IGCSE BIOLOGY 0610 · CHAPTER 10 NOTES · ~19 MIN READ

Gas exchange, respiration & excretion

How the lungs work and why the alveoli are perfect for gas exchange, what happens when you breathe, how cells release energy with and without oxygen, and how the kidneys and liver remove waste.

Lungs & alveoli | Breathing | Aerobic & anaerobic respiration | Kidneys | Liver

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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

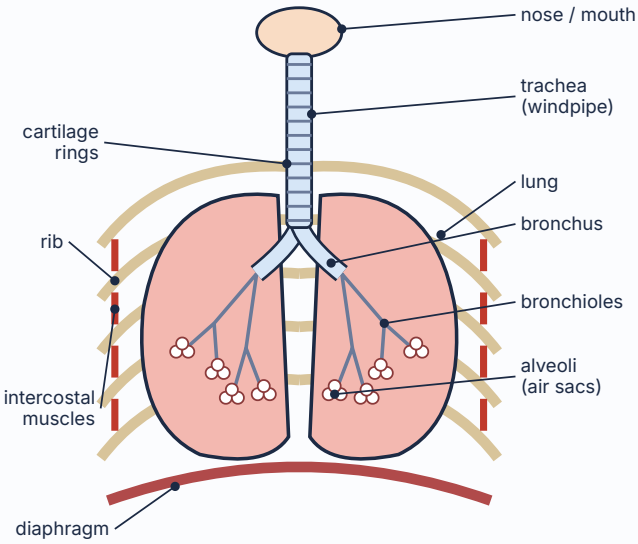
- **Gas exchange** happens in the **alveoli**. Oxygen **diffuses into** the blood and carbon dioxide **diffuses out**. The surface is **large, thin, moist, well supplied with blood and ventilated**.
- **Respiration** is the chemical reaction in **every living cell** that **releases energy from glucose**. **Aerobic** uses oxygen (**lots** of energy). **Anaerobic** does not (**little** energy): **lactic acid** in muscle, **ethanol + CO_2** in yeast.
- **Excretion** removes **waste made by the body's chemistry**. The **lungs** remove CO_2; the **kidneys** remove **urea, excess water and ions**; the **liver** makes the urea. EXT

BY THE END YOU CAN

- Name the parts of the breathing system and describe how the alveoli are adapted for gas exchange.
- Compare inspired and expired air and describe the limewater test for carbon dioxide.
- Describe how exercise changes breathing rate and depth, and why.
- State the uses of energy in living organisms.
- Define aerobic and anaerobic respiration and write the word equations.
- Describe an investigation into the effect of temperature on respiration in yeast.
- Identify the kidneys, ureters, bladder and urethra, and say what each does.
- Explain how ribs, intercostal muscles and the diaphragm ventilate the lungs. EXT
- Explain the roles of cartilage, goblet cells, mucus and cilia in the airways. EXT
- Write balanced equations and explain lactic acid and oxygen debt. EXT
- Describe the kidney, nephron (filtration and reabsorption) and the liver's role in making urea. EXT

1 Gas exchange in humans

The breathing system



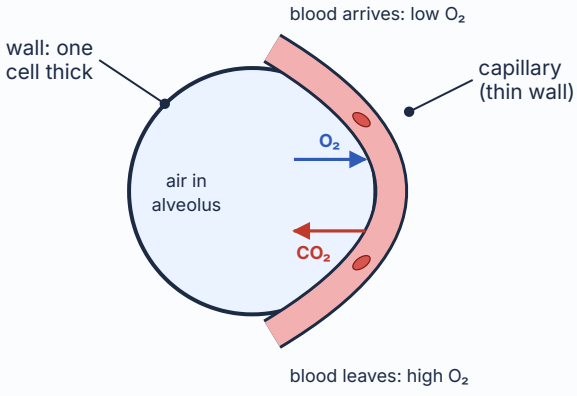
Air travels nose or mouth → trachea → bronchi → bronchioles → alveoli.

- **Path of air: nose or mouth → trachea (windpipe) → two bronchi → many bronchioles → alveoli**.
- The **ribs, intercostal muscles and diaphragm** make the air move in and out (see ventilation below).
- EXT The **trachea** has **C-shaped rings of cartilage** that **keep it open** when you breathe in, but the gap at the back lets food pass down the oesophagus.

MEMORY TRICK

Trachea → **B**ronchi → **B**ronchioles → **A**lveoli = **"The Big Bad Air"** (T-B-B-A).

The gas exchange surface



Big area	Thin wall	Moist lining	Blood supply	Ventilation
millions of tiny alveoli = huge area	one cell thick: short diffusion distance	gases dissolve in the water film first	blood keeps the gradient steep	breathing brings fresh air and removes CO_2

Each alveolus is wrapped in capillaries. Oxygen and CO_2 swap places by diffusion.

