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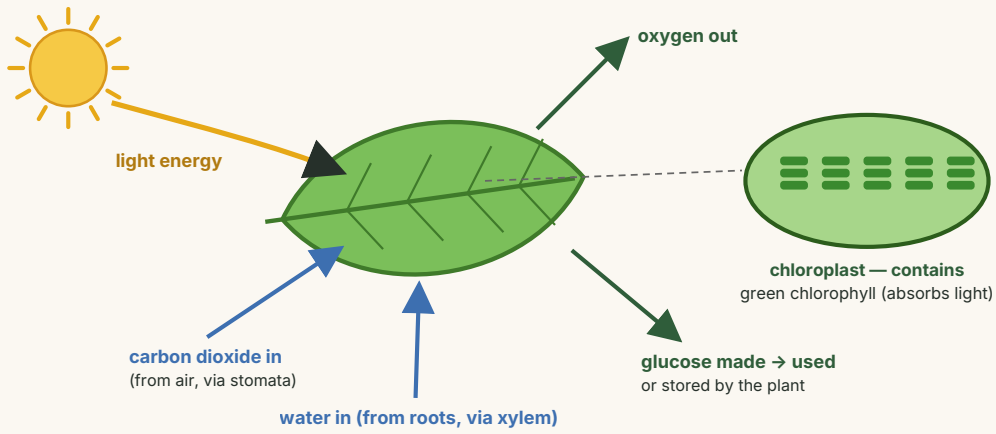
Specialist one-to-one Science, Maths & Economics tuition

AQA GCSE BIOLOGY · SPECIFICATION 4.4

Topic 4: Bioenergetics

Complete revision & exam preparation guide — key points to memorise, clear diagrams, practice questions and full answers

Key-point notes | Memory hooks | Required practical | Maths skills | Exam questions + answers



START HERE

Contents and how to use this guide

4.1 Photosynthesis: the reaction
4.2 How plants use glucose
4.3 Limiting factors
4.4 Graphs with more than one factor (HT)
4.5 Light intensity and photosynthesis (RP)
4.6 The inverse square law (HT)
4.7 Greenhouses and farming
4.8 Respiration and the uses of energy
4.9 Aerobic respiration
4.10 Anaerobic respiration
4.11 Exercise and oxygen debt
4.12 Metabolism
★ One-page memory sheet
✎ Summary questions
✓ Answers and mark scheme

How to use this guide

1. **Read** one section. Study the diagram and say the labels out loud.
2. **Learn the gold "Remember it" box** — short hooks that make facts stick.
3. **Cover and recall:** cover the page, write the key points and **equations** from memory, then check and correct in a different colour.
4. **Read the green "Exam tip" and red "Common mistake" boxes** — they show where marks are won and lost.
5. Finish with the **summary questions** (no notes), then mark them with the **answers**. Re-test the ones you got wrong 2–3 days later.

THE BIG IDEA OF TOPIC 4

Photosynthesis stores energy from light in **glucose** (endothermic). **Respiration** releases that energy from glucose in every living cell (exothermic). The two equations are the **reverse** of each other — learn one and you nearly know the other.

Key boxes in this guide

Box	What it means
Remember it	Memory hook, rhyme or shortcut to memorise
Exam tip	How to write the answer to get the marks
Common mistake	Errors examiners see every year
Maths skill	Calculations and graph skills you must be able to do
RP	AQA Required Practical — can be asked in the written exam
HIGHER TIER	Only examined on the Higher tier paper

Everything in Topic 4 is for both Combined Science (Trilogy) and Separate Biology.

PART A

Photosynthesis

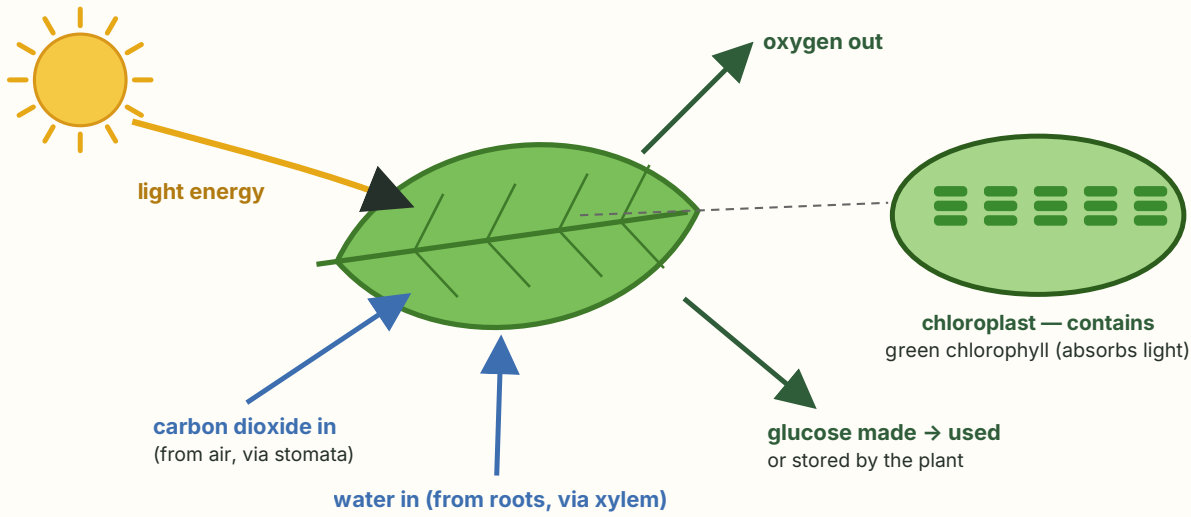
4.1 Photosynthesis: the reaction

AQA 4.4.1.1

- Plants (and algae) make their own food — **glucose** — by **photosynthesis**.
- It happens in **chloroplasts** in green plant cells (mainly the **palisade** cells of leaves).
- Chloroplasts contain **chlorophyll**, a green pigment that **absorbs light**.
- Energy is **transferred from the environment** to the chloroplasts by light.
- So photosynthesis is an **endothermic** reaction — it **takes in** energy.

carbon dioxide + water —light—▶ glucose + oxygen

$6CO_2 + 6H_2O$ —light—▶ $C_6H_{12}O_6 + 6O_2$



Where the raw materials come from and where the products go

Substance	Formula	Where it comes from / goes
Carbon dioxide	CO_2	From the **air**; diffuses in through **stomata**
Water	H_2O	From the **soil**; taken up by **root hair cells** and carried in the **xylem**
Glucose	$C_6H_{12}O_6$	Used or stored by the plant (see 4.2)
Oxygen	O_2	Used in respiration or **released** into the air through stomata

