BY2031
ADAPTATIONS FOR GAS EXCHANGE IN ANIMALS
NCEA LEVEL 2
EXPECTED TIME TO COMPLETE WORK
This work will take you about 10 hours to complete.

YOU WILL WORK TOWARDS THE FOLLOWING STANDARD:
Achievement Standard 91155 (Version 1) Biology 2.3
Demonstrate understanding of adaptation of plants or animals to their way of life
Level 2, Internal
3 credits

IN THIS BOOKLET YOU WILL FOCUS ON THESE LEARNING OUTCOMES:
• describing the adaptations of fish, insects and mammals to carry out gas exchange
• relating the adaptations for gas exchange to the animals’ way of life.

ALL THE WORK FOR THIS STANDARD IS IN THIS BOOKLET.
HOW TO DO THE WORK

When you see:

- Use the Topic webpage or the Internet.
- Complete the activity.
- Check your answers.
- Contact your teacher.
- Caution.
- Use the CD/DVD.

You will need:
- a pen and paper.

Keep this booklet for reference. Do not return it to your teacher.

Resource overview
For this particular standard most of the information you need to learn is provided here. However, you are encouraged to visit the links to websites and videos listed and to make notes. They provide useful and interesting supplementary information that helps to explain the subject content. Use this extra information together with the information in this book when attempting Achievement Standard 91155: Demonstrate understanding of adaptation of plants or animals to their way of life.

However, if you cannot access these websites you will not be disadvantaged, as all the information you need for the topic is in the booklet.
# INTRODUCTION TO THE TOPIC

This achievement standard is designed for you to explore the diverse ways in which animals and plants are able to survive in their chosen habitats. The key concepts you will have to work with are:

- adaptations
- way of life
- life processes.

All living organisms have a range of adaptations that help them carry out their life processes in the most efficient way. Adaptations therefore provide an advantage for an organism in its specific habitat and ecological niche.

Way of life encompasses the ways an organism carries out all its life processes. It includes interspecific and intraspecific relationships, reproductive strategies and adaptations to the organism’s physical habitat.

Life processes can be selected from:

- internal transport
- gas exchange
- transpiration
- nutrition
- excretion
- support and movement
- sensitivity and coordination
- reproduction.

The option Te Kura is offering is for you to study gas exchange across three taxonomic animal groups.

## ACHIEVEMENT CRITERIA

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<tr>
<th>Achievement</th>
<th>Achievement with Merit</th>
<th>Achievement with Excellence</th>
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<tbody>
<tr>
<td>Demonstrate understanding of adaptation of plants or animals to their way of life.</td>
<td>Demonstrate in-depth understanding of adaptation of plants or animals to their way of life.</td>
<td>Demonstrate comprehensive understanding of adaptation of plants or animals to their way of life.</td>
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This booklet discusses a range of adaptations and uses the life process of gas exchange in three animal groups (fish, insects and mammals) to illustrate the level of detail required for the formal assessment.
INTRODUCTION

In the formal assessment you will be asked to present a written report with the evidence from these three taxonomic animal groups. Therefore you will first have to complete this booklet (BY2031) Adaptations for gas exchange in animals, and its teacher-marked assignment (BY2031A). If you are graded at achieved or above level you will be offered the formal assessment (BY2031Y1).
LEARNING INTENTIONS
In this lesson you will learn to:
• define habitat
• describe adaptations
• describe biotic and abiotic environmental factors
• describe an organism’s way of life.

INTRODUCTION
In this topic you will study the adaptations of three animal groups (fish, insects and mammals) to carry out the process of gas exchange in relation to the animals’ way of life.

An organism’s ‘way of life’ or ‘ecological niche’ encompasses the ways in which an organism carries out all its life processes. This includes its interactions with its biotic and abiotic environment, its relationships with other organisms, its reproductive strategies to ensure the species survives and the adaptations it has to its physical habitat.

HABITAT
The habitat is the place, area or location where an organism lives. For instance, the terrestrial environment contains many habitats such as grassland, forest, subalpine areas, sand dunes and so on. Within each of these are many microhabitats.

Here are some organisms in their habitats.

The habitat of this snapper is the coastal waters of New Zealand and Australia.

The habitat of the white clover is a paddock or field.
WAY OF LIFE

The habitat of the southern royal albatross is at sea where it feeds and nests on rat-free subantarctic islands such as Campbell Island and the Auckland Islands.

It is easy to see that the clover could not survive in the fish’s habitat and the fish could not survive in the clover’s habitat! This is because every organism has special adaptations that allow it to survive in its habitat.

ADAPTATIONS
An adaptation is any inherited characteristic that enables an organism to survive and reproduce in its habitat.

Adaptations may be structural, behavioural or physiological.

STRUCTURAL ADAPTATIONS
These are features of body structure. Some examples of structural adaptations are shown below.

The wings of this falcon are an adaptation for flight. Its sharp claws are an adaptation for catching its food.

The snail’s shell is an adaptation for protection.
The fern’s leaves are an adaptation to carry out photosynthesis under low light levels.

**BEHAVIOURAL ADAPTATIONS**
These are types of behaviour that help an organism to survive. Look at the following examples.

A seabird (manu) is sitting on her eggs to keep them warm so that the chicks will hatch.

These seals breed in large colonies for the protection of the pups.

Crayfish hide under rocks for protection from predators.
WAY OF LIFE

PHYSIOLOGICAL ADAPTATIONS
These are often chemical or physical adaptations. Here are some examples.

Humans keep their body temperature the same (about 37°C) despite changes in the temperature of the environment outside.

The tubeworms in the photo to the right live in seawater. They regulate the concentration of salts in their body fluids so that it is the same as in the surrounding seawater. If the salts in their body fluids were more concentrated than seawater, water would flood into the tubeworm cells and burst them. If the salts in their body fluids were less concentrated than seawater, then the tubeworms would dehydrate.

