



Cell specialization

Revision notes · IB Biology B2.3: differentiation, stem cells, niches and potency, and cell size and the surface area-to-volume ratio.

For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

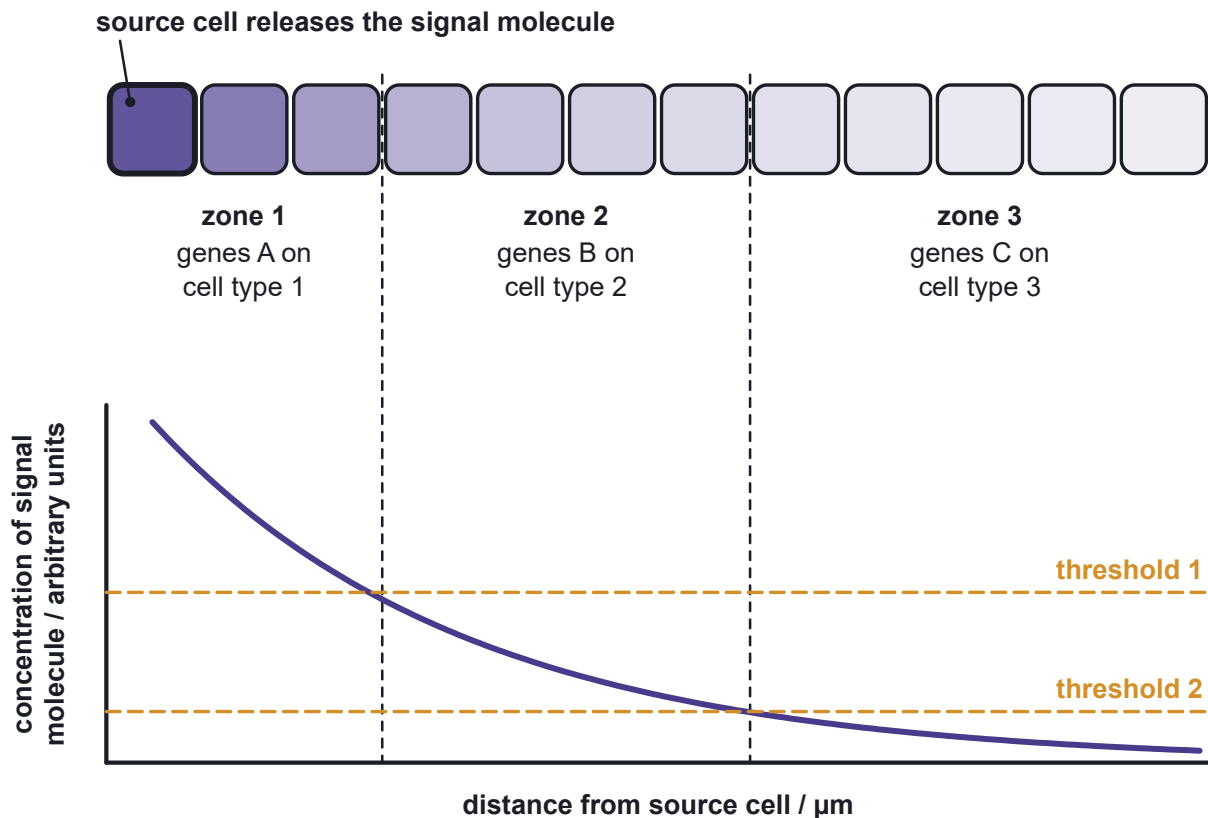
Cell specialization Spec B2.3

Differentiation and stem cells Spec B2.3.1-B2.3.4

From zygote to specialized cells

Fertilization produces a **zygote**, which divides by mitosis to form an embryo of unspecialized cells. These cells then develop into specialized cells by **differentiation**: each cell type expresses a different set of genes, so it makes different proteins and develops a different structure and function. All the cells still contain the same genes.