REMEMBER IT

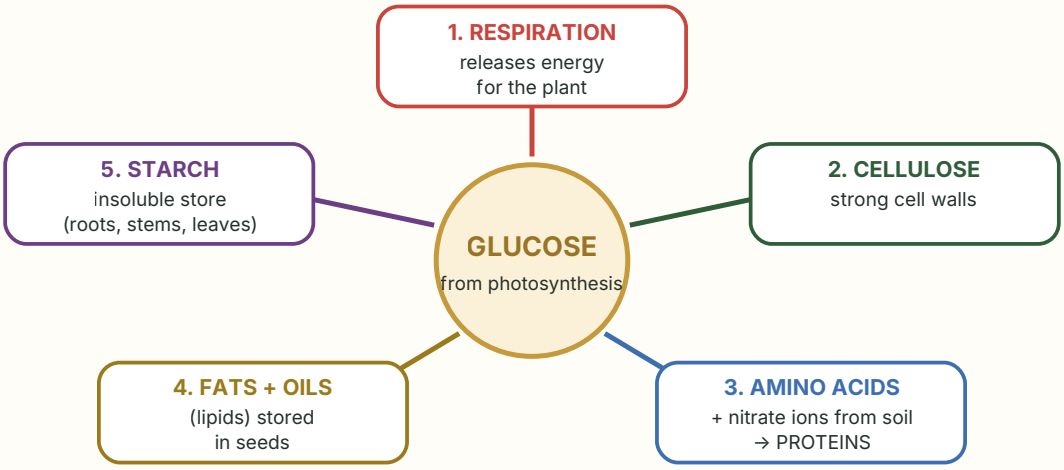
"Six, six, one, six" → **6**CO_2 + **6**H_2O → **1** $C_6H_{12}O_6$ + **6**O_2.
Glucose formula: **C_6 H_{12} O_6** = **"6, 12, 6"**.
Endo = Enter: energy goes **in** (from light).

COMMON MISTAKE

Light is **not** a reactant — write it **above the arrow**. And chlorophyll is **not** used up; it only absorbs the light.

4.2 How plants use glucose

AQA 4.4.1.3



The five main uses of glucose

Use	How and why
1. Respiration	Releases **energy** the plant needs, e.g. to make other substances
2. Making cellulose	Glucose is joined into **cellulose**, which builds strong **cell walls**
3. Making amino acids	Glucose + **nitrate ions** (absorbed from the soil) → **amino acids** → joined into **proteins**
4. Fats and oils	Glucose is turned into **lipids** for storage, especially in **seeds** (e.g. sunflower oil)
5. Starch	Stored in roots, stems and leaves for when photosynthesis isn't happening (e.g. winter, night)

WHY STORE GLUCOSE AS STARCH?

Starch is **insoluble**. So it doesn't affect the water concentration inside cells — it **doesn't draw water in by osmosis** and make them swell. Glucose is soluble, so it would.

REMEMBER IT

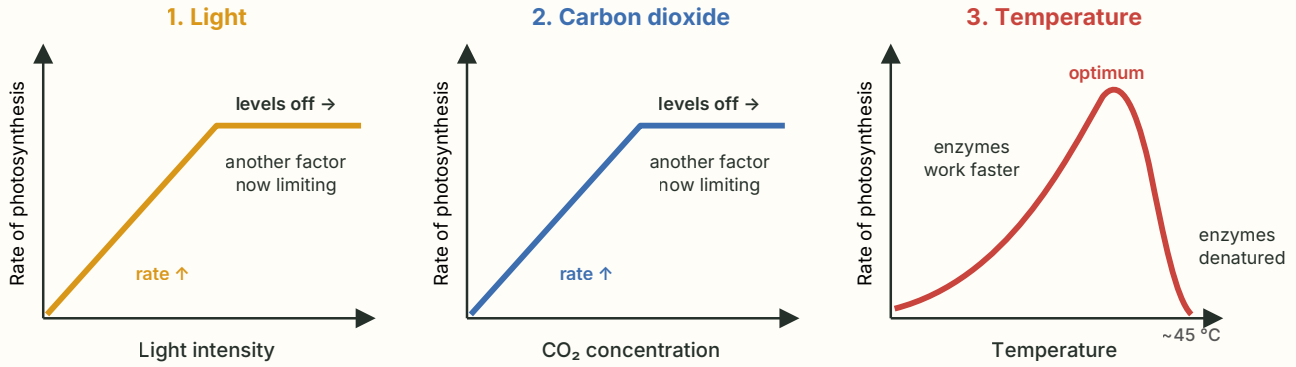
Five uses: **"Really Cool Plants Store Food"** → **R**espiration, **C**ellulose, **P**roteins (amino acids), **S**tarch, **F**ats and oils.
Amino acids need **N**itrate — "proteins need **N**".

4.3 Limiting factors

AQA 4.4.1.2

- The **rate** of photosynthesis is affected by: **light intensity**, **carbon dioxide concentration**, **temperature** and the **amount of chlorophyll**.
- A **limiting factor** is the factor in **shortest supply** that stops the rate going any faster.

- Which factor is limiting depends on the conditions: at **night** it is usually **light**; in **winter** often **temperature**; on a warm, bright day often **CO_2**.



The three limiting factor graphs — learn their shapes

Factor	What the graph shows
Light intensity	More light → more energy → **rate rises steadily**, but only up to a point. Then the line **levels off** because **CO_2 or temperature** is now limiting.
CO_2 concentration	CO_2 is a **raw material**. More CO_2 → faster rate, until the line **flattens**; then **light or temperature** is limiting.
Temperature	Photosynthesis is controlled by **enzymes**. Warmer → faster, up to an **optimum**. Too hot (about **45 °C**) → enzymes are **denatured** → rate drops quickly.
Chlorophyll	Less chlorophyll → less light absorbed. Can be reduced by **disease** (e.g. TMV), lack of **magnesium**, or environmental stress.