Did you know?
In June 2011, an Emperor Penguin that usually lives in the Antarctic was found on Peka Peka beach, north of Wellington. The penguin was disorientated and distressed. It began to eat sand that it mistook for ice. This is because in its native Antarctica habitat, a penguin would eat snow to obtain water and to keep its body temperature cold! The eating of snow is a behavioural and physiological adaptation that enables the penguins to survive in the harsh Antarctic environment that is their natural habitat. This penguin was named ‘Happy Feet’. It survived several operations to remove the sand from its stomach and was eventually released in the Southern Ocean.
ENVIRONMENTAL FACTORS
Although organisms are adapted to live in their particular habitats, the environment of those habitats affects the organisms living there.

In a bush community the different types of plants and animals could include trees, tree ferns, mosses, insects, birds, possums and so on. In a rocky shore community the different types of plants and animals could include algae and seaweed, mussels, periwinkles, barnacles and limpets. Most of the types of organisms found in the bush community are not found in the rocky shore community. This is because their environment is different.

The environment is the total of all the living (biotic) and non-living (abiotic) influences in a community.

BIOTIC (LIVING) FACTORS
All the organisms of every species in any community interact with each other and influence each other. Some species provide shelter and protect others while other species harm their neighbours in the community.

Biotic factors may be:
• intraspecific – between members of the same species (‘intra’ means within)
  or
• interspecific – between members of different species (‘inter’ means between).
Some examples of biotic factors are competition, exploitation and mutualism.

COMPETITION
Some species compete with each other for the resources of the environment such as food, water, nutrients, space, nesting sites and availability of mates.

Intraspecific competition can be intense, as all the individuals have the same requirements for resources.

Interspecific competition occurs if different species have similar requirements for any resource.

EXPLOITATION
Other species exploit some members of the community. In biology the term ‘exploitation’ has been reserved for those animal or plant processes where a host or prey is exploited to provide food. Some types of exploitation are:
• parasitism
• predation
• grazing.

Parasites exploit a host population but do not usually kill their host. It is in their interest to have live hosts to continue exploiting.
Parasitism is a relationship in which one species benefits at the expense of another – one species (the parasite) is benefited and the other (the host) is harmed. The head louse, whose eggs are the well known ‘nits’, is an example of parasitism.

A predator catches prey and eats it. This is how it obtains energy for living, growing and reproducing. Predators often feed on herbivores, though some may eat other predators. Predators regulate the number of their prey and are in turn regulated by the number of individuals available to be preyed on. An example is shown in the photo on the right, which is of a jumping spider capturing a juvenile praying mantis.

Grazers such as cows exploit plants by feeding on them and using their energy for living, growth and reproduction. Grazers often live in herds, and their massed feeding can have a major impact on the plants growing in an area. White butterfly caterpillars, for example, can destroy a cabbage crop if not controlled.

**Mutualism**

In a mutual relationship both organisms benefit from the association. An example is lichen, which is an association between algae cells and a fungus. The fungus provides a safe habitat for the algae and traps water for it. The algae in turn photosynthesise and provide the fungus with nutrients, so both benefit.

**Abiotic (Non-living) Factors**

There are many abiotic factors that affect the environment and the organisms living in a particular habitat.

Factors like soil, light, water, air, temperature and nutrients are non-living (abiotic) influences.

The amount of sunlight the environment receives affects the amount of photosynthesis the plants carry out and this in turn provides energy for all the other members of the community. The light intensity and the length of daylight affect the types of plants found in a community.

The temperature is important, as all chemical reactions in living organisms can only take place at certain temperatures. If the temperature is too high or too low, organisms that are not adapted to these temperatures will not survive to produce offspring. Only mammals and birds are able to control their internal body temperatures but even they need special adaptations to survive for long in extremes of heat or cold.

Many animals have **behavioural adaptations** to ensure that they move into areas where the temperature is more suited to their needs. For example, slaters (woodlice) hide under logs to escape from high temperatures on the soil surface during the day. Bears hibernate during the cold winter months, while some birds migrate long distances to escape winter and feed in warmer climates. Plants grow more slowly in winter because the cooler temperatures slow down the chemical reactions in their cells.
WAY OF LIFE (ECOLOGICAL NICHE)
In lesson 1 you read that an organism’s ‘way of life’ or ‘ecological niche’ encompasses the ways in which an organism carries out all its life processes. This includes its interactions with its environment, its relationships with other organisms, its reproductive strategies to ensure the species survives and the adaptations it has to its physical habitat.

You have now learned how all organisms are adapted to their particular habitat and are affected by both the biotic and abiotic factors in their environments. In order to describe an organism’s way of life or ecological niche you would need to study the organism in the wild and through laboratory investigations, so that you could answer questions like:

- Where does it live, what is its habitat?
- What does it eat? Is it a producer, a herbivore or a carnivore?
- Who eats it? What, if any, are its predators?
- Does it have a parasitic or mutualistic relationship with another species?
- How does it breed?
- How does it get shelter?
- What adaptations does it have that suit it to its habitat?

Answering these questions builds up an idea of the opportunities provided by the habitat and the way in which the organism uses the adaptations it has inherited to live and breed successfully in this habitat.

Here are the descriptions of two different ways of life (ecological niches).

A **kiwi**’s way of life (ecological niche) is that of a nocturnal, flightless bird that nests and roosts (sleeps) in burrows among tree roots. It is covered with feathers and has strong legs and heavy bones filled with marrow. It has a keen sense of smell and uses its long beak to forage for insects among the litter on the forest floor. It cannot fly and is easily predated by introduced mammals such as stoats, dogs and possums.

A **seal** is a carnivorous aquatic mammal. It has fur to keep warm and is streamlined for swimming. Its layer of fat and thick fur coat enable it to endure long periods in water, but can cause overheating on land. Seals are preyed on by larger aquatic species such as whales. Seals are social animals and a behavioural adaptation is that they breed in large colonies on land. There is a strong bond between mother seals and their pups.
Notice how the descriptions of the two ways of life (ecological niches) given link together the features of each organism’s habitat (the place where it lives) with the special adaptations that each organism has inherited to survive and reproduce in that particular habitat. The kiwi could not survive in the seal's habitat and vice versa.

Use the Topic webpage or the Internet to find out more information about adaptations in plants and animals. The booklet Ecology: Communities (BY2061) has good information about environmental factors and how to study them. Contact your teacher if you want to access this booklet to revise this information.

1. Define the following terms.

**Habitat:**

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**Adaptation:**

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**Biotic environmental factors:**

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**Abiotic environmental factors:**

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2. The bar-tailed godwit (*Limosa lapponica*) breeds in the open tundra of Alaska.

