Gas exchange, cell membranes and transport

Gas exchange surfaces and Fick's law, the mammalian lung, membrane structure and the fluid mosaic model, osmosis, and passive and active transport.

Gas exchange surfaces

An efficient gas exchange surface has:

- a **large surface area** to volume ratio,
- a **thin** barrier (short diffusion distance, often one cell thick),
- a **steep concentration gradient** maintained by ventilation and blood flow.

Fick's law

$$\text{rate of diffusion} \propto \frac{\text{surface area} \times \text{difference in concentration}}{\text{thickness of the exchange surface}}$$

So doubling the surface area doubles the rate, while doubling the thickness halves it.

The mammalian lung

- **Trachea, bronchi and bronchioles** carry air to the alveoli. The trachea has rings of cartilage that keep it open and **ciliated epithelium** and **goblet cells** that remove mucus and trapped particles.
- **Alveoli**: millions of tiny air sacs lined with a single layer of **squamous epithelium**, which gives a **large surface area** and short diffusion distance.
- A dense network of **capillaries** around each alveolus also has walls one cell thick. Together, the alveolar and capillary walls are about 0.5 µm thick.
- **Ventilation** (breathing) maintains a high O_2 concentration and low CO_2 concentration in the alveoli, and **blood flow** removes oxygen and brings carbon dioxide, so the gradients are steep.
- **Elastic fibres** in the walls recoil on breathing out. **Surfactant** reduces surface tension to stop alveoli collapsing.

Cell membranes

Structure: the fluid mosaic model

The **fluid mosaic model** describes the membrane as a **phospholipid bilayer** with proteins scattered in it like a mosaic, and the molecules free to move sideways (fluid).

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- **Phospholipids** have a **hydrophilic head** (phosphate, facing the water) and **hydrophobic tails** (fatty acids, facing inwards). The bilayer is a barrier to water-soluble substances.
- **Intrinsic (integral) proteins** span the bilayer. They include **channel proteins** and **carrier proteins**, and **receptors** and **enzymes**.
- **Extrinsic (peripheral) proteins** are on one surface.
- **Cholesterol** fits between phospholipids and **regulates fluidity**, reducing it at high temperature and preventing the membrane becoming too rigid at low temperature.
- **Glycoproteins** and **glycolipids** have carbohydrate chains on the outer surface for cell recognition and signalling.

The model is an **interpretation of data**: it was developed from electron microscope images and experiments (such as the movement of labelled proteins between fused cells) and has been modified as new evidence appeared. The earlier Davson–Danielli model (a protein-lipid-protein sandwich) did not fit the data.

Core Practical 3: membrane permeability

Beetroot cells contain a red pigment, **betalain**, in the vacuole. If the membrane is damaged the pigment leaks out.

1. Cut equal pieces of beetroot, rinse, and place each in the same volume of water or solution.
2. Vary the **temperature** (or the concentration of **alcohol**), keeping other variables constant.
3. After a set time, measure the **colour of the liquid** with a colorimeter (or compare with standards).

Higher temperatures **denature** the membrane proteins and make the phospholipids move more, so the **permeability** increases and more pigment leaks out. Ethanol **dissolves** the lipids in the membrane and has the same effect.

Movement across membranes

Diffusion and osmosis

Diffusion is the net movement of molecules from a region of higher concentration to lower concentration, down a concentration gradient. It is passive and needs no energy.

Osmosis is the net movement of **free water molecules** through a **partially permeable membrane**, from a region of **higher water potential** to a region of **lower water potential**.

- Pure water has the highest water potential, $\psi = 0$. Solutes make it **more negative**.
- A cell placed in a solution of lower water potential loses water. Animal cells shrink (**crenate**). Plant cells become **plasmolysed** as the membrane pulls from the wall.

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- In a solution of higher water potential, an animal cell may swell and burst (**lyse**). A plant cell becomes **turgid**, held by the cell wall.

Passive transport

Process	How it works
Simple diffusion	Small, non-polar molecules (O_2, CO_2) pass directly through the phospholipid bilayer
Facilitated diffusion	Polar molecules and ions pass through **channel proteins** (gated, specific) or **carrier proteins** (change shape). Down a gradient, no ATP

Active transport

Active transport moves substances **against** a concentration gradient using **ATP** (the immediate source of energy) and **carrier proteins**. The carrier binds the substance, **ATP is hydrolysed** and the carrier changes shape to release it on the other side. It can be selective, and is inhibited by respiratory poisons.

> **The difference between facilitated diffusion and active transport is that facilitated diffusion is down a gradient and needs no ATP, whilst active transport is against a gradient and uses ATP.**

Bulk transport

- **Endocytosis** takes material into a cell: the membrane folds in and pinches off a **vesicle**. **Phagocytosis** takes in solids and **pinocytosis** takes in liquids.
- **Exocytosis** releases material: a vesicle fuses with the membrane (e.g. secretion of enzymes and hormones).

Both need ATP.

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