

Gaseous exchange and transport

Gaseous exchange and transport systems transfer chemicals through the internal and between the external environments of plants and animals

Movement of chemicals in plants and animals

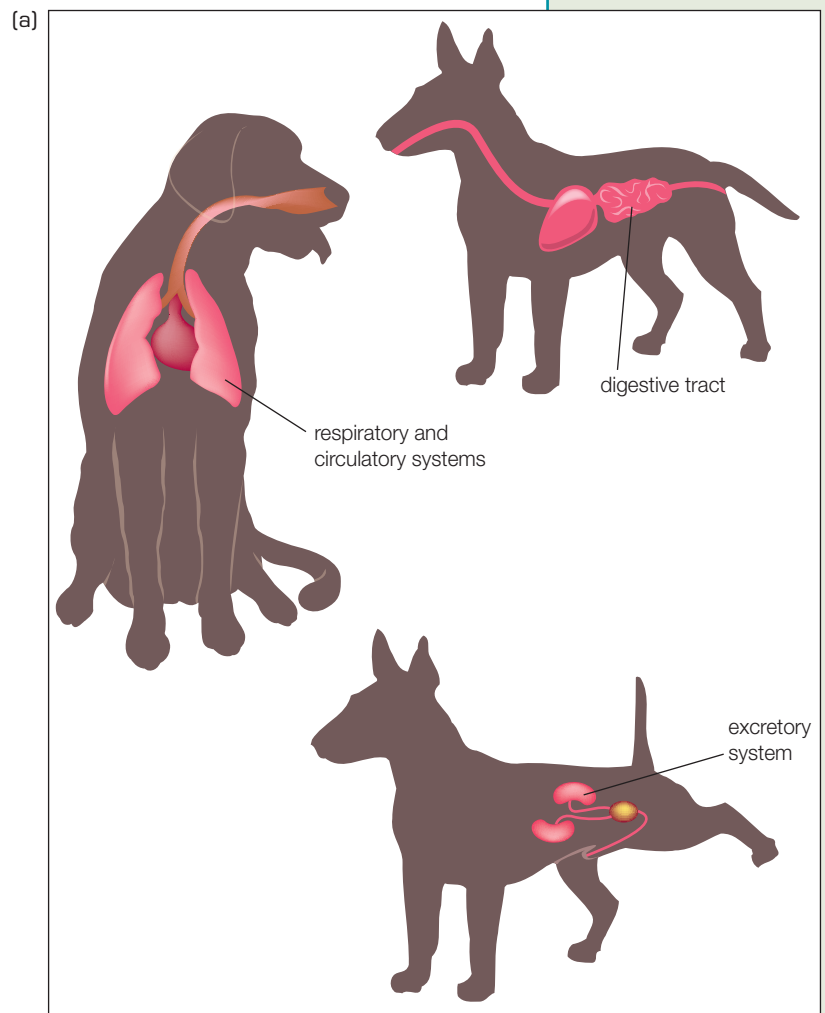
For the normal functioning of plants and animals chemical substances needed by the organism must be transported into and around the body, while waste substances must be transported from where they are produced to the outside. The movement of these chemicals may be summarised as follows:

- from the external environment into the organism. For example:
 - oxygen from the air into an animal for respiration
 - carbon dioxide from the air into a plant for photosynthesis
- from inside the organism (internal environment) to the outside. For example:
 - wastes such as carbon dioxide or urea out of an animal
 - oxygen produced by photosynthesis carried out of a plant
- within the organism (internally), from the site where they have been produced within the organism to the site where they will be used or expelled. For example:
 - food carried from leaves in plants to storage organs
 - oxygen carried from the lungs of an animal to the muscle cells, where energy is required
 - carbon dioxide carried from the muscle cells where it is a waste, produced as a result of cellular respiration, to the lungs where it can be expelled

—chemical messengers such as hormones from glands where they are produced in animals, to organs where they act.

4.1

Figure 4.1 Gaseous exchange and transport:
(a) in an animal



continued . . .

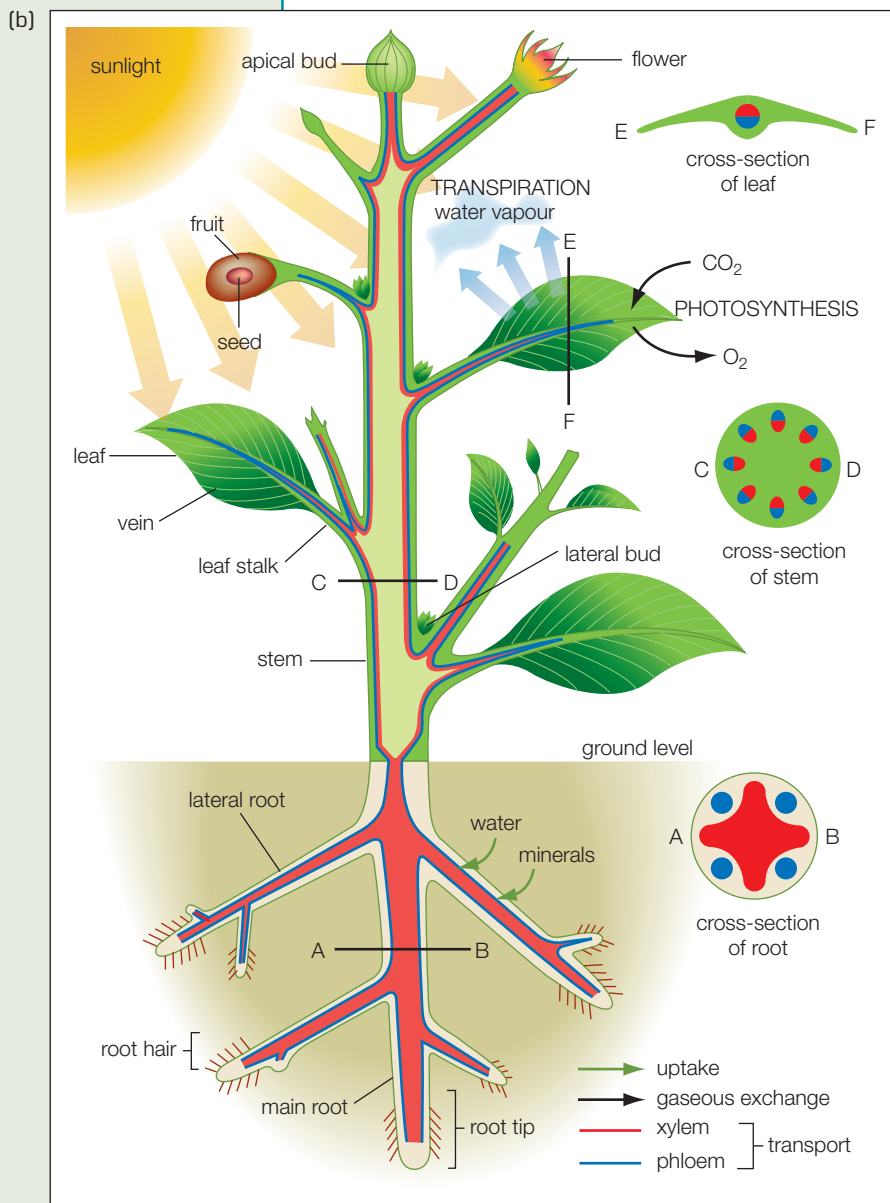


Figure 4.1
Gaseous exchange and transport:
(b) in a plant



Worksheet—diagrams of a plant and a human on which transport can be drawn

the **respiratory surface** or the *surface of gaseous exchange* and the gases move across this surface by the process of **diffusion**.

Once gases have crossed this surface, they need to be *transported* to the parts of the body that need them. Within unicellular organisms or small multicellular organisms, this movement of substances between the outside (external environment) and the inside (internal environment) of the organism occurs across the entire cell membrane or thin body wall. In large, multicellular organisms, however, special systems are needed to ensure the efficient movement of substances:

- a *gaseous exchange system* allows the exchange of oxygen and carbon dioxide with the external environment in plants and animals
- a *transport system* carries chemicals from where they enter the body or where they are produced, to where they are used. In the case of wastes, they are carried from where they were produced to where they leave the body (*excretion*).

The reason why special systems are needed in large multicellular organisms is dealt with in the following section.

If the chemicals that are being moved into the body, within the body or out of the body are gases, this movement is termed **gaseous exchange**.

When gases move into and out of an organism, they need to move across the *surface* of the body. In some organisms this could be a general movement across the *entire body surface* (e.g. across the moist skin of an earthworm), but in most, a *special surface area* has developed for this to occur (e.g. the gills in fish and tadpoles; lungs in land animals). The surface that these gases cross is called

4.2

The need for transport systems in multicellular organisms

■ *explain the relationship between the requirements of cells and the need for transport systems in multicellular organisms*

As we already know, *unicellular organisms* are so small that their surface area to volume ratio is adequate to allow them to rely on simple *diffusion* to supply requirements such as oxygen for cellular respiration and to remove waste products such as carbon dioxide, urea and other metabolic wastes. Water levels can also be maintained simply, through the passive process of *osmosis* across the body surface, because the surface area to volume ratio of these organisms is large enough.

Multicellular organisms are bigger in size and so their total surface area to volume ratio is smaller. Cells near

the centre of these organisms would be too far away from the surface for substances from the outside environment to reach them efficiently (remember, diffusion and osmosis are slow, passive processes). Large organisms that are active, such as complex animals, need more nutrients and oxygen to provide them with energy and they produce more wastes, so they have a greater need for transport. This problem is solved by the presence of a **transport system** within the bodies of large multicellular organisms.

The roles of respiratory, circulatory and excretory systems

4.3

■ *compare the roles of respiratory, circulatory and excretory systems*

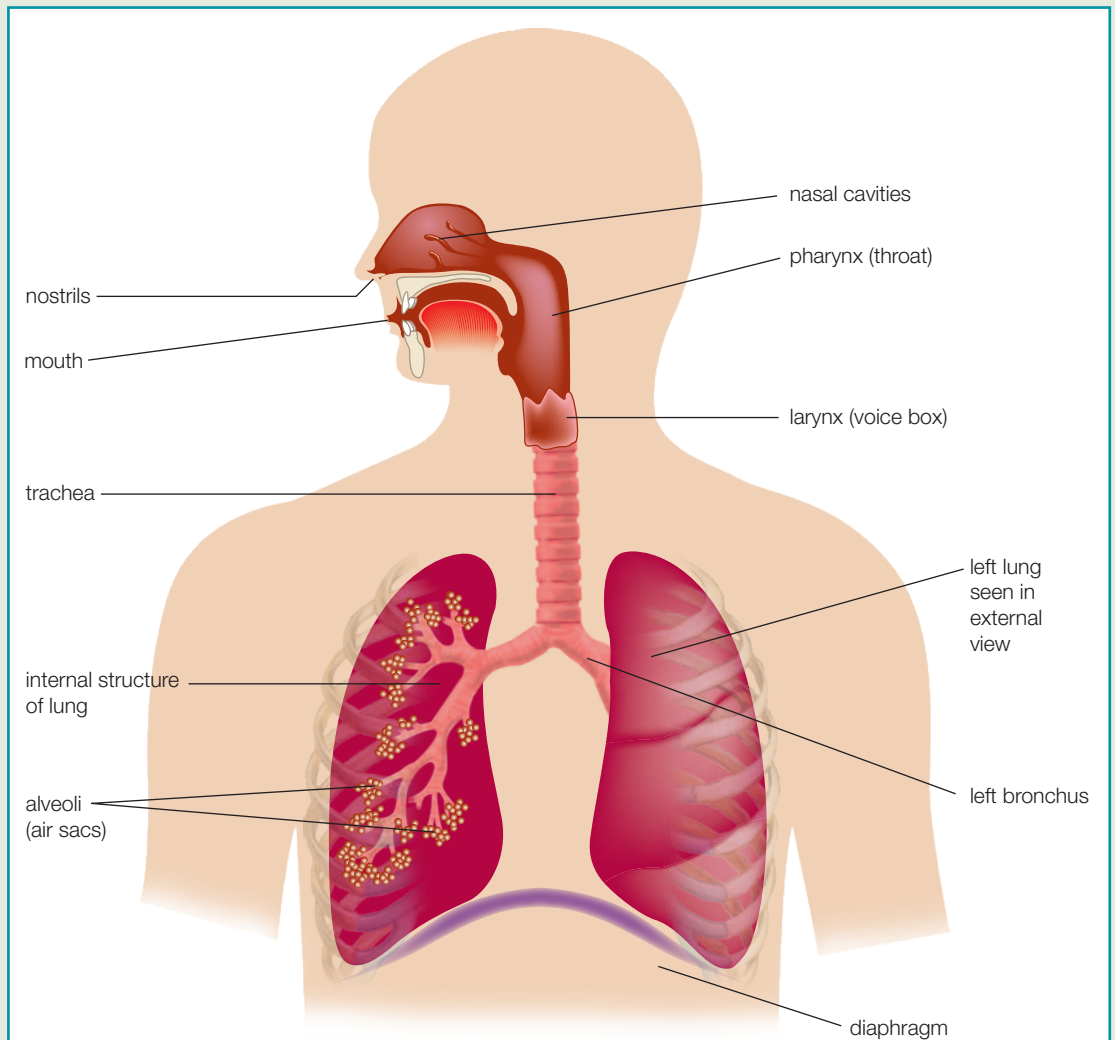
The respiratory system

Introduction to terminology

The terms **breathing**, **respiration** and gaseous exchange are all related, but do not mean the same thing. The following information should help you to distinguish between these terms:

