

## Diffusion and the Problem of Size

All organisms need to exchange substances such as food, waste, gases and heat with their surroundings. These substances must diffuse between the organism and the surroundings. The rate at which a substance can diffuse is given by **Fick's law**:

$$\frac{\text{Surface area} \times \text{concentration difference}}{\text{Distance}} \text{ Rate of Diffusion}$$

The rate of exchange of substances depends on the organism's surface area that is in contact with the surroundings. The requirements for materials depends on the volume of the organism, so the ability to meet the requirements depends on the surface area : volume ratio → As organisms get bigger their volume and surface area both get bigger, but volume increases much more than surface area.

A bacterium is all surface with not much inside, while a whale is all insides with not much surface. This means that as organisms become bigger it becomes more difficult for them to exchange materials with their surroundings. In fact this problem sets a limit on the maximum size for a single cell of about 100 μm. In anything larger than this materials simply cannot diffuse fast enough to support the reactions needed for life.

Organisms also need to exchange heat with their surroundings, and here large animals have an advantage in having a small surface area they lose less heat than small animals. Large mammals keep warm quite easily and don't need much insulation or heat generation. Small mammals and birds lose their heat very readily, so need a high metabolic rate in order to keep generating heat, as well as thick insulation. So large mammals can feed once every few days while small mammals must feed continuously.

**Gas exchange takes** place at a respiratory surface - a boundary between the external environment and the interior of the body. For unicellular organisms the respiratory surface is simply the cell membrane, but for large multicellular organisms it is part of specialised organs like lungs, gills or leaves. Gases cross the respiratory surface by diffusion, so from Fick's law we can predict that respiratory surfaces must have:

- a large surface area
- a thin permeable surface
- a moist exchange surface

### Simple Diffusion

Fat-soluble molecules, such as glycerol, can diffuse through the membrane easily. They dissolve in the phospholipid bilayer and pass through it in the direction of the **concentration gradient**, from a **high concentration** to a **low concentration**.

Water, oxygen and carbon dioxide can also diffuse through the bilayer, passing easily through the temporary small spaces between the 'tails' of the **phospholipids**.

### Facilitated Diffusion

Some molecules such as those that are soluble in water, cannot pass through the phospholipids in the bilayer. They are transported across the membrane by **carrier proteins**. A carrier protein will have a specific binding site for the substance it transports. Solute molecules moving about on either side of the membrane will randomly come into contact with their specific binding site. Once they bind, the protein changes shape and the molecules come off the binding site on the other side of the membrane.

### Active Transport

Some solutes have a higher concentration inside the cell than outside so they have to cross the membrane against the concentration gradient. This means they can't get in by passive transport, neither **simple diffusion** nor **facilitated diffusion** works. They must enter by way of a process known as active transport. We call it active because it requires energy from the cell.

Some of the carrier proteins found in the plasma membrane provide a means for this to take place. These carriers have binding sites which pick up specific molecules. They function in one direction only and require energy to change shape and move the solute. Notice the 'E' energy symbol in the animation below.