

ESAT

Biology

Animal organ systems

Free lesson notes

Covers	B9.2
Format	Lesson, worked examples, self-check
Price	Free

About this lesson

A single cell can get what it needs by diffusion across its surface. A large animal cannot: most of its cells are far from the outside world, so it needs specialised *organ systems* that each solve a particular problem. The nervous system detects changes and coordinates a response. The respiratory system takes in oxygen and removes carbon dioxide. The circulatory system moves substances around the body. The digestive system breaks food down and absorbs it. The excretory system removes waste, especially urea, and balances water.

This lesson takes each system in turn. In each case we ask what problem the system solves, what its structure is, *why* the structure suits the function, and how the parts work together. We begin with a recurring idea, surface area and diffusion, that explains the design of alveoli, villi, capillaries and nephrons; then we study the reflex arc, the lungs and ventilation, the heart, blood vessels, blood and the ECG, the digestive system and the kidney with its nephron. Worked examples include the calculations the ESAT likes to set (cardiac output, breathing volumes, heart rate from an ECG, percentage reabsorbed, surface area to volume ratio).

How to use it. Try each worked example yourself before reading the solution. There is no calculator in the real ESAT, so numbers are friendly. Finish with the self-check and the practice set. Specification covered: B9.2, organ systems: nervous (including the reflex arc), respiratory, circulatory (heart, ECG, vessels, blood), digestive, and excretory (kidney and nephron).

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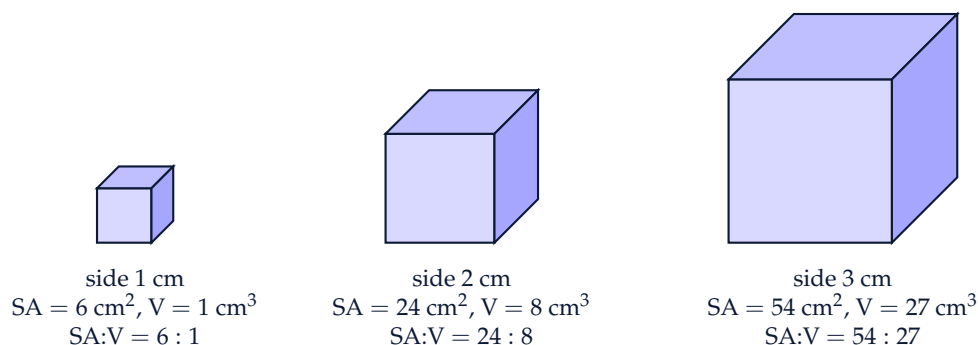
1 Why large animals need organ systems: surface area and diffusion

Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration, down a concentration gradient, as a result of their random motion. It needs no energy from the cell. Oxygen, carbon dioxide, glucose and urea all move into or out of cells and organs by diffusion in part of their journey. How fast diffusion happens depends on three things:

- the **surface area** across which it happens (bigger is faster);
- the **concentration difference** (a steeper gradient is faster);
- the **distance** the particles have to travel (a thinner barrier is faster).

Putting these together, the rate of diffusion is proportional to $\frac{\text{surface area} \times \text{concentration difference}}{\text{distance}}$. Nearly every specialised exchange surface in an animal is built to make the first factor large, the second kept large, and the third small.

Why not just use the body surface? Compare cubes of different sizes. A cube of side L has surface area $6L^2$ and volume L^3 , so its surface-area-to-volume ratio (SA:V) is $6L^2/L^3 = 6/L$. As an animal gets bigger, its volume (which needs supplying) grows faster than its surface (which does the supplying), and the ratio falls.



A mouse has a large SA:V ratio; it can lose heat and exchange gases through the skin quite effectively. An elephant has a

small one, so it needs specialised organs with huge, folded surfaces inside the body (lungs, gut lining, kidneys), plus a transport system (the blood) to carry substances to every cell.

Worked example: cubes and surface area to volume

Cut a cube of side 4 cm into 64 small cubes of side 1 cm. How does the total surface area change?
Big cube: $6 \times 4^2 = 96 \text{ cm}^2$. Each small cube: $6 \times 1^2 = 6$, so $64 \times 6 = 384 \text{ cm}^2$ in total. The total surface area is $384 \div 96 = 4$ times larger, though the volume is unchanged. This is why finely divided things (powdered sugar, droplets of fat, folded villi) react or absorb quickly.

Key ideas

- Diffusion rate $\propto$ (surface area $\times$ concentration difference) $\div$ distance.
- SA:V ratio falls as organisms get bigger, so large animals need exchange organs and a transport system.
- Good exchange surfaces are: large (folded), thin (one cell thick), well supplied with blood and, for gases, ventilated.

Common mistakes

- Saying diffusion “uses energy”. It is passive; the energy comes from the random motion of the particles.
- Saying “larger animals have a larger SA:V ratio”. They have a larger surface area but a smaller ratio.
- Forgetting that a steeper concentration gradient also speeds up diffusion. Blood flow and ventilation keep the gradient steep by carrying the substance away.

