# GAS EXCHANGE AND CIRCULATION

**Purpose**

Cellular respiration allows organisms to transform energy from glucose in food.

Cellular respiration requires oxygen gas and produces carbon dioxide gas as a waste product:

Carbon dioxide is a potentially harmful ____________________ product. It dissolves in cell fluids forming carbonic acid which can decrease cell pH making it more acidic.

Oxygen needs to be taken in to, and carbon dioxide needs to be released from, cells and _____________________ with their environment.

**Scientific Principles**

Gases move by diffusion. Diffusion is the net movement of particles in ___________________ (liquids and gases) from a region of higher to lower concentration down a concentration _______________________. Concentration of gases is referred to as partial pressure, so gases move down a partial pressure gradient.

For gas exchange in animals, gases diffuse across membranes of the respiratory system.

Water is the main constituent of __________________________ in cells and tissue fluids, and is where all important cellular reactions including respiration take place. Oxygen and carbon dioxide are both soluble in water; only _______________________ gases can diffuse through cell membranes.

Notes

Fick's Law describes the important factors that affect diffusion rate across a membrane:

$$\text{Diffusion rate} = c\,\frac{\text{Membrane surface area} \times \text{Difference in fluid concentration across membrane}}{\text{Membrane thickness}}$$

Diffusion rate across a membrane therefore depends on the ______________ of the available permeable surface, the effective diffusion distance which is determined by the ________________ of the surface and the fluid ________________________ gradient across the membrane.

As fluids diffuse they also become more dispersed and therefore less ______________________________, so diffusion is only effective at transporting substances over short distances.

Air contains 20.7% oxygen, whereas seawater typically contains less than ______% oxygen.  Although oxygen is more abundant in air than in water, water loss from gas exchange surfaces is greater in air.

Water is much _________________________ than air providing greater mechanical support.  Water is also 50x more _________________________ (resistant to flow) than air so is harder to move and move through.

Different organisms possess different physical and physiological _________________________ to exchange gases between their respiring cells and the environment.

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**Common Features**

All gas exchange surfaces (membranes) have certain common physical properties to maximise diffusion rate:

- ____________________________ membrane surfaces to enable gases to dissolve in
- ____________________________ membranes to allow dissolved substances to diffuse through
- ____________________________ membranes to reduce diffusion distances or paths and increase diffusion rate
- Large surface ____________________________ to increase the space available for diffusion to occur across

All organisms share common adaptations for efficient gas exchange:

- A large gas exchange surface area relative to their body volume. This gives a high gas exchange surface area:volume ratio to ensure that enough oxygen diffuses in to meet their body's ________________________________ demand
- Respiratory ____________________________ to temporarily bind and carry oxygen
- Some form of circulatory system to transport gases to and from the gas exchange system and maintain a high ______________________________________ _______________________________
- _______________________________ and physical adaptations to prevent gas exchange surfaces from desiccation or drying out in ____________________________ animals

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**Insects: tracheal system**

Insects have a hard, waxy, impermeable ________________________ to prevent water loss from the body, but which also prevents gas exchange across the body surface.

For gas exchange they have an extensive internal network of branching tubes called _________________________. To prevent their collapse they are lined with spirals of a protein called ____________________ to form taenidia which provide mechanical support. As the gas exchange surface is deep within the body cavity, high _____________________ is maintained and so water loss reduced.

The largest tubes termed ________________________ open to the outside of the body through spiracles. Most insects have one pair of spiracles per body segment. The spiracles possess fine 'hairs' which filter incoming air. Muscular valves control the size or aperture of the spiracular opening to regulate gas exchange rate and reduce water loss.

Tracheae branch into finer tubes called tracheoles which extend to within 5 microns (0.______________ of a metre) of the surface of almost every cell in the insect's body. The end of the tracheoles contains a _____________________ in which respiratory gases are dissolved. In small insects with a high surface area to volume ratio gases are exchanged by simple diffusion between the tracheolar fluid and the adjacent tissues.

