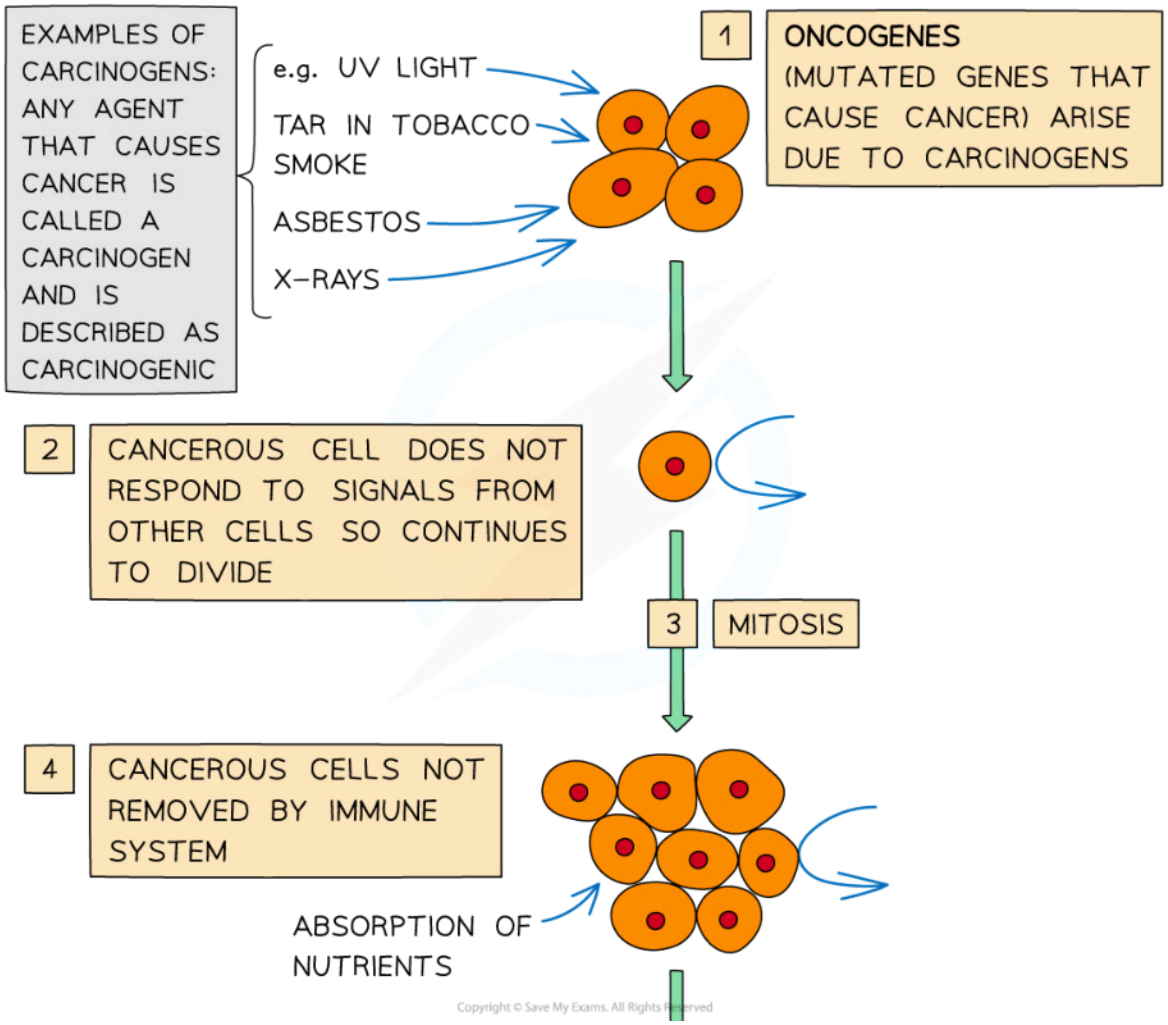
- Cancers demonstrate how important it is that **cell division** is **precisely controlled**, as cancers arise due to **uncontrolled mitosis**
- Cancerous cells divide repeatedly and uncontrollably, forming a **tumour** (an irregular mass of cells)
- Cancers start when **changes occur in the genes that control cell division**
  - A change in any gene is known as a mutation
- If the mutated gene is one that **causes cancer** it is referred to as an **oncogene**
- Mutations are common events and don't lead to cancer most of the time
  - Most mutations either result in **early cell death** or result in the cell being destroyed by the **body's immune system**
  - As most cells can be easily replaced, these events usually have no harmful effect on the body
- The mutations that result in the generation of cancerous cells **do not result in early cell death or in the cell being destroyed by the body's immune system**
- This means that the **harmful mutation** occurring in the original cell can be **passed on** to all that cell's descendants
- A typical tumour contains around a thousand million cancerous cells by the time it is detected