- *Respiration* is a biochemical process occurring in *all* cells (inside the mitochondria). During this process, energy (in the form of ATP) is released from nutrient molecules (food) that had combined with oxygen. (Remember, the main purpose of **RE**spiration is to **RE**lease **E**nergy from foods!) Details of this process were covered in Chapter 3 (see pages 20–22).
- *Breathing* is a mechanical (physical), rhythmic process involving muscles and the skeleton in animals, to allow an organism to inhale and exhale. It helps to increase the amount of gaseous exchange that can occur across a gas exchange surface.
- *Gaseous exchange* is a physical process in living organisms where gases move by diffusion, often across cell membrane(s). Gases required by organisms for their normal functioning move *into cells* and gases produced as a result of functioning are *expelled*. Gaseous exchange may take place either internally (between different parts of an organism's internal environment) or externally (between the external environment

Figure 4.2
The human respiratory system



and the internal environment). In mammals for example (see Fig. 4.2) exchange of gases occurs:

—*externally*: oxygen required for respiration moves from the air into the lungs, across the surface of the air sacs, into the bloodstream; carbon dioxide moves out of the bloodstream into the air sacs and out of the lungs

—*internally*: oxygen moves from the bloodstream out of a blood vessel, into the surrounding cells; carbon dioxide moves from the cells into the blood vessels.

Gases move by diffusion across a surface which separates the internal and external environment or the parts of the internal environment. These gaseous exchange surfaces will be discussed in more detail on pages 161–2.

The role of the respiratory system

The respiratory system enables organisms to take in oxygen and to remove carbon dioxide from their bodies—it allows gaseous exchange between an organism and its external environment. Oxygen is essential for almost all living organisms as it is needed for the *release of energy* from food during cellular respiration. Carbon dioxide is a waste that must be removed because it is *toxic* in large quantities. The respiratory system is made up of tissues and organs that are specialised for gaseous exchange—in animals the respiratory organs are varied, such as lungs in mammals, gills in fish and tadpoles and a tracheal system in insects (see Fig. 4.5). In plants, respiratory tissues include **stomates** and **lenticels** (see Fig. 4.15).

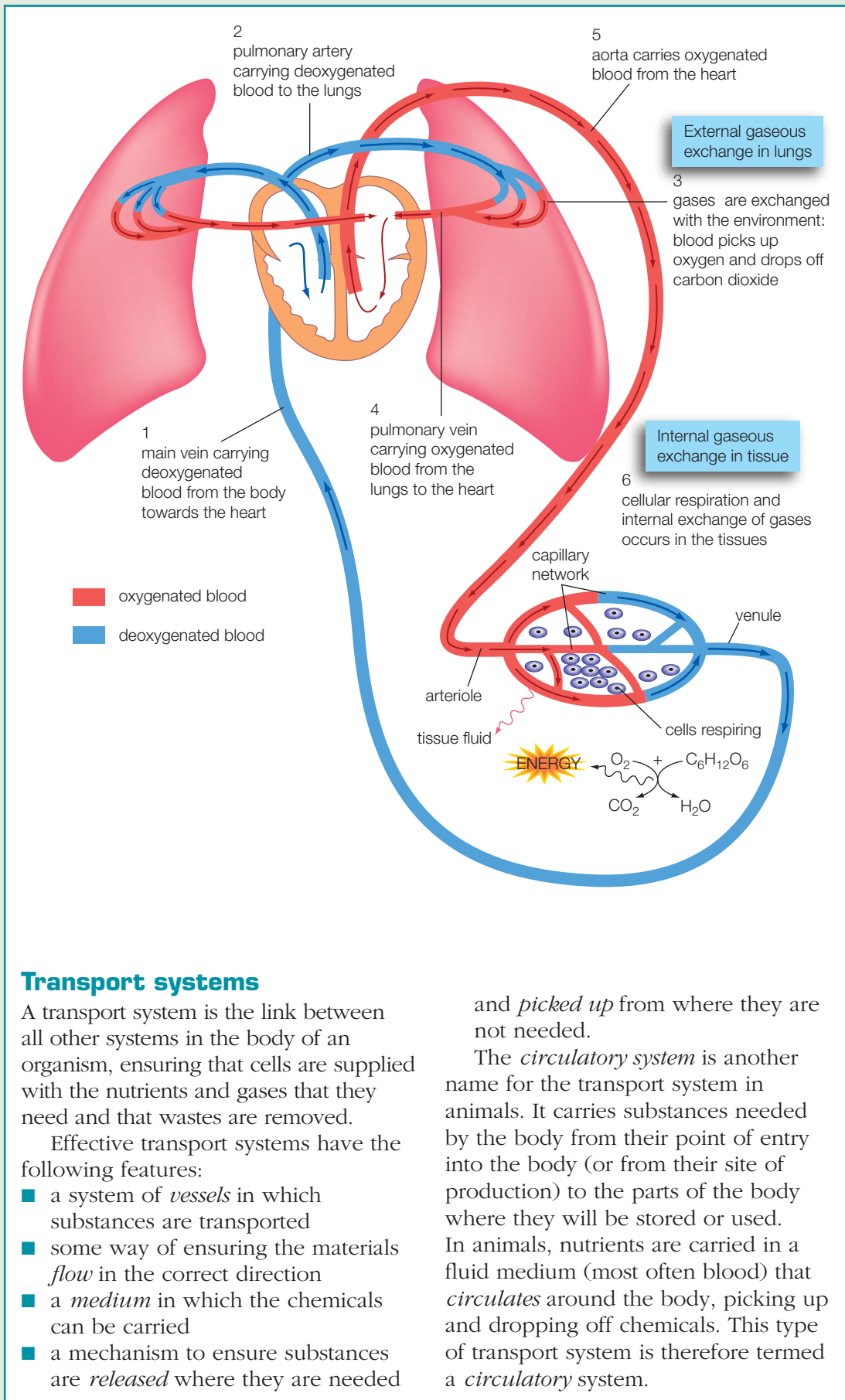


Figure 4.3 Scheme showing the link between external and internal gaseous exchange, cellular respiration and the transport of gases in humans

Transport systems

A transport system is the link between all other systems in the body of an organism, ensuring that cells are supplied with the nutrients and gases that they need and that wastes are removed.

Effective transport systems have the following features:

- a system of *vessels* in which substances are transported
- some way of ensuring the materials *flow* in the correct direction
- a *medium* in which the chemicals can be carried
- a mechanism to ensure substances are *released* where they are needed

and *picked up* from where they are not needed.

The *circulatory system* is another name for the transport system in animals. It carries substances needed by the body from their point of entry into the body (or from their site of production) to the parts of the body where they will be stored or used. In animals, nutrients are carried in a fluid medium (most often blood) that *circulates* around the body, picking up and dropping off chemicals. This type of transport system is therefore termed a *circulatory system*.

The role of the circulatory system

The main functions of the circulatory system are:

- transport of gases (oxygen and carbon dioxide), nutrients, waste products, hormones and antibodies
- maintenance of a constant internal environment (pH, ions, blood gases, osmotic pressure)
- removal of toxins and pathogens
- distribution of heat.

Excretory systems

Introduction to terminology

Excretion involves expelling *metabolic wastes* from the body—wastes that have been made by cells as a by-product of metabolism (chemical reactions in cells). (This should not be confused with the term *egestion*, which is simply passing out food that could not be digested in the body. Undigested food or faeces are not a form of excretory waste because they are not a by-product of metabolic activity.)

Nitrogenous wastes are the main excretory wastes in vertebrates and are toxic if they accumulate in the body. As their name implies, they contain the chemical element *nitrogen* which cannot be stored in the body. The commonest examples

of nitrogenous wastes that are excreted are the substances **urea**, **uric acid** and **ammonia**. These wastes are then transported from where they have been produced, to where they will be excreted.

The role of the excretory system

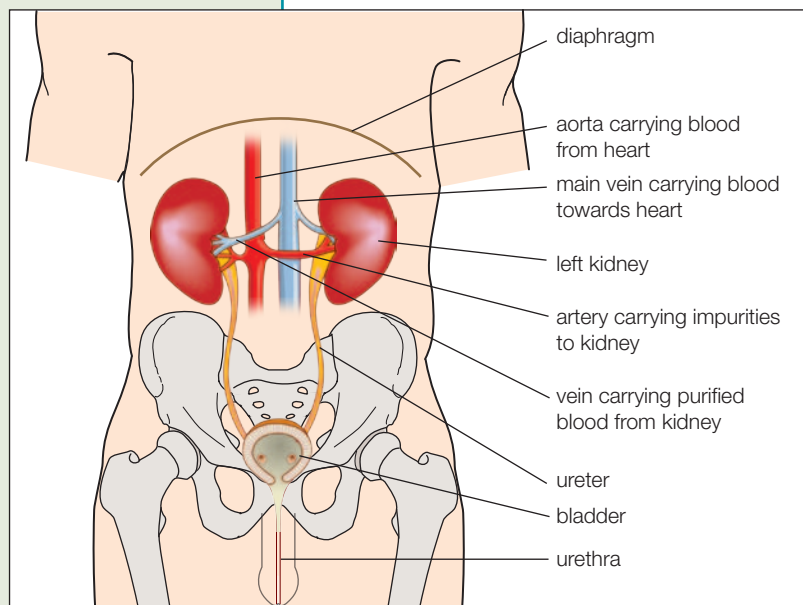
The main function of excretory systems is to remove metabolic wastes from the transport medium (e.g. blood) and to expel them to the outside:

- *nitrogenous wastes*, together with water and other substances such as salts are combined to form **urine** in mammals. The **kidneys** act as organs of excretion. Small amounts of urea are also lost in **sweat**
- *carbon dioxide* is an excretory waste which forms during cellular respiration (also a metabolic process). The lungs act as excretory organs, ridding the body of carbon dioxide.

Excretion is very closely linked with **water balance** in organisms—the more toxic the type of waste, the greater the amount of water required to dilute it for excretion. Different types of nitrogenous wastes excreted by vertebrates need different amounts of water to dilute them, depending on their toxicity. *Uric acid*, the least toxic form, is excreted with the least amount of water (e.g. white sludge excreted by birds). *Urea* requires more water to dilute it and is commonly found in the urine of mammals like us. *Ammonia*, the most toxic form of nitrogenous waste, must be diluted with the largest amount of water and so is usually only excreted by aquatic vertebrates such as freshwater fish, since water is freely available in their environment.

In some organisms, the role of the excretory system also includes the *elimination of excess salts*, *regulation of the pH* (acidity or alkalinity) of body fluids and their internal *pressure* (e.g. regulation of blood pressure in mammals).

Figure 4.4
The excretory system in humans



There is no recognised excretory system in plants (although some plants have specialised structures to eliminate excess salts). Most plants accumulate very few metabolic wastes because they are far less active than animals

and do not rely on ingested food for their energy. Excretion of any excess materials in plants is by means of diffusion across the surface of organs such as roots and leaves.