In larger insects with a lower surface area to volume ratio such as the grasshopper, the rate of unassisted diffusion is too low to support the animal's respiratory demand. As tracheoles get longer, friction between the moving air and the walls of the tracheoles is greater which slows the rate of air movement. Simple air _________________________ in the thorax ('chest') can be compressed and expanded by rhythmic body movements to ___________________________ or flush the trachea, pumping air in out: this is known as facilitated diffusion and uses ATP.

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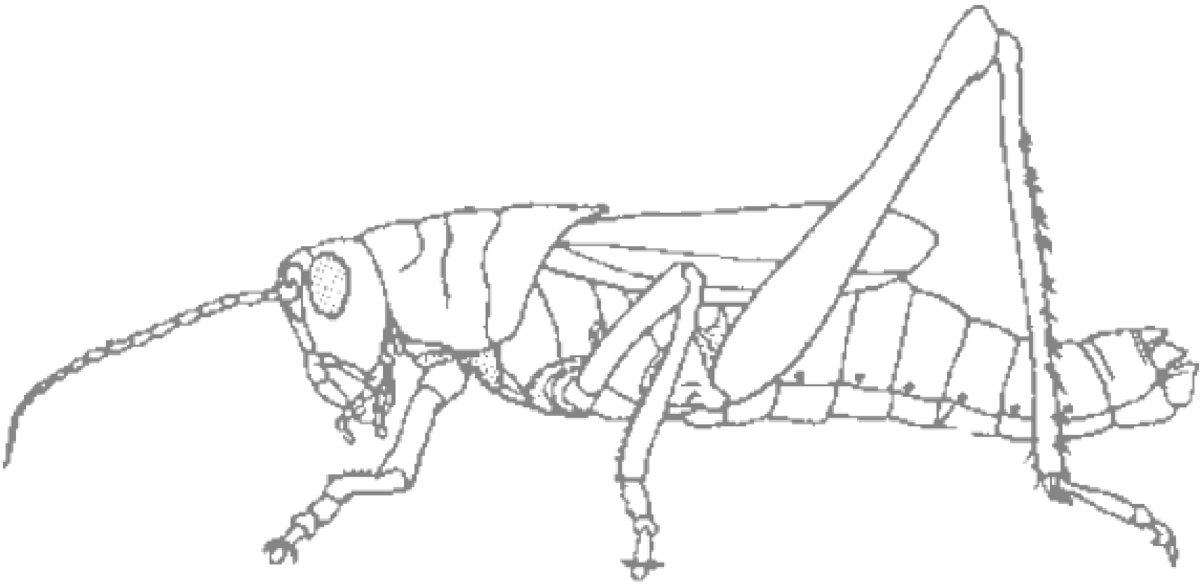


**Circulation system.**

Insects don't have veins or arteries, but they do have circulatory systems. When blood is moved without the aid of vessels, the organism has an ___________________________ circulatory system. Insect blood, properly called hemolymph, flows freely through the body cavity and makes direct contact with organs and tissues.