In autumn large flocks migrate to New Zealand and Australia. Migration enables the birds to avoid the northern hemisphere winter and feed in the southern hemisphere summer.

Describe an adaptation the godwit has that suits its way of life and state whether the adaptation is structural, behavioural or physiological.

3. The South Island edelweiss (*Leucogenes grandiceps*) is an alpine plant that can grow and reproduce at low temperatures in the Southern Alps.

The plants are miniature and compact, yet often have disproportionately large white flowers. They have woolly leaves. Their optimum rates for photosynthesis and respiration are at lower temperatures than for low altitude plants. Some alpine plants produce special carbohydrates that act as antifreeze chemicals in their leaves!

Describe some of the adaptations that alpine plants such as the Southern island edelweiss have and explain how these adaptations help the plants to survive in their alpine habitat.
4. Read the following description of the possum.

Possums are nocturnal, tree-dwelling marsupials. They can be found all across New Zealand, with the exception only of the high rainfall, mountainous terrain of Fiordland. Forests are their major habitat, but they also inhabit pasture margins.

Possums have thick fur, a long, bushy tail, a pointed snout and fox-like ears. They have large eyes, with good night vision and long claws. They have a glandular area of skin over the breastbone (sternum) called a sternal gland, which produces a special scent for marking territory.

As they are marsupials, their young are born in an immature state and climb into the mother’s pouch, where they complete their development. Possums are mainly solitary animals.

Young possums are weaned at 5–8 months, but they remain close to their mother until they are almost a year old.

Possums are voracious eaters. They are herbivores whose favoured food species are tall canopy species such as tawa, Northern and Southern rātā, kohekohe, kāmahi and Hall’s tōtara. They cause great damage to our native forests, by eating leaves, fruits and berries as well as eating native birds’ eggs and chicks, thereby decreasing the population sizes of our native bird species. In their original habitat in Australia they were predated by dingos and eagles but in New Zealand they have no natural predators; this has led to the rapid increase in possum numbers.

a. Describe the possum’s way of life (ecological niche).

b. Describe an adaptation of the possum that suits it to its habitat.
c. Describe a biotic and an abiotic factor and explain how each factor affects possums in their habitat.

Biotic factor:

Abiotic factor:

Check your answers.

<table>
<thead>
<tr>
<th>KEY WORDS</th>
<th>KEY POINTS</th>
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<td>habitat</td>
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</tr>
<tr>
<td>adaptations</td>
<td>• An adaptation is an inherited characteristic that enables an organism to survive and reproduce in its habitat.</td>
</tr>
<tr>
<td>biotic factors</td>
<td>• Adaptations may be structural, behavioural or physiological.</td>
</tr>
<tr>
<td>abiotic factors</td>
<td>• The biotic factors are the influences of living organisms on each other in a community.</td>
</tr>
<tr>
<td>way of life (ecological niche)</td>
<td>• The abiotic factors are the non-living influences on an organism in a community.</td>
</tr>
<tr>
<td></td>
<td>• The environment is the total of all the biotic and abiotic influences or factors which affect an organism.</td>
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<tr>
<td></td>
<td>• An organism’s way of life (or ecological niche) is a description of how the organism feeds, the opportunities provided by the habitat and the adaptive features of the organism which enable it to take advantage of these opportunities.</td>
</tr>
</tbody>
</table>
GAS EXCHANGE AND BREATHING

LEARNING INTENTIONS
In this lesson you will learn to:

• define gas exchange

• describe the difference between gas exchange and breathing.

INTRODUCTION
All organisms carry out gas exchange as one of the vital life processes. In this lesson you will learn what gas exchange is and the difference between gas exchange and breathing.

GAS EXCHANGE
Gas exchange means moving gases across a cell membrane. Usually this means taking in oxygen that is needed by cells for respiration, and removing carbon dioxide, which is a waste product of respiration.

The term ‘respiration’ can be confusing, as gas exchange and breathing are often referred to in some texts as ‘respiration’.

Remember that cellular respiration is a chemical process that takes place in the mitochondria of all living cells. In cellular respiration, energy-rich molecules such as glucose are broken down to form an energy-rich molecule, adenosine triphosphate (ATP), which powers all cell activities (metabolism). In this topic we will focus on gas exchange, not cellular respiration.

For gas exchange to happen, the cell membrane needs to be moist. This is because the gases have to be dissolved in water in order to diffuse across the cell membrane.

The cell membrane also needs to be very thin so that the gases can diffuse in and out easily.

The cell membrane needs to have a large surface area for enough gases to diffuse in and out quickly, so the membrane is often folded to increase its surface area.

(To revise the relationship between cell size and surface area to volume ratio, go to BY2044.)

GAS EXCHANGE AND BREATHING
All living organisms carry out gas exchange but, surprisingly, many organisms do not breathe! Some organisms ventilate their gas exchange surfaces (lungs or gills). This means they make rhythmic body movements to aid gas exchange. One form of ventilation is breathing.

Breathing is a physical movement, using muscles, to increase the rate of gas exchange in animals that have lungs. Breathing increases the amount of gas coming in and going out of the body. This will increase the amount of gas diffusing into body cells to be used for respiration and diffusing out of the cells as waste.

Some animals that do not have lungs can make rhythmic body movements to increase the rate of gas exchange. These movements are not strictly breathing but are a form of ventilation.
Many organisms don’t use any muscle movements to draw gases into, and out of, their bodies. These organisms rely solely on the **diffusion** of gases across their membranes, so these animals carry out gas exchange but they do **not** breathe, nor do they ventilate their gas exchange organs!

Take, for example, an amoeba.

An amoeba’s way of life is that of a unicellular organism that lives in water. Oxygen dissolved in the water can diffuse into the amoeba through its cell membrane, as the oxygen concentration in the water is greater than in the amoeba. Similarly, carbon dioxide that it produces as a result of respiration can diffuse out of the amoeba, as the concentration of carbon dioxide is higher in the amoeba than in the water. Clearly, an amoeba carries out gas exchange but it is not ‘breathing’, as it has no muscles to make any breathing or ventilation movements to aid the diffusion of gases across its membrane.