2 The nervous system and the reflex arc

The **nervous system** lets an animal detect a change in its surroundings (a **stimulus**) and respond rapidly. It consists of the **central nervous system** (CNS), the brain and the spinal cord, and the nerves that connect it to the rest of the body. Information travels along nerve cells (**neurons**) as tiny electrical impulses.

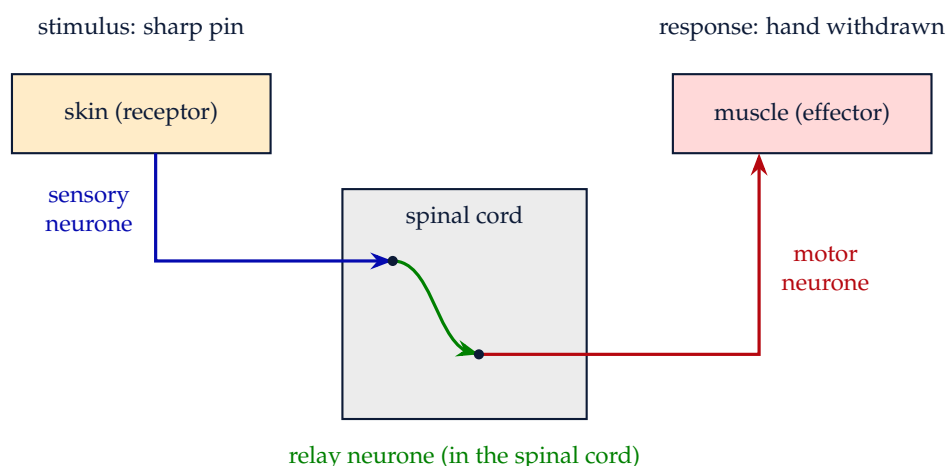
The chain of events. A **receptor** is a cell that detects a stimulus (a pain receptor in skin, a light receptor in the eye). An **effector** is a muscle or gland that carries out the response: muscles contract, glands secrete hormones or enzymes. Three kinds of neurone connect them:

- the **sensory neurone** carries impulses *from the receptor to the CNS*;
- the **relay neurone** passes impulses within the CNS (inside the spinal cord or brain);
- the **motor neurone** carries impulses *from the CNS to the effector*.

Between one neurone and the next there is a tiny gap called a **synapse**. The impulse does not jump the gap electrically: the first neurone releases a chemical *neurotransmitter*, which diffuses across the gap and triggers a new impulse in the next neurone. Impulses can only pass one way across a synapse, which keeps the system organised.

The reflex arc. A **reflex** is a fast, automatic response to a stimulus that does not need conscious thought. It is a survival mechanism: when you touch something hot, you pull your hand away *before* you feel pain. The pathway is the **reflex arc**:

stimulus $\rightarrow$ receptor $\rightarrow$ sensory neurone $\rightarrow$ relay neurone (CNS) $\rightarrow$ motor neurone $\rightarrow$ effector $\rightarrow$ response.



Reflexes are fast because there are only a few neurones and synapses and, in many reflexes, the signal is processed in the spinal cord without having to reach the brain first. (A signal *also* goes on to the brain, which is why you then feel the pain.) A *voluntary* response, by contrast, involves a decision in the brain: the pathway is longer and the response slower.

Worked example: the path of a reflex

You touch a hot pan with your finger and your hand is pulled back. List the structures in order and say which part is the effector.

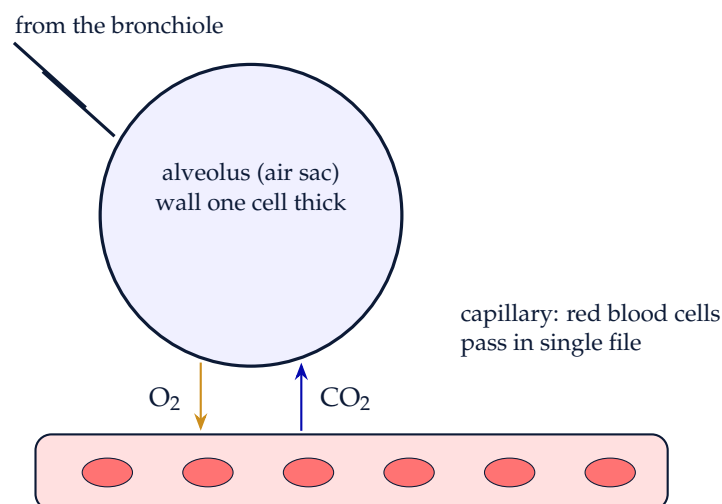
Heat (stimulus) → temperature receptor in the skin → sensory neurone → relay neurone in the spinal cord → motor neurone → muscle in the arm (the effector) which contracts → finger pulled away. The brain is informed afterwards, which is why the pain is felt a moment later.