- There are **millions of alveoli** in the lungs. Together they give a **huge surface area** of about **70 m²**, roughly 40 times the area of your skin.
- **Oxygen** is at a **higher concentration** in the alveolus than in the blood, so it **diffuses into the blood** (and is picked up by red blood cells). **Carbon dioxide** is **higher in the blood**, so it **diffuses out** into the alveolus and is breathed out (diffusion).
- **Why it works well:** a **large surface area**, a **thin wall** (one cell thick), a **moist lining**, a **good blood supply** and **ventilation**. Blood and breathing keep the **concentration gradient steep**.

EXAM TIP

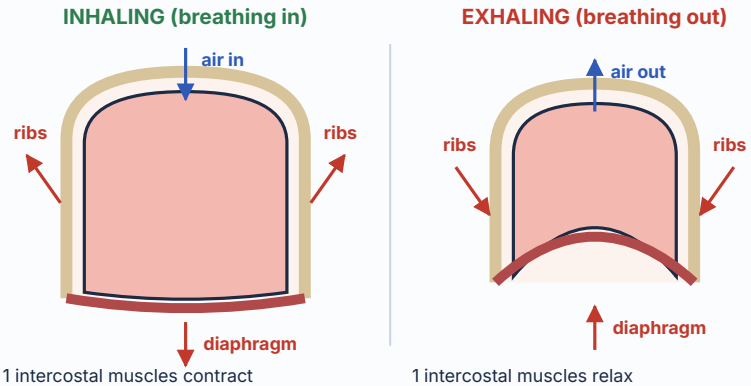
In an exam always link **a feature + what it does**: "**thin** wall, so the **diffusion distance is short**", "**good blood supply**, so oxygen is carried away and the gradient stays **steep**".

COMMON MISTAKE

"Oxygen goes in and CO_2 comes out **because** the lungs breathe." **No.** The gases move by **diffusion** along concentration gradients. Breathing keeps the gradients steep.

Ventilation: how breathing works

EXTENDED



1 intercostal muscles contract
2 ribs move up and out
3 diaphragm contracts and flattens
4 chest volume increases
5 pressure falls: air rushes in

1 intercostal muscles relax
2 ribs move down and in
3 diaphragm relaxes and domes up
4 chest volume decreases
5 pressure rises: air pushed out

Air always moves from HIGH pressure to LOW pressure.

EXT Muscles change the volume of the chest. Pressure changes make air flow.

- EXT **Breathing in:** the **external intercostal muscles contract** (ribs up and out) and the **diaphragm contracts** and **flattens**. **Chest volume increases**, **pressure falls** below atmospheric pressure, so **air rushes in**.
- EXT **Breathing out:** the **intercostal muscles relax** (ribs down and in) and the **diaphragm relaxes** and **domes up**. **Volume decreases**, **pressure rises**, so **air is pushed out**.

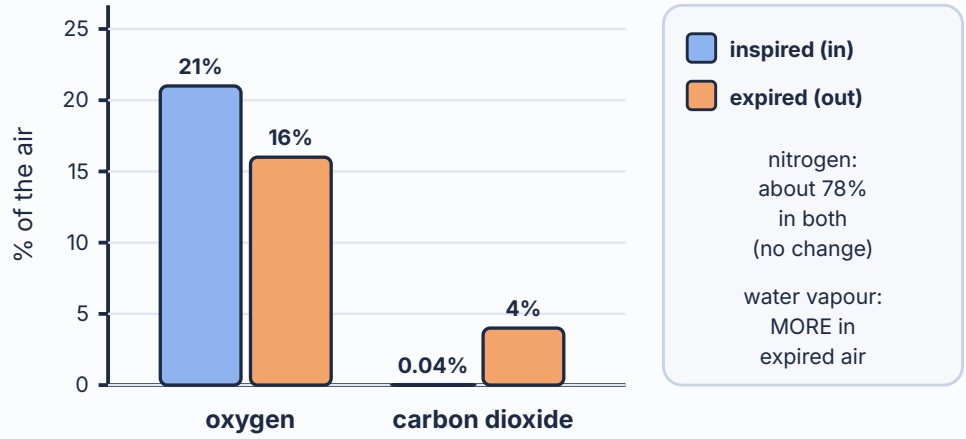
MEMORY TRICK

Volume UP → pressure DOWN → air IN. Volume DOWN → pressure UP → air OUT.

COMMON MISTAKE

"The lungs suck the air in." **The lungs have no muscles.** They are **pushed open** by the change in air pressure caused by the muscles around them.