REMEMBER IT

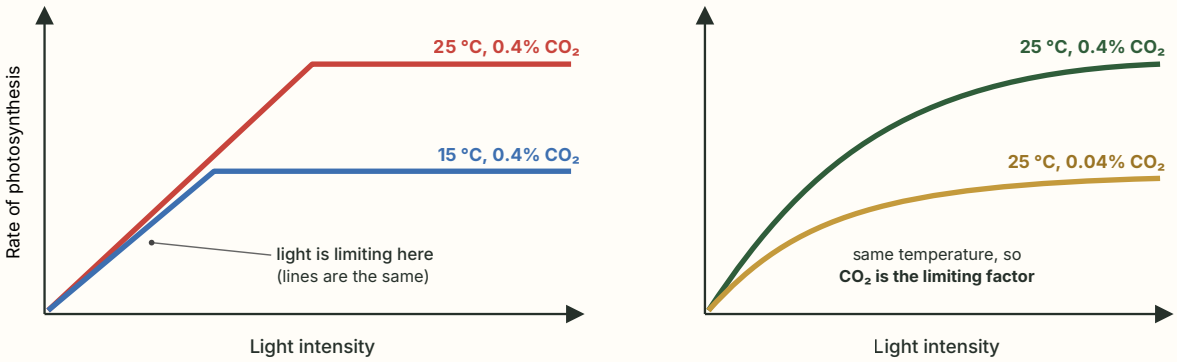
Limiting factors: **"Lazy Cats Take Cover"** → **L**ight, **C**O_2, **T**emperature, **C**hlorophyll.
Graph rule: **rising line** = the x-axis factor IS limiting · **flat line** = something ELSE is limiting.

COMMON MISTAKE

Light and CO_2 graphs **level off** — they do **not** go down. Only the **temperature** graph falls, because the enzymes become **denatured**.

4.4 Graphs with more than one factor HIGHER TIER

AQA 4.4.1.2



Reading graphs with two or three factors

- Where the lines **rise together** (same line), the factor on the **x-axis** (light) is limiting.
- When a line **levels off**, light is no longer limiting.
- If one line levels off **higher**, the factor that is different between the lines was limiting the lower line.
- Left graph: the 25 °C line levels off higher than the 15 °C line, so **temperature** was limiting at 15 °C.
- Right graph: both at 25 °C, but the 0.4% CO_2 line is higher, so **CO_2** was limiting at 0.04%.

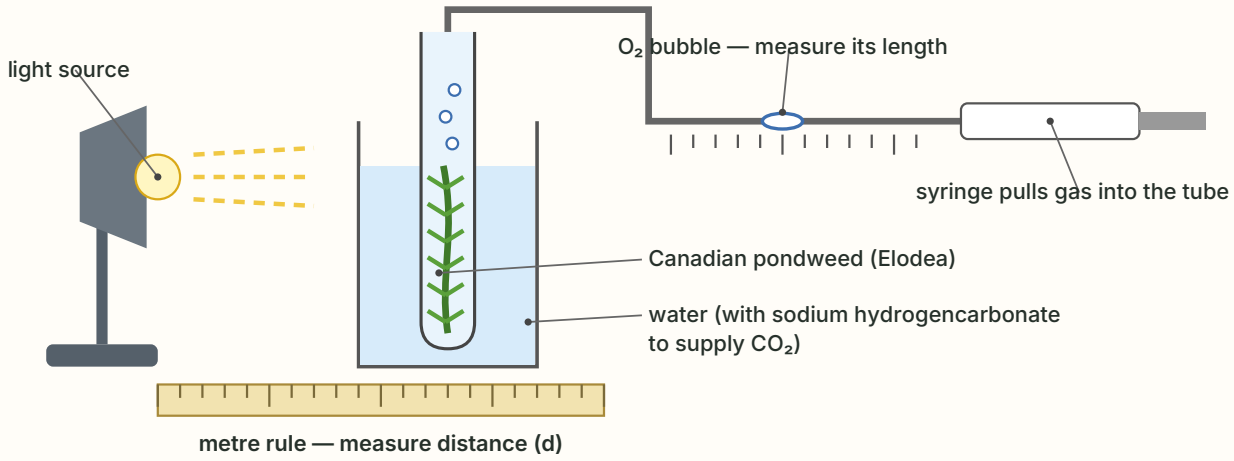
EXAM TIP — 3-STEP METHOD

1. Find where the line goes **flat**. **2.** Look at what is **different** between the lines (read the labels). **3.** That difference is the limiting factor for the **lower** line. Always **quote values** from the graph in your answer.

4.5 Light intensity and photosynthesis REQUIRED PRACTICAL

AQA 4.4.1.2

The rate of photosynthesis can be measured by the rate at which a water plant gives off **oxygen**. More oxygen per minute = faster photosynthesis.



Measuring the oxygen given off by pondweed

1. Put a piece of **Canadian pondweed** in a boiling tube of water containing **sodium hydrogencarbonate** (gives a steady supply of CO_2).
2. Place a lamp a measured distance away, e.g. **10 cm**, using a **metre rule**. Leave for **5 minutes** so the plant adjusts.
3. Count the **oxygen bubbles** given off in 1 minute — or collect the gas in a capillary tube and use a **syringe** to measure the **length of the bubble** (this is proportional to the volume of O_2).

4. Repeat at other distances, e.g. 20, 30, 40, 50 cm. Repeat each distance **3 times** and calculate a **mean**.

Independent	Dependent	Control variables
Light intensity (distance of lamp)	Number of bubbles / volume of O_2 per minute	**Temperature** (water bath, LED lamp or heat shield), **CO_2** concentration, same pondweed, same time

EXAM TIP — IMPROVING THE METHOD

Counting bubbles is less accurate: bubbles can be different sizes and it is easy to miscount. Measuring the **volume** of gas with a gas syringe or capillary tube is **more accurate**. A filament lamp also **heats** the water, so temperature changes — use an **LED** or a **beaker of water as a heat shield**.

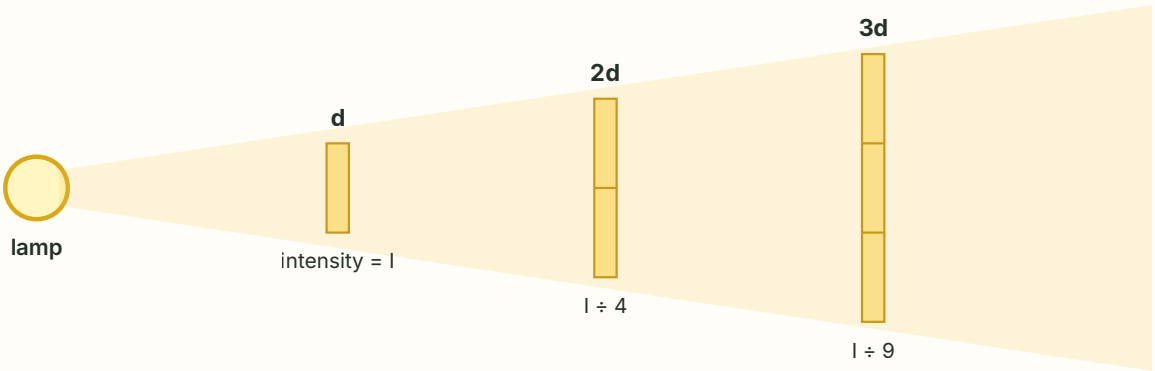
MATHS SKILL — RATE

Rate = amount of O_2 ÷ time. Example: 45 bubbles in 3 minutes → 45 ÷ 3 = **15 bubbles per minute**. 0.6 cm^3 of oxygen in 2 minutes → 0.6 ÷ 2 = **0.3 cm^3/min**.

