SL IB Biology

Cell Specialisation

Contents

Your notes

Stem Cells

Stem Cell Properties

- A **stem cell** is a cell that can **divide** (by mitosis) an **unlimited number of times**
- Each new cell (produced when a stem cell divides) has the potential to **remain a stem cell** or to develop into a **specialised cell** such as a blood cell or a muscle cell (by a process known as **differentiation**)

Stem Cell Niches

- After differentiation, a stem cell is **no longer** considered a stem cell
- However, some stem cells do **remain in specific locations** in the human body, this is called the **stem cell niche**
- Their presence **gives the capacity for these tissues to regenerate and repair**
- Some of the tissues which retain stem cells within a niche include
  - **Bone marrow**:
    - Bone marrow provides a niche for stem cells which are used to replace red blood cells, white blood cells and platelets
    - This is important for continual production of these cells which are required indefinitely
  - **Hair follicle**:
    - This niche is located at the root of the hair where the hair is anchored into the skin
    - Stem cells here promote continual hair growth
- The **environment** provided by the niche must have
  - The ability to maintain an **inactive** state of the stem cells
 - The ability to stimulate stem cell **proliferation** and **differentiation**

Stem Cell Potency

- The ability of stem cells to differentiate into more specialised cell types is known as **potency**
- There are four types of potency:
  - **Totipotency** – totipotent stem cells are stem cells that can differentiate into **any cell type found in an embryo, as well as extra-embryonic cells** (the cells that make up the placenta)
    - The zygote formed when a sperm cell fertilises an egg cell is totipotent
    - Also the embryonic cells up to the 16-cell stage of human embryo development are totipotent
  - **Pluripotency** - pluripotent stem cells are embryonic stem cells that can differentiate into **any cell type found in an embryo** but are **not able to differentiate into extra-embryonic cells** (the cells that make up the placenta)
  - **Multipotency** - multipotent stem cells are adult stem cells that can differentiate into closely related cell types
    - For example bone marrow stem cells differentiate into different blood cells
  - **Unipotency** - unipotent stem cells are adult cells that can only differentiate into their **own lineage**
    - For example heart muscle cells (cardiomyocytes) can generate new cardiomyocytes through the cell cycle to build and replace heart muscle. Most cells in animal bodies are unipotent

