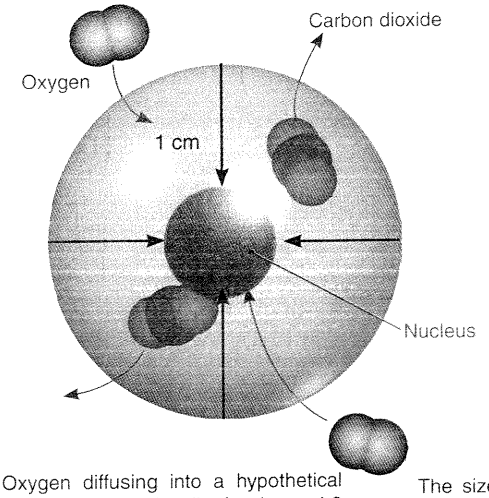
# Cell Size and Shape

Cells come in a wide range of types and forms, each adapted for a specific role. In humans, there are over 200 types of cell and they vary widely in their size and shape. The longest neurons can be over a metre long. In other animals, such as giraffes and giant squid, they can be very much longer (up to 12 m). Plants also have a large variety of cell types. Plants have a very different body form to animals, but many of the organelles inside the cells are the same. The variety of specialised cells in living organisms is a reflection of their specific roles in the organism. For example, animals require long, flexible neurons to carry signals about the body. Plants require specialised cells to transport manufactured food (sugar) around the plant body.

## Cell A

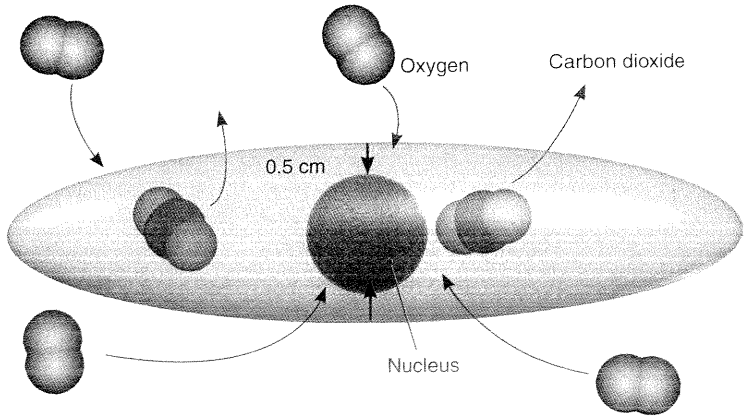
Radius = 1 cm
Volume = 4.2 $cm^3$
Surface area = 12.5 $cm^2$




Oxygen diffusing into a hypothetical spherical shaped cell of volume 4.2 $cm^3$ needs to cross 1 cm to reach the center of the cell when entering from any angle. There is a much lower surface area for diffusion than in an ellipsoid cell of the same volume: less oxygen per volume can diffuse into the spherical cell compared to an ellipsoid cell of the same volume.

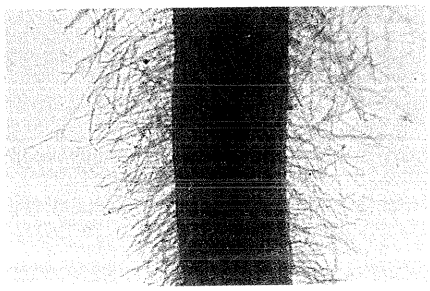
## Cell B

Radius a = 0.5 cm, b = 0.5 cm, c = 4 cm
Volume = 4.2 $cm^3$
Surface area = 19.7 $cm^2$

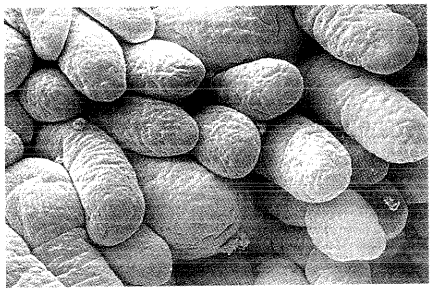



Oxygen diffusing into a hypothetical ellipsoid cell of volume 4.2 $cm^3$ needs to cross only 0.5 cm to reach the center of the cell when entering from the long axis. There is a greater surface area for diffusion than in a spherical cell of the same volume: more oxygen molecules diffuse into the cell per unit of volume than in a spherical cell of the same volume.

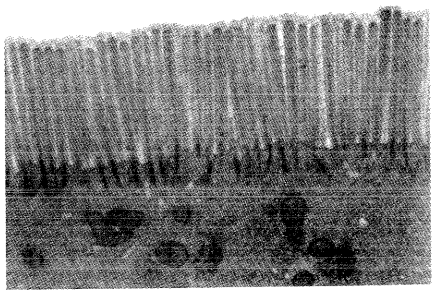
The size and shape of a cell reflects its function and the need for essential molecules to diffuse in and out. The greater the spherical diameter of a cell, the more material it contains, and the further molecules have to move in order to reach the center. Molecules diffusing into the cell are used up faster than they can be supplied and may not reach the cell's center, leaving it starved of essential molecules (e.g. oxygen). This can be solved by reducing the diameter of the cell along at least one axis.