The same apparatus can test **temperature** (put the tube in water baths at different temperatures) or **CO_2** (use different concentrations of sodium hydrogencarbonate).

4.6 The inverse square law HIGHER TIER

AQA 4.4.1.2



Same light spreads over a bigger area → the further away, the less light reaches each part

Light intensity falls quickly as distance increases

- As the lamp moves **further away**, the light intensity at the plant **decreases**.
- Light intensity is **inversely proportional** to the **square of the distance** — the **inverse square law**.

light intensity ∝ 1 / distance²

- **Double** the distance → light intensity is **4 times smaller** (÷ 2^2).
- **Triple** the distance → **9 times smaller** (÷ 3^2).
- **Halve** the distance → **4 times greater**.

MATHS SKILL — USING 1/D²

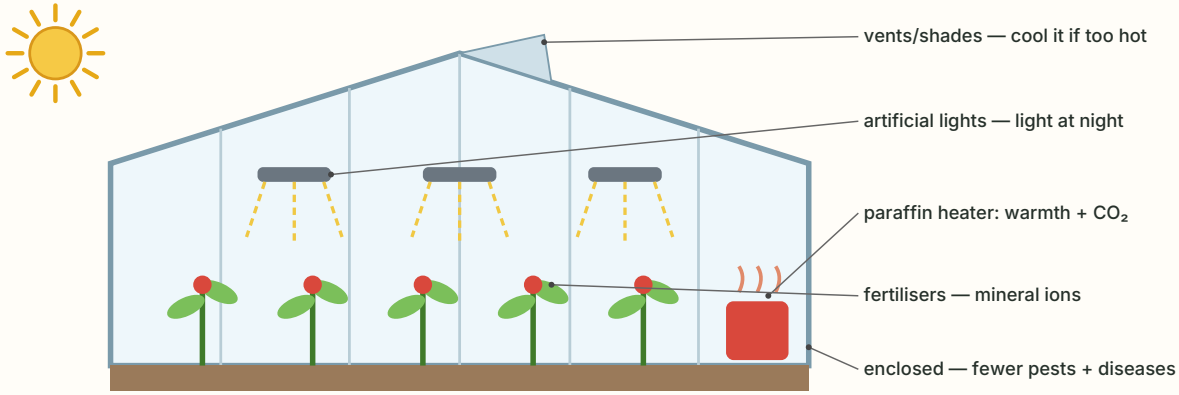
You can use **1/d²** as a measure of light intensity (in arbitrary units, a.u.).
Lamp at 10 cm → 1 ÷ 10^2 = 1 ÷ 100 = **0.01 a.u.**
Lamp at 20 cm → 1 ÷ 20^2 = 1 ÷ 400 = **0.0025 a.u.** (4 times smaller).
Lamp at 25 cm → 1 ÷ 625 = **0.0016 a.u.** = **1.6×10^{-3} a.u.**

REMEMBER IT

"Double the distance, a quarter the light." Square the distance, then flip it: **1/d²**.

4.7 Greenhouses and farming

AQA 4.4.1.2



Controlling limiting factors in a greenhouse

Farmers grow crops in **greenhouses** to create the **ideal conditions** for photosynthesis, so plants grow faster and give a **bigger yield**.

Factor	How it is controlled
Temperature	Glass traps the Sun's heat. A **heater** keeps it warm in winter; **vents and shades** cool it in summer
Light	**Artificial lights** after the Sun goes down → photosynthesis continues for longer
Carbon dioxide	A **paraffin heater** burns fuel → gives off **CO_2** as well as heat
Minerals	**Fertilisers** add the mineral ions needed for healthy growth
Pests + disease	Being **enclosed** keeps pests and diseases out more easily

Is it worth the money? HIGHER TIER

- Heaters, lights and CO_2 all **cost money** to buy and run.
- It is only **cost-effective** if the **extra crop** sells for **more than the extra cost**.
- There is **no point** increasing a factor that is **not limiting** — e.g. adding more CO_2 when light is limiting wastes money.
- Farmers use data to find the **right amount** of heat, light and CO_2 — enough to make plants grow well, but no more.

REMEMBER IT

Greenhouse checklist **"HLCF"**: **H**eat, **L**ight, **C**O_2, **F**ertiliser. Only pay for what is **limiting**.

PART B

Respiration and Metabolism

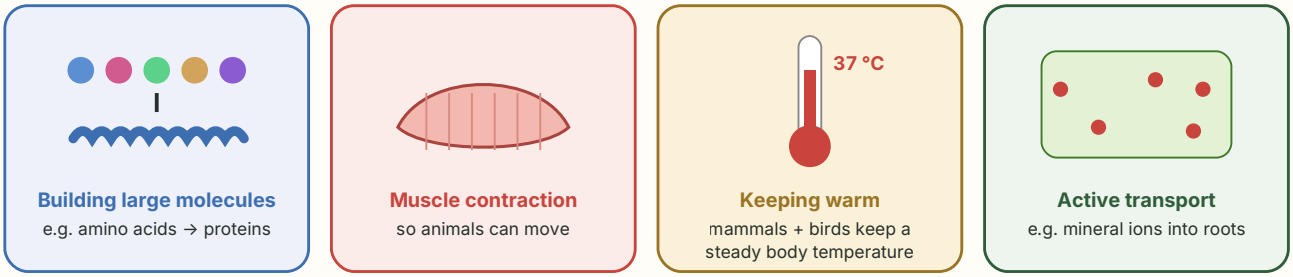
4.8 Respiration and the uses of energy

AQA 4.4.2.1

DEFINITION — LEARN IT

Respiration is an **exothermic** reaction that **transfers energy from glucose**. It happens **continuously** in **every living cell**.

- Respiration is **not** breathing. Breathing (ventilation) just moves air in and out of the lungs.
- **Exothermic** = energy is **transferred to the environment** (given out).
- **All** living things respire — plants, animals and microorganisms. Plants respire **day and night**.
- Organisms need the energy for **all living processes**.