Carcinogens

- **Mutagens** are agents that **alter** the **genetic material** of an organism
  - E.g. biological organisms (viruses), radiation (X-rays, UV light) or chemical substances (tar in tobacco smoke)
- If **mutagens cause cancers** they are called **carcinogens**
- **Carcinogens** are any agents that may cause cancer

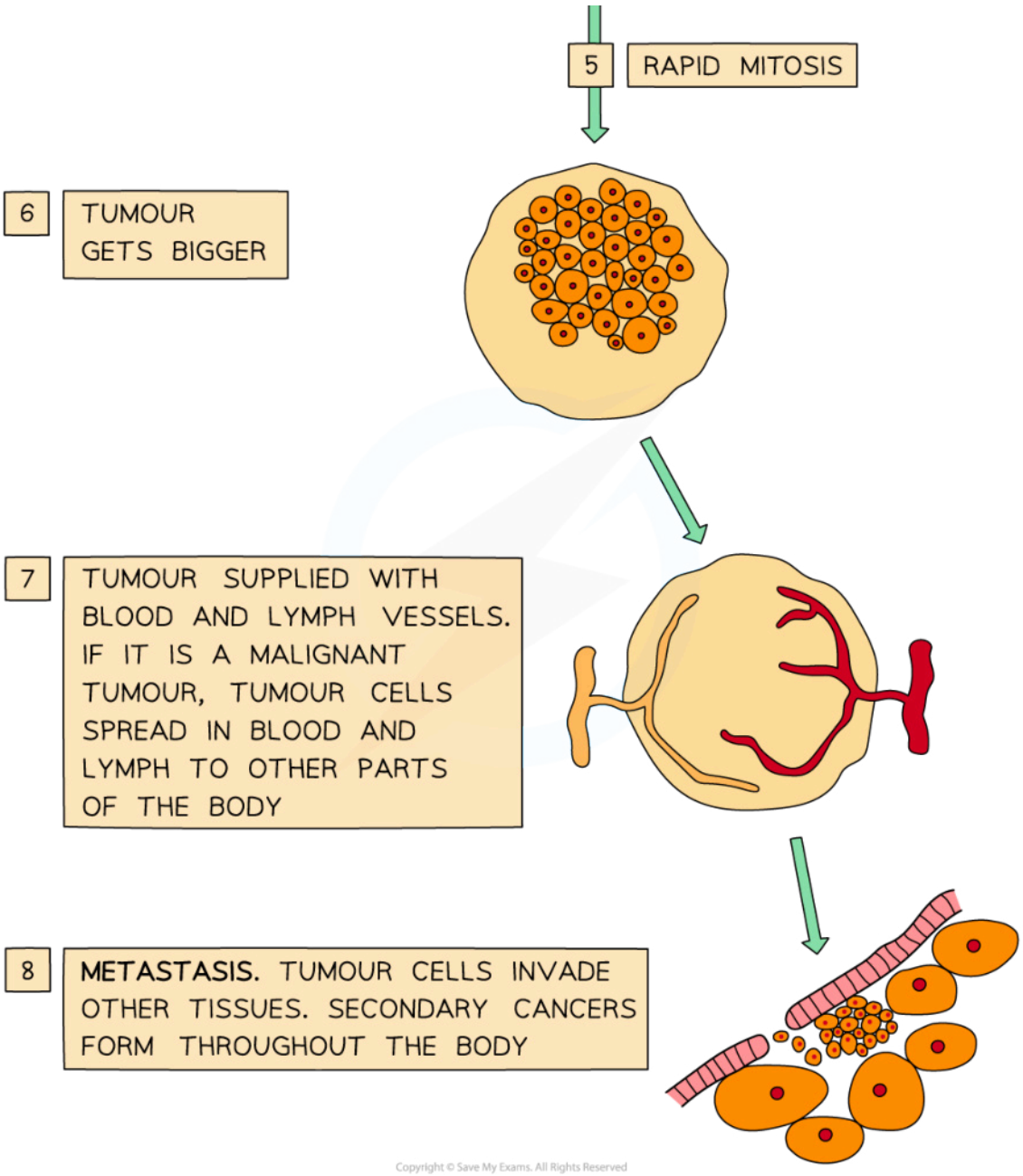
Types of tumour

- Some tumours (such as warts) do not spread from their original site – these are known as **benign** tumours and **do not cause cancer**
- Some tumours spread through the body, invading and destroying other tissues – these are known as **malignant** tumours and **cause cancer**
  - Malignant tumours **interfere with the normal functioning** of the organ/tissue in which they have started to grow (eg. they may block the intestines, lungs or blood vessels)
  - Malignant tumour cells can **break off the tumour and travel** through the **blood and/or lymphatic system** to form **secondary growths** in other parts of the body
  - The spreading of cancers in this way is known as **metastasis**
  - Metastasis is very dangerous as it can be **very difficult to detect, locate and remove** secondary cancers



Your notes

Your notes



Stages in the development of cancer

Examiner Tip

Make sure you know examples of mutagens. Also, you should know that some viruses (known as oncoviruses) cause cancer and can therefore also be described as mutagens.

Smoking & Cancer

- Scientists studying the incidence and distribution of certain cancers identified links between smoking and cancer
- However, it was only when laboratory investigations showed that cigarette smoke contained more than 4000 chemicals, at least **40** of which were **carcinogens,** that a **correlation** was established
- There is a **positive correlation** between smoking and cancer. The more cigarettes smoked per day the higher the chance of developing certain cancers (e.g. lung and mouth)


Your notes

1.4.4 Skills: Cell Division


Your notes

Mitotic Phases: Identification

- Cells undergoing different stages of the cell cycle can be identified using photomicrographs taken from microscope slides
- Cells undergoing certain stages of the cell cycle have distinctive appearances

Interphase

- As cells spend the majority of the cell cycle in this stage then most cells will be in this stage
- The **chromatin** is **visible** so the nuclei have a dark appearance

Prophase

- Chromosomes are **visible**
- The nuclear envelope is breaking down

Metaphase

- **Chromosomes** are lined up along the **middle** of the cell

Anaphase

- **Chromosomes are moving away** from the middle of the cell, towards opposite poles

