FACTFILE: GCSE BIOLOGY: UNIT 1.1

Rewarding Learning

Cells: Exchange Surfaces and Diffusion

Learning outcomes

Students should be able to:

1.1.9 explain the need for exchange surfaces and a transport system in multicelled organisms in terms of surface:volume ratio

1.1.10 describe and explain the process of diffusion, which transports substances, including oxygen, carbon dioxide, water, dissolved nutrient molecules and mineral ions, into and out of cells and organisms:

- as the movement of molecules from a region of high concentration to a region of low concentration; and
- the rate of diffusion is affected by temperature, surface area and concentration gradient

1.1.11 investigate the effect of surface area on the rate of diffusion;

The need for Exchange Surfaces

All organisms require a variety of substances to live, for example oxygen, carbon dioxide, water, together with dissolved nutrient molecules such as glucose and mineral ions. These substances must be taken in by the organism and delivered throughout that organism to all cells. It is also essential that waste products are removed from the organism to prevent damage caused by the build of poisonous waste materials such as urea and carbon dioxide.

Simple organisms receive or remove these substances directly through their skin using the processes of simple diffusion. However more complex organisms will require organ systems to take in or remove substances. For example mammals need the circulatory system and digestive system.

In respiration, oxygen can be delivered to some organisms by diffusion across their external surface directly to respiring tissues, for example a flatworm. For others the oxygen must be diffused via the lungs and the circulatory system such as found in mammals. However, when the organism gets bigger, diffusion alone is not capable of supplying sufficient oxygen to the tissues deeper within the organism. The cells deeper within the tissues are too far away for direct diffusion. When we have reached this point we can say that the surface area to volume ratio is getting too small, and a more complex delivery system would be needed.

Definition: *The surface-area-to-volume ratio (SA:V) is the amount of surface area per unit volume of an object or organism.*

In biochemical reactions involving cells and organisms, the surface area to volume ratio is an important factor for the reactivity, that is, the rate at which the molecules will move into the cell and rate at which the biochemical reaction will proceed.

The video link below is a tutorial on SA:Vol ratio which will enhance your understanding.
https://www.youtube.com/watch?v=yZU7Kvkk4js

When you increase surface area and volume of a cube, the volume increases more rapidly than the surface area. This means that there is more volume for each unit of surface area. Therefore, it would take longer for substances to diffuse into the organism.

Is surface area on its own enough?

We have already thought about the significance of the SA to volume ratio in aiding the effectiveness of exchange surfaces. In addition to this physical property, the level of activity of the organism also has a big influence. The fly does a lot of moving around to find food, it therefore needs more oxygen delivery and carbon dioxide removal to sustain the high level of respiration required to supply energy to the flying muscles of the fly. The flatworm is much less active and often functions as a bottom feeder waiting for food that it can consume. So even though the flatworm has a smaller surface area to volume ratio than the fly, the fly has a much greater metabolic need.

Simple single celled organisms have no problem with obtaining their metabolic needs. The two clips included show two common single celled organisms that have a favourable surface area to volume ratio and so can gain their metabolic needs directly from the medium in which they live. They can obtain food and gasses by diffusion directly across their outer surface.
https://www.youtube.com/watch?v=7pR7TNzJ_pA
(Amoeba video)
https://www.youtube.com/watch?v=l9ymaSzcsdY
(Paramecium video)

What is Diffusion?

Definition: *This is the movement of molecules (as gas or in solution) from a region of high concentration to a region of low concentration.*

You can smell food smells wafting from the school canteen through your classroom window because of diffusion. The smell of chips will be produced in the kitchen and a region of high concentration will build up there. There is a region of lower concentration of 'chip smell molecules' in your classroom but then these molecules will begin to physically move from the kitchen, through the air and into your classroom. The kinetic energy of air molecules and the chip smell molecules will provide the energy needed to get the smell molecules to make this journey.

Diffusion of any gas or liquid molecule will follow this same logic. If we have regions of differing concentration (a concentration gradient) and kinetic energy in the form of vibrating molecules, then we will have molecules diffusing.

Diffusion can happen in air or in liquid and can also happen through barriers such as cell membranes as long as that membrane is permeable.

Factors Affecting Diffusion Rate

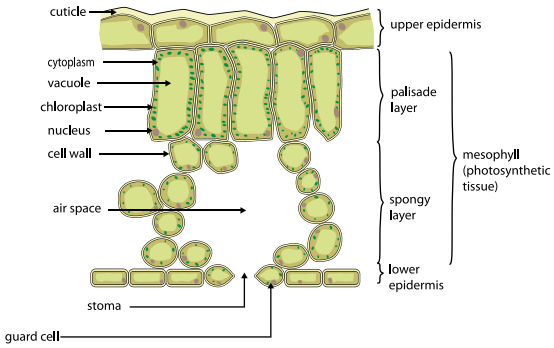
Three factors affect diffusion rate:

1. Temperature
2. Surface area
3. Concentration gradient

If you research exchange surfaces, for example alveoli, fish gills, small intestine, root hair cells and placenta, you will notice that these different tissues and organs have some features in common. Diffusion rate in all these examples will be affected in the same way by these factors.