What organisms use the energy from respiration for

REMEMBER IT

Energy uses: **"Big Muscles Keep Active"** → **B**uilding larger molecules, **M**uscle contraction, **K**eeping warm, **A**ctive transport.
Exo = Exit: energy goes **out**.

COMMON MISTAKE

Never write that respiration "**makes**" or "**produces**" energy. Energy cannot be made. Write: respiration **transfers** (or releases) energy from glucose.

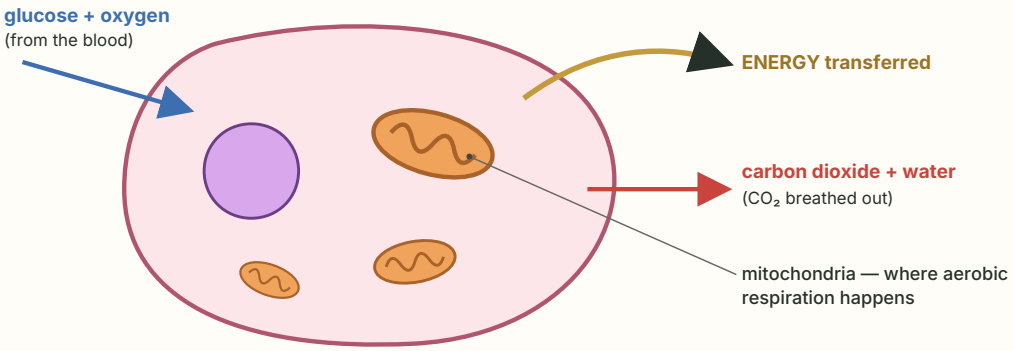
4.9 Aerobic respiration

AQA 4.4.2.1

- **Aerobic respiration** = respiration **using oxygen**.
- It happens **all the time** in plants and animals.
- It transfers the **most energy** from each glucose molecule — the most efficient way.
- Most of the reactions happen inside the **mitochondria**.

glucose + oxygen ⟶ carbon dioxide + water

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



Aerobic respiration takes place in the mitochondria

REMEMBER IT

Aerobic respiration is **photosynthesis backwards**: swap the two sides and remove the light. **A**erobic = with **A**ir (oxygen).

EXAM TIP

Cells that need lots of energy — **muscle cells**, **sperm cells** and cells doing **active transport** — have **lots of mitochondria**. Link this to Topic 1.

4.10 Anaerobic respiration

AQA 4.4.2.1

- **Anaerobic respiration** = respiration **without oxygen**.
- It happens when there is **not enough oxygen**, e.g. in muscles during **vigorous exercise**.
- Glucose is **not completely broken down** (incompletely oxidised), so it transfers **much less energy** than aerobic respiration.

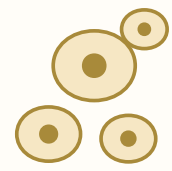
In muscle cells (animals)

glucose ⟶ lactic acid

- **Lactic acid** builds up in the muscles, which can be **painful** and leads to **muscle fatigue**.

In plant cells and yeast

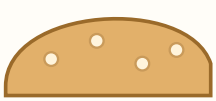
glucose ⟶ ethanol + carbon dioxide



yeast (a fungus)

glucose → ethanol + carbon dioxide

= FERMENTATION (anaerobic)



Bread: CO_2 makes the dough rise



Beer + wine: the ethanol (alcohol)

Anaerobic respiration in yeast is called fermentation

- In **yeast** cells this is called **fermentation**.

- It is very useful in the food and drinks industry: **bread-making** (the CO_2 makes dough rise) and making **beer and wine** (the ethanol is alcohol).

	Aerobic	Anaerobic (muscles)	Anaerobic (plants, yeast)
Oxygen?	Needed	Not needed	Not needed
Products	Carbon dioxide + water	Lactic acid	Ethanol + carbon dioxide
Energy transferred	**Lots**	Much less	Much less
Glucose broken down	Completely	Incompletely	Incompletely

REMEMBER IT

Anaerobic muscles → **L**actic acid ("**A**ching **L**egs").
Yeast → **E**thanol + **C**O_2 ("**Y**east makes **E**xcellent **C**akes and beer").

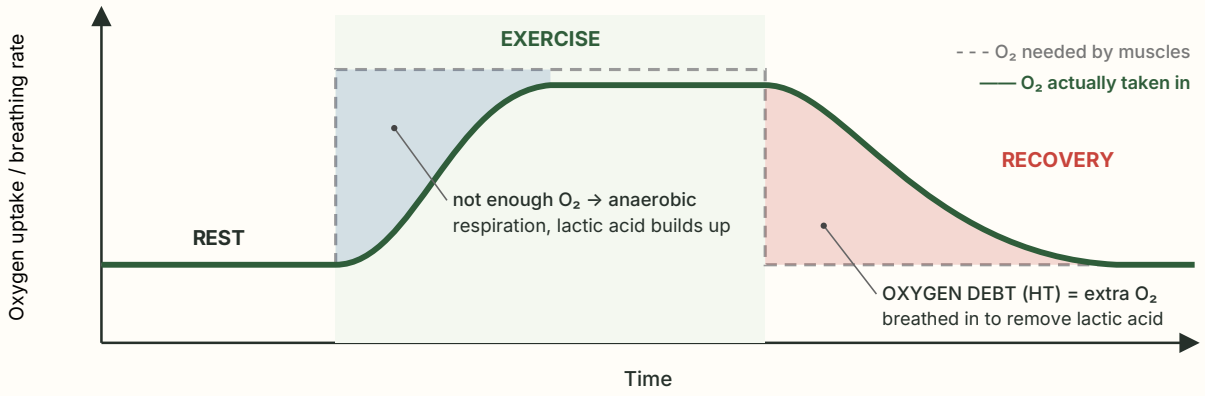
COMMON MISTAKE

Anaerobic respiration in **muscles** does **not** make carbon dioxide — only lactic acid. And humans never make ethanol by respiration.