In an early-stage embryo, certain cells release signal molecules (morphogens). These diffuse away from their source, forming a **concentration gradient** across the embryo. The concentration a cell receives depends on its position, and this determines which genes it expresses. Cells in different positions therefore follow different developmental pathways, which is how body axes such as head-to-tail are set up.



[\(opens full size in a new tab\)](#)

A **concentration gradient** of signal molecule tells each cell its position, so different genes are expressed in each zone (illustrative).

Properties of stem cells

Stem cells have two properties: they can **divide endlessly**, and they can **differentiate along different pathways** to become different cell types.

Stem cell niches in adult humans

A stem cell niche is a location in the body where stem cells are found. Conditions in the niche can either maintain the stem cells or promote their proliferation and differentiation, depending on the body's needs.

Two stem cell niches in adult humans		
Niche	Stem cells	Function
Bone marrow	Blood-forming (haematopoietic) stem cells	Produce red blood cells, white blood cells and platelets throughout life
Hair follicles	Stem cells in a region of the follicle called the bulge	Regenerate the hair follicle in each growth cycle and help repair the skin after wounding

Totipotent, pluripotent and multipotent stem cells

Potency of stem cells		
Type	Can form	Example
Totipotent	Any type of cell, including the placenta and other tissues outside the embryo; can form a whole organism	The zygote and cells of the very early embryo
Pluripotent	Any type of cell in the body, but not a whole organism	Embryonic stem cells, from the embryo a few days after fertilization
Multipotent	A limited range of related cell types	Adult stem cells, such as those in bone marrow, which form the different types of blood cell

Common mistake: Differentiated cells do not lose genes. Differentiation changes which genes are expressed, not which genes are present.

Cell size and surface area-to-volume ratio Spec B2.3.5, B2.3.6

Cell size as an aspect of specialization

Human cells vary greatly in size, and the size of each type suits its function.

Approximate sizes of some human cells

Cell	Approximate size	Link to function
Sperm (male gamete)	Head about 5 μm long; whole cell about 50–60 μm long	Small and streamlined, with little cytoplasm, so it can swim to the egg
Egg (female gamete)	About 110 μm (0.1 mm) in diameter, at the limit of what the naked eye can see	Large, with cytoplasm and nutrients for the early embryo
Red blood cell	About 7–8 μm in diameter	Small and flexible, so it can squeeze through narrow capillaries
White blood cells	About 7–20 μm in diameter, from small lymphocytes (similar to a red blood cell) to monocytes	Most are larger than red blood cells; phagocytes are large enough to engulf bacteria
Neuron	Cell body up to about 100 μm across; axons up to about 1 m long	Long axons carry impulses over long distances, such as from the spinal cord to the foot
Striated muscle fibre	Up to about 100 μm wide and many centimetres long	Long fibres contract along their whole length

Surface area-to-volume ratio

A cell exchanges materials such as oxygen, nutrients and waste across its surface, so the rate of exchange depends on its **surface area**. The need for exchange depends on how much cytoplasm is carrying out metabolism, which is the cell's **volume**.

As a cell gets larger, its volume increases faster than its surface area. For a cube of side length L , surface area = $6L^2$ but volume = L^3 , so the **surface area-to-volume ratio** ($6 \div L$) falls as L increases. A large cell may not be able to exchange materials fast enough to meet its needs, and the distance from the surface to the centre becomes long for diffusion. This constrains cell size.