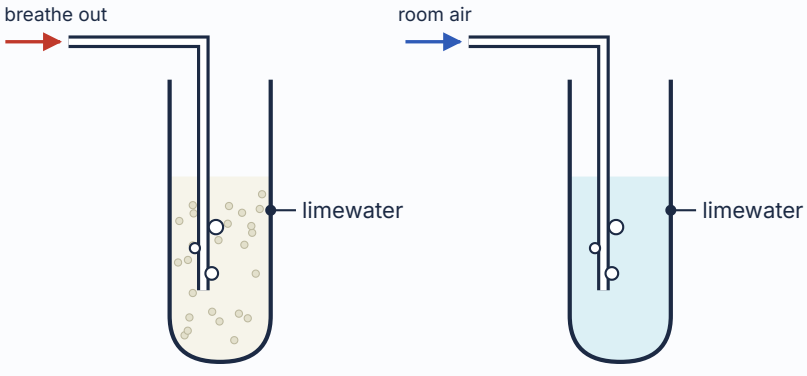
Inspired and expired air



Cells use oxygen and make CO_2, so expired air has less O_2 and more CO_2.

Gas	Inspired (in)	Expired (out)
oxygen	about **21%**	about **16%**
carbon dioxide	about **0.04%**	about **4%**
nitrogen	about **78%**	about **78%** (no change)
water vapour	**variable** (usually less)	**more** (lungs are moist)

- **Why oxygen falls:** cells use it for **respiration**. **Why CO_2 rises:** cells **make** it in respiration. **Why water vapour rises:** water evaporates from the **moist lining** of the lungs.



CO_2 turns limewater milky. Expired air has about 100× more CO_2 than inspired air.

The limewater test for carbon dioxide.

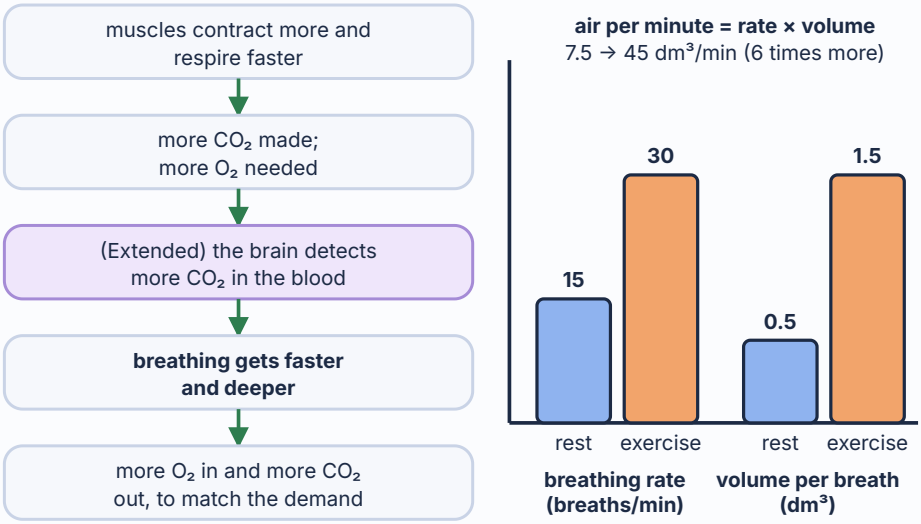
- **Limewater test:** bubble the gas through **limewater**. It turns **milky** if CO_2 is present. Air breathed **out** turns it milky **quickly**; air breathed **in** takes **much longer**.

WORKED EXAMPLE

Inspired air has 21% oxygen and expired air has 16%. Inspired CO_2 is 0.04% and expired is 4%. Find the percentage of the oxygen removed and how many times CO_2 increases.

1. oxygen removed = 21 − 16 = **5** percentage points
2. percentage of the oxygen = 5 ÷ 21 × 100 = **23.8%** (about 24%)
3. **CO_2 increase = 4 ÷ 0.04 = 100 times greater**

Exercise and breathing



During exercise you breathe faster (rate) and deeper (volume per breath).

- **During exercise** both **breathing rate** and **depth** increase. The muscles respire **faster**, so they need **more oxygen** and make **more CO_2** that must be removed.
- EXT **Control:** the **brain detects the rise in CO_2 in the blood** and sends signals that make the **intercostal muscles and diaphragm** work harder.
- **To investigate:** count the breaths in **one minute** at rest, then **after 2 minutes of exercise** (for example step-ups), and again as you **recover**. Change **one factor** only.

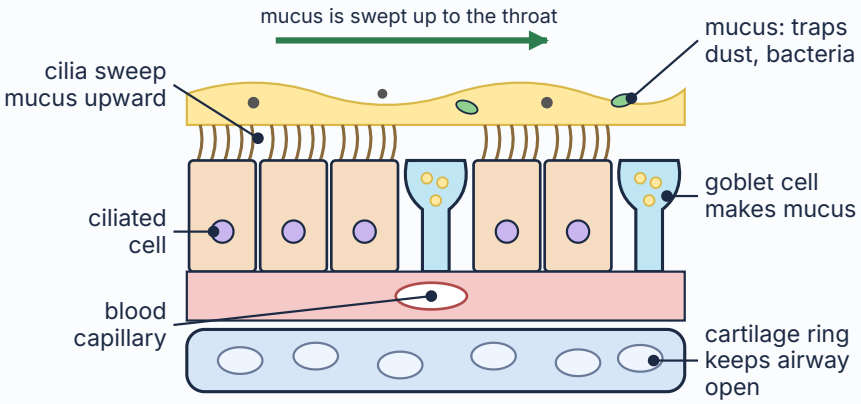
WORKED EXAMPLE

At rest a person takes 15 breaths per minute, 0.5 dm³ each. During exercise: 30 breaths per minute, 1.5 dm³ each. Find the volume of air per minute each time and the percentage increase.

