- **Movement of environmental medium** – e.g. air, to maintain a diffusion gradient (Fick's law)
- **Movement of internal medium** – e.g. blood, to maintain a diffusion gradient (Fick's law)

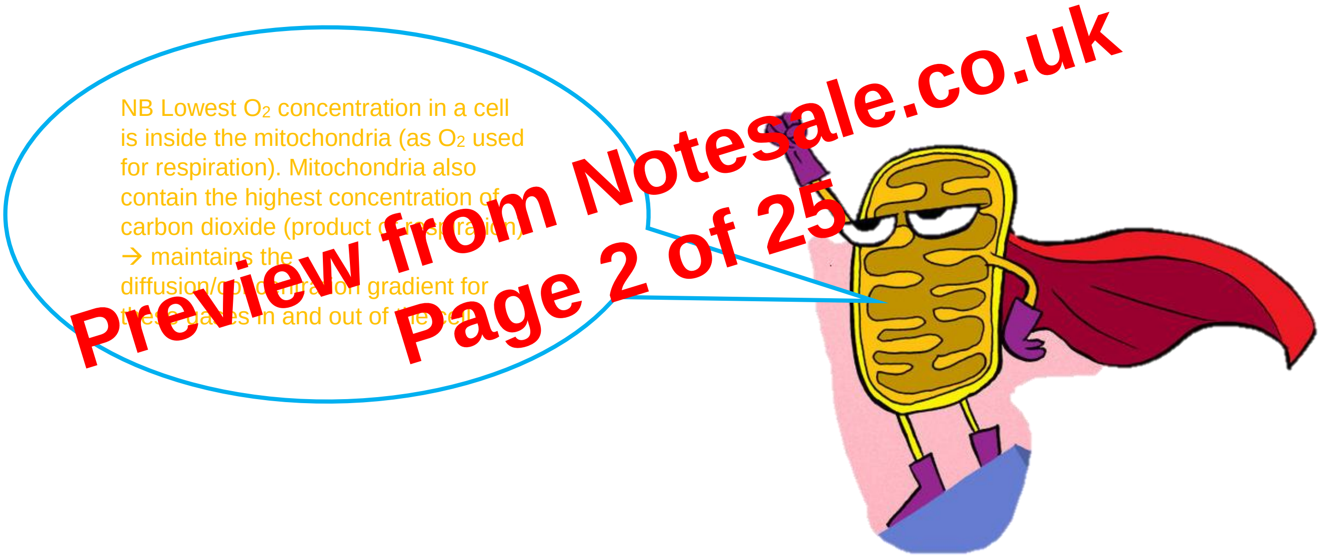
Remember- Fick's law:

$$\text{Rate of diffusion} \propto \frac{\textbf{surface area of membrane x DIFFERENCE in concentration}}{\textbf{length of diffusion path (distance)}}$$

The SA:V problem

Small objects (e.g. a cell) have a **large SA in comparison to its volume** → diffusion will be an effective way to transport materials into the cell.

As an **object becomes larger, its SA compared to its volume is smaller** → diffusion no longer an effective way to transport materials to the inside. Therefore to overcome this problems, larger multicellular organisms have evolved various adaptive features to improve their effective SA (e.g. big ears on an elephant) and have a specialised gas exchange surface.



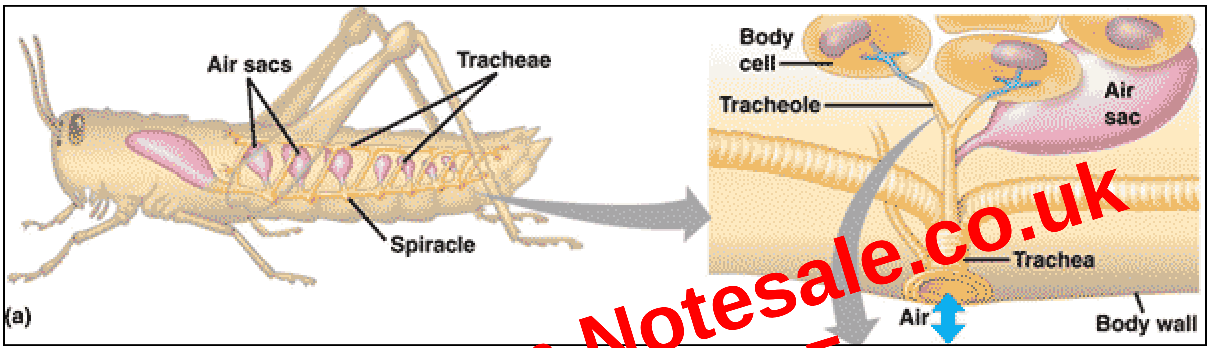
Why might exchange surfaces be located inside an organism?