Now think about an earthworm.

An earthworm’s way of life is that of a soil dweller. It lives in narrow, damp, dark burrows where it is safe from predators and where the burrows prevent it from drying out. Its moist skin allows gases to diffuse in and out along the length of its body. To ensure the skin stays moist, the earthworm secretes mucus onto the skin. The skin is full of tiny blood vessels called capillaries that carry the gases to and from the body cells. The earthworm carries out gas exchange but does not make any breathing movements. Its long slender shape provides a large surface area to volume ratio to allow for sufficient gas exchange to take place to suit its way of life.

Many other organisms such as bacteria and plants all carry out gas exchange **without** breathing.

In larger animals, the surface area to volume ratio is not big enough for efficient diffusion to occur, as happens in the amoeba and the earthworm, for example. Larger animals have evolved gas exchange organs to allow them to carry out gas exchange that is efficient for their way of life.

As you will see in the next lessons, those organisms that do make breathing movements are able to increase the amount of gas diffusing in and out of their bodies, which allows their way of life to be more active.
1. Define the following terms.

Gas exchange:

Cellular respiration:

Breathing:

Ventilation:
2. Explain how the earthworm's gas exchange system suits its way of life.

Check your answers.

<table>
<thead>
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<tbody>
<tr>
<td>gas exchange</td>
<td>• Gas exchange is the movement of gases across a cellular membrane.</td>
</tr>
<tr>
<td>breathing</td>
<td>• Breathing is a physical movement, using muscles, to increase the rate of gas exchange in <strong>animals that have lungs</strong>.</td>
</tr>
<tr>
<td>ventilation</td>
<td>• Ventilation is the rhythmic body movements made by some <strong>animals without lungs</strong>, to increase their rate of gas exchange.</td>
</tr>
</tbody>
</table>
LEARNING INTENTION
In this lesson you will learn to:
• describe the adaptations for gas exchange in fish.

INTRODUCTION
Fish occupy aquatic environments, living in both saline (salt) water and fresh water.

Most fish have a compact body shape. This means the skin doesn’t provide enough surface area for gases to diffuse into and out of the body at a rate which enables a high level of activity.

Fish have a system of gills that can be angled outside the body, as the adaptations for gas exchange. The gills are used to extract oxygen from the water they are bathing in and to release carbon dioxide back into the water. An advantage of using gills is that they are constantly kept moist by the water flowing over them. A disadvantage of using water to obtain oxygen is that the oxygen concentration in water is low. In fact, the warmer and saltier the water is, the less oxygen it can hold!

GAS EXCHANGE ORGANISMS
The parts of the gill system are:
• A gill cover or operculum in bony fish, which opens out to help regulate the flow of water over the gills. In cartilaginous fish, such as sharks, the gills slits are open to the water.
• The gill arch, which has two rows of gill filaments.
• The gill filaments (called lamellae), where gas exchange takes place, and which have a rich blood supply.
• The gill rakers, which prevent food particles from lodging in the gill filaments.

The large number of filaments in each gill, multiplied by the many individual gills, exposes a very high surface area of blood-rich tissue to the water.

Look at the photographs on the right, showing different views of gills.
Go to the Topic webpage and watch a dissection of a fish. Look carefully at the structure of the gills.

**HOW GAS EXCHANGE OCCURS**

For gas exchange to occur, fish have to actively pump water over their gills. Fish can do this by opening their mouth to let in water, closing the operculum (gill covering) and then raising the floor of the mouth.

Go to the Topic webpage and watch the YouTube video clip of mouth and operculum working together to allow gas exchange in bony fish.

The air we breathe is made up of about 20% oxygen. In water the oxygen concentration is much lower, so special strategies are required if the aquatic animal is to be very active.

**VENTILATING THE GILLS**

There are two strategies fish can use to maximise contact between water and gills. One is to swim with the mouth open. Primitive fish, such as sharks, do this. If they are prevented from moving, they can die from lack of oxygen. The other strategy, used by more advanced bony fish, is to actively pump water over the gills. This is called ventilating the gills and involves inspiration (drawing water in) and expiration (forcing water out). The inner mouth and throat area, called the pharynx, lifts up and down, pushing water backwards through slits in the pharynx and over the gills. As the water passes through the lamellae, capillaries in the lamellae pick up the oxygen from the water and release carbon dioxide into the water. The fish then opens the operculum and water passes out.

See this in the diagram on the right.
**THE COUNTER-CURRENT SYSTEM**

The other strategy that fish use to maximise uptake of oxygen from water is using the counter-current principle. Look at the next two diagrams. In diagram 1 the water and the blood in the gill are moving in opposite directions. In diagram 2 the water and gill blood are moving in the same direction.

Diagram 1 shows the counter-current system, because water flows through the lamellae in one direction and blood flows through in the opposite direction. The two flows are moving counter to (against) each other. In a counter-current system, water enters the gill with a high oxygen content (10). Blood enters the gill with a low level of oxygen (1). Oxygen diffuses rapidly from the water into the blood and by the time blood passes out of the gill it is saturated in oxygen.

Where blood and water flow in the same direction (diagram 2), the blood absorbs oxygen until both blood and water have a similar concentration (5). Oxygen obeys the laws of diffusion by moving from an area of high concentration to an area of lower concentration. With water and blood flowing in the same direction, the fish would be able to extract about half the amount of oxygen than in a counter-current system.

Go to the Topic webpage to watch videos and visit a website explaining the fish gas exchange system.

**THE FISH WAY OF LIFE**

Fish are highly active animals. They swim rapidly; some leap rapids; some – such as tuna – swim the seas for great distances. Their gas exchange and transport systems must be very efficient to allow these activities to occur. You have already seen that the counter-current system of gas exchange is very efficient at extracting oxygen from water. Their single-circuit blood transport system delivers oxygen and food rapidly to all parts of the body.

Fish are cold-blooded (poikilothermic) but some species are able to raise their body temperature substantially above that of the surrounding water by generating much heat in their muscles. This enables them to operate at a higher level of activity than would otherwise be the case.