1. volume per minute = rate × volume per breath
2. rest: 15 × 0.5 = **7.5 dm³/min**
3. exercise: 30 × 1.5 = **45 dm³/min**
4. **increase = (45 − 7.5) ÷ 7.5 × 100 = 500% (six times as much)**

Keeping the airways clean

EXTENDED



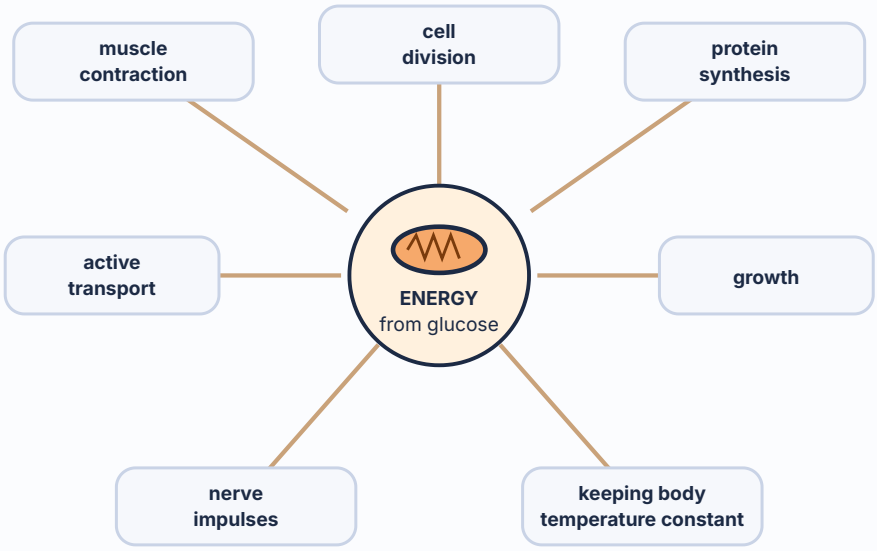
Smoking damages cilia, so mucus and microbes stay in the lungs.

EXT Mucus catches dust and microbes; cilia sweep the mucus up to the throat.

- EXT **Goblet cells** in the lining make **mucus**, which **traps dust and bacteria**.
- EXT **Ciliated cells** have **cilia** that **beat** and **move the mucus upwards** to the throat, where it is swallowed. This is part of the body's **first line of defence** (body defences).
- EXT **Cigarette smoke** damages cilia, so **mucus and microbes stay in the lungs**, causing coughing and infections.

2 Respiration

Why do living things need energy?



Energy released by respiration is used by every cell.

Respiration — the **chemical reactions in all living cells** that **release energy from glucose**.

- **Uses of energy: muscle contraction**, **protein synthesis**, **cell division**, **active transport**, **growth**, **passage of nerve impulses** and **maintaining a constant body temperature** (in mammals and birds).
- Most of the reactions happen in **mitochondria**. Some of the energy is released as **heat**.

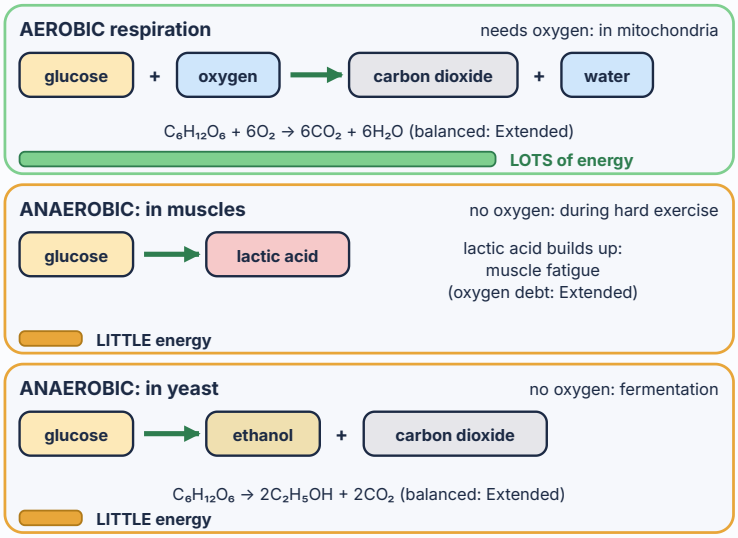
COMMON MISTAKE

"Respiration is breathing." **No. Breathing (ventilation)** moves air in and out. **Respiration** is the chemical reaction in **cells** that releases energy. All living things respire, even plants.

COMMON MISTAKE

"Respiration **makes** energy." Energy cannot be made. It is **released** from the chemical energy stored in glucose.