Stem Cell Potency Diagram

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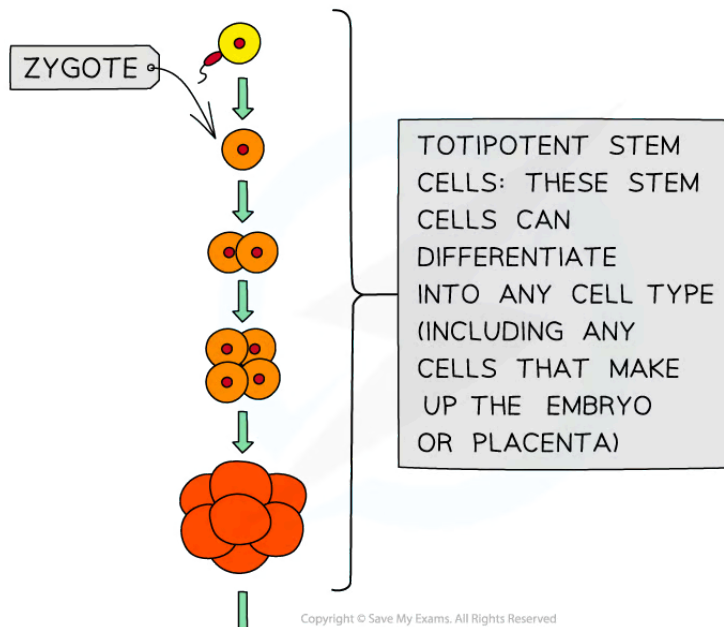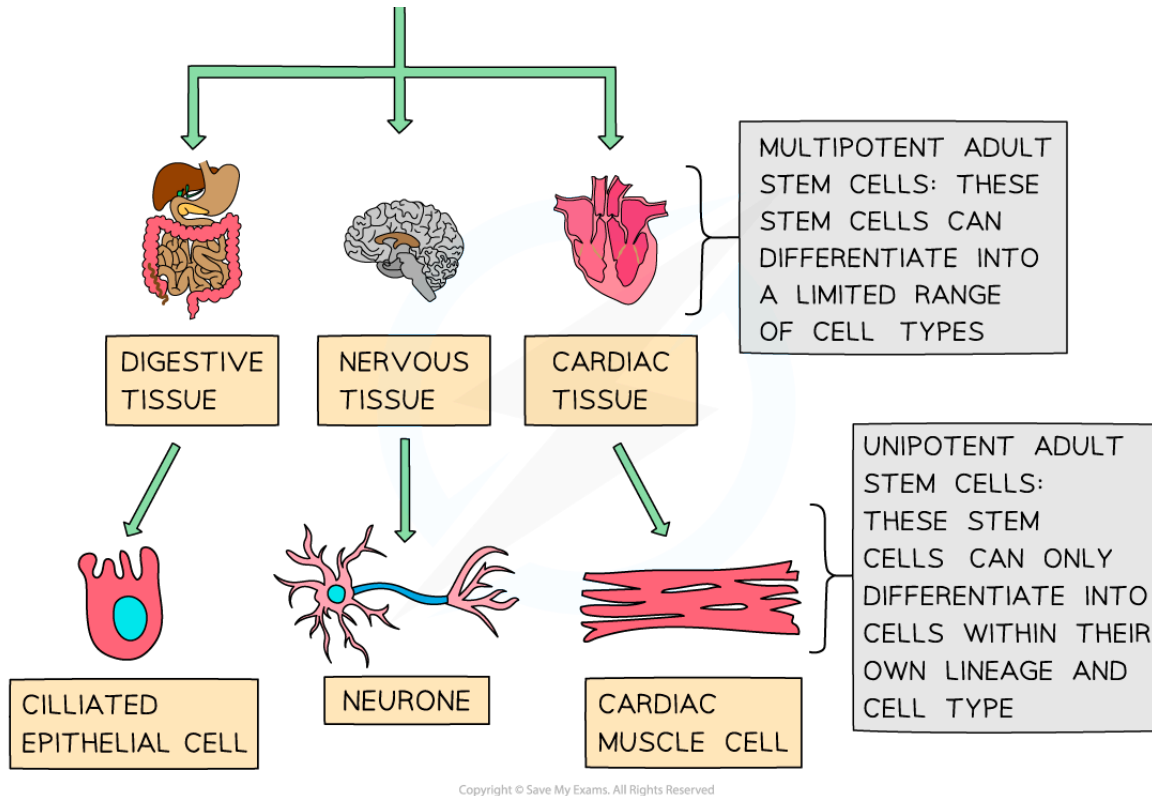
There are different levels of potency that cells can have. Totipotent cells have the highest potency and can therefore differentiate into any type of cell. Unipotent cells have the lowest potency, only being able to divide into one cell type.

> 🔵 **Examiner Tip**
>
> Remember the **two** key properties of stem cells are that they can **self-renew** (capacity to divide) and can **differentiate**. Make sure you learn the levels of potency of stem cells described above, and what range of cell types these stem cells can differentiate into.
>
> Don't forget, while still classed as stem cells (as they can divide any number of times), only a limited range of specialised cells can be formed from adult stem cells as they have already partially differentiated. For example, stem cells in bone marrow can only produce cells that differentiate into the different types of blood cells.
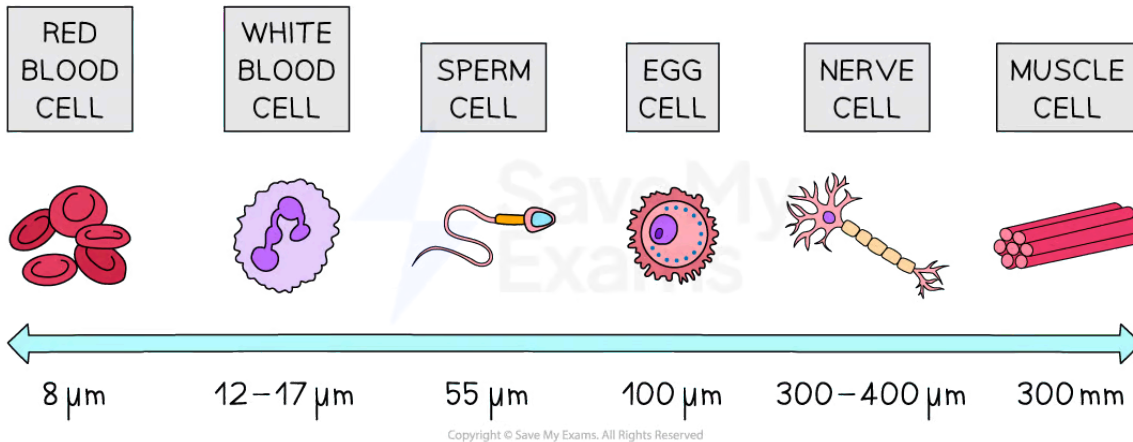
Cell Specialisation