4.11 Exercise and oxygen debt

AQA 4.4.2.2

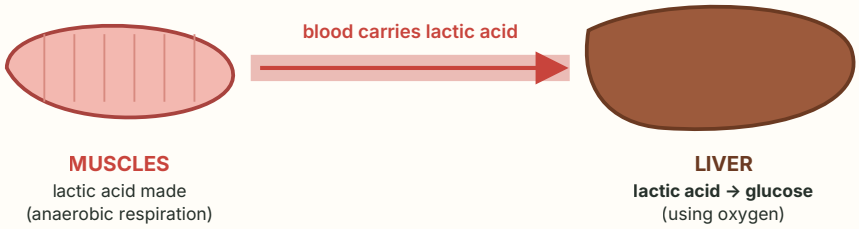
- During exercise, muscles **contract more**, so they need **more energy** → more **respiration** → more **oxygen and glucose**, and more **CO_2** to remove.
- The body responds with an increase in **heart rate**, **breathing rate** and **breath volume**.
- This gets **more oxygenated blood** to the muscles faster, and removes **CO_2** more quickly.
- During **vigorous** exercise, the body can't supply enough oxygen → muscles also respire **anaerobically** → **lactic acid** builds up.
- Long periods of exercise cause **muscle fatigue** — muscles get tired and stop contracting efficiently.



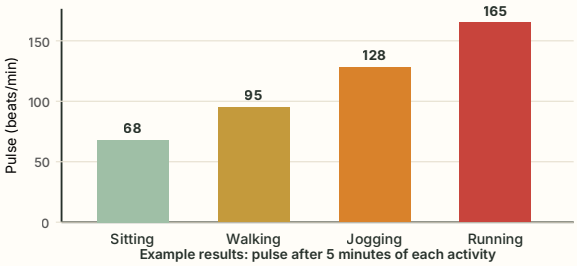
Oxygen uptake before, during and after exercise

Oxygen debt HIGHER TIER

- **Oxygen debt** is the amount of **extra oxygen** the body needs after exercise to **react with the lactic acid** that has built up and remove it from cells.
- That is why you keep **breathing hard** and your **heart rate stays high** after you stop.
- Blood carries the lactic acid to the **liver**, where it is **converted back into glucose**.



Removing lactic acid



Investigating the effect of exercise

Investigating exercise:

- Measure **breathing rate** by counting breaths, and **heart rate** by taking the **pulse** (count beats in your wrist or neck for 15 s and × 4).
- Record your pulse after sitting, then after 5 minutes of walking, jogging and running.
- Rest between activities so your pulse returns to normal.
- Use a **group** and calculate the **mean** to reduce the effect of random errors.

REMEMBER IT

Exercise ↑ **"HBB"**: **H**eart rate, **B**reathing rate, **B**reath volume.
Oxygen debt = **"paying back"** the oxygen you didn't get — the liver turns lactic acid back into **glucose**.

4.12 Metabolism

AQA 4.4.2.3

- **Metabolism** is the **sum of all the reactions** in a cell or the body.
- The energy transferred by **respiration** is used by cells to make new molecules.
- These reactions are controlled by **enzymes**. Some **build** larger molecules from smaller ones; others **break down** larger molecules.

glucose	BUILD →	starch (plants) · glycogen (animals) · cellulose (plant walls)
1 glycerol + 3 fatty acids	BUILD →	lipid
glucose + nitrate ions	BUILD →	amino acids → proteins
glucose	BREAK →	respiration (energy released)
excess protein	BREAK →	urea → excreted in urine

Metabolic reactions you must know

Reaction	What happens
Carbohydrates	Glucose is joined into **starch** (store in plants), **glycogen** (store in animals, liver and muscles) and **cellulose** (plant cell walls)
Lipids	Each lipid is made from **one molecule of glycerol** and **three fatty acids**
Proteins	Glucose + **nitrate ions** → **amino acids**, which are joined to make **proteins**
Respiration	Glucose is broken down to transfer energy
Urea	**Excess proteins** are broken down to make **urea**, which is excreted in **urine**

REMEMBER IT

Metabolism = **"all the reactions"**. Store forms: **S**tarch in **S**hoots (plants), **G**lycogen in the **G**uts and muscles (animals).
Lipid = **1 + 3** (one glycerol, three fatty acids).

EXAM TIP

"Give two examples of metabolic reactions" — any two from the table, e.g. glucose → starch, and excess protein → urea. Don't just write "respiration" twice in different words.

★ LAST-MINUTE

One-page memory sheet

Topic	Must-know facts
Photosynthesis	carbon dioxide + water → glucose + oxygen (light). $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. Endothermic. In chloroplasts; chlorophyll absorbs light.
Uses of glucose	Respiration · cellulose (cell walls) · amino acids → proteins (+ nitrate ions) · fats and oils (seeds) · starch (insoluble store).
Limiting factors	Light, CO_2, temperature, chlorophyll. Light + CO_2 graphs rise then level off. Temperature graph rises to optimum then falls (enzymes denatured ~45 °C).
HT graphs	Lines the same = x-axis factor limiting. Higher plateau → the factor that differs was limiting the lower line.
Required practical	Pondweed + sodium hydrogencarbonate. Vary lamp distance; count bubbles or measure O_2 volume per minute. Control temperature and CO_2. Repeat and mean.
Inverse square law (HT)	Light intensity $\propto 1/d^2$. Double distance → ¼ the light. Use $1/d^2$ as light intensity (a.u.).
Greenhouses	Heaters, artificial light, paraffin heater (CO_2), fertilisers, fewer pests. HT: only worth it if extra profit > cost; only add a factor that is limiting.
Respiration	Exothermic, transfers energy from glucose, in every living cell, all the time. Energy for building molecules, muscle contraction, keeping warm, active transport.
Aerobic	glucose + oxygen → carbon dioxide + water. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$. In mitochondria. Most energy.
Anaerobic	Muscles: glucose → lactic acid. Plants + yeast: glucose → ethanol + CO_2 (fermentation: bread, beer, wine). Incomplete oxidation, much less energy.
Exercise	Heart rate, breathing rate, breath volume increase. Vigorous → anaerobic → lactic acid → muscle fatigue.
Oxygen debt (HT)	Extra O_2 needed after exercise to react with lactic acid. Blood takes lactic acid to the liver → converted back to glucose.
Metabolism	Sum of all reactions. Glucose → starch / glycogen / cellulose · glycerol + 3 fatty acids → lipid · glucose + nitrate → amino acids → protein · respiration · excess protein → urea.

PRACTICE

Summary questions

Try every question **without notes**. Tick each one you get fully right; redo the rest in 2–3 days. Answers are in the next section.