Exchange surfaces usually **thin** (Fick's law → increase rate of diffusion) ∴ can be easily damaged.

- **Ventilation** – rhythmic movement of muscles in insects creates mass movements of air in & out of tracheae → **further speeds up exchange of respiratory gases**.

The gases move by **diffusion** across the **moist** lining **directly to and from the tissues** (see above). The **end** of each tube contains a small amount of fluid in which **the respiratory gases are dissolved**. The fluid is **drawn** into the **muscle tissues during their contraction**, and is **released back into the tracheole when the muscle rests**. **Dissolved oxygen is delivered to muscle fibres by the fluid.**

Spiracles:
Gases enter & leave trachea through tiny pores called **spiracles** on the body surface. **Spiracles** are **opened and closed** by **valves** that form the exit point of trachea from the body.
When **spiracles open**, **water can evaporate** from insect ∴ for much of day spiracles are **kept closed** to **prevent water loss**.
- Spiracles open **periodically** to **allow gas exchange**.



Gas exchange in aquatic insects

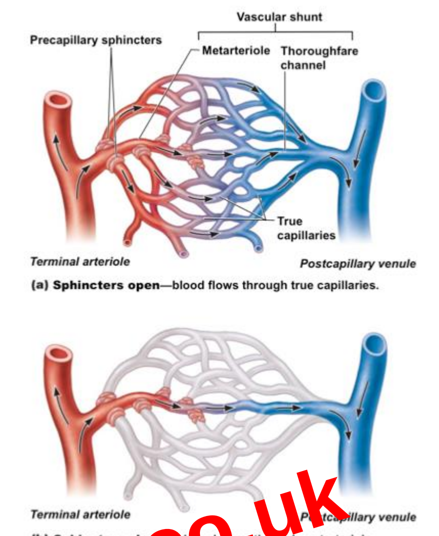
Availability of O_2 is v. low relative to air – **O_2 diffuses into water v.slowly** and it is not very soluble (unlike CO_2). Furthermore as **water temp. increases, amount of O_2 that can be dissolved decreases.**
In aquatic insects, like in terrestrial insects, gases move to and from the tissues via the **trachea:** the network of air-filled tubes that forms the insect's respiratory system.

Method by which oxygen enters this system is different.

Aquatic insect larvae rely on **diffusion across the body surface** (with or without gills). This diffusion is **enhanced by the presence of tracheal gills** which may account for 20%-70% of O_2 uptake, depending on their SA.
- Adult insects **carry air** with them when **submerged**.
- Air may be carried as a **distinct bubble** beneath the wings, or stay **trapped by regions of unwettable (hydrofuge) hairs.**
    - A thin film of air trapped by hairs is called a **plastron**- it provides a source of oxygen and acts as a non-compressible diffusion gill, into which oxygen can diffuse from the water.

Although the capillaries are small, they cannot serve every single directly ∴ the final journey of metabolic materials is made in a liquid solution that bathes the tissues → **tissue fluid**.

NB microscopic blood vessels in some dense organs, such as the liver, are called **sinusoids**. They are wider than capillaries and follow a more convoluted path through the tissue. Instead of the usual endothelial lining, they are lined with phagocytic cells. Like capillaries, sinusoids transport blood from arterioles to venules.



(a) Sphincters open—blood flows through true capillaries.
(b) Sphincters closed—blood flows through metarteriole – thoroughfare channel and bypasses true capillaries.

Capillaries form **branching networks** where exchanges between the blood & tissues take place. The flow of blood through a capillary bed is called **microcirculation**. In most parts of the body, there are 2 types of vessels in a capillary bed: the **true capillaries** where exchange takes place and a vessel called a **vascular shunt**, which connects the arteriole and venule at either end of the bed.