Development of Specialised Cells

- In complex **multicellular** organisms eukaryotic cells become **specialised** for **specific functions**. This can also be referred to as **the division of labour**
- The process occurs after **fertilisation** to allow development of different tissues within the embryo
- Specialisation enables the cells in these tissues to function more efficiently as they develop specific adaptations for their role. The development of these distinct specialised cells occurs by differentiation
- These specialised eukaryotic cells have **specific adaptations** to help them carry out their functions
- For example, the **structure of a cell** is adapted to help it carry out its function (this is why specialised eukaryotic cells can look extremely **different** from each other)
  - Structural adaptations include:
    - The **shape** of the cell
    - The organelles the cell contains (or doesn't contain)
      - For example: Cells that make large amounts of **proteins** will be adapted for this function by containing **many ribosomes** (the organelle responsible for protein production)

Cell Size & Specialisation

- During the differentiation process, cell sizes can vary drastically
- Size is a feature of adaptation which means that cells require different dimensions to carry out their jobs efficiently

Cell Specialisation Diagram

| RED BLOOD CELL | WHITE BLOOD CELL | SPERM CELL | EGG CELL | NERVE CELL | MUSCLE CELL |

| 8 μm | 12 – 17 μm | 55 μm | 100 μm | 300 – 400 μm | 300 mm |

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Cells that have differentiated are specialised cells; they come in all shapes and sizes

How differentiation makes cells adapted to their function

- **Red blood cells** are small to allow movement through narrow capillaries
- **Active white blood cells** are larger than inactive white blood cells to allow space for **rER** and **Golgi apparatus** to allow protein (antibody) synthesis
- **Sperm cells** are long to allow for **movement** towards the egg cell, they also have narrow **streamlined** heads to **reduce resistance** to reaching the egg cell
- An **egg cell** body has the **largest volume** of all cells to allow for stored food reserves.
- A **nerve cell** has a **large cell body to** allow for **protein synthesis** to maintain the structure of the **long axon** which is required for rapid delivery of **impulses** around the nervous system
- **Muscle cells** are larger than normal cells, length and diameter is designed to exert **force during muscle contraction**

Constraints on Cell Size

Surface area to volume ratio

- For cells to survive, metabolic reactions must be occurring; these reactions rely on materials being constantly **exchanged** across the plasma membrane at the cell's **surface**
- The metabolic requirements of a cell will vary depending on the **volume** or mass of cytoplasm (as this is where the reactions take place); a cell with a **larger volume will have higher metabolic requirements**, and vice versa
- As cells increase in size their **surface area to volume ratio (SA:V)** decreases as there is **less surface area in relation to the volume** of the organism
- So, an increase in volume will increase a cell's metabolic requirements, but its ability to carry out exchange with its environment **does not increase at the same rate**