Table 4.1 Excretory organs in mammals

Excretory organ	Excretory waste	Role of excretory organ	Excreted as:
Lungs	Carbon dioxide	Removes CO ₂ from the blood	CO ₂ gas in air
Kidney	Urea	Removes urea from the blood	Urine (fluid)
Skin	Urea	Removes small quantities of urea from the blood	Sweat
Liver	Bile salts	Removes pigment (haemoglobin) from worn out red blood cells	Bile salts (in faeces)

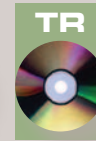


Summary of excretory system

STUDENT ACTIVITY

Comparing these systems in mammals

Complete the table of comparison between the respiratory, transport and excretory systems on the Student Resource CD.



Student activity table

Gaseous exchange in animals

- *identify and compare the gaseous exchange surfaces in an insect, a fish, a frog and a mammal*

Introduction

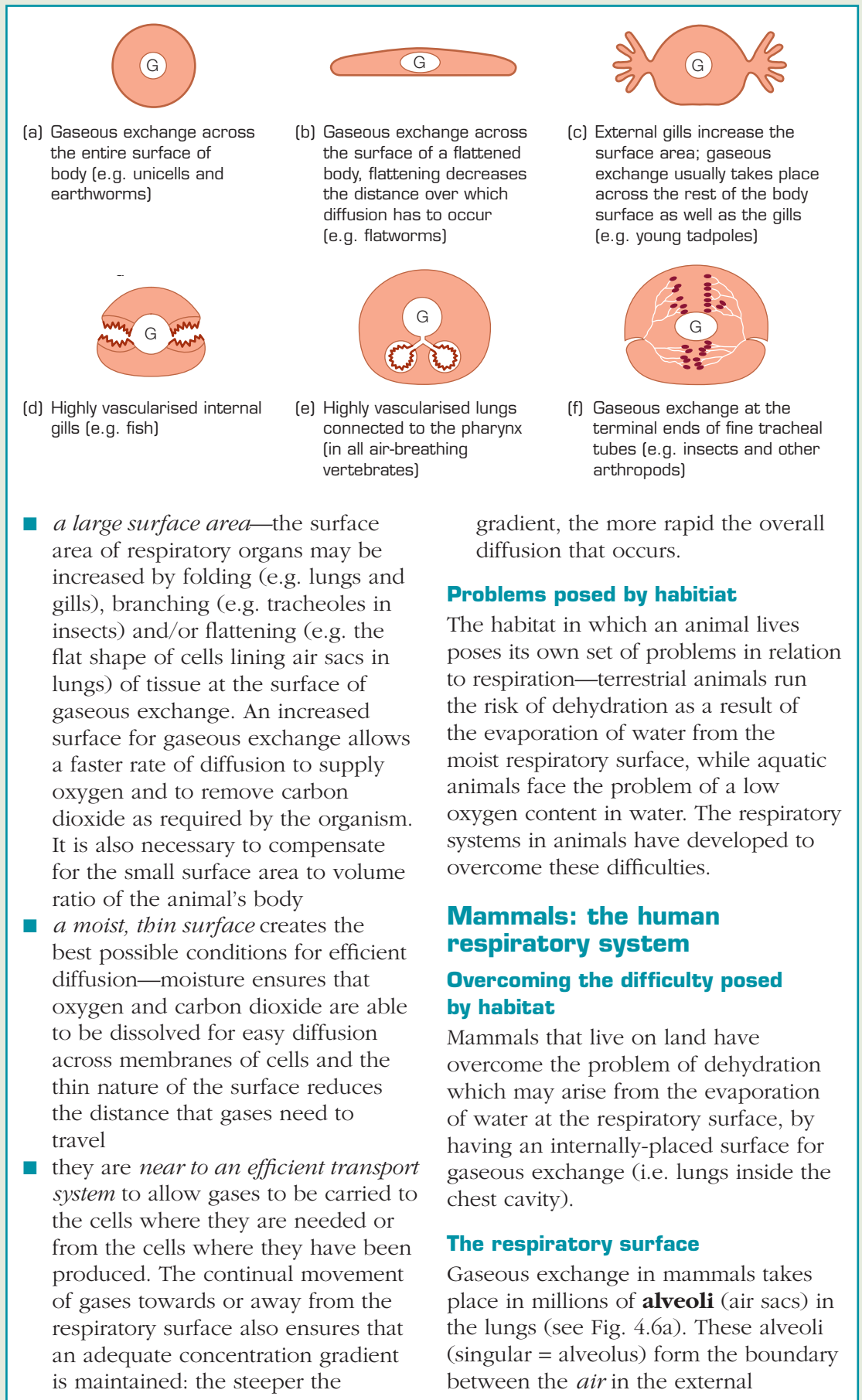
Animals have high energy demands because they actively move to search for food and escape predators. As a result, they need a large amount of oxygen and they release large amounts of carbon dioxide. Since their body surface area to volume ratio is not large enough to meet their high demand for gaseous exchange, specialised respiratory systems have evolved.

Respiratory surfaces

Respiratory surfaces are body surfaces that are in contact with the external environment and have become specialised for gaseous exchange. The types of respiratory organs vary from one type of organism to another but, to ensure efficient exchange of gases by diffusion, all gaseous exchange surfaces share certain common features:

4.4

Figure 4.5 Types of respiratory (gaseous exchange) surfaces in animals





Worksheet on human respiratory system

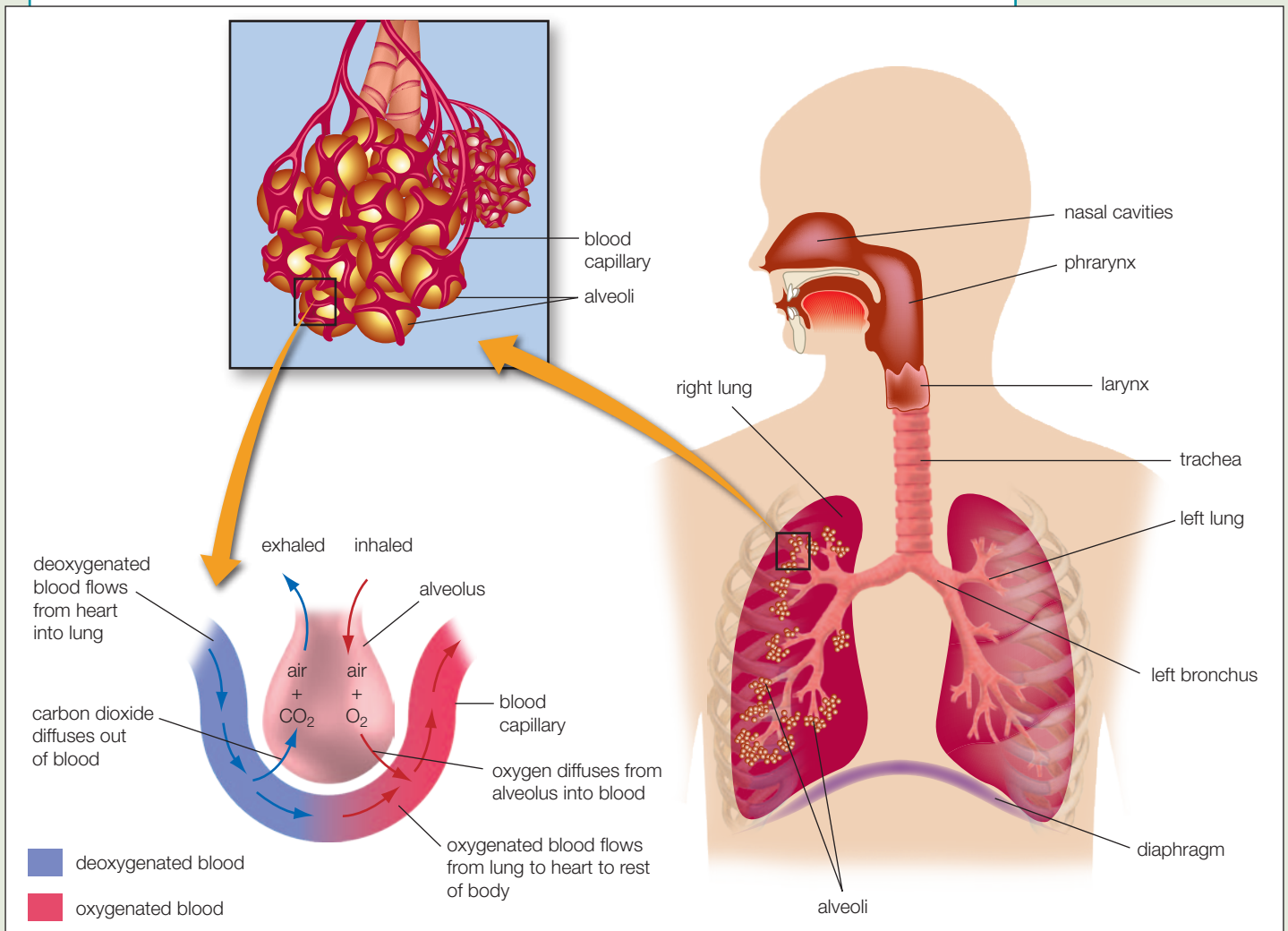
Figure 4.6 (a) Human respiratory system showing detail of alveoli in the lungs; (b) alveoli and blood supply; (c) one alveolus cut through in section, showing exchange of gases with an adjacent capillary

environment and the *blood capillaries* in the body (internal environment). The lungs have all the typical features of an efficient gaseous exchange surface:

- *increased surface area*: contact between the alveolar air and the respiratory surface is increased by the folding of the thin lining of the air sacs making up the lungs. There are numerous examples of *folding* and *branching* to increase the respiratory surface of the lungs—the lungs are lobed, the trachea divides into bronchi which further subdivide, eventually forming tiny tubules called bronchioles. Each bronchiole ends in a cluster of further folded air sacs, the alveoli (see Fig. 4.6b). An adult human has

approximately 300 million alveoli, supplied by 280 million capillaries. If we were able to flatten the alveoli of the lungs out completely, they would cover the surface area of a tennis court!

- *thin*: alveoli have an extremely thin lining made up of a single layer of flattened cells called squamous epithelium. This facilitates diffusion as the thin layer which forms the respiratory surface reduces the distance that gases must travel to enter the body
- *moist*: the epithelial cells lining the respiratory tubules secrete *mucus* and moisten the air entering the lungs. The air inside the alveoli is saturated with *water vapour* and the mucus-lined epithelium reduces



the evaporation of this water. The moisture ensures that the oxygen and carbon dioxide that diffuse across the gaseous exchange surface are in a dissolved form

- *well supplied with blood*: numerous blood capillaries closely surround the outside of each alveolus. Capillary walls are also only one cell layer thick, keeping to a minimum the distance that gases need to travel between the respiratory surface and the bloodstream.

Gaseous exchange

When gases move between the air in the alveoli and the blood stream, they need to cross only a thin barrier—one layer of alveolar cells and one layer of capillary cells. Movement is by means of diffusion along a concentration gradient. Inhaled air contains approximately 20 per cent oxygen and 0.04 per cent carbon dioxide. Exhaled air contains approximately 15 per cent oxygen and 4 per cent carbon dioxide.

Oxygen in the incoming alveolar air is in a higher concentration than that in the bloodstream, so oxygen diffuses from the air sacs into the body; *carbon dioxide* is in higher concentrations in the bloodstream (a by-product of cell metabolism), so it diffuses along a concentration gradient from the capillaries, through the alveolar lining and into the alveolar air, where it will be breathed out. This movement of gases between the external environment (alveolar air) and internal environment (bloodstream) is known as *gaseous exchange*. There is always some air in the respiratory tract—it never empties completely. Breathing movements which cause ventilation (air to be drawn into and expelled from the respiratory organs) are brought about by the contraction of the diaphragm and muscles between the ribs, which influence the size and shape of the ribcage.

Fish

Overcoming the difficulty posed by habitat

The respiratory system of fish is adapted to use oxygen dissolved in water. The main problem that fish need to overcome is that water has a much lower oxygen content than air. Oxygen diffuses slowly from the surrounding air into a body of water across its surface. Water is much denser and more viscous than air and so it has an overall lower oxygen saturation. The exact percentage of oxygen saturation varies, depending on the depth of water, surface area exposed to air and temperature. The typical oxygen content of water would be approximately 4 to 6 per cent, as opposed to approximately 20 per cent oxygen saturation in air.