Common mistakes

- Putting the motor neurone before the relay neurone, or leaving out the relay neurone.
- Calling the muscle a “receptor”. A receptor detects; an effector acts.
- Saying a reflex does not involve neurones, or is controlled by hormones. It is a nervous response.
- Thinking the brain is always in the pathway before the response. In a reflex the response starts in the spinal cord.

3 The respiratory system: gas exchange and ventilation

The cells of the body need a constant supply of oxygen for aerobic respiration, and must get rid of the carbon dioxide produced. The **respiratory system** does this. Air passes through the *trachea* (windpipe), which divides into two *bronchi*, then into smaller *bronchioles*, which end in millions of tiny air sacs called **alveoli**. Gas exchange takes place across the walls of the alveoli.



Each alveolus is wrapped in a network of capillaries. Oxygen diffuses from the air in the alveolus (high concentration) into the blood (low concentration, because it has just come from the body); carbon dioxide diffuses the other way. The alveoli are well adapted for this:

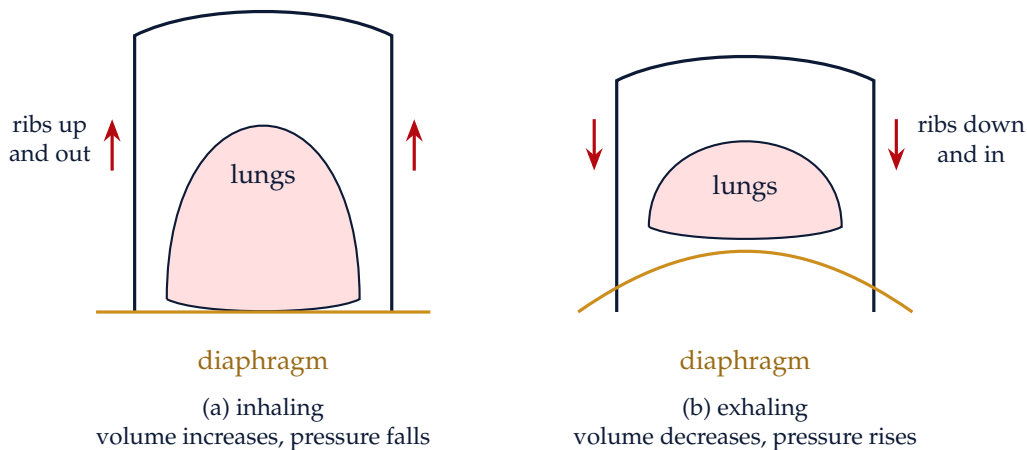
- a **huge number** of alveoli (hundreds of millions), giving an enormous total surface area (roughly the area of a tennis court, though the exact number does not matter);
- walls **one cell thick**, and capillary walls one cell thick, so the diffusion distance is tiny;
- a **rich blood supply**, which keeps taking oxygen away and bringing carbon dioxide, maintaining steep concentration gradients;
- **ventilation**, which keeps bringing in fresh air with a high oxygen concentration.

Ventilation (breathing). Air moves in and out because of changes in pressure, produced by the *diaphragm* (a sheet of muscle below the lungs) and the *intercostal muscles* between the ribs. The lungs have no muscle of their own.

- **Inhaling:** the intercostal muscles contract, pulling the ribs up and out, and the diaphragm contracts and flattens. The

volume of the chest cavity increases, so the pressure inside falls below atmospheric pressure, and air is pushed into the lungs by the higher pressure outside.

- **Exhaling:** the muscles relax; the ribs move down and in, and the diaphragm relaxes and domes upwards. The volume decreases, the pressure rises above atmospheric, and air is pushed out.



Breathing volumes. The **tidal volume** is the volume of air in one normal breath (about 500 mL at rest). The **breathing rate** is the number of breaths per minute. Their product is the **minute ventilation**:

$$\text{minute ventilation} = \text{tidal volume} \times \text{breathing rate}.$$

During exercise both rise, so more oxygen is delivered and more carbon dioxide is removed.

Worked example: minute ventilation

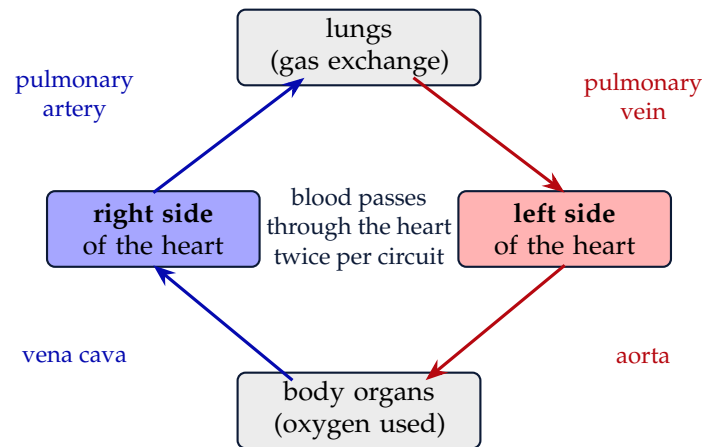
At rest a person breathes 12 times per minute with a tidal volume of 500 mL. During exercise the rate is 30 per minute and the tidal volume is 2000 mL. Find the minute ventilation in each case and the factor of increase.
 Rest: $500 \times 12 = 6000 \text{ mL/min} = 6 \text{ L/min}$. Exercise: $2000 \times 30 = 60\,000 \text{ mL/min} = 60 \text{ L/min}$. The factor is $60 \div 6 = 10$.