Aerobic and anaerobic respiration



Three equations to learn. Anaerobic respiration releases far less energy.

Aerobic respiration — the **chemical reactions** in cells that use **oxygen** to **break down nutrient molecules (glucose)** to **release a relatively large amount of energy**.

Anaerobic respiration — the **chemical reactions** in cells that **break down nutrient molecules to release a relatively small amount of energy**, **without oxygen**.

glucose + oxygen → carbon dioxide + water

aerobic respiration (word equation)

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

EXT balanced equation, aerobic respiration

glucose → lactic acid

anaerobic respiration in muscles

glucose → ethanol + carbon dioxide

anaerobic respiration in yeast (fermentation)

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

EXT balanced equation, yeast

- **Why anaerobic yields less energy:** the glucose is **only partly broken down**; lactic acid and ethanol still hold a lot of chemical energy.
- **Uses of yeast:** the **CO_2** makes bread **rise**; the **ethanol** is the alcohol in brewing.

	Aerobic	Anaerobic
oxygen needed?	**yes**	**no**
energy released	**large** amount	**small** amount
products (muscle)	CO_2 + water	**lactic acid**
products (yeast)	CO_2 + water	**ethanol + CO_2**
where	mitochondria (mostly)	cytoplasm

MEMORY TRICK

Anaerobic = "**without air**". **An-aerobic**: the "an" means **not**.

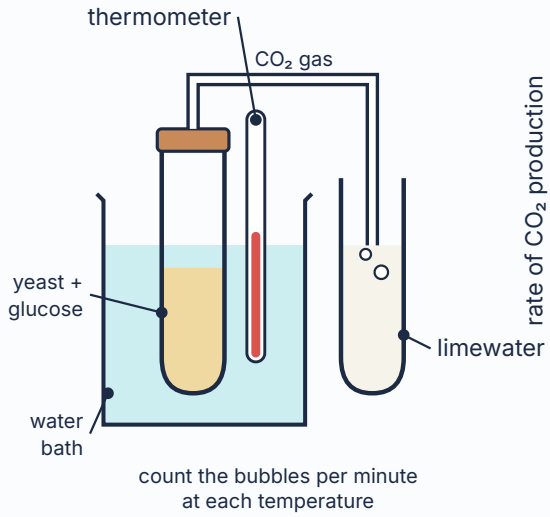
Respiration and photosynthesis

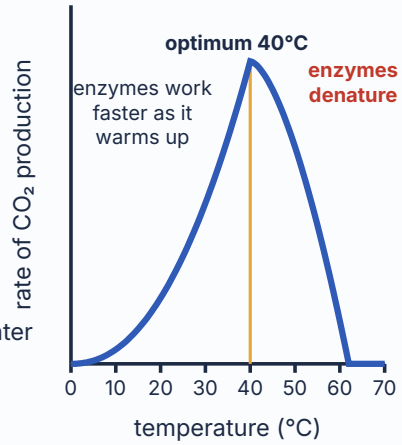
Feature	Respiration	Photosynthesis
energy	**releases** energy	**stores** energy (from light)
uses	glucose + oxygen	CO_2 + water
makes	CO_2 + water	glucose + oxygen
happens in	**all** living cells, all the time	cells with **chloroplasts**, in the light

- Many exam questions ask you to **compare** them. They are **opposite** reactions. Link: photosynthesis.

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Investigating respiration in yeast





Yeast respiration speeds up with temperature, then falls when enzymes denature.

- **Method:** mix **yeast and glucose solution** in tubes. Put each in a **water bath** at a different temperature (for example 10, 20, 30, 40, 50, 60 °C). Count the **bubbles of CO_2** per minute (or collect the gas).
- **Control variables:** same **mass of yeast**, same **volume and concentration of glucose**, same **time**, same **apparatus**. The **independent variable** is temperature. The **dependent variable** is the **rate of CO_2 production**.
- **Result:** the rate **rises with temperature** up to about **40 °C** (the **optimum**), then **falls sharply** because the **enzymes denature** (enzymes).
- **Reliability:** repeat each temperature **three times** and calculate the **mean**.