Gaseous exchange

The respiratory organs of fish are **internal gills**. (The scaly skin of fish cannot exchange gases with the surrounding water.) Water moves through the respiratory system in only one direction: as the fish swims, it opens its mouth so that water enters and flows over the gills and then it lifts its opercula (gill coverings) to let the water out (see Fig. 4.7a). Movements of the floor of the mouth (buccal cavity) and the opening and closing of the opercula assist with drawing water into the mouth and its movement over the gills and out of the body. As the water flows over the gills, gaseous exchange takes place. Water movement is slowed down because of the highly branched nature of the gill filaments and because the gills are closely stacked, relying on the flow of water to keep the tips of these filaments apart. There are four curved gill arches closely stacked together on each side of the pharynx (throat) of the fish, covered by an operculum (see Fig. 4.7b). Each gill has two rows of very delicate gill filaments, subdivided to increase the surface area for gaseous exchange with the surrounding water. The gill filaments

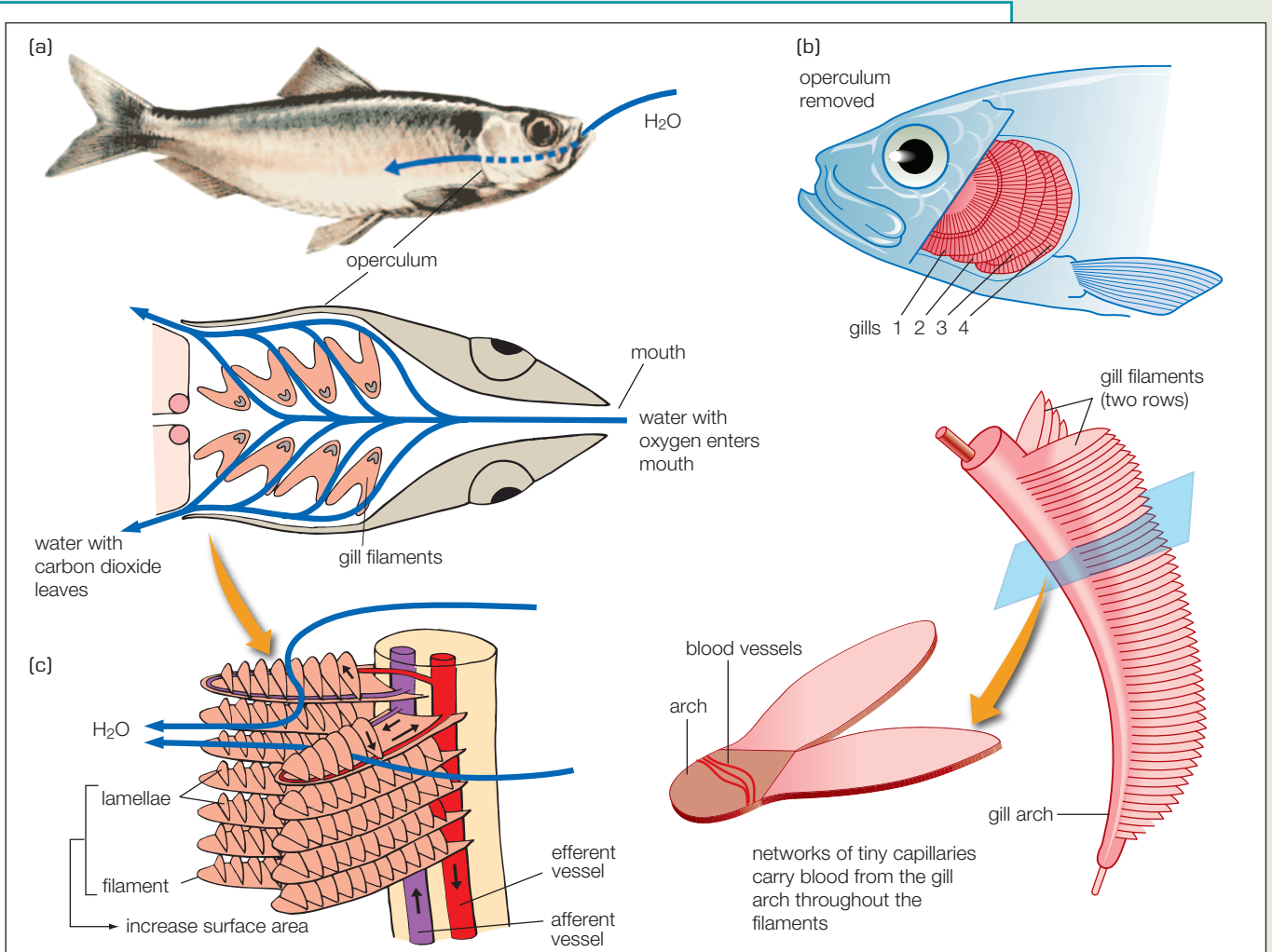


Figure 4.7 Respiratory system of fish: (a) water movement; (b) gill structure; (c) gill filaments

appear pink or red in colour, due to the presence of the rich supply of blood capillaries. Each filament is covered by an extremely thin layer of cells, so that gases can enter and leave easily (see Fig. 4.7c). As water flows over the gills, oxygen diffuses across the filaments into the blood capillaries and carbon dioxide diffuses out. The water leaving through the external gill slits has a higher concentration of carbon dioxide and a lower concentration of oxygen than the water which entered the mouth.

Frogs

Overcoming the difficulty posed by habitat

Frogs are partly aquatic (tadpole stages live in water) and partly terrestrial (most adult frogs live on land and are air-breathing, but must return to water

for breeding). These changes of habitat within the life cycle present a challenge to the respiratory system:

- *adult frogs* have retained certain respiratory characteristics typical of simple aquatic organisms (e.g. a *naked, moist skin* that can be used for gaseous exchange) as well as developing terrestrial features (e.g. *simple lungs*)
- *tadpoles* (immature, larval stages of frogs' lifecycles) use their *thin, moist skin* and *gills* for respiration. Young tadpoles have external gills and these become internal gills as the tadpole matures. The surface area to volume ratio of tadpoles is large (because of their small body size and their long thin tail), so they can rely on diffusion to adequately meet their oxygen needs.



Extension activity: fish further increase their efficiency of gaseous exchange with a counter-current system

Gaseous exchange

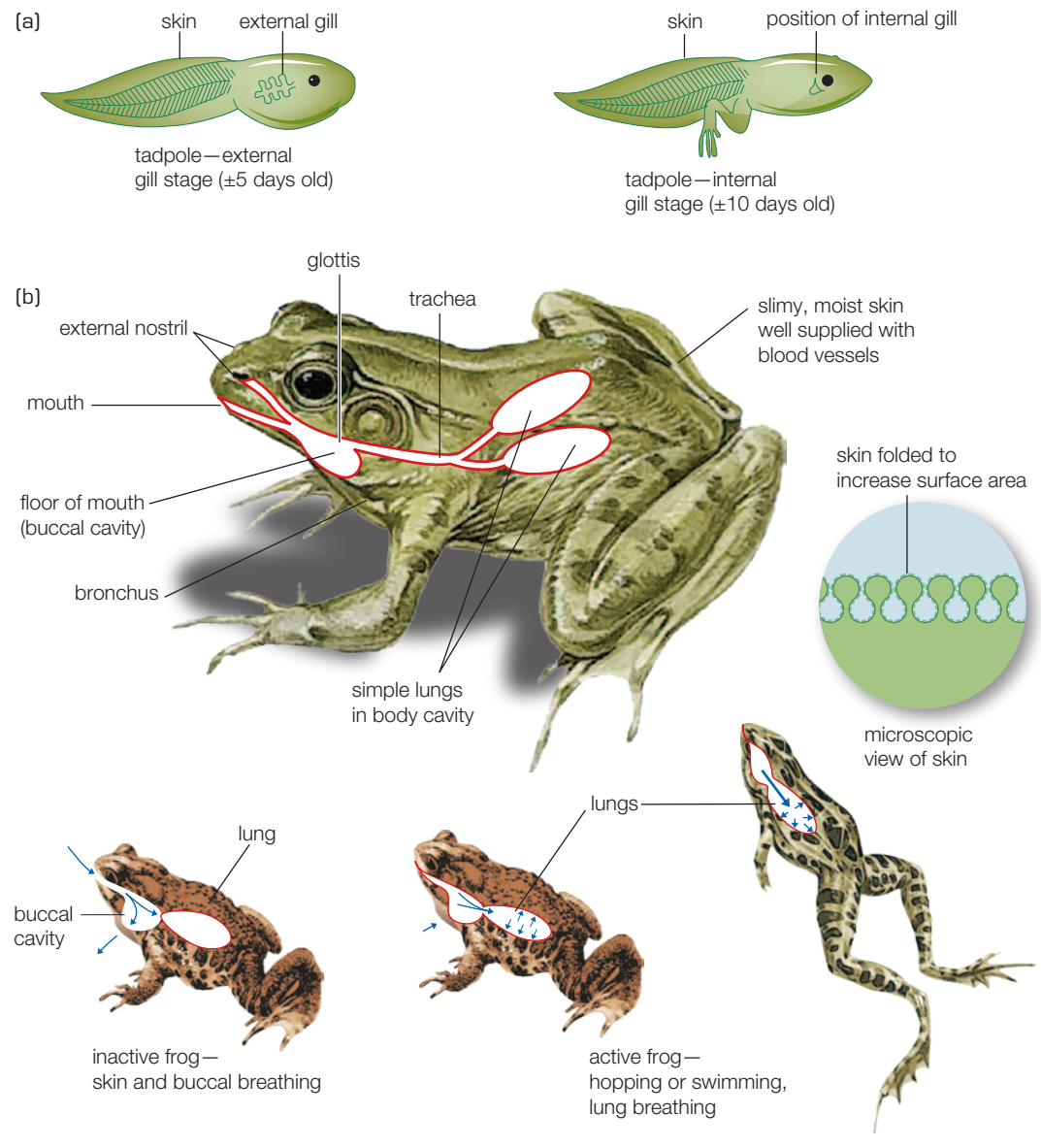
Adult frogs use three surfaces for gaseous exchange:

1. the *skin* is the main site for respiration when the frog is in water or when it is relatively inactive on land. The skin is very well supplied with blood vessels
2. the *floor of the mouth* is large and well supplied with blood capillaries. It serves as a buccal pump, ventilating the lungs. Some gaseous exchange may also occur across the inner lining of the buccal cavity

3. frogs have two simple, sac-like *lungs* and, although internal (like those of terrestrial vertebrates), they are not greatly folded like those typical of mammals. Frogs only use their lungs for gaseous exchange when they are physically active (e.g. during hopping and when on land). The nostrils have valves which close to prevent the entry of water into the lungs during swimming.

All three respiratory surfaces are kept moist, are thin and are well supplied with blood vessels.

Figure 4.8
Respiratory organs of:
(a) tadpoles; (b) frogs



In addition, frogs have an increased body surface area: the small size and flattened shape of the body of a frog means that its external surface area to volume ratio is quite high. Mucus on the skin and in the buccal cavity ensures that these surfaces remain moist and the air inside the sac-like lungs usually has high water vapour content. The fact that the lungs are internal reduces the chances of this water vapour from evaporating. The skin of some frogs shows microscopic folding on its surface, further increasing the surface area.

An interesting related fact is that, because of their permeable skins, frogs are extremely sensitive to changes in environmental chemicals such as air or water pollution. Frogs are therefore often used as a 'sentinel' species, similar to canaries in coal mines—their loss from an area is often a warning of harmful changes in the environment.

Insects

Overcoming the difficulties posed by habitat

Insects, being terrestrial, face the challenge of reducing the loss of water from their respiratory surfaces. Like other terrestrial animals, they have an internal respiratory surface. Insects take in and expel air through breathing pores called **spiracles**, which have *valves* to regulate their opening and closing, ensuring that they are not constantly exposed to the drying effects of the external environment. (See Fig. 4.9.) Furthermore, little or no gaseous exchange can occur through their body covering.

Although small in size, insects are very active during parts of their life cycle and many insects require large quantities of energy to sustain their flying. Therefore they need an efficient respiratory system.