$$\text{surface area-to-volume ratio} = \text{surface area} \div \text{volume}$$

Calculating SA:V

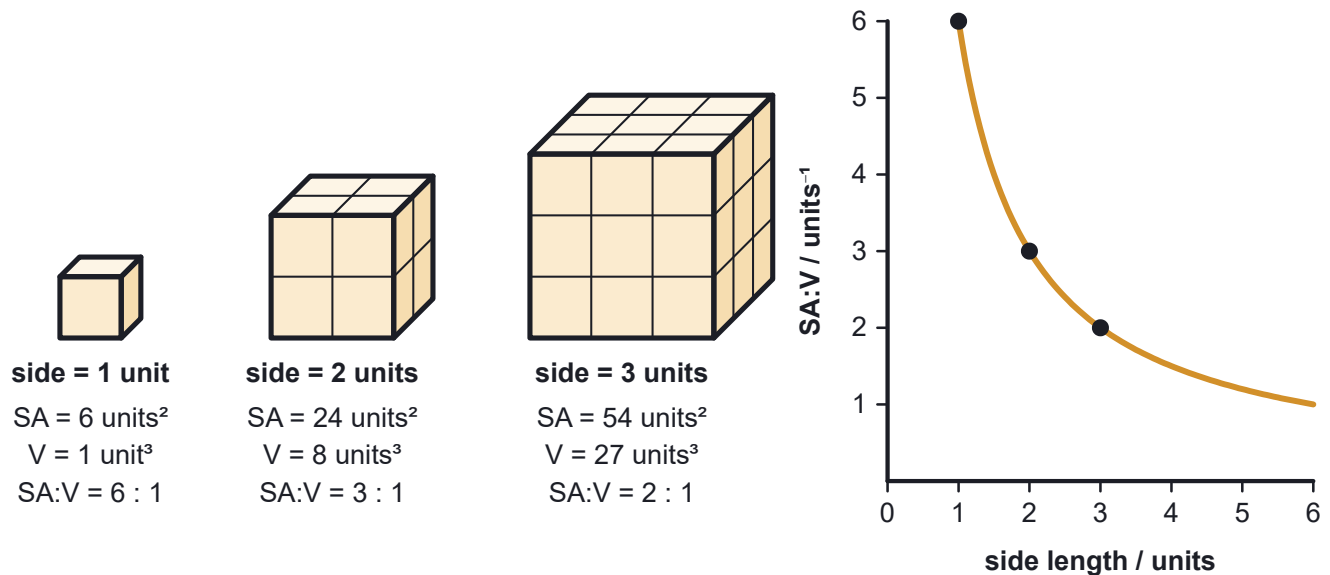
Model two cells as cubes with sides of 10 μm and 20 μm . Calculate the surface area-to-volume ratio of each and state the effect of doubling the side length.

- 10 μm cube: surface area = $6 \times 10^2 = 600 \mu\text{m}^2$; volume = $10^3 = 1000 \mu\text{m}^3$
- SA:V = $600 \div 1000 = 0.6 \mu\text{m}^{-1}$ (0.6 : 1)
- 20 μm cube: surface area = $6 \times 20^2 = 2400 \mu\text{m}^2$; volume = $20^3 = 8000 \mu\text{m}^3$
- SA:V = $2400 \div 8000 = 0.3 \mu\text{m}^{-1}$ (0.3 : 1)

Answer: Doubling the side length multiplies surface area by 4 but volume by 8, so SA:V halves, from 0.6 to 0.3 μm^{-1} .

Maths skill: Give SA:V in μm^{-1} (or cm^{-1}) or as a ratio such as 0.6 : 1. Work out surface area (squared units) and volume (cubed units) separately before dividing.

Practical skill: Model SA:V with agar cubes of different side lengths containing an indicator, placed in acid. The percentage of each cube's volume that changes colour in a fixed time shows how exchange falls behind as cubes get larger. Models are simplified: cubes are simpler than real cells, but scale factors work in the same way.



[\(opens full size in a new tab\)](#)

As side length increases, volume grows faster than surface area, so the **SA:V ratio falls**.

Exam tip: Linking question: what are the advantages of small size and large size in biological systems? Small cells exchange materials quickly; large organisms need extra adaptations such as lungs and a circulatory system.

Quick check

1. State the two properties of stem cells.
2. Name two stem cell niches in adult humans.
3. What type of stem cell is found in adult bone marrow?
4. What happens to the SA:V of a cube when its side length doubles?

Quick check answers

Cell specialization

1. They can divide endlessly and differentiate along different pathways.
2. Bone marrow and hair follicles.
3. Multipotent.
4. It halves.