WORKED EXAMPLE

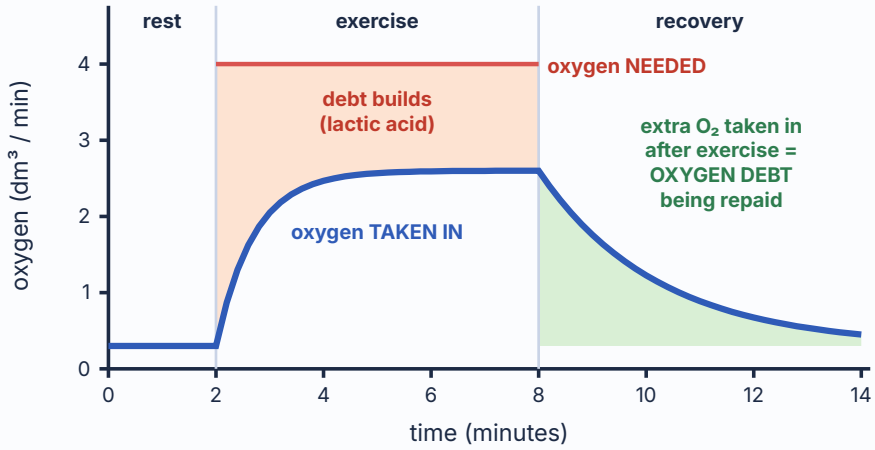
A student counts bubbles per minute. At 40 °C three counts are 38, 41 and 41. At 20 °C the mean is 14 and at 30 °C it is 28. Find the mean at 40 °C and the percentage increase from 20 °C to 30 °C.

1. mean at 40 °C = (38 + 41 + 41) ÷ 3 = 120 ÷ 3 = **40 bubbles/min**
2. increase = 28 − 14 = 14
3. percentage = 14 ÷ 14 × 100 = **100%** (the rate doubled)
4. **enzyme activity rises with temperature until the optimum**

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Oxygen debt

EXTENDED



EXT During hard exercise the muscles run short of oxygen and make lactic acid. Afterwards you pay it back.

- EXT During **vigorous exercise** the muscles need energy faster than the blood can bring **oxygen**, so they also respire **anaerobically** and **lactic acid builds up**. It causes **muscle fatigue**.
- EXT After the exercise you keep **breathing hard** and your **heart beats fast**. The extra oxygen **breaks down the lactic acid** (in the liver and muscles). This is **removing the oxygen debt**.
- EXT **Oxygen debt** = the **extra oxygen** needed after exercise to **remove the lactic acid** made by anaerobic respiration.

EXAM TIP

Fitter people **recover faster** (heart rate recovery): their circulation delivers oxygen better, so they build up a smaller debt.

3 Excretion in humans

What is excretion?

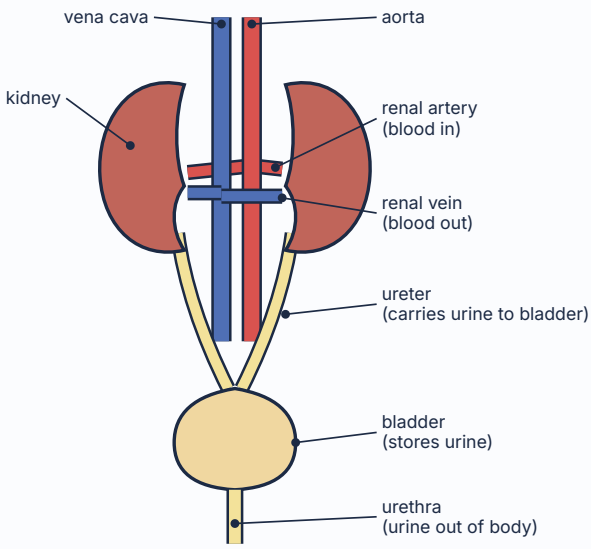
Excretion — the removal from organisms of the **waste products of metabolism** (chemical reactions in cells, including respiration), **toxic materials** and **substances in excess of requirements**.

Waste	Where it is made	Excreted by
carbon dioxide	**respiration** in all cells	the **lungs** (breathed out)
urea	the **liver** (from excess amino acids)	the **kidneys** (in urine)
excess water and mineral ions	taken in with food and drink	the **kidneys** (in urine)

COMMON MISTAKE

"Faeces are excreted." **No.** Faeces are **undigested food** that never entered the cells, so removing them is **egestion**, not excretion.

The urinary system



Urine is made in the kidneys and leaves through the ureters, bladder and urethra.

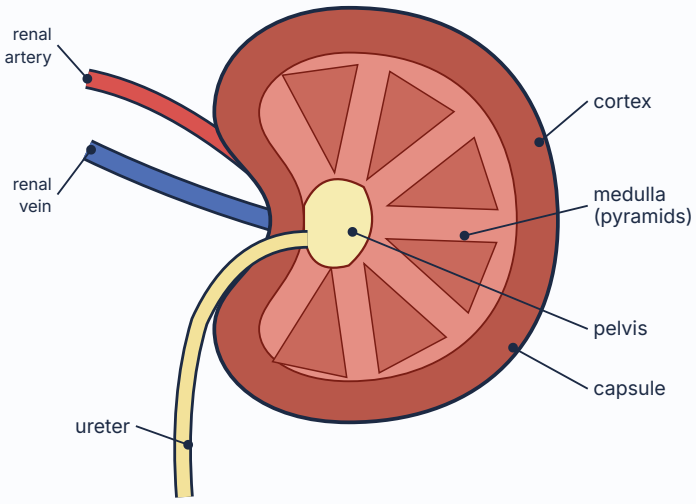
- **Kidneys: filter the blood** and make **urine** (urea, excess water, excess ions).
- **Ureters:** tubes that **carry urine to the bladder**.
- **Bladder: stores** urine until you urinate.
- **Urethra:** tube that **carries urine out** of the body.