Common mistakes

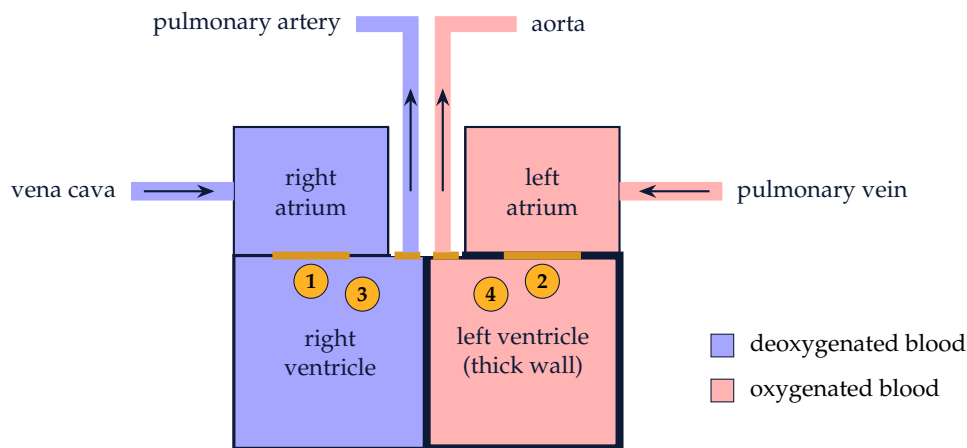
- Saying the lungs “expand because the lung muscles contract”. The lungs are passive; the chest volume changes, and the lungs follow.
- Getting the pressure backwards: inhaling needs the pressure *inside* to be *lower* than outside.
- Saying the alveolus is “one cell thick” but forgetting the capillary wall is also one cell thick (both keep the distance short).
- Saying oxygen is *pumped* into blood. It diffuses.

4 The circulatory system: the heart

The **circulatory system** carries oxygen, glucose, hormones, heat and waste around the body. It is a **double circulation**: blood passes through the heart *twice* on each complete circuit of the body. One loop takes blood to the lungs, to pick up oxygen; the other takes blood from the heart to the rest of the body. Why two loops? Blood leaving the lungs is at low pressure (it has passed through narrow capillaries); returning it to the heart lets the heart boost the pressure again before sending it around the body, which has far more resistance.



The heart is a muscular pump with four chambers. The two upper chambers, the **atria**, receive blood; the two lower chambers, the **ventricles**, pump it out. The right and left sides are separated by a wall (the septum), so oxygenated and deoxygenated blood do not mix.



1 tricuspid valve 2 bicuspid (mitral) valve 3 pulmonary (semilunar) valve 4 aortic (semilunar) valve

Follow the blood (note: the heart is drawn as seen from the front, so its right side is on the left of the page):

1. **Vena cava** brings deoxygenated blood from the body into the **right atrium**.
2. The atrium contracts; blood passes through the **tricuspid valve** into the **right ventricle**.
3. The ventricle contracts; the tricuspid valve shuts, and blood leaves through the **pulmonary (semilunar) valve** into the **pulmonary artery**, to the lungs.
4. In the lungs the blood is oxygenated. The **pulmonary vein** brings it into the **left atrium**.
5. Through the **bicuspid (mitral) valve** to the **left ventricle**, which contracts strongly and pumps blood through the **aortic valve** into the **aorta** and round the body.

Valves allow blood to flow in only one direction: they open when pressure behind them is higher than in front and close when it is lower, so blood cannot flow backwards. The **left ventricle** has a much thicker muscular wall than the right, because it must pump blood at higher pressure all the way round the body, while the right ventricle sends it only to the nearby lungs. The heart muscle itself needs its own blood supply, delivered by the **coronary arteries**; blockage of one causes a heart attack.

Cardiac output. The volume of blood pumped out by one ventricle in one beat is the **stroke volume**. Multiplying by the number of beats per minute gives the **cardiac output**, the volume pumped per minute:

$$\text{cardiac output} = \text{heart rate} \times \text{stroke volume}.$$

Worked example: cardiac output at rest and in exercise

At rest a heart beats 60 times per minute with a stroke volume of 80 mL. In exercise it beats 150 times per minute with a stroke volume of 120 mL. Find the cardiac output in each case and the factor of increase.