They are very well-adapted for life in water because:
- most have a covering of mucus and scales to protect the skin
- they have a streamlined body for quick movement against the frictional drag of water
- they have gills, which efficiently carry out gas exchange in water
- the kidneys of freshwater fish are able to dispose of surplus water entering the body
- their circulatory blood transport system distributes oxygen quickly around the body, allowing a high level of activity in a cold-blooded animal.
1. Describe the features of the fish gas exchange system.

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2. Explain how the counter-current system helps to extract the maximum amount of oxygen from water.

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Check your answers.
## GAS EXCHANGE IN FISH

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<tr>
<th><strong>KEY WORDS</strong></th>
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<tbody>
<tr>
<td>gills</td>
<td>• Fish use gills as an aquatic gas exchange organ.</td>
</tr>
<tr>
<td>lamellae</td>
<td>• Gills, being richly supplied with blood, are an efficient gas exchange organ.</td>
</tr>
<tr>
<td>counter-current system</td>
<td>• The large number of gill filaments provides a large surface area for gas exchange to take place.</td>
</tr>
<tr>
<td></td>
<td>• A counter-current system helps the gas exchange process.</td>
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</table>
GAS EXCHANGE IN INSECTS

LEARNING INTENTION
In this lesson you will learn to:

• describe the adaptations for gas exchange in insects.

INTRODUCTION
An advantage to obtaining oxygen from air rather than water is that air holds more oxygen per unit volume than water does. Gases therefore diffuse faster into the animal’s blood stream in air than in water. A disadvantage of obtaining oxygen from air is that the gas exchange organs have to be large and kept moist, to ensure efficient gas exchange. Animals that live on land have their gas exchange system inside their bodies.

THE TRACHEAL GAS EXCHANGE SYSTEM OF INSECTS
The gas exchange system of insects consists of three main elements:

• spiracles
• tracheae (trachea = singular)
• tracheoles.

Insects use a system of tubes called tracheae, which run throughout the body, to deliver oxygen directly to the body cells. The trachea open to the outside via tiny holes in the insect’s thorax and abdomen, called spiracles. The tracheae are held open by rings of chitin. As they spread through the insect’s body, they branch into smaller tubes called tracheoles, which end on the moist cell membranes of every cell in the body. Gases diffuse across the moist cell membranes at these tracheole endings.

The following diagrams explain how the spiracles, tracheae and tracheoles work.

SPIRACLES
These are openings on the insect’s thorax and abdomen. They connect the interior of the body to the outside atmosphere in much the same way as your mouth and nose connect your lungs to the atmosphere. Look how each spiracle has a muscle which controls opening and shutting the valve.

Spiracles.

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GAS EXCHANGE IN INSECTS

THE TRACHEAE

The spiracles open into a system of tubes called tracheae (plural). These tubes run throughout the insect’s body, and in larger flying insects they may be expanded into portions called air sacs. The air sacs can change shape as the insect moves, which helps circulate air through the tracheae.

TRACHEOLES

The tracheae are lined with spirals of chitin, the hard substance which makes up the insect’s exoskeleton. As tracheae subdivide and become smaller they no longer need the supporting spiral and are then called tracheoles. These very fine tubes have a fluid-filled ending among the various cells. Oxygen from air diffuses into the fluid and from there to the cells. Carbon dioxide from the cells diffuses through the water and into the air and is carried out by air movements.

The term cuticle in the diagram refers to the outer layer of the exoskeleton. By dividing into so many fine tubes, a very high surface area is provided for gas exchange to take place.

Insects have a blood and circulatory system but their blood does not need to carry gases to their cells. As you have seen above, the gases diffuse in and out of the cells directly into their tracheal system.

VENTILATING THE TRACHEAL SYSTEM

Larger insects and flying insects have increased energy demands and need to ventilate the tracheal system. You may have noticed that bees, for example, sometimes make ‘in and out’ movements with their abdomens. These rhythmic movements compress and expand the tracheae and tracheoles like bellows, increasing the amount of gases that move through them. In flying insects, contracting and relaxing the flight muscles compresses and expands the body, which pumps air through the tracheal system. In some insects the tracheoles end in air sacs that expand and contract, to increase the rate of gas exchange.

Go to the Topic webpage to watch videos on the insect gas exchange system.
THE INSECT WAY OF LIFE
Insects have colonised a rich diversity of habitats: the terrestrial (land) habitat, the air and the aquatic habitat. They are one of the most successful forms of animal life. There are more than one million known species of insects! More are discovered every year, especially from the equatorial and tropical habitats.

The aquatic insects have, in the main, evolved a form of gill to carry out gas exchange, as gills are very efficient gas exchange organs in the aquatic environment. Terrestrial insects use the tracheal system to obtain air. Insects prevent their gas exchange systems from drying out by incorporating their gas exchange surfaces (tracheae) deep within the body. Insects are very active animals. Flying requires a lot of energy. This in turn means that much oxygen is needed to produce this energy. The tracheal system is a highly successful method of gas exchange for insects.

Did you know?
The largest insects ever were dragonflies in the Palaeozoic era, 300 million years ago! These dragonflies had wing spans of almost a metre. They were able to grow as large as that because the oxygen concentration in the air in the Palaeozoic era was about 50% more than it is today. Insects living today cannot grow as large, as they are limited by the size of their tracheal systems. As insects become larger, more of their body is taken up by tracheal tubes. Eventually they reach a limit to how big they can be. The more oxygen that is available, the smaller that system needs to be and the bigger they can grow.

1. Describe the features of the insect gas exchange system.
GAS EXCHANGE IN INSECTS

2. Why do you think only aquatic insects use gills as gas exchange organs?

3. Flying insects usually show body movements (ventilation) to increase the air flow through the body, as described in the diagrams alongside.

Breathing movements in a flying locust.

Expiration
- abdomen contracts, increasing pressure and squeezing air out
- air goes out through spiracles in abdomen and thorax

Inspiration
- abdomen expands, decreasing pressure and drawing air in
- air goes in through spiracles in thorax

How would this increase the efficiency of their gas exchange system?

Check your answers.
### KEY POINTS
- Insects use a tracheal system for gas exchange.
- The three elements of this system are spiracles, tracheae and tracheoles.
- Moisture is required at the ends of the tracheole tubes so that gas exchange can take place.
- Tracheoles provide a very high surface area for gas exchange.