Telophase

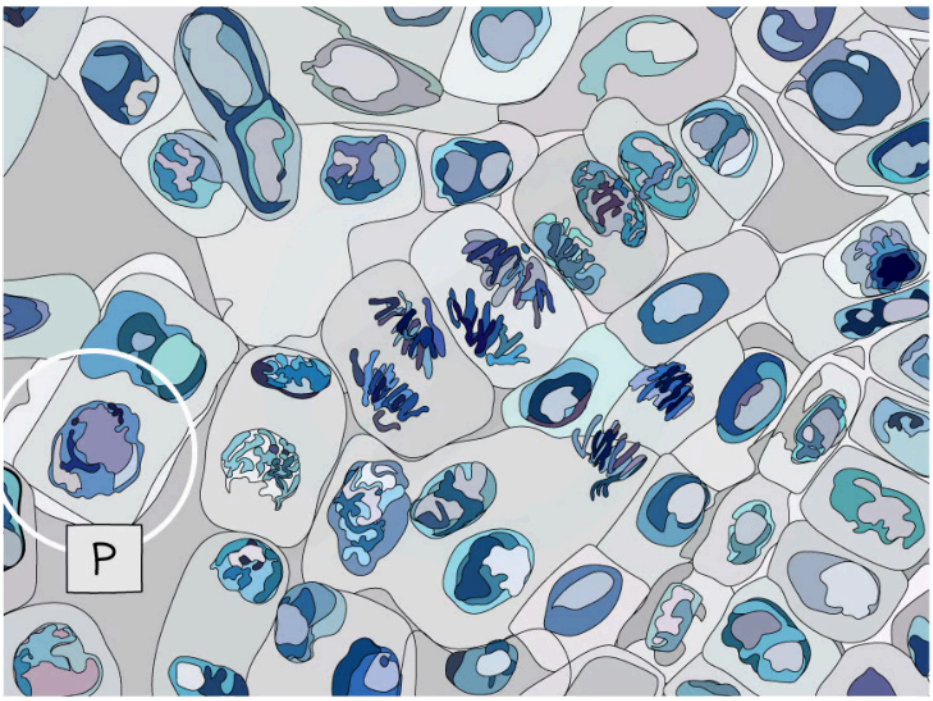
- Chromosomes have arrived at **opposite poles** of the cell
- Chromosomes begin to **uncoil** (are no longer condensed)
- The nuclear envelope is reforming

Cytokinesis

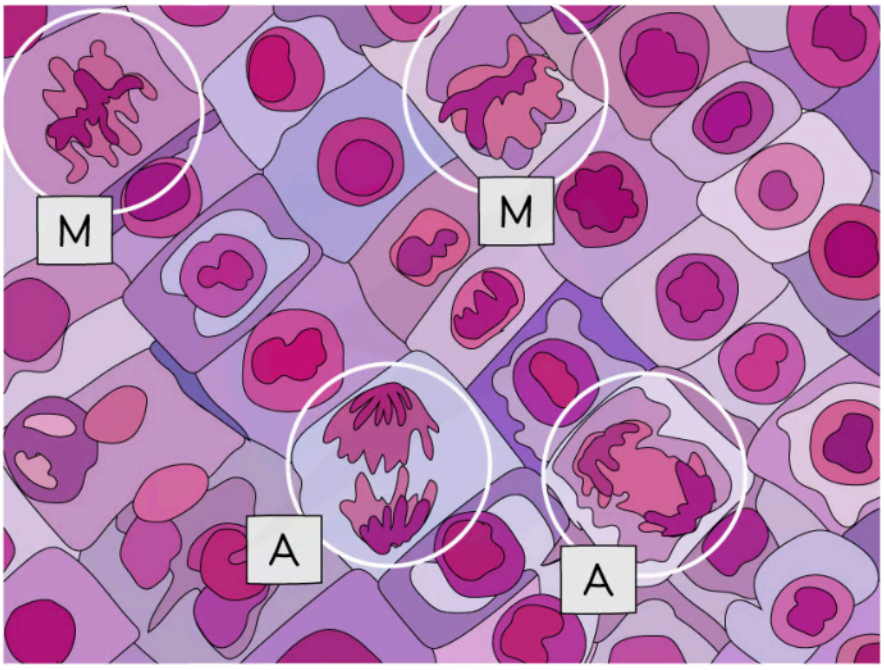
- Animal cells: a **cleavage furrow** forms and separates the daughter cells
- Plant cells: a **cell plate** forms at the site of the metaphase plate and expands towards the cell wall of the parent cell, separating the daughter cells