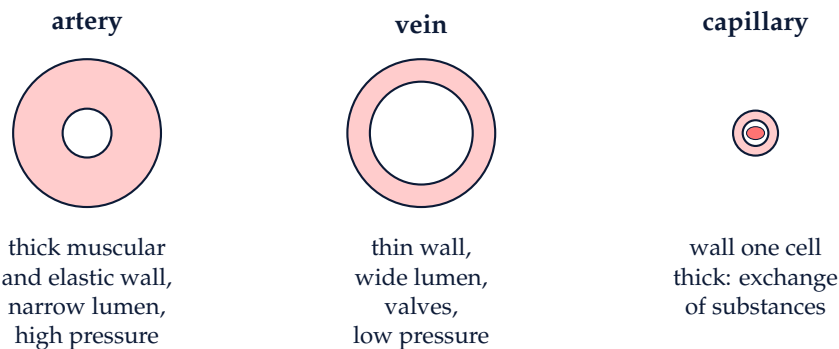
Rest: $60 \times 80 = 4800 \text{ mL/min} = 4.8 \text{ L/min}$. Exercise: $150 \times 120 = 18000 \text{ mL/min} = 18 \text{ L/min}$. Factor: $18000 \div 4800 = 3.75$. Heart rate rose 2.5 times and stroke volume 1.5 times, and $2.5 \times 1.5 = 3.75$.

Common mistakes

- Labelling the left and right sides of the heart as you see them. The *patient's* right is on your left.
- Saying the pulmonary vein carries deoxygenated blood. The pulmonary *artery* (away from the heart, to the lungs) carries deoxygenated blood; the pulmonary vein carries oxygenated blood. Arteries carry blood *away* from the heart; veins carry it *to* the heart.
- Saying the left ventricle is thicker “because it pumps harder to the lungs”. It pumps to the whole body.
- Believing oxygenated and deoxygenated blood mix in the heart. The septum separates them.

5 Blood vessels, blood and the ECG

Blood vessels. There are three types, each matched to its job.

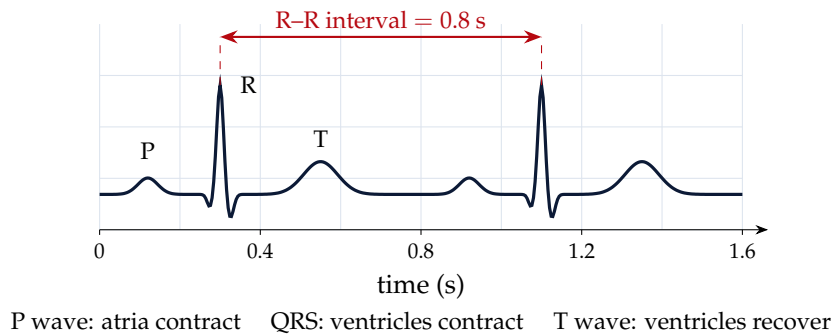


- **Arteries** carry blood *away from* the heart at high pressure. They have thick, muscular and elastic walls that can stretch and recoil as the pulse of blood passes, and a narrow lumen.
- **Veins** carry blood *to* the heart at low pressure. They have thinner walls, a wide lumen (less resistance to flow) and **valves** that stop backflow. Movement of the surrounding muscles squeezes blood along them.
- **Capillaries** are the tiny vessels that run between cells. Their walls are one cell thick, so substances (oxygen, glucose, carbon dioxide, urea) can diffuse quickly between blood and tissue. Their large total surface area also helps.

Blood is a tissue with four components:

- **Plasma:** a pale yellow liquid, mostly water, that carries dissolved substances: glucose, amino acids, carbon dioxide (as hydrogencarbonate), urea, hormones and heat.
- **Red blood cells** carry oxygen. They contain the red pigment **haemoglobin**, which binds oxygen in the lungs (forming oxyhaemoglobin) and releases it in the tissues. Their biconcave disc shape gives a large surface area and they have no nucleus, leaving more room for haemoglobin.
- **White blood cells** defend against disease (some engulf pathogens, some make antibodies); you will meet them in the next lesson.
- **Platelets** are cell fragments that help blood to clot at a wound, preventing blood loss and entry of microbes.

The ECG. An **electrocardiogram** (ECG) records the tiny electrical signals the heart produces each time it beats. Each beat gives a characteristic pattern: the **P wave** (the atria contract), the sharp **QRS complex** (the ventricles contract; its peak is the R wave) and the **T wave** (the ventricles recover).