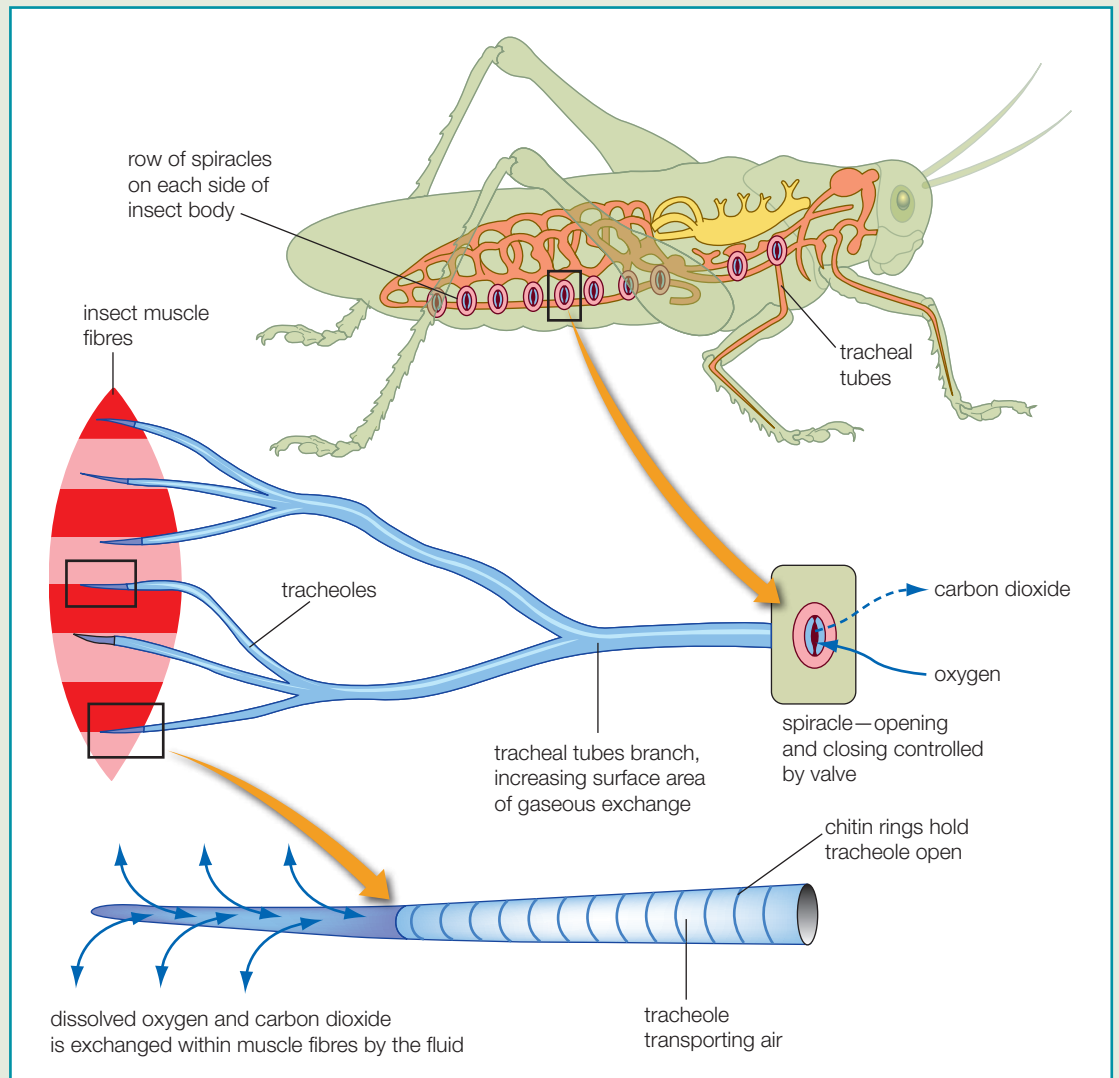
Insects differ from terrestrial vertebrates in that insects do not have lungs or blood capillaries. Instead they have a system of branching air tubes called **tracheal tubes** which carry air directly to the cells of the body—blood is not involved in the transport of gases.

Gaseous exchange

Air enters the insect body through a row of small breathing pores or spiracles on each side of the abdomen of the insect's body (the locust has ten pairs of spiracles). Each spiracle has a valve which regulates its opening and closing. Air that enters the spiracles is drawn into **tracheae** (tracheal tubes) which are kept open by spiral rings of chitin (an insoluble chemical substance that functions in support) to prevent them from collapsing. Tracheae branch extensively into smaller tubules called **tracheoles**, creating a very large surface area for gaseous exchange. Tracheoles carry the air directly to and from the cells of the body.

The respiratory surface in insects differs from all other internal respiratory systems in that it has no blood or blood capillaries involved in the transport of gases. The ends of the tracheoles are filled with a watery fluid in which the gases dissolve. Oxygen from the air, dissolved in this fluid, diffuses directly into the cells and carbon dioxide diffuses directly out of the cells into the tracheoles. The rate of respiration in insects is generally controlled by the number of open and closed spiracles—more are open when the insect is active. Muscular movements of the thorax and abdomen during movement and general body movements when flying also help to ventilate the tracheal system.

Figure 4.9 Tracheal system of insects



STUDENT ACTIVITY



Draw up a table to compare the gaseous exchange surfaces of insects, fish, frogs and mammals. The following headings are suggested:

- Respiratory organs
- Surface of gaseous exchange
- How it is kept moist
- How the surface area is increased
- Transport of gases to and from the respiratory surface.



Student activity

Transport in animals

■ compare open and closed circulatory systems using one vertebrate and one invertebrate as examples

Introduction: closed versus open circulatory systems

The cells of active, complex organisms require a large supply of nutrients and oxygen and the continual removal of waste products. A circulatory system is a more efficient means of achieving this than simply relying on diffusion, but not all circulatory systems are equally efficient. A circulatory system is classified as *closed* or *open*, depending on the flow of its transport fluid. In a **closed circulatory system** the transport fluid flows in *vessels* only, but in an **open circulatory system**, at some stage of circulation the transport fluid leaves the vessels and enters spaces or cavities in the body, bathing the organs directly.

Open circulatory system in an invertebrate

An open circulatory system is characteristic of invertebrate animals such as spiders, insects, crabs and snails. The transport fluid is pumped forward in the body by a long, pulsating vessel, the **heart**, into shorter vessels near the head end, which in turn *empty into large spaces* (called **sinuses**) *in the body cavity* (see Fig. 4.10). The transport fluid in an open circulatory system is called **haemolymph** (rather than blood) and it flows freely in the sinuses, directly bathing the cells. The exchange of nutrients and wastes relies on direct diffusion between the haemolymph and the cells. (Remember that gases in insects are not transported by the haemolymph but by tracheoles.). Haemolymph returns to the heart by moving from the posterior (rear) sinuses back into the open end of the tubular heart, or it may enter the heart through tiny holes in the sides called **ostia**.

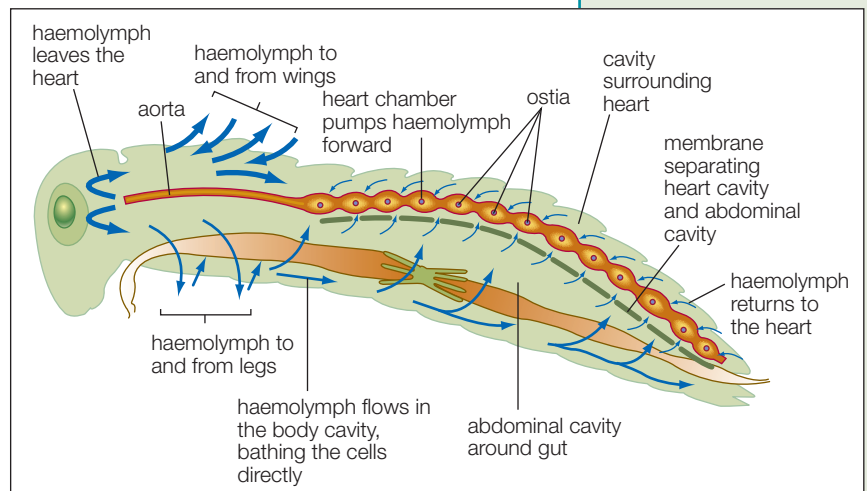
Open circulatory systems are not very efficient, as the *fluid pressure* is *low* and so the transport fluid *circulates slowly*. This type of transport system meets the needs of smaller animals such as insects.

Closed circulatory system in a vertebrate

A closed circulatory system (see Fig. 4.11) is characteristic of all vertebrates such as fish, frogs, reptiles, birds and mammals (including humans). The transport fluid is *blood* which is *contained in vessels at all times* and never flows through body cavities. The heart is a muscular organ that pumps the blood around the body. In mammals, the heart may be two-chambered (e.g. fish), three-chambered (e.g. frogs and some reptiles), or four-chambered as in other reptiles, all birds and mammals.

Blood flows through three types of **blood vessels**: **veins** which carry blood from body organs towards the heart, **arteries** which carry blood away from the heart to the organs and **capillaries** which form a link between arteries and veins. The *arteries* branch into smaller *arterioles* which subdivide

Figure 4.10
The open blood system of a locust



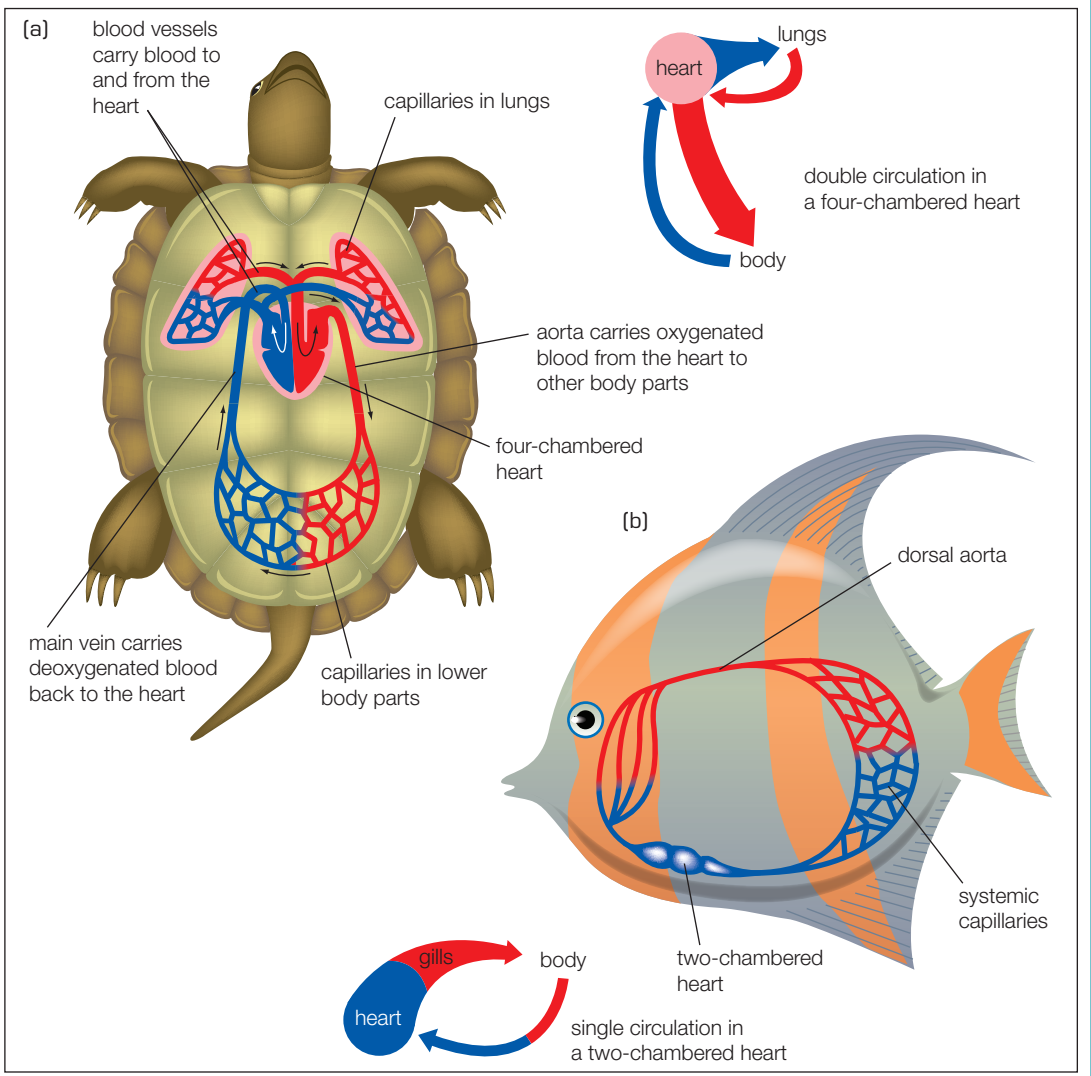
further into a network of *capillaries*. These capillaries branch extensively throughout the tissues, so that no cell is very far from a capillary (see Fig. 4.11). The exchange of nutrients, wastes and gases takes place between blood in the capillaries and fluid surrounding the cells which the capillaries supply. Blood remains in the capillaries at all times, but any chemical substances required by cells leave the capillaries in a dissolved form—the fluid containing the nutrients, gases and wastes is called tissue fluid or **interstitial fluid**. (The tissue fluid makes internal organs appear ‘wet’.). *Capillaries* join up to form *venules*, which in turn join up to form *veins*, returning blood to the heart.