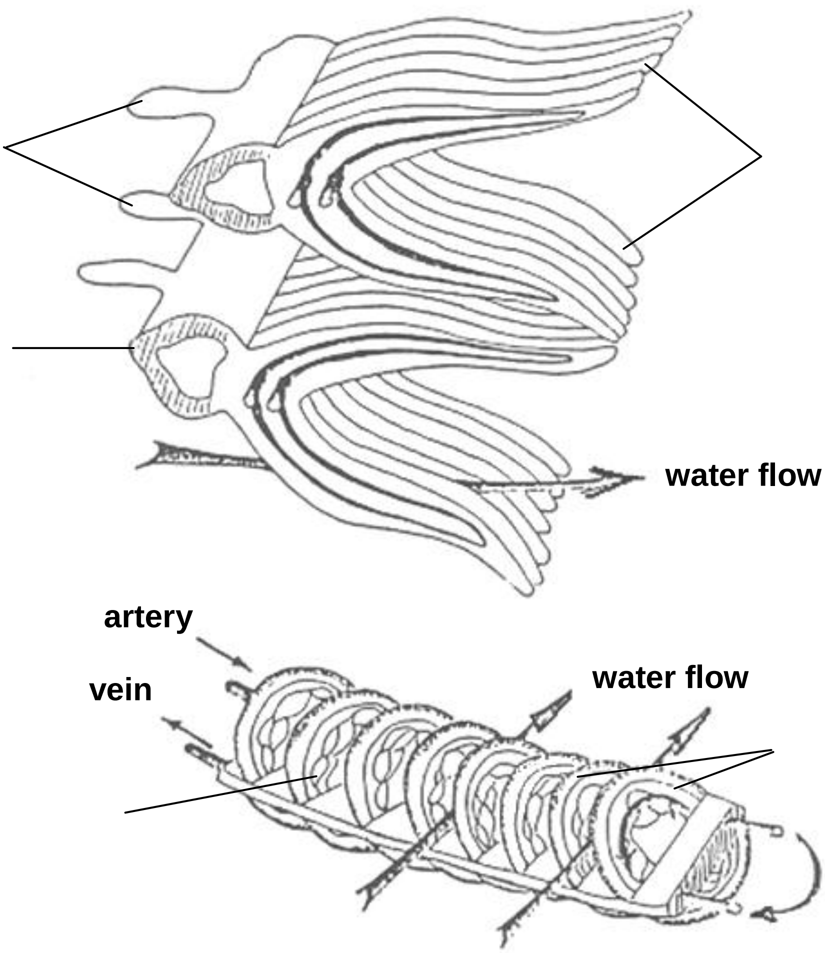
A single blood vessel runs along the _____________________________ side of the insect, from the head to the abdomen. In the abdomen, the vessel divides into chambers and functions as the insect heart. Perforations in the heart wall called __________________________ allow hemolymph to enter the chambers from the body cavity. Muscular contractions push the hemolymph from one chamber to the next, moving it ___________________________ toward the thorax and head. In the thorax, the blood vessel is not chambered. The vessel simply directs the flow of hemolymph to the head.

Insect blood is only about 10% blood cells; most of the hemolymph is watery plasma. The insect circulation system does not carry _____________________________, so the blood does not contain red blood cells as ours does and is usually green or yellow.

Notes

**Fish: gills**

Fish have ____________________________ gas exchange surfaces called gills. Four pairs of gills are located to the side and rear of the buccal cavity and are composed of thin, highly-folded, structures called gill __________________________ supported on semi-rigid cartilaginous gill arches. Each filament has many thin, membranous ____________________________ to increase the surface area for gas exchange. In bony fish the gills are covered by a protective operculum (gill cover).




Water is more ____________________________ than air and resists flow so must be actively forced across the gills by ventilation. Bony fish 'gulp' water in 2 stages:

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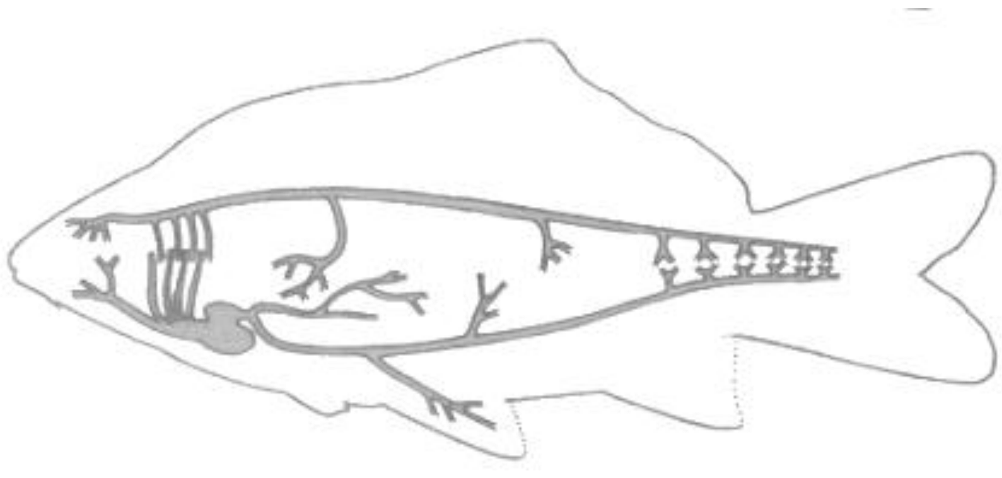
1. water enters the mouth, passes through a slit in the pharynx called the oral valve while the operculum is ________________________;
2. the mouth and oral valve close and a current of water is passed over the gills and out through the open operculum.