The ECG is used to check the heart's rhythm and to detect problems (a too-fast, slow or irregular rhythm). To find the **heart rate** from an ECG, measure the time between two successive R peaks (the R-R interval, one beat). Then

$$\text{heart rate (beats per minute)} = \frac{60}{\text{R-R interval in seconds}}.$$

Worked example: heart rate from an ECG

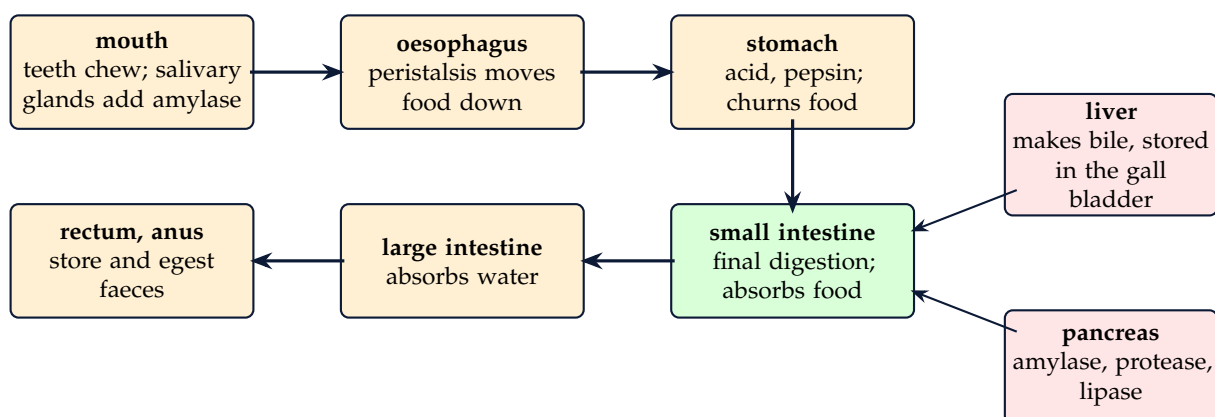
In the trace above the time between R peaks is 0.8 s. A second ECG has 5 beats in 3 s of trace. Find both heart rates. First: $60 \div 0.8 = 75$ beats per minute. Second: 5 beats in 3 s is $5/3$ beats per second, so $\frac{5}{3} \times 60 = 100$ beats per minute (equivalently the R-R interval is $3 \div 5 = 0.6$ s and $60 \div 0.6 = 100$).

Common mistakes

- Using the time between P and R rather than between two successive R peaks.
- Using interval $\times 60$ instead of $60 \div \text{interval}$.
- Saying red blood cells have a nucleus, or that they carry carbon dioxide mainly: most carbon dioxide travels dissolved in plasma.
- Saying veins have thick walls because they carry blood to the heart. They have thin walls because the pressure in them is low.

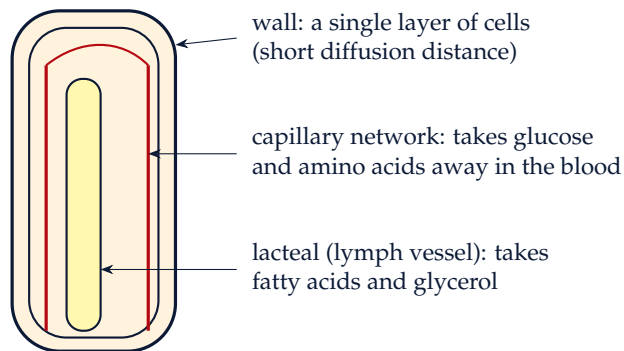
6 The digestive system

The **digestive system** is a long muscular tube, the gut, together with organs that make digestive juices. Its job is to break food down (*digestion*, as seen in the Enzymes lesson) and absorb the small soluble products into the blood. Food that is not digested or absorbed leaves the body as faeces (*egestion*).



The path of food. In the *mouth*, teeth cut and grind food (mechanical digestion), and saliva from the salivary glands contains amylase. The food is swallowed and pushed down the *oesophagus* by waves of muscle contraction called **peristalsis**. In the *stomach*, muscular walls churn the food; glands secrete hydrochloric acid, which kills most microbes and gives the right pH (about 2) for the protease **pepsin**. The *small intestine* receives bile from the liver (via the gall bladder) and juices containing amylase, protease and lipase from the pancreas, so most chemical digestion occurs here and in its lining. It is also where nearly all the digested food is absorbed. The *large intestine* absorbs the remaining water, leaving faeces, which are stored in the *rectum* and egested through the anus.

Absorption in the small intestine. Its inner wall is covered in millions of tiny finger-like projections called **villi**. Each villus is an exchange surface designed like the alveolus:



one villus (millions line the small intestine)

- villi greatly increase the surface area for absorption;
- the wall is a *single layer of cells*, so the diffusion distance is short;
- a dense network of *capillaries* carries away glucose and amino acids, keeping the concentration gradient steep;
- a *lacteal* (a lymph vessel) in the middle of each villus carries away fatty acids and glycerol.

Some glucose is absorbed by diffusion, and some by *active transport*, which uses energy (from respiration) to absorb glucose against a concentration gradient, especially when the concentration in the gut has become low. The blood then carries the absorbed glucose and amino acids to the liver, which regulates their level and stores some glucose as glycogen (see the homeostasis lesson).

Worked example: how much does folding increase the surface area?