In a closed circulatory system, the muscular heart pumps blood under

high pressure, ensuring efficient transport, which suits large, active animals such as vertebrates. A four-chambered heart is the most efficient pumping mechanism, as it keeps oxygenated and deoxygenated blood separate. (Not all vertebrates have a four-chambered heart—fish have a heart with only two chambers.)

In both an open and closed circulatory system, the blood vessels are responsible for the transport of blood and its contents, but the capillary networks (closed system) or fluid in the body cavity (open system) carry out the other functions such as the exchange of nutrients and wastes, and maintaining a stable internal environment in the body of the organism.

Figure 4.11
The closed blood system of vertebrates: (a) turtles; (b) fish



STUDENT ACTIVITY

Draw a comparative diagram of each type of circulatory system and then complete the table below to compare open and closed circulatory systems.

Table 4.2 Comparing open and closed circulatory systems

Open circulatory system	Closed circulatory system
<i>Similarities</i>	
<i>Differences</i>	
Example: _____	Example: _____
Transport fluid is _____	Transport fluid is _____
Transport fluid flows through body cavities and bathes tissues directly	Vessels divide into capillaries, no cell is very far from a capillary
Tubular heart pumps fluid; pressure is low; suits smaller animals (e.g. insects)	Distributes and collects gases (O_2 and CO_2) as well as foods and wastes



Table 4.2

Gaseous exchange and transport in plants

- **outline the transport system in plants, including:**
 - root hair cells**
 - xylem**
 - phloem**
 - stomates and lenticels**

Introduction

In simple plants such as certain algae and moss, there are no specialised transport tissues and the movement of substances relies on diffusion and active transport through all cells. In more advanced plants such as ferns, conifers and flowering plants, special tissues have developed for transport. These transport tissues are the **vascular tissues** and there are two types—**xylem** and **phloem**.

The distribution of vascular tissue in flowering plants (see Fig. 4.12):

- in *roots*, xylem is found in the centre of roots, usually in a star or cross shape with phloem tissue between the arms of the xylem
- in the *stem*, the xylem and phloem tissue divides into vascular bundles
- bundles of vessels of xylem and phloem continue from the stem up leaf stalks, forming the veins in *leaves*.

4.6

Root hair cells

Transport in plants was been introduced in Chapter 3, root hairs were dealt with in detail and so only a general summary is given here. Revise the information on transport in plants on pages 140–1 and then read the additional details on xylem, phloem, stomates and lenticels in this chapter.

Water and dissolved nutrients move from the soil into roots, through the root epidermal cells, with most of the uptake being in the region of the root hairs. Water then moves across the root tissues from the outer epidermal layer to the vascular stele (transport tissue) in the centre of the root and into the xylem tissue (see Fig. 3.15b).

Gaseous exchange between roots and soil also takes place, relying on diffusion of gases. Cells of the root cannot photosynthesise (they are not exposed to sunlight and have no chlorophyll) but they do respire like all living cells.

Xylem

Xylem is specialised tissue for the transport of water and dissolved inorganic minerals from the roots to the leaves.

Structure of xylem

Xylem tissue consists of two main types of elements—**xylem tracheids** and **xylem vessels** (see Fig. 4.12), with other cells such as parenchyma and fibres in between. Tracheids are elongate with end walls that taper to a point. Most of the xylem in flowering plants occurs in the form of xylem vessels. Xylem vessels form continuous tubes for the transport of water. When cells specialise to become xylem vessels, their transverse walls break down, so the cells that are stacked on top of each other become continuous

tubes. The cell contents die, leaving hollow vessels for the easy flow of water and dissolved mineral salts. The walls of xylem vessels and tracheids are reinforced with **lignin** thickenings laid down in rings, spirals or other regular patterns. These thickenings prevent the vessels from collapsing, and help the easy movement of water and dissolved substances.

Fibres give support to the xylem tissue and the parenchyma tissue conducts materials from one region of xylem to another and may function in storage.

Transport role of xylem

The function of xylem is to transport water and dissolved inorganic nutrients as *ascending sap*, from the roots up the plant to the leaves and the reproductive structures such as flowers. The movement of water up the xylem vessels occurs mainly as a result of a **transpiration stream** that develops: as water evaporates through the stomates of leaves, it sets up a concentration gradient across the leaf, creating a suction pull on the water and dissolved minerals in the xylem tissue. It is this suction force or *transpiration stream* that ensures the upward movement of ascending sap in the xylem (i.e. there is no pump mechanism such as the heart in animals).

Lateral movement of water in plants

Water moves laterally across plant organs (e.g. from root hairs to xylem, or from xylem tissue into mesophyll in leaves) via one of three pathways:

1. the apoplast pathway through the cellulose cell wall
2. the symplast pathway through the cytoplasm and plasmodesmata
3. the vacuolar pathway, from vacuole to vacuole.

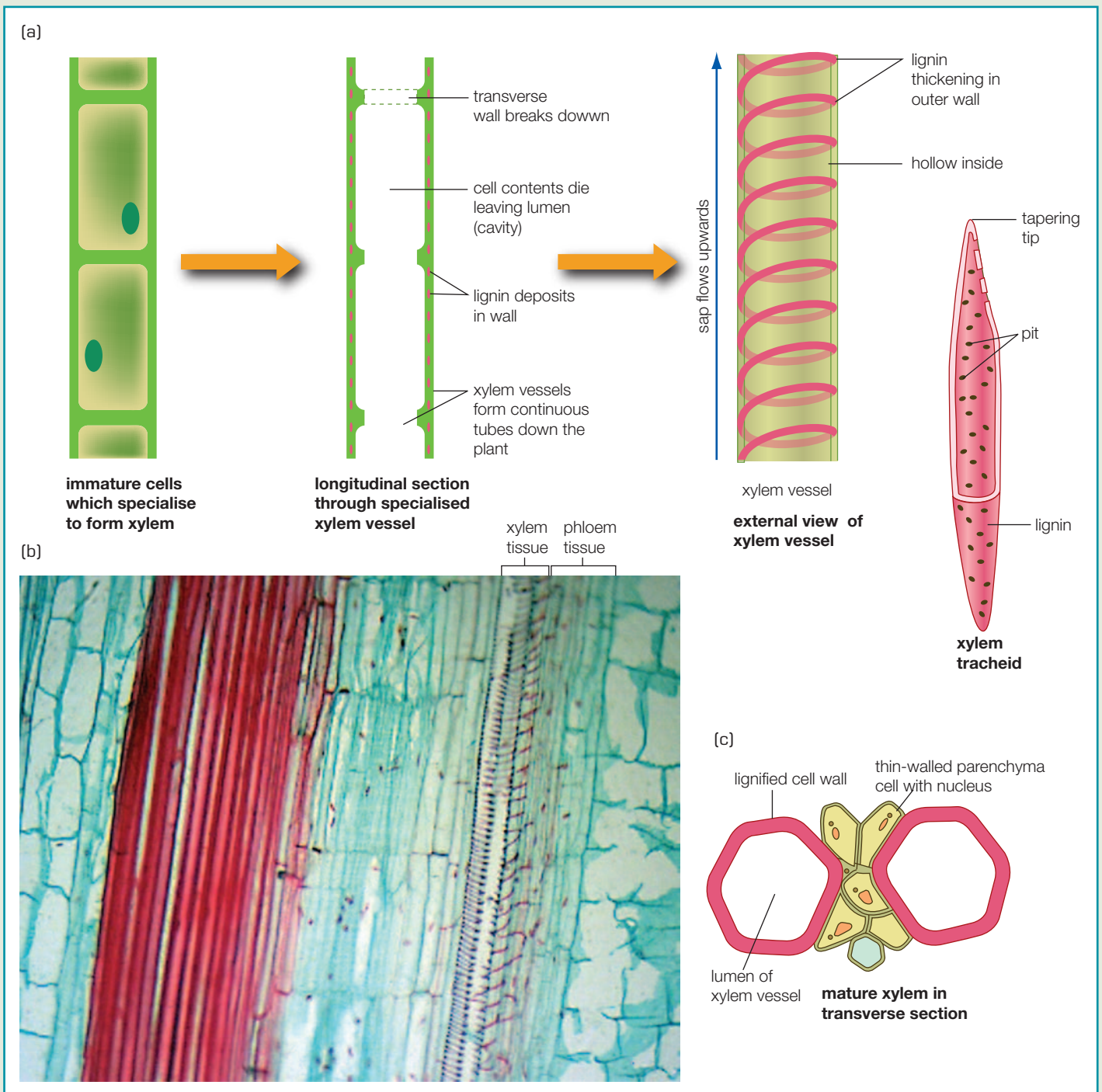


Figure 4.12 Xylem tissue: (a) scheme showing specialisation of xylem vessels; (b) photomicrograph of mature xylem tissue showing a variety of wall thickenings (light microscope view in longitudinal section); (c) mature xylem tissue seen in a transverse section (light microscope view)

Phloem

Phloem is specialised tissue that transports sugars (produced by photosynthesis) from the leaves to the rest of the plant.

Structure of phloem

(See Fig. 4.13.) There are two main types of phloem cells (sometimes referred to as phloem elements) in plants—**sieve tube elements** and **companion cells**. Unlike xylem vessels, sieve tube elements are cells with *living* contents (cytoplasm), but they do not have a nucleus or any other organelles besides mitochondria. Companion cells are small cells that are associated with each sieve tube element and they are responsible for keeping the sieve tubes alive.

Organic nutrients such as sugars, produced by photosynthesis, move down or up the plant through the sieve tube elements, a process known as **translocation**. The active loading of sugars (dissolved in water) into phloem requires energy. The sap flows from one element to the next, through perforated transverse walls. (Perforations are tiny holes that pierce the cell wall.) These perforated end walls are known as **sieve plates**.

Transport role of phloem

Movement in phloem occurs in both directions, upwards from the leaves to the upper parts of the plant and down towards the roots. Numerous experiments have been done to show this dual movement, but the current theories of how movement actually occurs in phloem will be studied in Year 12. It is sufficient for you to know that movement is as a result of flow along a concentration gradient, so once again there is no pumping mechanism. The flow of materials through phloem has been shown using radioactively-labelled carbon dioxide which is taken

up during photosynthesis. Biologists can then trace the pathway taken by the radioactive carbon dioxide: from its entry into the leaf, its incorporation into sugar products and eventually the flow of sugars through phloem until they are used or converted into other organic compounds for storage.

Stomates and lenticels

Most gaseous exchange in plants takes place through stomates and lenticels.

Stomates

Structure of stomates

(The structure of stomates has been briefly dealt with in Chapter 3 on pages 142–3.) Stomates or *stomata* are pores in the epidermis of leaves, bordered by two bean-shaped guard cells. These guard cells are unlike other epidermal cells because guard cells contain chloroplasts and the inner wall of each is thicker than the outer wall.

Transport role of stomates

When stomates are open, gases are able to diffuse through them, but when they are closed, no gases are transported. Many theories have been put forward to account for the opening and closing of stomates, but at Preliminary Level it is probably sufficient for students to understand that—when the guard cells fill with water and become turgid, the thin outer walls (which are more elastic) stretch outwards, but the thick inner walls (fairly inelastic) do not bulge, so they are pulled apart and the pore between them widens. When stomates lose water, the outer walls no longer bulge, so the inner walls move together again, closing the pore (see Fig. 4.14c). What causes water to move into and out of the guard cells is still being researched, but current theories suggest it is linked to the movement of potassium ions.