Section A — Quick recall (1–2 marks each)

1. Where in a plant cell does photosynthesis take place?
2. What is the job of chlorophyll?
3. Write the word equation for photosynthesis.
4. Write the balanced symbol equation for photosynthesis.
5. Why is photosynthesis described as endothermic?
6. How does carbon dioxide get into a leaf?
7. Give the five main ways a plant uses glucose.
8. What does a plant need to combine with glucose to make amino acids?
9. Why is glucose stored as starch?
10. What is a limiting factor?
11. Name four factors that affect the rate of photosynthesis.
12. Why does the rate of photosynthesis fall at high temperatures?
13. Which factor is most likely to be limiting at night?
14. Give two things that can reduce the amount of chlorophyll in a plant.
15. In the pondweed practical, why is sodium hydrogencarbonate added to the water?
16. Give two control variables in the pondweed practical.
17. (HT) State the inverse square law for light.
18. Give one way that a farmer can increase CO_2 in a greenhouse.
19. Why might a farmer use artificial lights in a greenhouse?
20. What is respiration?
21. What is an exothermic reaction?
22. Give three things animals use the energy from respiration for.
23. Write the word equation for aerobic respiration.
24. In which organelle does most aerobic respiration happen?
25. Write the word equation for anaerobic respiration in muscle cells.
26. What are the products of anaerobic respiration in yeast?
27. What is anaerobic respiration in yeast called?
28. Why does anaerobic respiration transfer less energy than aerobic?
29. Give three changes in the body during exercise.
30. What causes muscle fatigue?

31. (HT) What is oxygen debt?
32. What is metabolism?
33. What is a lipid molecule made from?
34. What is made when excess protein is broken down?

Section B — Exam-style questions

35. Explain why a plant needs light, carbon dioxide and water to grow. [4 marks]
36. Describe how a plant uses the glucose it makes in photosynthesis. [5 marks]
37. Describe and explain the shape of a graph showing the effect of temperature on the rate of photosynthesis. [4 marks]
38. A student found that the rate of photosynthesis stopped increasing above a certain light intensity. Explain why. [2 marks]
39. Describe a method to investigate the effect of light intensity on the rate of photosynthesis in pondweed. [6 marks]
40. Suggest why measuring the volume of oxygen gives more accurate results than counting bubbles. [2 marks]
41. (HT) Explain why it may not be cost-effective for a farmer to add more carbon dioxide to a greenhouse. [3 marks]
42. Compare aerobic and anaerobic respiration in humans. [4 marks]
43. Explain why bakers use yeast to make bread. [3 marks]
44. Explain the changes in heart rate and breathing during exercise. [4 marks]
45. (HT) Explain why a runner continues to breathe heavily after finishing a race. [4 marks]
46. Describe what is meant by metabolism and give three examples of metabolic reactions. [4 marks]
47. Explain why muscle cells contain many mitochondria. [2 marks]

Section C — Maths skills

48. A lamp is 20 cm from a plant. Calculate the light intensity using $1/d^2$. Give your answer in standard form. [2 marks]
49. (HT) A lamp is moved from 15 cm to 45 cm away. By what factor does the light intensity change? [2 marks]
50. Pondweed gave off 1.8 cm^3 of oxygen in 6 minutes. Calculate the rate of photosynthesis. [1 mark]
51. A student counted 38, 42 and 40 bubbles per minute in three repeats. Calculate the mean. [1 mark]
52. A student breathed 384 times in 24 minutes. Calculate the mean breathing rate. [1 mark]
53. A pupil's pulse was 70 bpm at rest and 154 bpm after running. Calculate the percentage increase. [2 marks]
54. Balance this equation: $C_6H_{12}O_6 + __O_2 \rightarrow __CO_2 + __H_2O$ [1 mark]

ANSWERS

Answers and mark scheme

Section A — Quick recall

1. **Where in a plant cell does photosynthesis take place?**
   In the chloroplasts.
2. **What is the job of chlorophyll?**
   To absorb light energy for photosynthesis.
3. **Write the word equation for photosynthesis.**
   carbon dioxide + water → glucose + oxygen (light above the arrow).
4. **Write the balanced symbol equation for photosynthesis.**
   $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
5. **Why is photosynthesis described as endothermic?**
   Energy is transferred from the environment (as light) into the reaction.
6. **How does carbon dioxide get into a leaf?**
   It diffuses in through the stomata.
7. **Give the five main ways a plant uses glucose.**
   Respiration; making cellulose; making amino acids/proteins; making fats and oils; storing as starch.
8. **What does a plant need to combine with glucose to make amino acids?**
   Nitrate ions (from the soil).
9. **Why is glucose stored as starch?**
   Starch is insoluble, so it doesn't affect water movement by osmosis / doesn't make cells swell.
10. **What is a limiting factor?**
    The factor in shortest supply that stops the rate of photosynthesis increasing.
11. **Name four factors that affect the rate of photosynthesis.**
    Light intensity, CO_2 concentration, temperature, amount of chlorophyll.
12. **Why does the rate of photosynthesis fall at high temperatures?**
    The enzymes that control photosynthesis are denatured.
13. **Which factor is most likely to be limiting at night?**
    Light intensity.
14. **Give two things that can reduce the amount of chlorophyll in a plant.**
    Disease (e.g. TMV), magnesium deficiency, environmental stress (any two).
15. **In the pondweed practical, why is sodium hydrogencarbonate added to the water?**
    To give a steady supply of carbon dioxide, so CO_2 is not limiting.
16. **Give two control variables in the pondweed practical.**
    Temperature, CO_2 concentration, type/size of pondweed, time (any two).
17. **(HT) State the inverse square law for light.**
    Light intensity is inversely proportional to the square of the distance from the source ($\propto 1/d^2$).
18. **Give one way that a farmer can increase CO_2 in a greenhouse.**
    Use a paraffin heater (burning fuel releases CO_2).
19. **Why might a farmer use artificial lights in a greenhouse?**
    So photosynthesis can continue after dark / for longer → faster growth.

20. **What is respiration?**
    An exothermic reaction that transfers energy from glucose, happening continuously in every living cell.
21. **What is an exothermic reaction?**
    One that transfers energy to the environment.
22. **Give three things animals use the energy from respiration for.**
    Building larger molecules, muscle contraction, keeping warm (also active transport).
23. **Write the word equation for aerobic respiration.**
    glucose + oxygen → carbon dioxide + water
24. **In which organelle does most aerobic respiration happen?**
    Mitochondria.
25. **Write the word equation for anaerobic respiration in muscle cells.**
    glucose → lactic acid
26. **What are the products of anaerobic respiration in yeast?**
    Ethanol and carbon dioxide.
27. **What is anaerobic respiration in yeast called?**
    Fermentation.
28. **Why does anaerobic respiration transfer less energy than aerobic?**
    Glucose is not completely broken down (incomplete oxidation).
29. **Give three changes in the body during exercise.**
    Heart rate, breathing rate and breath volume all increase.
30. **What causes muscle fatigue?**
    Long periods of vigorous exercise / build-up of lactic acid from anaerobic respiration.
31. **(HT) What is oxygen debt?**
    The extra oxygen needed after exercise to react with the lactic acid and remove it from cells.
32. **What is metabolism?**
    The sum of all the reactions in a cell or the body.
33. **What is a lipid molecule made from?**
    One molecule of glycerol and three fatty acids.
34. **What is made when excess protein is broken down?**
    Urea, which is excreted in urine.