Root hairs are the elongated extensions of root-hair cells in the epidermis of plant roots. They increase the surface area available for absorption of water and nutrients.



Villi are protrusions of the intestinal wall. They increase the surface area for absorption of nutrients from the small intestine. Their surface is lined with cells which are covered in microvilli.



Microvilli are extensions of a cell's plasma membrane, greatly increasing its surface area. In the small intestine they increase the area for absorbing nutrient from food.

1. Why do cells need to be a variety of shapes and sizes?_____

_____

2. Use the dimensions of the hypothetical cells above to answer the following questions:

   (a) For both cell A and B, oxygen diffuses across the plasma membrane at a rate of 100 molecules per $cm^2$ per minute. Calculate the total number of oxygen molecules that enter the cells during a period of 5 minutes:

   Cell A: _____

   Cell B: _____

   (b) Calculate the number of oxygen molecules available per $cm^3$ of cell during the 5 minute period:

   Cell A: _____

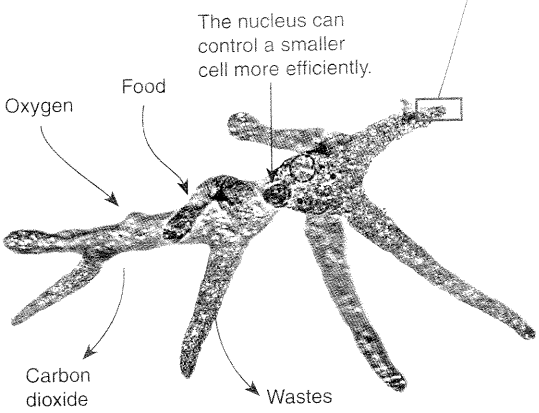
   Cell B: _____

When an object (e.g. a cell) is small it has a large surface area in comparison to its volume. In this case diffusion will be an effective way to transport materials (e.g. gases) into the cell. As an object becomes larger, its surface area compared to its volume is smaller. Diffusion is no longer an effective way to transport materials to the inside. For this reason, there is a physical limit for the size of a cell, with the effectiveness of diffusion being the controlling factor.

## Diffusion in Organisms of Different Sizes

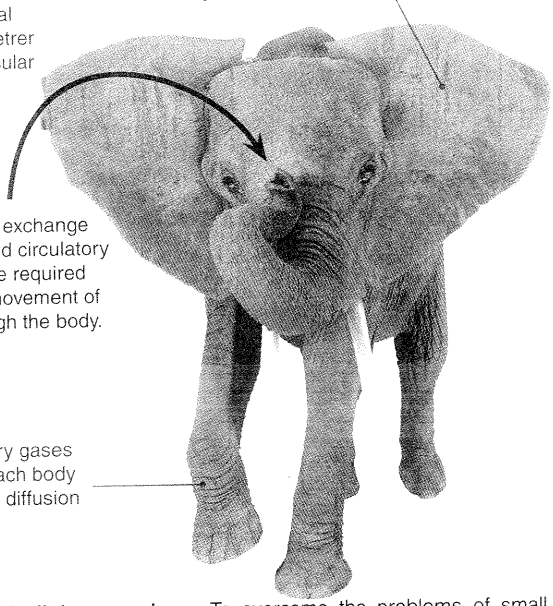
Respiratory gases and some other substances are exchanged with the surroundings by diffusion or active transport across the plasma membrane.

The **plasma membrane**, which surrounds every cell, functions as a selective barrier that regulates the cell's chemical composition. For each square micrometrer of membrane, only so much of a particular substance can cross per second.




The surface area of an elephant is increased, for radiating body heat, by large flat ears.

A specialised gas exchange surface (lungs) and circulatory (blood) system are required to speed up the movement of substances through the body.