Demonstration activity of stomate functioning using a long balloon and sticky tape

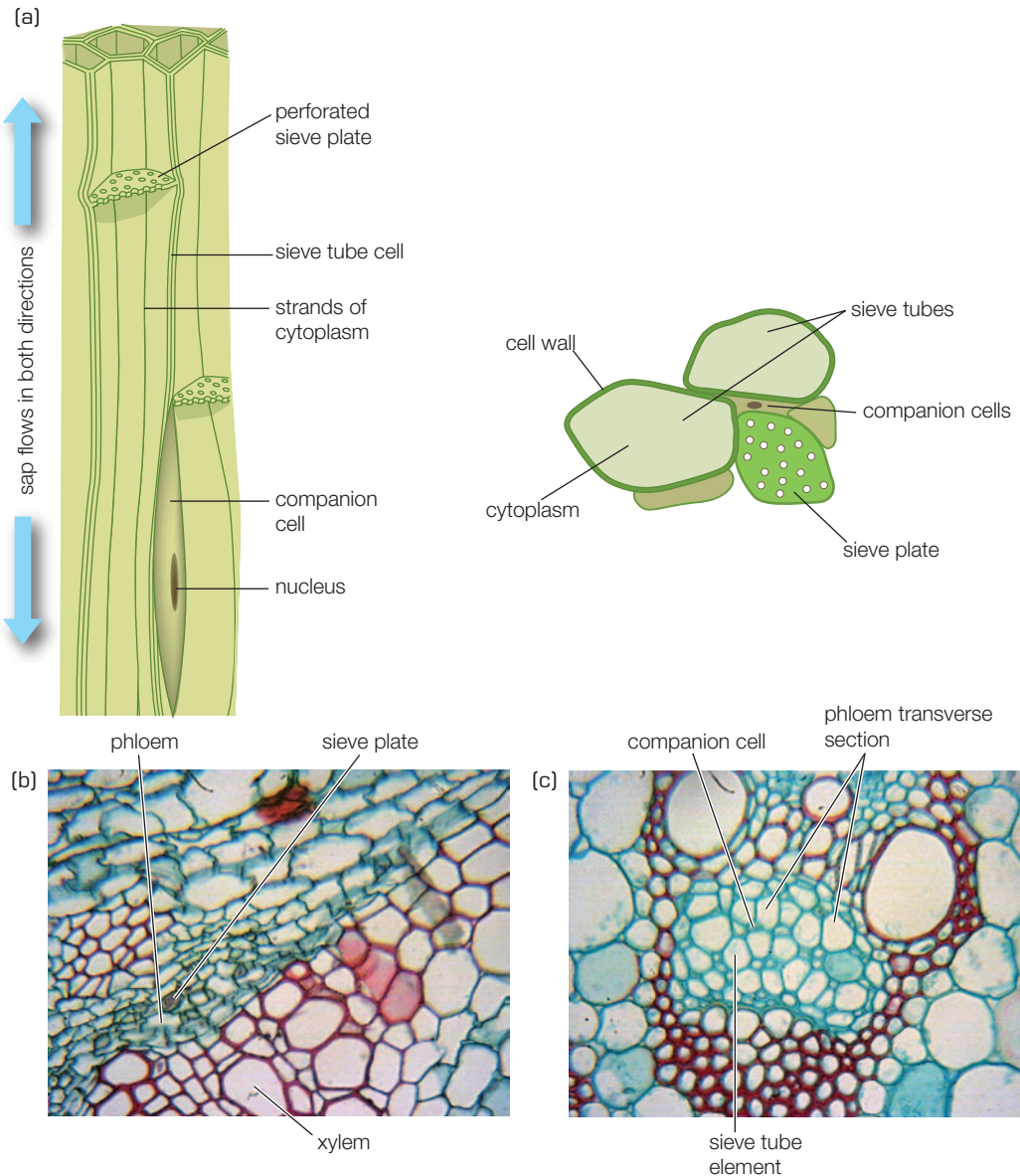


Figure 4.13 Phloem tissue: (a) longitudinal section (light microscope view); (b) light micrograph showing sieve plate (in transverse section); (c) transverse section (light microscope view)

Lenticels

Structure of lenticels

Lenticels are pores through which gaseous exchange occurs in the woody parts of plants such as the trunks and branches of trees and woody shrubs. They appear as small dots to the naked eye, but on microscopic examination, it can be seen that they are clusters of loose cells in the cork layer of bark.

Transport role of lenticels

The diffusion of oxygen, carbon dioxide and water vapour takes place through lenticels, relatively slowly.

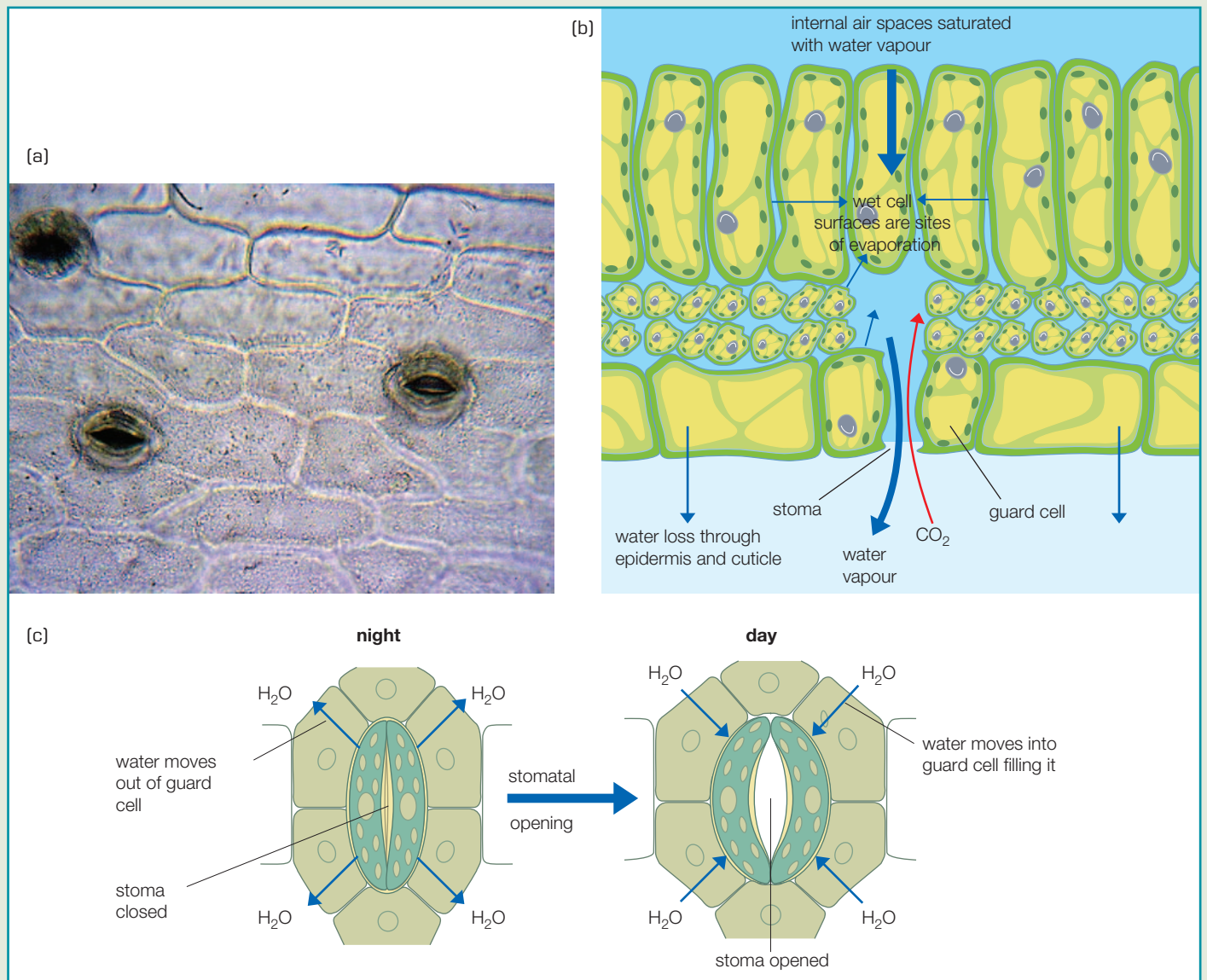


Figure 4.14 Stomates: (a) surface view of epidermal and guard cells; (b) scheme of a transverse section through guard cells (highly magnified) (c) the functioning of stomates (closed and open)



FIRST-HAND INVESTIGATION
BIOLOGY SKILLS

P11.3
P12.1; 12.2; 12.4
P13.1
P14.1

Investigating the movement of materials in xylem

■ *perform a first-hand investigation of the movement of materials in xylem or phloem*

Aim

To investigate the direction and rate of movement of water and a dissolved dye through xylem tissue.

Materials

- celery
- 1000 mL beaker
- water with eosin dye
- permanent marker pen

- stopwatch
- razor blade
- glass microscope slide and coverslip
- light microscope.

Safety

- Wear a laboratory coat to prevent eosin from staining clothes.
- Wear disposable gloves to keep hands stain-free.
- Handle razor blade with care.

Method

1. Place a stick of celery, with leaves attached, into a 1000 mL beaker containing 200 mL of water and eosin dye. (In the absence of eosin, food colouring may be used.)
2. Mark off three 1-centimetre intervals on the celery stem above the meniscus of the liquid. Time how long it takes for the dye to travel each centimetre and record your results. Calculate the average time taken for the dye to move 1 cm. Describe the direction of movement of the water and the dissolved dye.
3. Slice a very thin transverse section through a portion of the celery stem through which the dye has moved. Prepare a wet mount of this tissue to view under the light microscope.
4. On the diagram provided (see Student Resource CD) shade the tissue in the celery stem which has been stained orange by the dye and record the structural features which enabled you to identify the tissue. (Use Figs. 4.13 and 4.15 to help you to identify the tissue in the stems.)
5. Optional: Locate one vascular bundle and peel it longitudinally in the stained region. Make a wet mount of this tissue and observe it under the microscope. Draw a diagram to show its appearance in longitudinal section.
6. Replace the remaining celery stem, with leaves still attached, into the coloured water and leave overnight. Observe the celery after 24 hours and describe the distribution of the dye.

Results

Record your results in a suitable format.

Discussion questions

1. **Explain** the purpose of the eosin dye in this experiment.
2. **Describe** evidence from the experiment that supports the hypothesis that water and dissolved nutrients are transported by xylem tissue in stems.
3. **Predict** the rate of movement of a coloured solution that has been made using warm water.
4. In which direction(s) did water move in the stem?
5. **Identify** the force that you think made the water move. Is your answer to this question an inference or a conclusion? Explain why.
6. **Describe** another way (besides changing the temperature of the solution) that you could use to increase the rate of movement up the xylem.
7. **Describe** the appearance of the xylem tubes.
8. Relate the structure of the xylem tubes to their function.

Conclusion

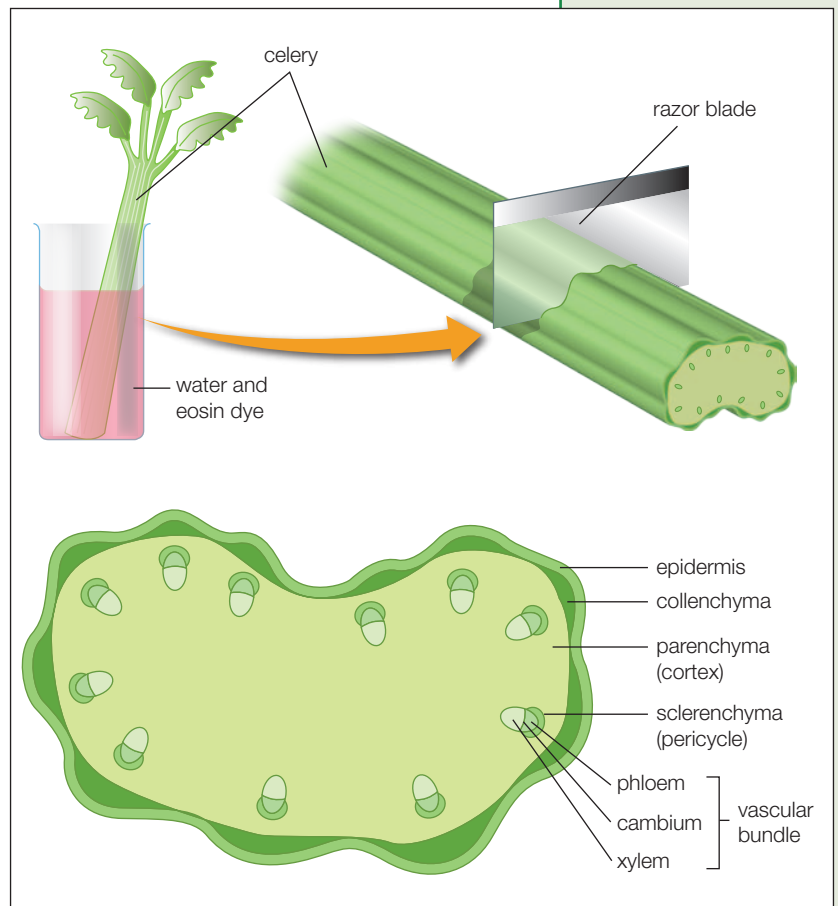
(Students to write their own conclusion.)