The viscosity of water provides mechanical support for the fine gill structures and holds the lamellae _________________________, hence the gills do not need to be rigid.  Fine, comb-like gill-rakers on the leading edge of the gills remove particles which might obstruct or damage the lamellae.

**Circulation.**

Fish are generally active and can attain large sizes *e.g.* whale sharks reach up to 15m long. They have an efficient __________________________ circulation system to meet there high respiratory demand. A two-chambered heart pumps blood through an extensive network of capillaries close to the gill surface, and circulates oxygen and carbon dioxide between the body tissues and the gills, helping to maintain a high concentration gradient between the blood and the __________________________ washing over the gills.



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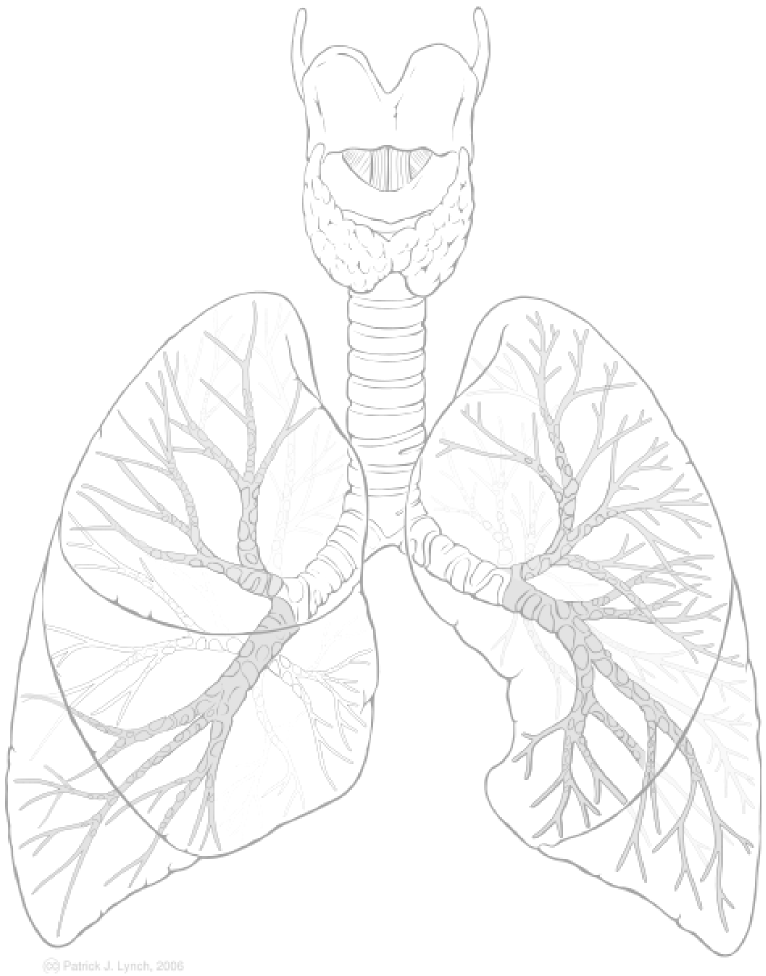
Blood flows in the lamellae in the opposite direction to water and dissolved oxygen and carbon dioxide are rapidly exchanged. This ______________________________________ exchanger also maintains the high concentration gradient between the blood in the gill capillaries and water in the mouth, increasing diffusion rate and maximising gas exchange.

Fish blood also contains red blood cells which allows their blood to carry more oxygen than could be carried dissolved in the ___________________________ (see next section).