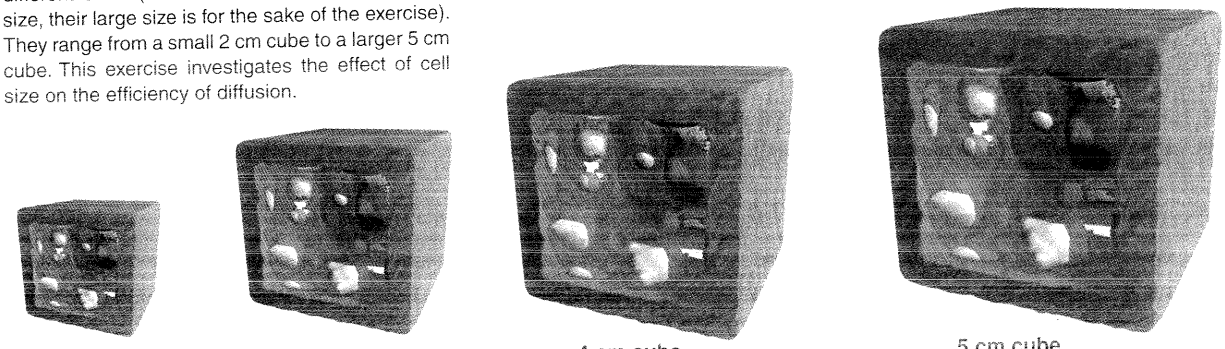


Respiratory gases cannot reach body tissues by diffusion alone.

***Amoeba***: The small size of single-celled protists, such as *Amoeba*, provides a large surface area relative to the cell's volume. This is adequate for many materials to be moved into and out of the cell by diffusion or active transport.

**Multicellular organisms**: To overcome the problems of small cell size, plants and animals became multicellular. They provide a small surface area compared to their volume but have evolved various adaptive features to improve their effective surface area.

The diagram below shows four imaginary cells of different sizes (cells do not actually grow to this size, their large size is for the sake of the exercise). They range from a small 2 cm cube to a larger 5 cm cube. This exercise investigates the effect of cell size on the efficiency of diffusion.



2 cm cube | 3 cm cube | 4 cm cube | 5 cm cube

1. Calculate the volume, surface area and the ratio of surface area to volume for each of the four cubes above (the first has been done for you). When completing the table below, show your calculations.

| Cube size | Surface area | Volume | Surface area to volume ratio |
|---|---|---|---|
| 2 cm cube | $2 \times 2 \times 6 = 24\ cm^2$ (2 cm x 2 cm x 6 sides) | $2 \times 2 \times 2 = 8\ cm^3$ (height x width x depth) | 24 to 8 = 3:1 |
| 3 cm cube | | | |
| 4 cm cube | | | |
| 5 cm cube | | | |



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2. Create a graph, plotting the surface area against the volume of each cube, on the grid on the right. Draw a line connecting the points and label axes and units.

3. Which increases the fastest with increasing size: the **volume** or the **surface area**?

_____

4. Explain what happens to the ratio of surface area to volume with increasing size.

_____

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_____

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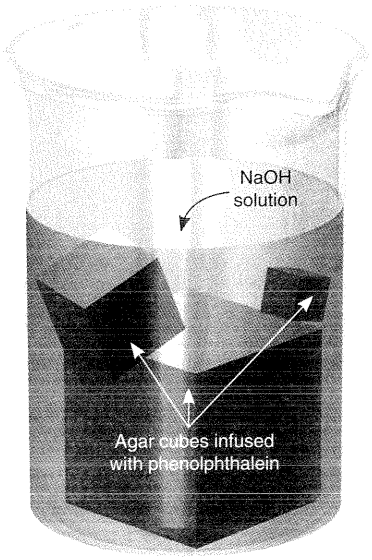
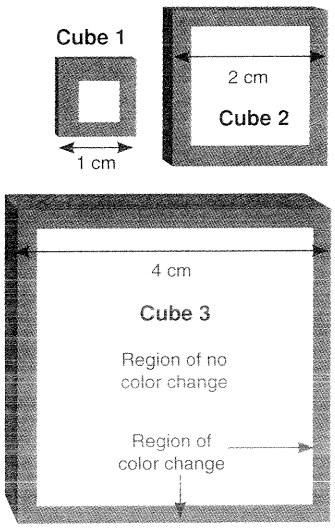
_____



5. The diffusion of molecules into a cell can be modelled by using agar cubes infused with phenolphthalein indicator and soaked in sodium hydroxide (NaOH). Phenolphthalein turns a pink color when in the presence of a base. As the NaOH diffuses into the agar, the phenolphthalein changes to pink and thus indicates how far the NaOH has diffused into the agar. By cutting an agar block into cubes of various sizes, it is possible to show the effect of cell size on diffusion.

(a) Use the information below to fill in the table on the right:




Cubes shown to same scale

| Cube | 1 | 2 | 3 |
|---|---|---|---|
| 1. Total volume ($cm^3$) | | | |
| 2. Volume not pink ($cm^3$) | | | |
| 3. Diffused volume (1. – 2. ) ($cm^3$) | | | |
| 4. Percentage diffusion | | | |

(b) Diffusion of substances into and out of a cell occurs across the plasma membrane. For a cuboid cell, explain how increasing cell size affects the effective ability of diffusion to provide the materials required by the cell:

_____

_____

_____

_____

6. Explain why a single large cell of 2 cm x 2 cm x 2 cm is less efficient in terms of passively acquiring nutrients than eight cells of 1 cm x 1 cm x 1 cm:

_____

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