### KEY WORDS
- spiracles
- tracheae
- tracheoles
- tracheal system
GAS EXCHANGE IN MAMMALS

LEARNING INTENTION
In this lesson you will learn to:

• describe the adaptations for gas exchange in mammals.

INTRODUCTION
Mammals and birds are the most highly evolved vertebrates. They colonise a wide variety of habitats – terrestrial, aerial and aquatic. Mammals include whales, bats, rats, cows, sheep, monkeys, apes, humans, dogs, cats, horses and many other animals.

Mammals all have the following features:

• Their skin is covered with fur or hair.
• They give birth to live young, which helps the survival rate of their offspring.
• They produce milk to feed their young.
• They are warm-blooded (homeothermic), which means they maintain a stable body temperature despite what the environmental temperature is.
• They breathe air, using lungs.
• They have a four-chambered heart.

Mammals use lungs, the most advanced adaptation for gas exchange. Unlike the insect’s tracheal system which extends throughout the body, lungs are restricted to one place in the body, called the thorax. This means that the place where gas exchange occurs is not in direct contact with other cells in the body. Therefore, a circulatory (blood transport) system is used to carry the gases between the lungs and the body’s cells, where respiration takes place.

GAS EXCHANGE IN MAMMALS
Mammals use lungs to obtain oxygen and to get rid of carbon dioxide. To do this they must meet the needs of the diffusion process.

These are:

• The surfaces for gas exchange must be kept moist.
• A large surface area must be present.
• A very thin surface must separate blood from air.
• Air must be moved in and out of the gas exchange organ (ventilation by breathing), because diffusion alone will not provide adequate contact between air and lung surface.

The gas exchange organs are made up of:
1. The nose, where air enters and exits the body through the nostrils.
2. The pharynx, a pipe at the back of the throat that connects the nasal passages to the trachea.
3. A large tube called the trachea, which is supported by rigid rings of cartilage. This leads from the throat to the bronchial tubes. The ring of cartilage makes sure that the trachea always stays open.
4. **Bronchial tubes or bronchi** (plural), which lead from the trachea to each lung. These divide into finer tubes called bronchioles, which lead to the alveoli or air sacs.

5. The alveoli or air sacs make up the bulk of the lungs. They are tiny blind endings, richly supplied with blood, moist and thin-walled.

You can see all of these structures in the following diagrams of human lungs.

---

**The human respiratory system.**

**Close-up of the right lung.**
Look carefully at the following photos showing a dissection of a sheep's lung. See if you can identify the trachea, the two bronchi and lungs. Like with the fish gills, lung tissue is red because of the many blood vessels present.

### INTO THE NOSE AND THROAT
Air enters via the nose and mouth. Immediately, your body begins to modify this air. Warming and moistening of the air happen as air passes over the moist tissue lining the nose and throat. Mucous cells secrete mucus, which traps solid particles. This prevents dust reaching the delicate tissue deep inside the lungs.

Fine hairs called cilia move the mucus from the throat and nose. It’s worth noting that tobacco smoke paralyses these cilia. This removes the early defence your body relies on to keep dust out of your lungs.

### INTO THE TRACHEA AND BRONCHI
Cells lining these tubes also have cilia. There are special mucus-producing cells called goblet cells which help protect the lung against solid particles. The cilia produce a current which carries mucus back up the trachea. You are aware of this when you swallow crumbs into your trachea. The reflex action of coughing expels the materials from the tube up into the throat.

### THE ALVEOLI
Air finally arrives at the alveoli. These are blind endings of the bronchioles. They are moist, thin-walled, have a good blood supply and their surface area is increased by being subdivided into grape-like shapes. The alveoli are deep within the body. This helps cut down water loss and protects them from the outer environment.
VENTILATING THE LUNGS (BREATHING)
Mammals ventilate their lungs to increase the rate of gas exchange and, yes, this process is called breathing! Breathing is the alternate inspiration (breathing in) and expiration (breathing out) of air, aided by muscles in the chest.

INSPIRATION AND EXPIRATION
The lungs can only function if air is moved in and out. Because the alveoli are blind endings, air cannot flow through in a continuous current. This air movement, like a tidal flow, is achieved by movements of the ribs and the diaphragm. The diaphragm, a sheet of muscle, separates the chest cavity from the abdomen. The ribs are flexible because they are held together by ligaments and muscle. The muscles are known collectively as the intercostal muscles. The external intercostals contract to raise the ribs. The internal intercostals contract to bring the ribs back down.

Look at the following two diagrams, which show what is happening as you breathe in and out:
Aquatic mammals like whales and dolphins, also breathe air, just like we do. They have blowholes on the top of their heads through which air is breathed in and out. They need to come to the surface of the water, open their blowhole and inhale air. Then they close the blowhole and submerge again. When they next need to draw breath, they come to the surface and open the blowhole and breathe out. This can sometimes be seen as a plume of spray coming out of the blowhole. In addition, aquatic mammals have a special oxygen-storing protein called myoglobin in their muscles that can be used as a source of oxygen during long dives. These adaptations suit them to their aquatic way of life.

Did you know?
Our breathing is controlled by two centres in the brain, the medulla oblongata and the pons. The medulla's centre sets our basic breathing rhythm. It also monitors the amount of carbon dioxide in our blood – it is the level of carbon dioxide (rather than oxygen) that regulates our breathing!

Go to the Topic webpage to view a video and an animation that explains mammalian gas exchange. See also:
- an animation explaining gas exchange in humans
- a webpage explaining the mammalian gas exchange system in detail
- a video showing a whale and its blowhole
- a webpage that is good for revision on the gas exchange systems of fish, insects and mammals.

1. Place your fingers on the lower part of your ribcage so that you can feel your ribs.
   - Breathe in and out, making sure you fill your lungs and empty them as best you can.
   - Repeat the action several times until you can feel the stretching and contraction of your ribcage.

What do you feel happening to your ribcage as you breathe in and out? Explain how these movements ventilate your lungs.
2. Explain why lungs are a suitable adaptation for gas exchange in terrestrial animals such as mammals.

Check your answers.