MEMORY TRICK

Kidneys **K**eep blood clean → **U**reters **U**rine → **B**ladder **B**ags it → **U**rethra **U**ses the exit.

Inside the kidney

EXTENDED

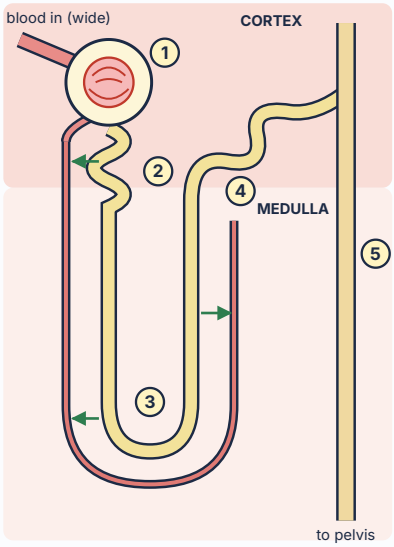


EXT The cortex is the outer layer. The medulla holds the pyramids. Urine collects in the pelvis.

- EXT The outer **cortex** is where the blood is **filtered**. The inner **medulla** (the pyramids) contains the **tubes** that carry the filtrate. **Urine collects in the pelvis** and drains down the ureter.
- EXT Blood arrives in the **renal artery** (with **urea**) and leaves in the **renal vein** (with **much less urea**).

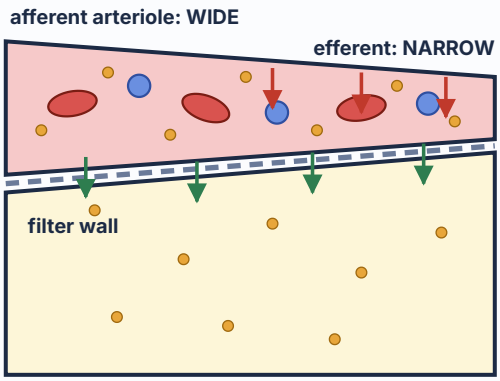
The nephron: filtering and reabsorbing

EXTENDED



1. glomerulus + Bowman's capsule: ULTRAFILTRATION
2. proximal tubule: ALL glucose + amino acids, most water, many ions back
3. loop of Henle: more water and ions reabsorbed
4. distal tubule: final adjustment of water and ions
5. collecting duct: urine flows to the kidney pelvis

EXT Each kidney has about a million nephrons. Follow the numbers.



PASS THROUGH

- water, glucose, amino acids, urea, mineral ions

STAY IN THE BLOOD

- blood cells
- proteins (too big)

HIGH PRESSURE forces small molecules out of the blood (ultrafiltration)

Bowman's capsule: the filtrate collects here

Filtrate = blood plasma without the blood cells and big proteins

EXT Ultrafiltration: high pressure in the glomerulus forces small molecules out through the filter wall.

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- EXT **1 Ultrafiltration:** blood enters the **glomerulus** in a **wide** vessel and leaves in a **narrow** one, so the **pressure is high**. This forces **small molecules** (water, glucose, amino acids, urea, ions) into the **Bowman's capsule**. **Blood cells and large proteins** are too big and stay in the blood.
- EXT **2 Selective reabsorption:** useful substances are taken back into the blood. **All the glucose** and **amino acids** are reabsorbed in the **proximal tubule** (using active transport), along with **most of the water** and **many ions**. More water and ions are reabsorbed in the **loop of Henle**.
- EXT **3 Urine formation:** what is left (**urea, excess water and excess ions**) flows through the **collecting duct** to the **pelvis**. The amount of **water and ions** reabsorbed depends on what the body needs.

Substance (g per 100 cm^3)	Blood plasma	Filtrate	Urine
protein	8.00	**0**	**0**
glucose	0.10	0.10	**0**
urea	0.03	0.03	**2.00**

- EXT **Reading the table: protein is absent from the filtrate** (too big to be filtered). **Glucose is in the filtrate but not in urine** (it was **all reabsorbed**). **Urea is much more concentrated in urine** because **water was reabsorbed** but the urea was not.
- EXT **Glucose in urine** is a sign of **diabetes** (blood glucose control).