Diagram of celery tissue

Figure 4.15

Movement of materials in xylem: (a) experiment using celery to show the movement of materials in xylem; (b) plan diagram of transverse section through celery stem showing tissue distribution (light microscope view)



Transpiration in plants

FIRST-HAND INVESTIGATION

PFAs

P2

BIOLOGY SKILLS

P12.1; 12.2

P13

P14

P15

P16

- *use available evidence to perform a first-hand investigation and gather first-hand data to identify and describe factors that affect the rate of transpiration*

Background information

- Transpiration is the evaporation of water through the stomates of leaves. To replace the water lost from a plant during transpiration, water is drawn in by the roots.
- Water is needed by the plant:
 - for photosynthesis
 - to make the cells turgid and thus help support the plant
 - as a medium of transport and for the metabolic processes within the cells.
- There are several factors which can affect the rate of transpiration: wind, temperature, light and humidity are the main factors which could increase or decrease the rate of transpiration.
- A **potometer** is an instrument used to measure the rate of absorption by a shoot. This is assumed to be equal to the rate of transpiration from the leaves. The rate at which water moves along the potometer is a direct indication of the rate of transpiration.

Aim

To determine how wind, light and air movement affect the rate of transpiration.

Hypothesis

A plant exposed to hot windy conditions/bright light will transpire *more/less* than a similar plant exposed to cooler, still air/little light. (Cross out the italic word which you think does not apply.)

Materials

Read through the method and then list all equipment that you will need to conduct this investigation.

Safety

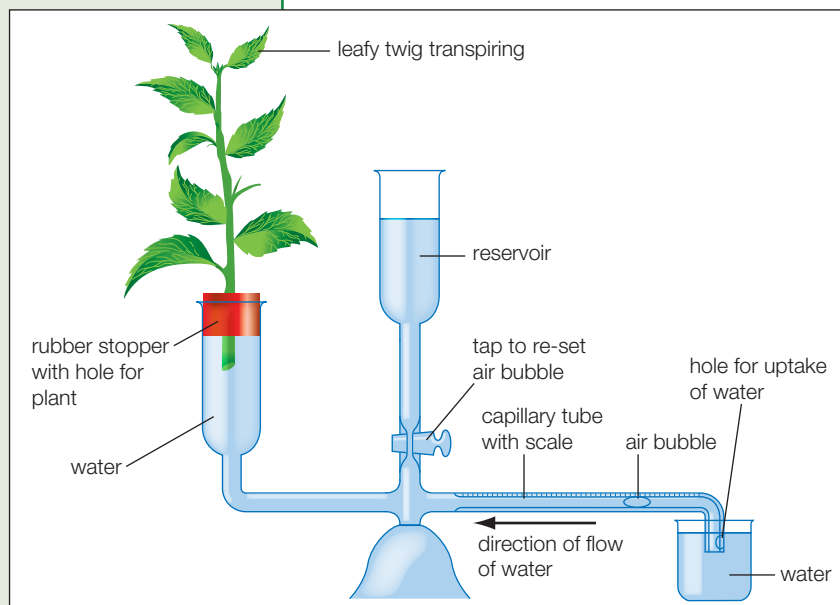
Read through the method and list safety precautions. Also record how you will ensure that your selection of plants complies with non-destructive testing.

Method

1. Set up the potometer as shown in Figure 4.16. Some factors that should be taken into account when selecting the plant to be used are listed below:
 - the diameter of the stem is important—have the rubber stopper that you will use on hand; try to match the diameter with that of the opening as closely as possible, as this needs to be airtight
 - you will need a set of experimental apparatus and a control. You may use the same plant twice (read the Method carefully and decide whether you should conduct the investigation under the experimental or control conditions first) or select two very similar plants. They should be of the same species, have a similar number of leaves on the stem and have a stem of similar diameter and length
 - cut the stem underwater with a sharp blade and insert it through the stopper underwater to prevent air bubbles from forming an air lock. Transfer the stem directly into the water in the potometer
 - ensure all seals (e.g. between the stem and the stopper and between the stopper and the potometer) are airtight and watertight by drying them well and placing vaseline where they meet

Figure 4.16

Potometer set up to measure the rate of absorption in relation to transpiration



- create the air bubble in the capillary tube using a corner of a tissue or sponge to suck out some water from the hole in the side of the capillary tube and then place the end of the capillary tube into a small beaker of coloured water. The colour makes it easier to see the movement of the bubble along the capillary tube. The beaker should have enough water to create pressure to ensure the air bubble gets pushed upwards and across into the part of the capillary tube marked with a graded scale
 - the air bubble can be reset to the end of the tube by opening the tap on the reservoir carefully.
2. Measure the rate at which water moves along the potometer under the following conditions:
- plant exposed to air in the laboratory (describe the day's conditions). This will be the control
 - plant exposed to hot, windy conditions (simulated using a fan heater or a hair dryer). This will be the experiment.

Results

Present your results in a table with suitable headings.

Conclusion

Write your own conclusion, after reading the aim and hypothesis again.

Discussion questions

1. **Explain** the link between transpiration and the absorption of water in this experiment.
2. **Discuss** your choice of using either one plant or two separate plants for the experimental and the control in this investigation.
3. **Predict** whether the rate of transpiration would increase or decrease, as compared with your control plant, if you subjected a similar plant to each of the following conditions:

Environmental conditions	Rate of transpiration compared with control
1. Increased temperature	
2. Increased wind	
3. Increased humidity	
4. Brighter light	
5. Cool, windy conditions	

4. Explain how and why each of the following factors affects the rate of transpiration:
 - (a) heat
 - (b) light
 - (c) wind
 - (d) humidity.



Answers to investigation questions and the results table

The use of radioactive isotopes to trace transport in plants and animals

- *use available evidence to discuss, using examples, the role of technologies, such as the use of radioisotopes in tracing the path of elements through living plants and animals*

Introduction

Isotopes are atoms of the same element with different numbers of neutrons. Isotopes are usually named for their mass numbers (that is, the total number of neutrons and protons). For example, most carbon atoms have six neutrons and six protons, i.e. ^{12}C , but the isotopes of this are ^{13}C and ^{14}C . **Radioisotopes** are isotopes that emit radiation—they are said to be **radioactive** (they emit radioactive waves

or particles to try to achieve a stable state). The emission of these radioactive particles or waves can be measured using photographic film, a cloud chamber, a Geiger counter or a scintillation counter. Their presence can be detected and so they can be distinguished from normal elements. Therefore radioisotopes have become very useful as tracers—technologies can be used to trace their path in physical, chemical and biological systems.

SECONDARY SOURCE INVESTIGATION

PFA's

P5

BIOLOGY SKILLS

P11.1; 11.3

P12.3; 12.4

P13.1

P14.1; 14.3



Radioactive isotopes are produced in Australia by a company called ANSTO (Australian Nuclear and Science Technology Organisation). Radioisotopes are used as a diagnostic tool, giving information about the functioning of organs and tissues in living things. Radioisotopes can be chemically attached to molecules that will enter living tissue. The movement of these molecules can then be traced and their use in particular tissues and organs provides helpful information. Modern computer software can convert the information into three-dimensional images so that investigators can 'see' where the radioactively-labelled chemicals are moving or stored in living organisms.

The use of radioactive isotopes in animals and humans

In animals and humans, radioactively-labelled isotopes are used to study the circulatory system. Technetium-99 is the most commonly used medical isotope. It can be combined with a tin compound and injected into the bloodstream, where it readily attaches to red blood cells, so its path through the circulatory system can be traced. It is useful to determine abnormalities in heart functioning and in blood vessels.

Radioactive particles do carry some risk in that they may be mutagenic (cause mutations in the DNA of cells). Radioisotopes that have a short half-life (such as Technetium-99 which has a half-life of 6 hours) are used in humans, to reduce the person's exposure to radiation and any risks associated with it.

The use of radioactive isotopes in plants

Radioactive isotopes are also used to trace the path of nutrients and gases through plants.

Melvin Calvin was awarded a Nobel Prize in 1961 for his work using a carbon-14 tracer, to show that sunlight acts on the chlorophyll in a plant to begin the manufacturing of organic compounds, rather than on carbon dioxide as was previously believed.

Another experiment was conducted to trace whether the oxygen released during photosynthesis originated from the oxygen atom in water or that in carbon dioxide. Plants that were given water that contained radioactive atoms of oxygen showed that all of the radioactive oxygen atoms from the water molecules were released as oxygen gas, proving that *water* (and not carbon dioxide) was the source of oxygen gas released during photosynthesis:



*Single oxygen atoms from the water in adjacent chloroplast molecules combine to form O₂, oxygen gas, which is then released.

Biologists can trace in which parts of plants the radioactive atoms have been taken up and how quickly they are absorbed. This helps them to develop fertiliser programs for commercial crops. ¹³N is being used to trace nitrogen movement in plants.

STUDENT ACTIVITY



Investigate two more uses of radioisotopes—one in plants and one in animals. Use the search words: 'radioisotope tracers in . . .' (i.e. in plants, animals or humans); or 'technology to trace nutrients in plants' to refine your search on the Internet. You could also search for 'radioisotopes in medical imaging' or 'imaging the heart'.



REVISION QUESTIONS

1. Complete the Table 4.3 **comparing** examples of substances transported in plants with those transported in large multicellular animals.



Table 4.3 Comparing substances transported in plants and animals

	Direction of movement	Examples in plants	Examples in animals
Gaseous exchange system	Oxygen from external environment into the organism		Oxygen from the air into the lungs
	Carbon dioxide from organism to the external environment		Carbon dioxide from the lungs into the air
Transport system	From where the substances entered the body to where they are needed		Oxygen from the lungs to the cells of an animal's body
	From where the substances were produced in the body to where they will be used/excreted		Carbon dioxide from the cells where it was produced to the lungs
Excretory system	From where the substances were produced by metabolism in the body to outside the body		Urea from the kidneys to the outside

2. In the form of a table, **compare** the percentage content of oxygen and carbon dioxide in inhaled air with that of exhaled air in humans. Account for the difference.
3. **Explain** why unicellular organisms and small, simple multicellular organisms do not need respiratory structures.
4. (a) **Distinguish** between the terms *respiration* and *breathing*.
 (b) Write the word equation for cellular respiration.
 (c) **Describe** what is meant by a respiratory surface or surface of gaseous exchange.
 (d) **Describe** two differences and one similarity between the respiratory surface of a fish and that of an insect.
 (e) **Explain** how each respiratory surface compared in Question 4(d) above is suited to its particular environment.
5. **Identify** four gaseous exchange surfaces in frogs. Which of these surfaces is also used for gaseous exchange in:
 (a) fish
 (b) mammals
 (c) insects?
6. State two reasons why fish can survive in water, even though there is far less oxygen in water than there is in air.
7. Mammals have a closed circulatory system whereas insects have an open circulatory system. **Discuss** the advantages and disadvantages of these transport systems for the organisms in which they occur.
8. Two leafy shoots were taken, each one from a different species of plant, to determine which species had the greater rate of transpiration under set conditions.
 (a) What piece of apparatus would be used to measure the transpiration rate in each?
 (b) State two precautions that should be taken when selecting the leafy shoots to ensure that this is a valid experiment (fair test) and the results are comparable in the two species.
 (c) **Describe** the conditions under which you might measure the transpiration rate.
9. The following is a list of biological tools. **Outline** how each may be used to study transport in plants:
 (a) light microscope
 (b) radioisotopes
 (c) biological dyes.
10. **Outline** the path that water takes through plants: from when it enters the root from the soil, its passage through the plant and its final exit through the leaves. Specify the tissues that it travels through in each part of the plant and name the process(es) involved at each point.



Answers to
revision questions