Constraints on cell size

- Single-celled organisms have a **high SA:V ratio**; this means that they can survive by exchanging substances with their environment by **simple diffusion at the cell surface**
  - Their **metabolic requirements** are relatively **low**
  - The surface area is large enough to allow for sufficient absorption of **nutrients** and **gases** and secretion of **waste products**
  - The small volume means the **diffusion distance to all organelles is short**
- SA:V ratio decreases as cells get larger; this means that cells **cannot grow bigger indefinitely**; for larger cells the **SA:V ratio is too small** for cells to survive using only diffusion at the cell surface
  - Their metabolic requirements are **higher**
  - The surface area does not increase at the same rate as the metabolic requirements, so is **not large enough** too allow for a sufficiently high rate of exchange with the environment
  - The large volume means that the **diffusion distance to the centre of the cell is long**, so substances cannot diffuse quickly enough across the cell to reach the organelles where they are needed
- This means that once the SA:V ratio becomes too small, growth must stop and the cells must divide, giving rise to multicellular organisms
- Multicellular organisms have **evolved adaptations** to facilitate:
  - The exchange of substances between their internal tissues and the external environment, e.g.
    - Gas exchange systems
    - Digestive systems
  - Efficient transport of substances within their bodies
    - Circulatory systems

Surface area to volume ratio diagram

Your notes
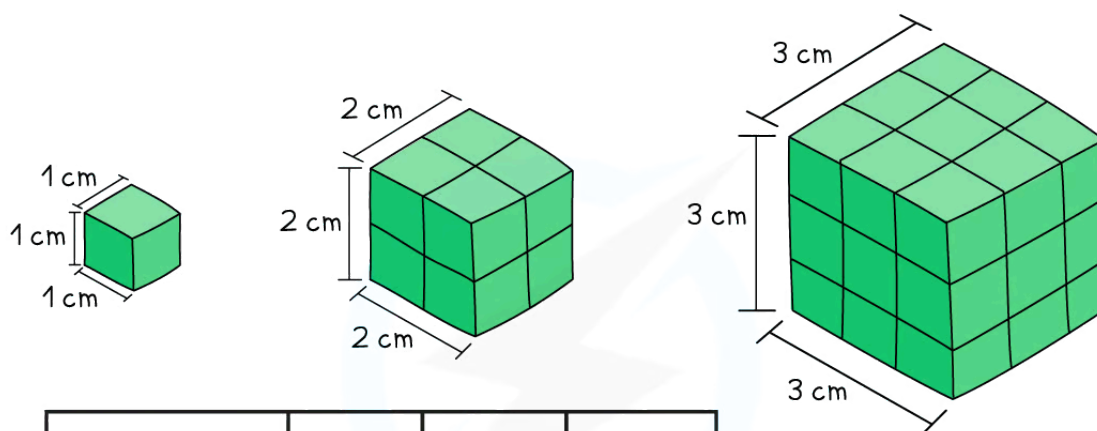
Surface area	6 cm²	24 cm²	54 cm²
Volume	1 cm³	8 cm³	27 cm³
Surface area: volume	6:1	3:1	2:1

As the size of an organism increases, its surface area : volume ratio decreases; this means that as it gets larger, it becomes more difficult for an organism to gain enough oxygen and nutrients at its cell surface, as its requirements will increase faster than the available surface for diffusion

> 💡 **Examiner Tip**
>
> Remember that the rate of metabolism is dependent on the mass or volume of the cell, whereas the rate of exchange is dependent on the surface area.

NOS: Students should recognise that models are simplified versions of complex systems

- Scientists use **models** to represent real world ideas, organisms, processes and systems that cannot be easily investigated
- Scientists can **experiment** on the models enabling them to **test predictions** and develop **explanations** for observations made
- The investigation below uses **agar cubes** to model the effect of changing surface-area-to-volume ratio on the rate of ion **diffusion**
- Although the cubes do not perfectly represent the shapes of real organisms, the **scale factors** and the resulting affect on diffusion still applies