- The shunt **diverts blood** past the true capillaries when the metabolic demands of the tissue are low (e.g. vasoconstriction in the skin when conserving body heat). When tissue activity increases, the entire network fills with blood.

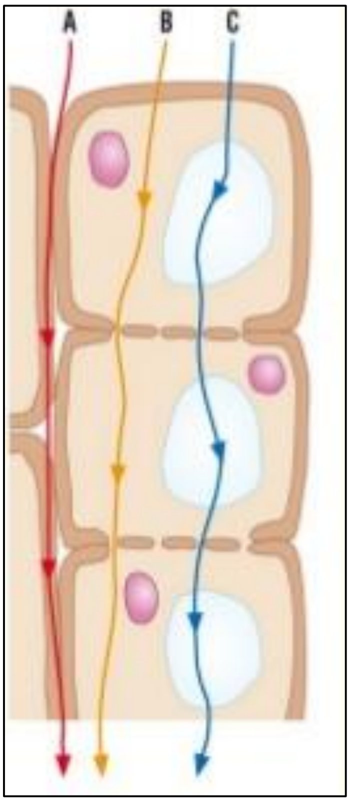
Tissue fluid (aka interstitial fluid)

- **Tissue fluid- watery liquid containing glucose, amino acids, fatty acids, salts and oxygen**.
- Tissue fluid supplies all of **these substances to the tissues**, and in return **receives CO_2** and **other waste materials** from the tissues.
- **Tissue fluid is the means by which materials are exchanged between blood and cells and ∴ bathes all the cells of the body.**

It is the immediate environment of cells and is, in effect, where they live. Tissue fluid is formed form blood plasma and the composition of the blood plasma is controlled by various homeostatic systems. As a result, tissue fluid provides a mostly constant environment for the cells it surrounds.

Formation of tissue fluid:

1) Blood pumped by the heart passes along arteries, the narrower arterioles and then the even narrower capillaries → this creates a pressure called **hydrostatic pressure** at the **arterial end of the capillaries**.
2) This **hydrostatic pressure forces water and small molecules** (which form the tissue fluid) **out of the blood plasma through the permeable capillary wall** when blood enters a capillary, providing the tissues with nutrients and oxygen.
3) The **hydrostatic pressure decreases** as **blood flows along the capillary**. When it falls **below the solute potential**, **fluid begins to drain back into the blood**, taking with it **wastes** such as urea and CO_2.



A= Apoplastic pathway

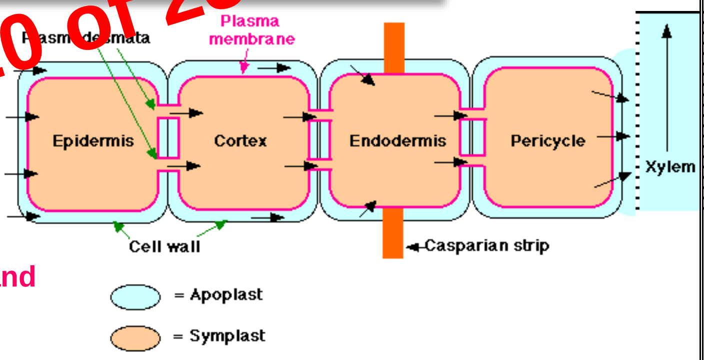
B= Symplastic pathway

C= Vacuolar pathway

Made from a waxy, waterproof material called suberin.

Passage of water into the xylem:

Before water & minerals can pass into the xylem, they must pass through the **endodermis** (the thin membrane surrounding the xylem). The **casparian strip** (a waterproof layer) fills all the gaps between the endodermal cells and **prevents the water from progressing further along the cell wall and entering the xylem via the apoplast pathway**.



At this point, water is forced into the **living protoplast of the cell**, where it **joins water** that has arrived there by the **symplastic pathway**. This is significant because, with the symplast pathway, **water and ions must pass through living material and membranes thus the plant has a degree of control over what passes into the xylem.**

Active transport of salts is the most likely mechanism by which water now gets into the xylem. Endodermal cells actively transport salts into the xylem. This process requires energy and ∴ can only occur within living tissue. It takes place along **carrier proteins** in the cell-surface membrane. If water is to enter the xylem, it must first enter the cytoplasm of endodermal cells → explains why water from the apoplastic pathway is forced into the cytoplasm of the endodermal cells by the Casparian strip.