Section B — Exam-style questions

35. **Explain why a plant needs light, carbon dioxide and water to grow.** [4]
    - They are needed for photosynthesis (1)
    - Light provides the energy; CO_2 and water are the raw materials/reactants (1)
    - Photosynthesis makes glucose (1)
    - Glucose is used for respiration and to make cellulose, proteins etc. for growth (1)
36. **Describe how a plant uses the glucose it makes in photosynthesis.** [5]
    - Respiration to release energy (1)
    - Converted to cellulose for strong cell walls (1)
    - Combined with nitrate ions to make amino acids → proteins (1)
    - Converted to fats/oils for storage in seeds (1)
    - Stored as insoluble starch (1)

37. **Describe and explain the shape of a graph showing the effect of temperature on the rate of photosynthesis.** [4]
    - Rate increases as temperature increases (1) because enzymes and particles have more energy / more collisions (1)
    - Rate peaks at an optimum temperature (1)
    - Above the optimum, rate falls steeply because enzymes are denatured (1)

38. **A student found that the rate of photosynthesis stopped increasing above a certain light intensity. Explain why.** [2]
    - Light is no longer the limiting factor (1)
    - Another factor, such as CO_2 concentration or temperature, is now limiting the rate (1)

39. **Describe a method to investigate the effect of light intensity on the rate of photosynthesis in pondweed.** [6]
    - Pondweed in a boiling tube of water with sodium hydrogencarbonate
    - Lamp placed at a measured distance (metre rule), e.g. 10 cm; leave to acclimatise
    - Count bubbles / collect gas and measure the volume of O_2 in a set time (e.g. 1 min)
    - Repeat at different distances (e.g. 20, 30, 40 cm)
    - Repeat each distance and calculate a mean
    - Control temperature (LED/heat shield/water bath) and CO_2; same pondweed
    - *Level marking: 5–6 marks for a logical, detailed method with controls.*

40. **Suggest why measuring the volume of oxygen gives more accurate results than counting bubbles.** [2]
    - Bubbles may be different sizes (1)
    - Bubbles can be missed or miscounted if they come off quickly (1)

41. **(HT) Explain why it may not be cost-effective for a farmer to add more carbon dioxide to a greenhouse.** [3]
    - CO_2 may not be the limiting factor (e.g. light or temperature is limiting) (1)
    - so adding CO_2 won't increase the rate of photosynthesis/yield (1)
    - The extra cost of CO_2 would be more than any extra profit from the crop (1)

42. **Compare aerobic and anaerobic respiration in humans.** [4]
    - Aerobic needs oxygen; anaerobic does not (1)
    - Aerobic produces CO_2 and water; anaerobic produces lactic acid (1)
    - Aerobic transfers much more energy (1)
    - In aerobic, glucose is completely oxidised; in anaerobic it is incompletely oxidised (1)

43. **Explain why bakers use yeast to make bread.** [3]
    - Yeast respires anaerobically / fermentation (1)
    - producing carbon dioxide (and ethanol) (1)
    - The CO_2 gas makes the dough rise (1)

44. **Explain the changes in heart rate and breathing during exercise.** [4]
    - Muscles contract more, so need more energy (1) from increased respiration
    - Heart rate increases to deliver more oxygen (and glucose) to muscles in the blood (1)
    - Breathing rate and breath volume increase to take in more oxygen (1)
    - and to remove more carbon dioxide (1)

45. **(HT) Explain why a runner continues to breathe heavily after finishing a race.** [4]
    - During the race, muscles respired anaerobically, producing lactic acid (1)
    - The body has an oxygen debt (1)
    - Extra oxygen is needed to react with/remove the lactic acid (1)
    - Lactic acid is carried in the blood to the liver and converted back to glucose (1)

46. **Describe what is meant by metabolism and give three examples of metabolic reactions.** [4]
    - Metabolism is the sum of all the reactions in a cell or the body (1)
    - Any three (3): glucose → starch/glycogen/cellulose; glycerol + 3 fatty acids → lipids; glucose + nitrate ions → amino acids → proteins; respiration; excess protein → urea

47. **Explain why muscle cells contain many mitochondria.** [2]
    - Mitochondria are where aerobic respiration happens (1)
    - Muscle cells need lots of energy for contraction (1)

Section C — Maths skills

48. **A lamp is 20 cm from a plant. Calculate the light intensity using $1/d^2$. Give your answer in standard form.** [2]
    $1 \div 20^2 = 1 \div 400$ (1) $= 0.0025 =$ **2.5×10^{-3} a.u.** (1)

49. **(HT) A lamp is moved from 15 cm to 45 cm away. By what factor does the light intensity change?** [2]
    Distance × 3 (1) → light intensity is $3^2 =$ **9 times smaller** (1)

50. **Pondweed gave off 1.8 cm^3 of oxygen in 6 minutes. Calculate the rate of photosynthesis.** [1]
    $1.8 \div 6 =$ **0.3 cm^3/min**

51. **A student counted 38, 42 and 40 bubbles per minute in three repeats. Calculate the mean.** [1]
    $(38 + 42 + 40) \div 3 =$ **40 bubbles per minute**

52. **A student breathed 384 times in 24 minutes. Calculate the mean breathing rate.** [1]
    $384 \div 24 =$ **16 breaths per minute**

53. **A pupil's pulse was 70 bpm at rest and 154 bpm after running. Calculate the percentage increase.** [2]
    $154 - 70 = 84$ (1) → $84 \div 70 \times 100 =$ **120%** (1)

54. **Balance this equation: $C_6H_{12}O_6 + __O_2 \rightarrow __CO_2 + __H_2O$** [1]
    $C_6H_{12}O_6 + \mathbf{6}O_2 \rightarrow \mathbf{6}CO_2 + \mathbf{6}H_2O$

FINAL EXAM ADVICE

Use the **key words** examiners look for: *chloroplast, chlorophyll, endothermic, exothermic, limiting factor, optimum, denatured, inverse square law, aerobic, anaerobic, mitochondria, lactic acid, fermentation, oxygen debt, metabolism, glycogen, urea*. Learn **both equations** in words and symbols, and always quote **values from graphs**.

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