A segment of intestine is modelled as a smooth tube of length 10 cm with a lining area of 100 cm^2 . The lining is covered with villi that raise the lining's area by a factor of 10. By how much does the area for absorption increase, and what would be the effect on the rate of absorption if everything else stayed the same?

Area increases from 100 to $100 \times 10 = 1000 \text{ cm}^2$, an increase of 900 cm^2 . Since the rate of diffusion is proportional to surface area, the rate of absorption is about 10 times greater.

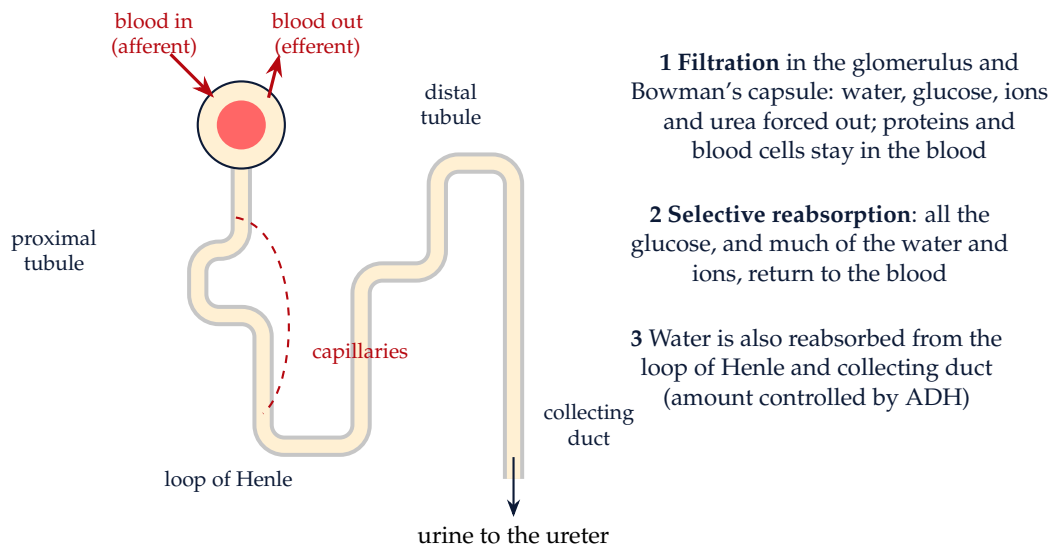
Common mistakes

- Saying digestion happens in the villi, or that food passes through the liver. Digestion happens in the gut cavity; absorption occurs through the villi.
- Saying bile is made in the gall bladder. It is made in the *liver* and stored in the gall bladder.
- Saying peristalsis is churning or chewing. It is a wave of muscle contraction that pushes food along.
- Saying amylase is made only in the salivary glands. The pancreas and small intestine also make it.

7 The excretory system: the kidney and the nephron

Excretion is the removal of the waste products of the body's chemical reactions. The main excretory waste products are carbon dioxide (from respiration, removed by the lungs) and **urea** (removed by the kidneys). Urea is formed in the **liver** when excess amino acids are broken down, because amino acids cannot be stored. It is then carried in the blood to the kidneys.

The two **kidneys** filter the blood. Blood arrives in the *renal artery* and leaves in the *renal vein*; the fluid made is **urine**, which flows down the *ureters* to the *bladder* and leaves through the *urethra*. Each kidney contains about a million microscopic filtering units called **nephrons**.



What the nephron does.

- 1. Filtration.** Blood is forced at high pressure from a knot of capillaries, the *glomerulus*, into the cup-shaped *Bowman's capsule*. Small molecules (water, glucose, urea, ions) pass through the thin walls and form the *glomerular filtrate*. Large molecules (proteins) and cells (red blood cells) are too large and stay in the blood. This is *filtration by size* and not selection by usefulness: the filtrate contains useful substances as well as waste.
- 2. Selective reabsorption.** As the filtrate passes along the *proximal tubule*, the body takes back what it needs: *all* the glucose (by active transport, using energy), and much of the water and ions, which return to the blood in the surrounding capillaries.
- 3. Water balance.** Further water is reabsorbed in the loop of Henle and the collecting duct. How much is controlled by the hormone ADH (next lesson).
- 4. Urine.** What remains (water, urea and excess ions) flows through the collecting duct to the ureter.

The nephron thus makes urine that is much more concentrated in urea than blood plasma, with no glucose and no protein in a healthy person. Finding glucose in the urine suggests that blood glucose is too high for the kidney to reabsorb it all (as in untreated diabetes); finding protein or blood suggests that the filter is damaged.

Worked example: how much of the filtrate is reabsorbed?

The kidneys of an adult filter about 180 L of fluid from the blood each day, and the person produces 1.8 L of urine. What percentage of the filtrate volume is reabsorbed?

Reabsorbed volume = $180 - 1.8 = 178.2$ L. Percentage = $\frac{178.2}{180} \times 100 = 99\%$. Equivalently, urine is $1.8 \div 180 = 1\%$ of the filtrate.