Method

Your notes

- **Coloured agar is made up and cut into cubes** of the required dimensions (eg. 0.5cm x 0.5cm x 0.5cm, 1cm x 1cm x 1cm and 2cm x 2cm x 2cm)
  - Purple agar can be created if it is made up with very dilute sodium hydroxide solution and Universal Indicator
  - Alternatively, the agar can be made up with Universal Indicator only
- The **surface area, volume and surface area to volume ratio of these cubes is calculated** and recorded
- The cubes are then **placed into boiling tubes containing a diffusion solution** (such as dilute hydrochloric acid)
  - The same volume of dilute hydrochloric acid should be carefully measured out into each boiling tube
  - The acid should have higher molarity than the sodium hydroxide so that its diffusion can be monitored by a change in colour of the indicator in the agar blocks
- Measurements can be taken of either:
  - The time taken for the acid to completely change the colour of the indicator in the agar blocks
  - The distance travelled into the block by the acid (shown by the change in colour of the indicator) in a given time (e.g. 5 minutes)
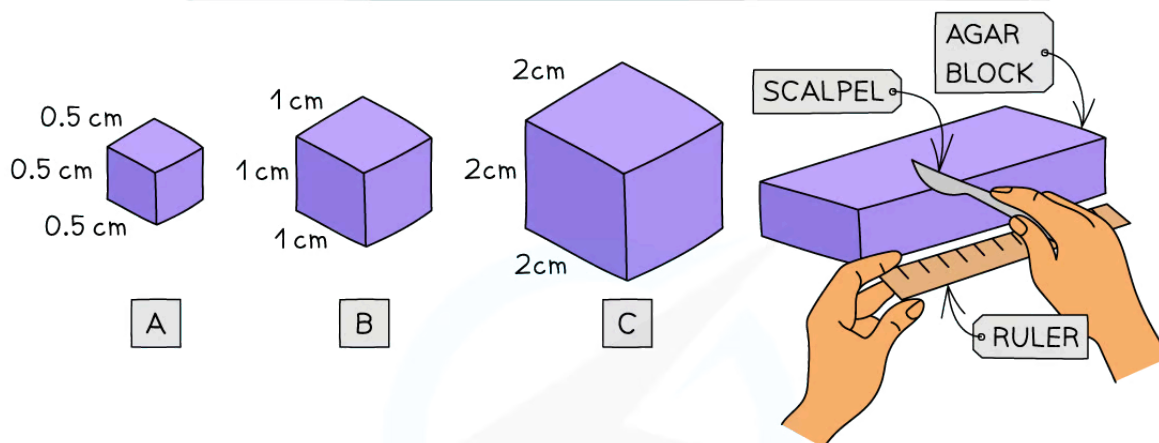
Your notes

INVESTIGATING SA WITH AGAR METHOD

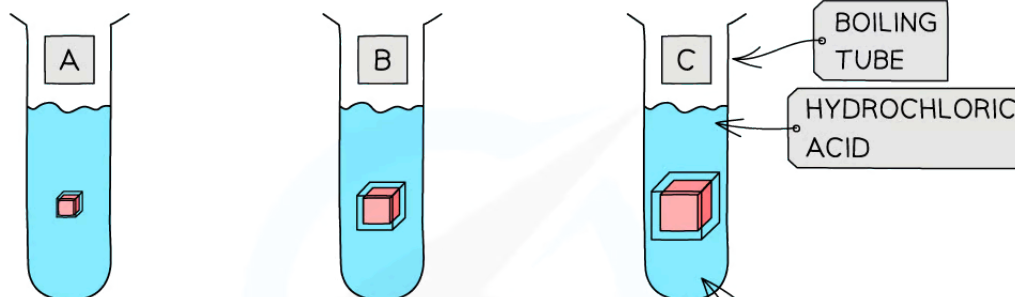**1** CUT COLOURED AGAR INTO CUBES OF REQUIRED DIMENSIONS

0.5 cm
0.5 cm
0.5 cm

A

1 cm
1 cm
1 cm

B

2cm
2cm
2cm

C

SCALPEL   AGAR BLOCK

RULER

2 CALCULATE SURFACE, AREA, VOLUME, AND SURFACE AREA: VOLUME RATIO OF EACH CUBE

Cube	SA (cm²)	Vol (cm³)	SA : Vol
A	1.5	0.125	12 : 1
B	6	1	6 : 1
C	24	8	3 : 1

3 | PLACE AGAR CUBES INTO BOILING TUBES CONTAINING THE DIFFUSION SOLUTION

A   B   C

BOILING TUBE

HYDROCHLORIC ACID

AS THE HYDROCHLORIC ACID DIFFUSES INTO THE AGAR CUBE, THE COLOUR OF THE INDICATOR CHANGES (IN THIS CASE IT GOES COLOURLESS)