**KEY WORDS**
- lungs
- trachea (sing.)
- tracheae (plural)
- bronchi (plural)
- bronchiole(s)
- alveoli (plural)
- breathing

**KEY POINTS**
- Mammals have complex lungs which evolved as part of the blood circulatory system.
- Gas exchange occurs in the alveoli of each lung.
- Alveoli have a high surface area, are thin-walled and moist.
- Alveoli are protected by being deep within the body.
- Large numbers of alveoli in each lung ensure an efficient gas exchange system.
- Lungs can be ventilated by breathing. Inspiration and expiration move gases in and out of the lungs by the diaphragm and ribs moving together.
NEXT STEPS
In this lesson have a quick look back at all the lessons you have completed in this topic. Think about what you have learned. When you are ready, try the teacher-marked assignment BY2031A.

If you did not receive this with your booklet, contact your teacher.

When you have finished, complete the self-assessment section at the end of this booklet. Send this self-assessment and the teacher-marked assignment to your teacher.

Make sure that you have written your name and ID number on the cover sheet (the back cover of your booklet) and the teacher-marked assignment. You can also use a label if you have one at hand.

BY POST:
Put the booklet and teacher-marked assignment in the plastic envelope provided. Make sure that the address card shows the address for Te Aho o Te Kura Pounamu (The Correspondence School). Seal the envelope with tape before you post it.

BY EMAIL:
Scan the pages including the cover sheet and email to your teacher. The standard format for Te Kura teacher email addresses is: firstname.lastname@tekura.school.nz
If you aren’t sure who your teacher is, call 0800 65 99 88.

Before you finish off this topic you should have agreed your next steps with your teacher. If you do not have your next set of study materials, contact your teacher immediately. If you are not sure what to do next, ask your teacher for advice.
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<tr>
<th>** Glossary</th>
<th>Definition</th>
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<td><strong>abiotic factors</strong></td>
<td>The abiotic factors are the non-living influences on an organism in a community.</td>
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<tr>
<td><strong>adaptations</strong></td>
<td>Adaptations are any inherited characteristics that enable an organism to survive and reproduce in its habitat. Adaptations may be structural,</td>
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<td></td>
<td>behavioural or physiological.</td>
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<tr>
<td><strong>alveoli</strong></td>
<td>Alveoli are sac-like endings at the ends of the bronchioles in lungs.</td>
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<tr>
<td><strong>biotic factors</strong></td>
<td>The biotic factors are the influences of living organisms on each other in a community.</td>
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<tr>
<td><strong>breathing</strong></td>
<td>Breathing is a physical movement, using muscles, to increase the rate of gas exchange in animals with lungs.</td>
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<tr>
<td><strong>bronchi</strong></td>
<td>Bronchi are the pair of breathing tubes that lead from the trachea into the lungs.</td>
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<tr>
<td><strong>bronchioles</strong></td>
<td>Bronchioles are the smaller breathing tubes that lead from the bronchi into the alveoli in the lungs.</td>
</tr>
<tr>
<td><strong>counter-current system</strong></td>
<td>This is a system in fish whereby water flows through the lamellae of the gills in one direction and blood flows through in the opposite direction. This maximises oxygen uptake from the water and the release of carbon dioxide into the water.</td>
</tr>
<tr>
<td><strong>environment</strong></td>
<td>The environment is the total of all the biotic and abiotic influences or factors which affect an organism.</td>
</tr>
<tr>
<td><strong>gas exchange</strong></td>
<td>Gas exchange is the movement of gases across a cellular membrane.</td>
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<tr>
<td><strong>gills</strong></td>
<td>Gills are the gas exchange organs of fish and some other aquatic animals.</td>
</tr>
<tr>
<td><strong>habitat</strong></td>
<td>The habitat is the place where an organism lives.</td>
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<tr>
<td><strong>lamellae</strong></td>
<td>Lamellae are the gill filaments where gas exchange takes place in fish.</td>
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<tr>
<td><strong>lungs</strong></td>
<td>Lungs are the gas exchange organs in mammals.</td>
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<tr>
<td><strong>spiracles</strong></td>
<td>Spiracles are the openings on the side of an insect’s abdomen through which gases enter and exit.</td>
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<tr>
<td><strong>trachea</strong></td>
<td>The trachea is the windpipe that leads from the throat to the bronchial tubes in mammals.</td>
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<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>tracheae</td>
<td>Tracheae are tiny tubes that branch throughout an insect’s body and are part of its gas exchange system.</td>
</tr>
<tr>
<td>tracheal system</td>
<td>This is the system of branching tubes that makes up the gas exchange system of insects.</td>
</tr>
<tr>
<td>tracheoles</td>
<td>These are small tubes at the ends of the trachea that are in contact with the body cells in an insect and are part of its gas exchange system.</td>
</tr>
<tr>
<td>ventilation</td>
<td>Ventilation is rhythmic body movements that increase the rate of gas exchange in active animals.</td>
</tr>
<tr>
<td>way of life (ecological niche)</td>
<td>An organism’s way of life (or ecological niche) is a description of how the organism feeds, the opportunities provided by the habitat and the adaptive features of the organism which enable it to take advantage of these opportunities.</td>
</tr>
</tbody>
</table>
2. WAY OF LIFE

1. The habitat is the place where an organism lives.
   An adaptation is an inherited characteristic that enables an organism to survive and reproduce in its habitat.
   The biotic environmental factors are the influences of living organisms on each other in a community.
   The abiotic environmental factors are the non-living influences on an organism in a community.

2. Students will have their own answers but could include:
   Wings (structural adaptation) to fly long distances.
   Light, hollow bones (structural adaptation) for flying.
   Migration (behavioural adaptation) to avoid winter and to go to feeding grounds.
   High metabolic rate (physiological adaptation) to allow it to fly long distances without feeding.

3. Alpine plants have physiological adaptations that allow them to grow and reproduce at low temperatures – for example, their rates of photosynthesis and respiration are optimum at lower temperatures. They produce special carbohydrates that prevent their leaves freezing, which is a physiological adaptation.
   They have large white flowers to attract pollinators, which is a structural adaptation.
   They have woolly leaves, another structural adaptation, to help trap heat, reduce transpiration, and protect against wind, abrasion, and ultraviolet radiation.
   The plants are low growing or grow in rock crevices, for protection from wind.