The images below will act as a reminder.

Cell Structure of a leaf



Leaf Mesophyll

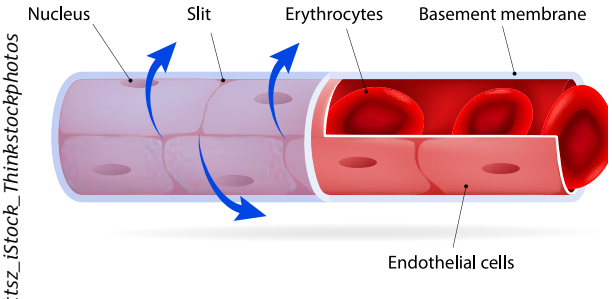
Where is the large surface area?

What is being diffused?

Wheatgrass with roots exposed

Where is the large surface area?
What is being diffused?

CAPILLARY



Capillaries

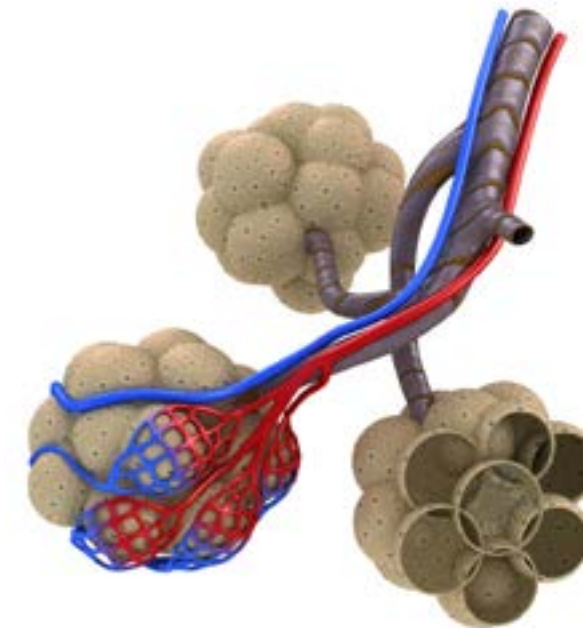
Where is the large surface area?

What is being diffused?

Red Blood Cells Isolated

Where is the large surface area?

What is being diffused?



Alveoli in lungs

Where is the large surface area?

What is being diffused?

Effect of Temperature

Relationship: *The higher the temperature, the greater the rate of diffusion.*

Diffusion needs vibrating molecules to allow them to move. Molecules can then collide with each other and with the molecules of the air solution they are in. These collisions will allow molecules of the diffusing substance to move from the region of high concentration to the region of lower concentration.

The greater the temperature then the greater the kinetic energy which can be transferred the vibrating molecules, therefore speeding up the rate of diffusion.

The Effect of Surface Area

Relationship: *The larger the surface area, the faster the rate of diffusion.*

From the features of the exchange surfaces you looked at above you should have noticed that they all share a large surface area. That means there will be a very large surface over which gas exchange can take place. If we spread out the total surface of all alveoli in the lungs, or the total surface of the entire spongy mesophyll surface in spongy mesophyll, we would see a surprisingly large layer of cells that would now be available for exchange.

This practical below may be discussed, or even carried out, and will help explain for you how cubes of jelly absorb hydrochloric acid into them more quickly if they have a high surface area : volume ratio than if they have a smaller surface area : volume ratio. The jelly cubes have sodium hydroxide and universal indicator in them so as hydrochloric acid diffuses into them the indicator will change colour.
http://www.nuffieldfoundation.org/practical-biology/effect-size-uptake-diffusion

The Effect of Concentration Gradient

Relationship: *The greater the difference in concentrations (the steeper the concentration gradient), the faster the rate of diffusion.*

We have already mentioned that diffusion will occur from a region of higher to lower concentration. We refer to the situation where there is a difference in concentration between two regions as a 'concentration gradient'. If we have more of a substance in one place and very little in another, then there will be a large concentration gradient. When the difference becomes less, then so does the concentration gradient. Eventually we will reach a situation where the concentration of a substance is the same everywhere and the concentration gradient as such will not exist. We say at this point that equilibrium has been reached.

Glossary

- Multicelled – an organism consisting of many cells
- Surface Area:Volume Ratio – the surface-area-to-volume ratio, (SA:V), is the amount of surface area per unit volume of an object or organism.
- Concentration Gradient – the movement (by diffusion) of particles from a high to a low concentration as long as there is a difference in concentration between two regions.
- Diffusion – diffusion is the net movement of molecules or atoms from a region of high concentration to a region of low concentration.