4 | MEASURE THE TIME TAKEN FOR THE AGAR CUBES TO GO COLOURLESS

START   STOP   STOPWATCH

06:25

hrs mins secs

The steps used to investigate the effect of changing the surface area to volume ratio on diffusion

Analysis

- If the time taken for the acid to completely change the colour of the indicator in the agar blocks is recorded, these times can be converted to rates
- A graph could be drawn showing how the rate of diffusion (rate of colour change) changes with the surface area : volume ratio of the agar cubes
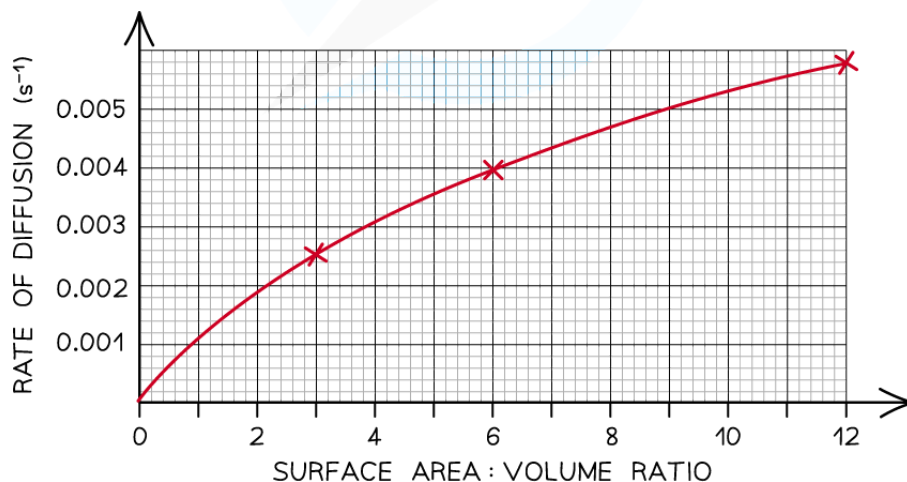
Your notes

INVESTIGATING SA WITH AGAR ANALYSIS

1 CALCULATE THE RATE OF DIFFUSION IN EACH AGAR CUBES

Cube	SA (cm²)	Vol (cm³)	SA : Vol	Time (s) (seconds)	Rate (s⁻¹) (1/Time)
A	1.5	0.125	12 : 1	176	0.0057
B	6	1	6 : 1	259	0.0039
C	24	8	3 : 1	384	?

TIME TAKEN FOR AGAR CUBES TO GO COLOURLESS

$$\text{RATE} = \frac{1}{\text{TIME TAKEN}}$$

$$= \frac{1}{384 \text{ s}}$$

$$= 0.0026 \text{ s}^{-1}$$

2 PLOT A GRAPH FOR RATE OF DIFFUSION AGAINST SURFACE AREA : VOLUME RATIO

3 | **USE THE GRAPH TO WRITE A CONCLUSION**

AS THE SURFACE AREA TO VOLUME RATIO OF THE AGAR CUBE INCREASES, THE RATE OF DIFFUSION THROUGH THE AGAR CUBE ALSO INCREASES. FOR EXAMPLE, CUBE C (2cm × 2cm × 2cm) HAD THE SMALLEST SURFACE AREA TO VOLUME RATIO (3:1) AND A RATE OF DIFFUSION OF $0.0026\ s^{-1}$, WHEREAS CUBE A (0.5cm × 0.5cm × 0.5cm) HAD THE LARGEST SURFACE AREA TO VOLUME RATIO (12:1) AND RATE OF DIFFUSION OF $0.0057 s^{-1}$.

To analyse the results of the investigation, calculate the rates of diffusion before drawing a graph for rate of diffusion against surface area : volume ratio

Your notes