Identification of phases

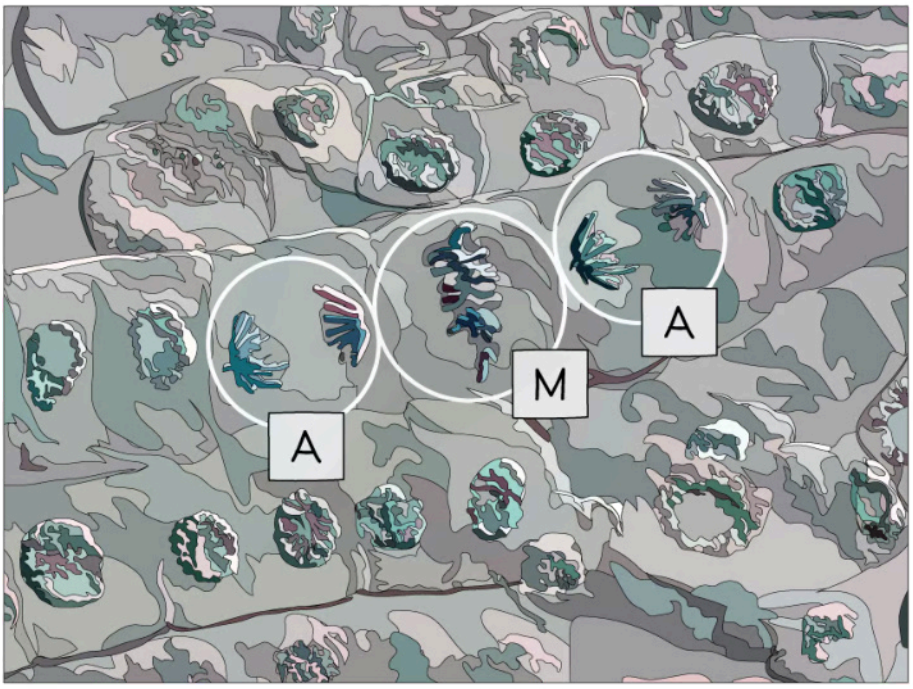
Your notes



Micrograph showing a cell undergoing prophase (P)

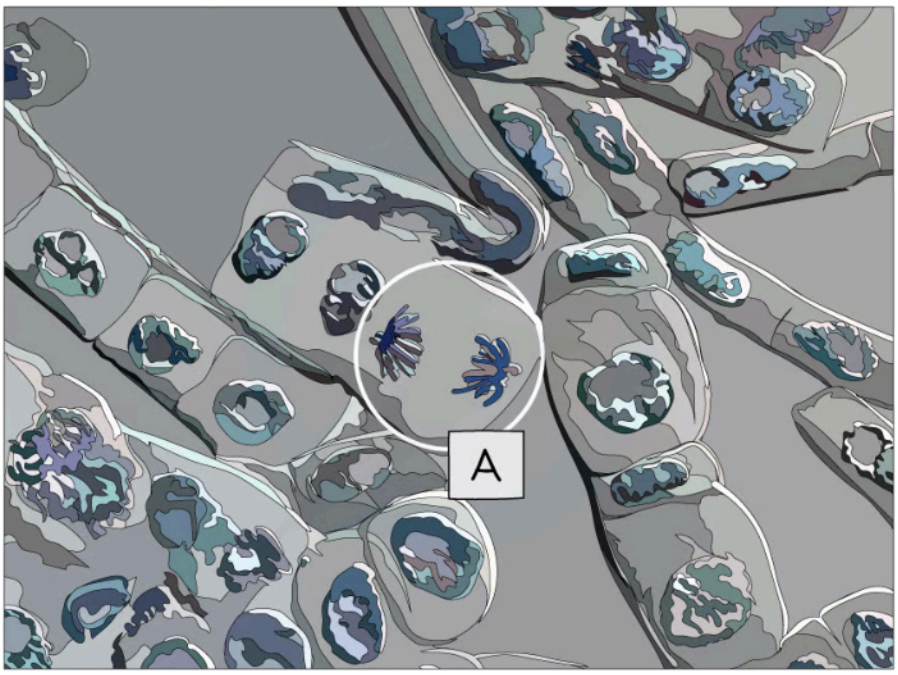


Micrograph showing cells undergoing metaphase (M) and anaphase (A)



Micrograph showing cells undergoing metaphase (M) and anaphase (A)

Your notes



Micrograph showing a cell undergoing anaphase (A)

Examiner Tip

It is important to be able to recognise each mitotic stage from electron micrographs and to be able to explain why that cell is in the stage you have selected.It can be difficult to tell prophase and telophase apart in some photomicrographs. In prophase, there is only one group of chromosomes while in telophase there are two groups, one at each pole.