4. a. The possum’s way of life is that of a nocturnal, tree-dwelling marsupial. Possums have large eyes with good night vision, and long claws for climbing trees. Their young are born immature and develop in the marsupial pouch. They are herbivores, who eat mainly leaves but also fruit, berries and birds’ eggs.
   b. Possible answers are: large eyes for good night vision; long claws for climbing trees; thick fur for warmth; large ears for good hearing; scent glands to mark territory.
   c. Biotic factors: Forests which provide food and shelter; native birds whose eggs are a source of food; other possums who are competitors for food and mates; predator species – they have no natural predators in New Zealand so numbers have increased compared to Australia, where their natural predators keep numbers in check.
      Abiotic factors: Rainfall, which affects where they live (they prefer dryer areas); light, which affects their nocturnal habits; temperature, which affects where they live.
3. GAS EXCHANGE AND BREATHING

1. Gas exchange is the movement of gases across a cellular membrane.
   Cellular respiration is a chemical process that takes place in the mitochondria of all living cells. Energy-rich molecules such as glucose are broken down to form an energy molecule, adenosine triphosphate (ATP), which is used by the cells for metabolic activities.
   Breathing is a physical movement, using muscles, to increase the rate of gas exchange in animals with lungs.
   Ventilation means using rhythmic body movements to aid gas exchange in animals without lungs.

2. An earthworm lives in moist burrows in the ground. The earthworm gets nourishment from eating the decaying plant matter in the surrounding soil. Its gas exchange system is its moist, mucous-covered skin, which is richly supplied with blood vessels. Gases diffuse in and out through the moist skin, along the whole length of its body. Its long, slender shape means it has a large surface area to volume ratio. This means it is able to efficiently obtain enough oxygen, and release carbon dioxide, to suit its way of life, which is that of a slow-moving and not very active soil burrower.

4. GAS EXCHANGE IN FISH

1. The gills system consists of a gill covering, the operculum, in some fish; gill arches, which each have two gill filaments (lamellae) that have a rich blood supply, and where gas exchange takes place; and gill rakers, which prevent food particles from lodging in the gill filaments.
   The large number of filaments in each gill, multiplied by the many individual gills, exposes a very high surface area of blood-rich tissue to the water. Oxygen is extracted from the water and carbon dioxide released into the water, as the water flows through the lamellae. Fish can ventilate their gills to increase the flow of water over the gills and use a counter-current system to maximise oxygen uptake from the water.

2. In the counter-current system, water flows through the lamellae in one direction and blood flows through in the opposite direction. The two flows are moving counter to (against) each other. In a counter-current system, water enters the gill with a high oxygen content. Blood enters the gill with a low level of oxygen. Oxygen diffuses rapidly from the water into the blood and by the time blood passes out of the gill it is saturated in oxygen.
   Oxygen and carbon dioxide obey the laws of diffusion by moving from an area of high concentration to an area of lower concentration. With water and blood flowing in the same direction, the fish would be able to extract about half the amount of oxygen as in a counter-current system.
5. **GAS EXCHANGE IN INSECTS**

1. The tracheal system consists of spiracles, which are openings in the insect’s abdomen, through which gases enter and exit; tracheae, which are tubes extending throughout the insect’s body; tracheoles, which are finer tubes, with fluid-filled endings surrounding the body cells. Gases diffuse in and out of the cells into the fluid of the tracheoles. Insects that have high energy and therefore high oxygen demands can ventilate their tracheae to increase the rate of gas exchange.

2. Aquatic insects use gills for gas exchange, as they are living in water, and gills are the ideal gas exchange system where water surrounds the gas exchange surfaces. Gills are not a good organ for gas exchange on land because of the high rate of water loss, so terrestrial insects cannot use gills and have evolved the tracheal system of gas exchange to prevent their gas exchange surfaces from drying out.

3. Ventilating the tracheal system increases the rate at which gases enter and exit the body. This means more oxygen is available for respiration in the insect’s cells, which in turn provides more energy for activities such as flying that have high energy demands. In larger and more active insects, a simple in-out flow is not sufficient to provide enough oxygen for flight.

6. **GAS EXCHANGE IN MAMMALS**

1. You should feel your ribcage expanding and contracting as you breathe deeply. The ribcage is quite flexible, as the bones are connected by cartilage at their ends and the individual ribs are held in place by soft tissues such as the intercostal muscles and ligaments. Breathing in (inspiration) and breathing out (expiration) causes the diaphragm to change shape. When it moves downwards, the volume of the chest is increased. Air is sucked in. When the diaphragm returns to its resting position, air is pushed out of the lungs as the chest decreases in volume.

2. In terrestrial animals such as mammals, lungs are an adaptation to breathing air. Lungs are protected within the chest cavity and are bathed with blood. Lungs developed together with an efficient blood circulatory system so that gases can be taken to and from the body cells by the blood. The surfaces for gas exchange must be kept moist, so they are bathed in fluid and held deep inside the chest cavity to prevent them drying out. A large surface area is needed for sufficient gas exchange to occur. Lungs provide this by having many alveoli that together provide a large surface area for gas exchange to take place. The alveoli walls are very thin and enclosed with capillaries, so that the gases can easily diffuse in and out of the alveoli. Lungs can be ventilated by breathing movements of the ribs, the intercostal muscles and diaphragm. Air is lighter and easier to pump than water, so ventilation of the lungs requires less energy than ventilation of gills, for example. Ventilation of the lungs provides a faster rate of gas exchange, which is needed for very active animals with high metabolic rates.
ACKNOWLEDGEMENTS

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Fill in your name and ID number.

Student name: ________________________  Student ID: __________

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<th>Understood some</th>
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<td>Describe the adaptations of fish, insects and mammals to carry out gas exchange.</td>
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<td>Relate the adaptations for gas exchange to the animals’ way of life.</td>
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Please place your comments in the relevant boxes below.

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<td>Any further student comments.</td>
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Phone, fax or email your teacher if you want to talk about any of this work.
Freephone 0800 65 99 88

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**Teacher comment**

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### STUDENTS – PLACE STUDENT ADDRESS LABEL BELOW OR WRITE IN YOUR DETAILS.

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### AUTHENTICATION STATEMENT

I certify that the assessment work is the original work of the student named above.

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