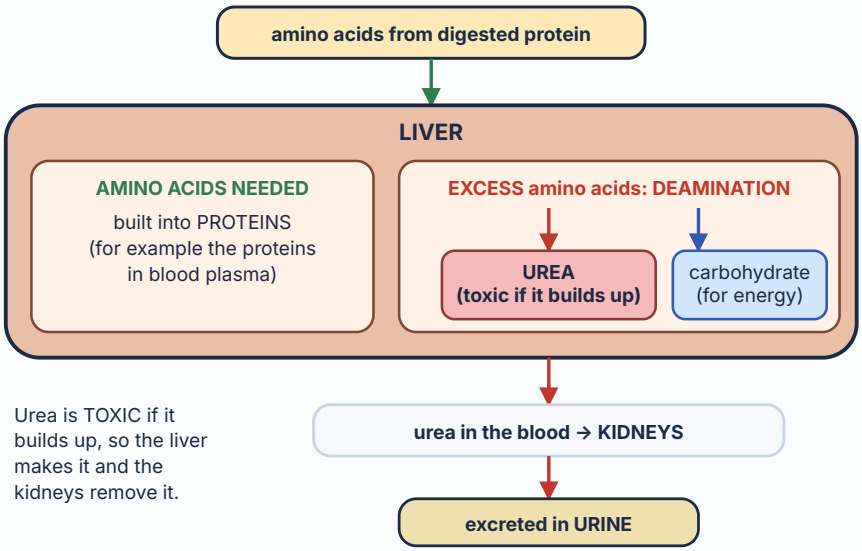
WORKED EXAMPLE

EXT **The kidneys filter about 180 dm^3 of fluid a day but produce about 1.5 dm^3 of urine. The urea is 0.03 g per 100 cm^3 in plasma and 2.00 in urine. Find the percentage of the filtrate reabsorbed and how many times more concentrated urea is in urine.**

1. reabsorbed = 180 − 1.5 = **178.5 dm^3**
2. percentage = 178.5 ÷ 180 × 100 = **99.2%** (about 99%)
3. concentration factor = 2.00 ÷ 0.03 = **66.7 times** (about 67)
4. **water is reabsorbed but urea is not, so urea becomes concentrated**

The liver and urea

EXTENDED



EXT The liver sorts amino acids. Needed ones make proteins. Excess ones are deaminated and the nitrogen leaves as urea.

- EXT **Amino acids** absorbed from the gut go to the **liver**. Some are used to make **proteins** (for example the proteins in blood plasma).
- EXT **The body cannot store excess amino acids.** The liver **removes the amino group** (**deamination**) and turns it into **urea**. The rest of the molecule becomes **carbohydrate**, used for **energy**.
- EXT **Urea is toxic if it builds up.** It travels in the blood to the **kidneys** and leaves in **urine**.

MEMORY TRICK

Liver makes urea; kidneys remove urea.

Aiza Ma'am

4 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Name the tubes that carry air from the throat to the alveoli.
2. Give two features of the gas exchange surface.
3. What happens to carbon dioxide in the alveoli?
4. How do you test a gas for carbon dioxide?
5. Which gas is higher in expired air than in inspired air?
6. Why do you breathe faster during exercise?
7. Give two uses of energy in the body.
8. Write the word equation for aerobic respiration.
9. What is made by anaerobic respiration in muscle?
10. What is made by anaerobic respiration in yeast?
11. Which organ makes urea?
12. What do the kidneys remove from the blood?
13. EXT What do the intercostal muscles do when you breathe in?
14. EXT What is the job of cilia in the trachea?
15. EXT What is deamination?

EXAM-STYLE

16. Describe how the alveoli are adapted for gas exchange. [4]
17. Describe how you could investigate the effect of temperature on respiration in yeast. [4]
18. EXT Explain how the ribs, intercostal muscles and diaphragm cause air to enter the lungs. [4]
19. EXT Explain why muscles produce lactic acid during exercise and what happens afterwards. [4]
20. EXT Explain why glucose is found in the filtrate but not in urine. [3]

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Show answers

1. trachea, bronchi, bronchioles
2. large surface area, thin wall, good blood supply, moist, ventilated
3. it diffuses from the blood into the alveolus and is breathed out
4. bubble it through limewater, which turns milky
5. carbon dioxide
6. muscles respire faster, so more oxygen is needed and more CO_2 must be removed
7. muscle contraction, growth, protein synthesis, cell division, active transport, nerve impulses, keeping warm
8. glucose + oxygen → carbon dioxide + water
9. lactic acid
10. ethanol and carbon dioxide
11. the liver
12. urea, excess water and excess mineral ions
13. contract, pulling the ribs up and out
14. to move mucus (with trapped dust and microbes) up to the throat
15. removal of the amino group from excess amino acids, forming urea
16. large surface area from millions of alveoli
    thin wall, one cell thick, short diffusion distance
    good blood supply keeps concentration gradient steep
    ventilation brings fresh air
17. mix yeast and glucose solution
    put in water baths at different temperatures
    count bubbles of CO_2 per minute
    keep other variables the same and repeat
18. intercostal muscles contract, ribs move up and out
    diaphragm contracts and flattens
    chest volume increases
    pressure falls so air is pushed in from outside
19. oxygen cannot be delivered fast enough
    muscles respire anaerobically
    lactic acid builds up causing fatigue
    after exercise extra oxygen breaks it down (oxygen debt repaid)
20. small molecules pass into the filtrate
    all the glucose is reabsorbed in the proximal tubule
    by active transport back into the blood

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