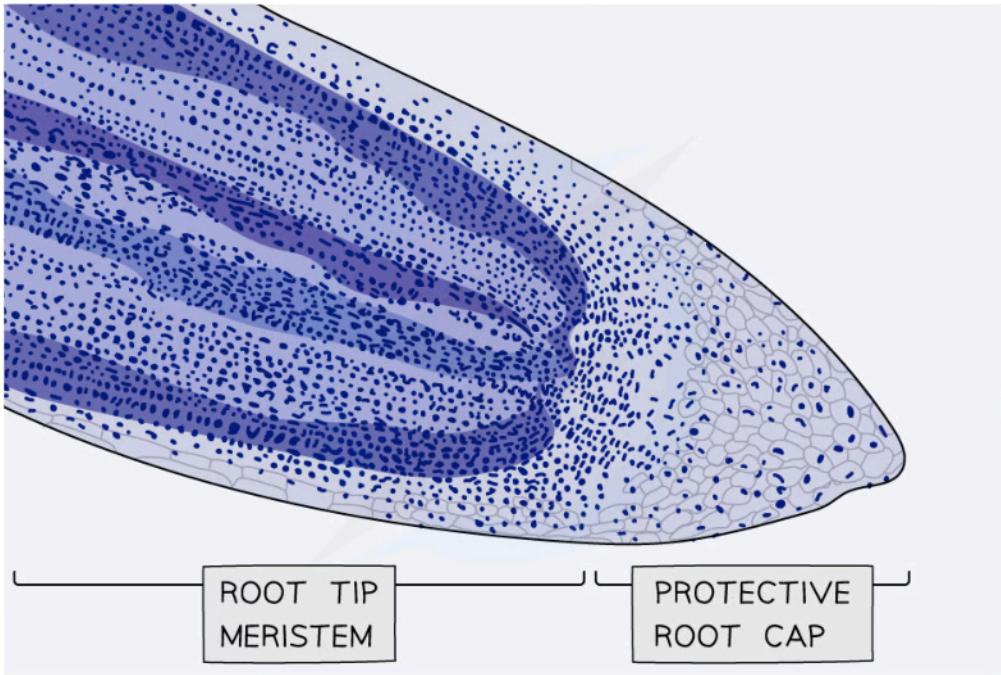
Your notes

Determination of Mitotic Index

Your notes

Investigating mitosis in root tissue

- Growth in plants occurs in specific regions called **meristems**
- The root tip meristem can be used to study **mitosis**
- The root tip meristem can be found **just behind the protective root cap**
- In the root tip meristem, there is a **zone of cell division** that contains cells undergoing **mitosis**
- Pre-prepared slides of root tips can be studied or temporary slides can be prepared using the **squash technique** (root tips are **stained** and then **gently squashed**, spreading the cells out into a thin sheet and allowing individual cells undergoing mitosis to be clearly seen)



Micrograph showing a stained root tip

Analysis

- Cells undergoing mitosis (similar to those in the images below) can be seen and drawn
- Annotations can then be added to these drawings to show the **different stages of mitosis**
- The **mitotic index** can be calculated

The mitotic index

- The mitotic index is the **proportion** of cells (in a group of cells or a sample of tissue) that are **undergoing mitosis**
- The mitotic index can be calculated using the formula below:

Your notes

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

- You can multiply the answer by **100** if you need to give the mitotic index as a **percentage**

Worked example

A student who wanted to observe mitosis prepared a sample of cells. They counted a **total of 42** cells in their sample, **32 of which had visible chromosomes**. Calculate the mitotic index for this sample of cells (give your answer to 2 decimal places).