Notes

**Mammals: lungs**

Many terrestrial vertebrates (mammals, reptiles, birds and some amphibians) are relatively large and very active; hence they have a high respiratory demand and so need a large, efficient gas exchange surface.  As they obtain oxygen from air, this has to be internal to reduce water loss by evaporation.  Lungs are internal, sac-like organs in the ____________________ cavity.




The lungs are spongy, non-muscular organs and cannot move by themselves.  Ventilation or breathing is brought about by muscular contractions of the diaphragm and intercostal muscles between the ribs - a process that requires energy.  The diaphragm is a muscular

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sheet at the base of the thoracic cavity beneath the lungs. During inhalation, the diaphragm contracts, ____________________ and drops, and the intercostal muscles move the ribcage upwards and outwards. This increases the ____________________ of the chest cavity and decreases air pressure inside the chest. External air pressure is now _____________________ and forces fresh air into the lungs to _____________________ the pressure (as air moves down a pressure gradient), and so inflates them. As the elastic diaphragm relaxes it rises and forces air out of the lungs. This action is known as ______________________.

Air is drawn into the lungs through the nostrils and mouth during inhalation, passes through the larynx into the trachea, and through the bronchi (*sing.* bronchus) leading to each lung. C-shaped ______________________ rings give mechanical support to the trachea and bronchi and prevent collapse, especially during inhalation. The bronchi branch into many finer ______________________ which extend throughout the entire lung and terminate in clusters of air sacs called alveoli (*sing.* alveolus) at the end of alveolar ducts.

Alveoli are the site of gas exchange and human lungs contain over 300 million of them. Each alveolus is tightly enclosed by a network of pulmonary _______________________ and is separated from them by a thin, permeable respiratory membrane (only 0.5 micrometres thick) allowing for rapid diffusion. The inside of the alveoli is covered by a thin layer of fluid surfactant which reduces surface tension of the lung tissue and prevents the walls of the alveoli from sticking together after their contraction during exhalation.

Blood returning to the lungs from the tissues of the body is depleted of oxygen (approx. 16% oxygen) or _______________________, and contains high levels of carbon dioxide due to cellular respiration. Inhaled air in the alveoli has a higher concentration of oxygen and lower levels of carbon dioxide: therefore concentration gradients for both substances exist across the respiratory membrane. Oxygen gas in the inhaled air ___________________ in the moist internal surfaces of the alveoli and diffuses across the respiratory membrane into the capillaries from an area of high oxygen concentration inside the air sac to an area of low concentration in the ______________________.

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Diagram showing gas exchange between inhaled air in the alveolar sac and the blood in the pulmonary capillaries in an alveolus.

Oxygen binds with haemoglobin in red blood cells. Haemoglobin is a respiratory ______________________ in red blood cells which binds oxygen when oxygen levels are high (as in the lungs), and releases it when carbon dioxide levels are high (and oxygen levels are low - as in active body tissues). Haemoglobin enables more oxygen to be carried in the blood than could be carried dissolved in the plasma alone. Carbon dioxide is transported in the _______________________ and diffuses down its concentration gradient out into the alveoli where it is exhaled.

Fine ____________________ in the nostrils filter small particles out of inhaled air; blood vessels in the nose also help to warm and moisten the air. _______________________ epithelial cells lining the respiratory tract secrete mucus to trap pathogens and dust and _______________________ it away from the lungs towards the nose and throat.

**Circulation***

Mammals have a ___________________ circulation system. A four-chambered heart pumps blood through the pulmonary capillaries, and circulates oxygen and carbon dioxide between the body tissues and the air in the lungs.

Notes

## Glossary

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| an adaptation | |
| ciliated | |
| circulation system | |
| concentration | |
| concentration gradient | |
| counter-current | |
| diffusion | |
| diffusion path | |
| epithelial | |
| equilibrium | |
| exhalation | |
| inhalation | |
| oxygenated | |
| permeable | |
| respiration | |
| respiratory demand | |
| respiratory gases | |
| respiratory pigments | |
| soluble | |
| ventilation | |
| viscous/viscosity | |

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