Worked example: reading a concentration table

Concentrations in g per 100 mL: protein is 7 in plasma, 0 in filtrate and 0 in urine; glucose is 0.1 in plasma, 0.1 in filtrate and 0 in urine; urea is 0.03 in plasma, 0.03 in filtrate and 1.8 in urine. Interpret.

Protein: present in plasma but not the filtrate, so it is too large to be filtered. Glucose: same as plasma in the filtrate (small, freely filtered) but zero in urine, so all reabsorbed. Urea: filtered, and urine is $1.8 \div 0.03 = 60$ times as concentrated as plasma, so water has been reabsorbed and most of the urea has stayed in the tubule.

Common mistakes

- Saying the filtration is selective. Filtration is by *size*; selective reabsorption comes later in the tubule.
- Saying urea is made in the kidney. It is made in the liver and filtered by the kidney.
- Saying glucose is found in the urine of a healthy person. All the glucose is reabsorbed.
- Confusing the ureter (kidney to bladder) with the urethra (bladder to outside).

8 Putting it together

A routine for organ-system questions. (1) Name the problem the system solves (for example: get oxygen in, carry it round, remove urea). (2) Identify the exchange surface or key structure and explain how its shape gives a large surface area, a short distance, and a steep gradient. (3) Trace the pathway in order, noting what is in each vessel or chamber (oxygenated or not). (4) If calculating, write the formula first (minute ventilation = tidal volume $\times$ rate, cardiac output = HR $\times$ SV, HR = 60 $\div$ R-R) and check units.

Connections. The systems work together. Digestion supplies glucose; the lungs supply oxygen; the blood delivers both to cells, where respiration releases energy; carbon dioxide goes back by the blood to the lungs, and the urea goes to the kidneys. When you exercise, muscle respiration speeds up, so the nervous system raises heart and breathing rates to meet the demand.

Features that recur. Alveoli, villi, capillaries and nephrons all have a thin wall, a large surface area and a good blood supply. If a question asks why a structure is “adapted”, go through large area, short distance, steep gradient, and say how this one achieves it.

Worked example: emphysema and diffusion

In emphysema the walls between alveoli break down, so the total alveolar surface area is halved, and scar tissue doubles the thickness of the barrier between air and blood. Other factors are unchanged. By what factor does the rate of oxygen diffusion change?

Rate $\propto \frac{\text{area} \times \text{gradient}}{\text{distance}}$. Area is $\times \frac{1}{2}$ and distance is $\times 2$, so the rate is multiplied by $\frac{1}{2} \div 2 = \frac{1}{4}$. Oxygen diffuses at a quarter of the original rate, which is why sufferers are short of breath.

Exam tip

“Explain how the structure is adapted to its function” is nearly always a diffusion question: area, distance, gradient. Use all three words.

Common mistakes

- Giving only the structure (“it has lots of villi”) without saying what that does (“so there is a large surface area for absorption”).
- Mixing up the two sides of the heart and the two types of circulation.
- Forgetting units: litres versus millilitres in volume-per-minute calculations.

Check yourself

Try these without looking back, then compare with the answers on the next page.

1. List, in order, the structures of a reflex arc.
2. Explain how the diaphragm and ribs cause air to enter the lungs.
3. Give three adaptations of alveoli for gas exchange.
4. Trace a red blood cell from the vena cava until it enters the aorta.
5. A heart beats 72 times a minute with a stroke volume of 75 mL. Find the cardiac output.
6. Why does a vein need valves and an artery not?
7. Where is bile made and stored, and what does it do?
8. Why is there no glucose in the urine of a healthy person?

Answers to the self-check

1. Receptor, sensory neurone, relay neurone (in the CNS), motor neurone, effector.
2. The diaphragm contracts and flattens and the intercostal muscles raise the ribs. This increases the chest volume and decreases the pressure below atmospheric, so air flows in.
3. Very large surface area (many alveoli); walls one cell thick, with thin capillary walls; rich blood supply; ventilation keeps the gradient steep.
4. Vena cava, right atrium, tricuspid valve, right ventricle, pulmonary artery, lungs, pulmonary vein, left atrium, bicuspid valve, left ventricle, aorta.
5. $72 \times 75 = 5400 \text{ mL/min}$, i.e. 5.4 L/min .
6. Blood in veins is at low pressure and could flow backwards; valves prevent it. Blood in arteries is at high pressure and flows forwards.
7. Made in the liver, stored in the gall bladder. It neutralises stomach acid and emulsifies fats, increasing their surface area for lipase.
8. Glucose is filtered at the glomerulus but all of it is reabsorbed (by active transport) in the proximal tubule.

Next step

Heurisco's *ESAT Biology: Animal Organ Systems Practice Set* has twenty original exam-style questions on this lesson, with ECG traces, graphs and organ diagrams, in order of difficulty, with a full worked solution, a common-trap note and the specification code for every question.