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{32}{42}$$

mitotic index = **0.76**

Worked example

The table below shows the number of cells in different stages of mitosis in a sample from a garlic root tip. Calculate the mitotic index for this tissue (give your answer to 2 decimal places).

Stage of mitosis	Number of cells
Interphase	36
Prophase	14
Metaphase	5
Anaphase	3
Telophase	6


Your notes

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{(\text{prophase} + \text{metaphase} + \text{anaphase} + \text{telophase})}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{(14 + 5 + 3 + 6)}{(36 + 14 + 5 + 3 + 6)}$$

$$\text{Mitotic index} = \frac{28}{64}$$

mitotic index = **0.44**

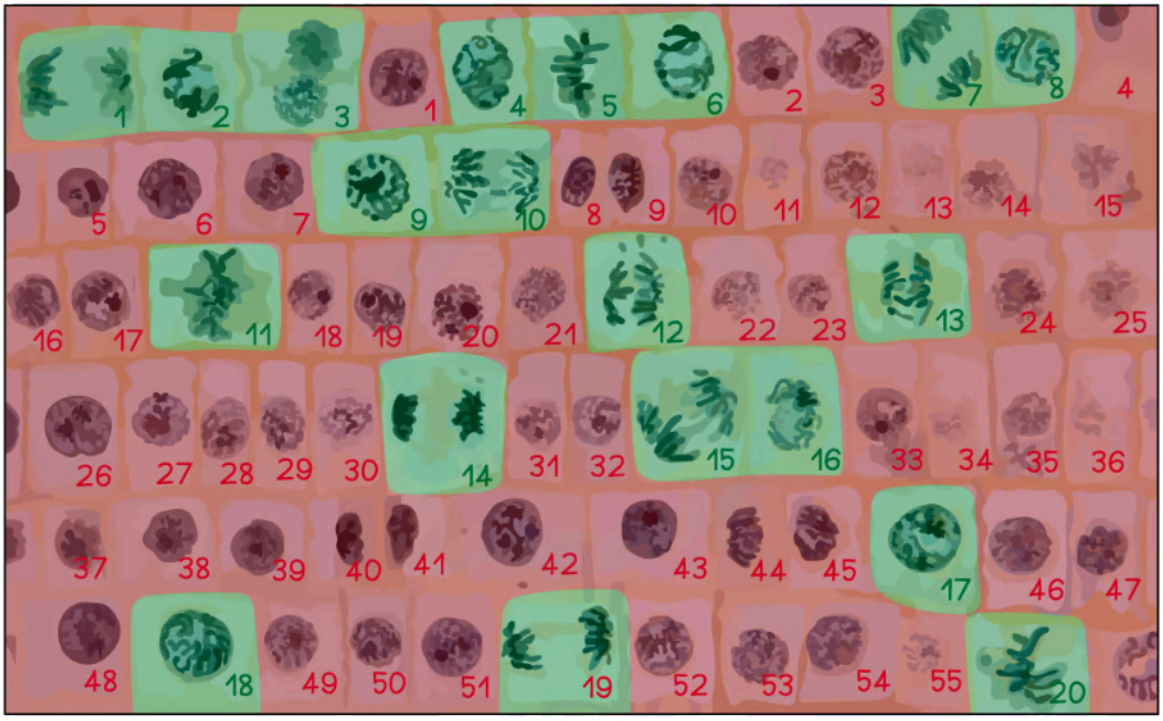
Worked example

The micrograph below shows a sample of cells from an onion root tip. Calculate the mitotic index for this tissue (give your answer to 2 decimal places).

A sample of cells from an onion root tip

Step 1: Identify the cells undergoing mitosis

Your notes



Your notes

Number of cells with visible chromosomes (green) = 20

Step 2: Count the total number of cells

Total number of cells (green + red) = 20 + 55 = 75

Step 3: Substitute numbers into the equation

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{20}{75}$$

mitotic index = **0.27**

Examiner Tip

You will need to remember the mitotic index formula as it will not be given to you.