

Bioenergetics revision notes

Plants use light to make glucose in photosynthesis, which also releases oxygen. Living things then use that glucose in respiration to transfer the energy they need for life. This topic covers both processes, what limits photosynthesis, how the body responds to exercise, and how all the reactions in a cell are linked as metabolism.

For AQA GCSE Biology 8461 and Combined Science: Trilogy 8464. **Triple only** is not in Combined Science. **Higher tier** is only on the Higher paper.

1 Photosynthesis Spec 4.4.1

The photosynthetic reaction Spec 4.4.1.1

Plants make their own food by **photosynthesis**. In plants it happens in the **chloroplasts**, which contain the green pigment chlorophyll.

Photosynthesis is represented by the equation:

carbon dioxide + water → glucose + oxygen (in the presence of light)

$6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ (in the presence of light)

Chemical symbols to recognise

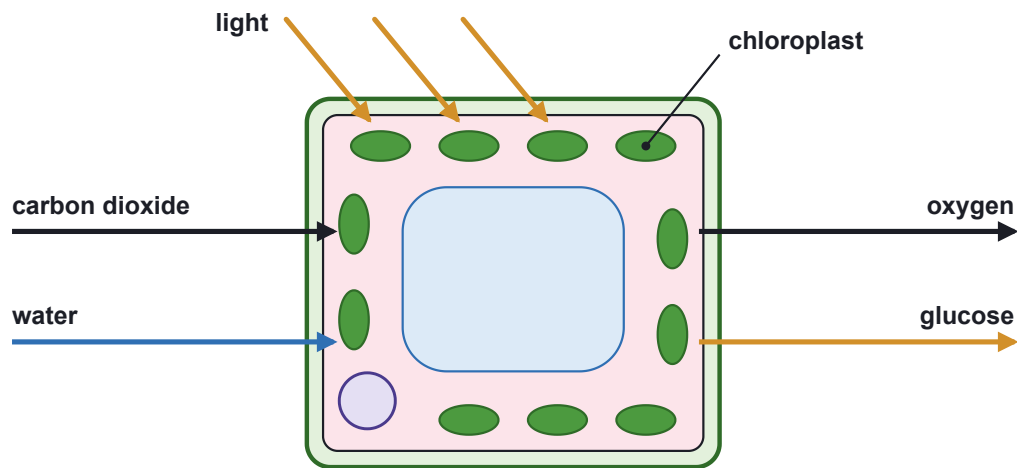
Substance	Symbol
Carbon dioxide	CO_2
Water	H_2O
Glucose	$\text{C}_6\text{H}_{12}\text{O}_6$
Oxygen	O_2

Photosynthesis is an **endothermic** reaction. **Energy is transferred from the environment to the chloroplasts by light**. This is why the reaction needs a constant supply of light to keep going.

In an endothermic reaction, energy is taken in from the surroundings. The energy ends up stored in the glucose that is made.

Exam tip: Reactants (carbon dioxide and water) go on the left and products (glucose and oxygen) on the right. Write light above the arrow, because it is not a reactant.

Common mistake: Do not write light as a reactant. Say that energy is transferred from the environment to the chloroplasts by light.



Photosynthesis in a leaf cell: **light** transfers energy to the **chloroplasts**.

Factors that affect the rate of photosynthesis Spec 4.4.1.2

Four factors affect the **rate of photosynthesis**. If one of them is in short supply, it **limits** the rate. Raising any other factor will make no difference until the limiting factor is increased.

Effects on the rate of photosynthesis		
Factor	Effect on rate	Why
Light intensity	Rate increases as light intensity increases, up to a point	Light provides the energy for the reaction. When light is no longer the limiting factor, the rate levels off.
Carbon dioxide concentration	Rate increases as concentration increases, up to a point	Carbon dioxide is a reactant. When it is no longer limiting, the rate levels off.
Temperature	Rate increases as temperature increases up to an optimum, then falls	Photosynthesis is controlled by enzymes. Warmer particles move faster and collide more often. Above the optimum, the enzymes denature and the rate drops quickly.
Amount of chlorophyll	Less chlorophyll means a lower rate	Chlorophyll absorbs the light. Fewer chloroplasts or damaged leaves (for example from disease) absorb less light.

Exam tip: When explaining a graph that levels off, say that the factor on the x-axis is no longer limiting and that something else is now in short supply. Name the other factor if the question allows.

Measuring and calculating the rate

You can measure the rate of photosynthesis by finding how much oxygen is made, or how many bubbles are released, in a set time. The bigger the volume or number of bubbles, the faster the rate.

$$\text{rate} = \text{volume of oxygen produced} \div \text{time}$$

Calculating a rate

A piece of pondweed produced 24 cm^3 of oxygen in 8 minutes. Calculate the rate of photosynthesis in cm^3 per minute.

1. $\text{rate} = \text{volume} \div \text{time}$

2. $\text{rate} = 24 \div 8$

Answer: 3 cm^3 per minute

Rearranging the equation

A different piece of pondweed photosynthesises at 2.5 cm^3 per minute. How long will it take to produce 15 cm^3 of oxygen?

1. $\text{rate} = \text{volume} \div \text{time}$, so $\text{time} = \text{volume} \div \text{rate}$

2. $\text{time} = 15 \div 2.5$

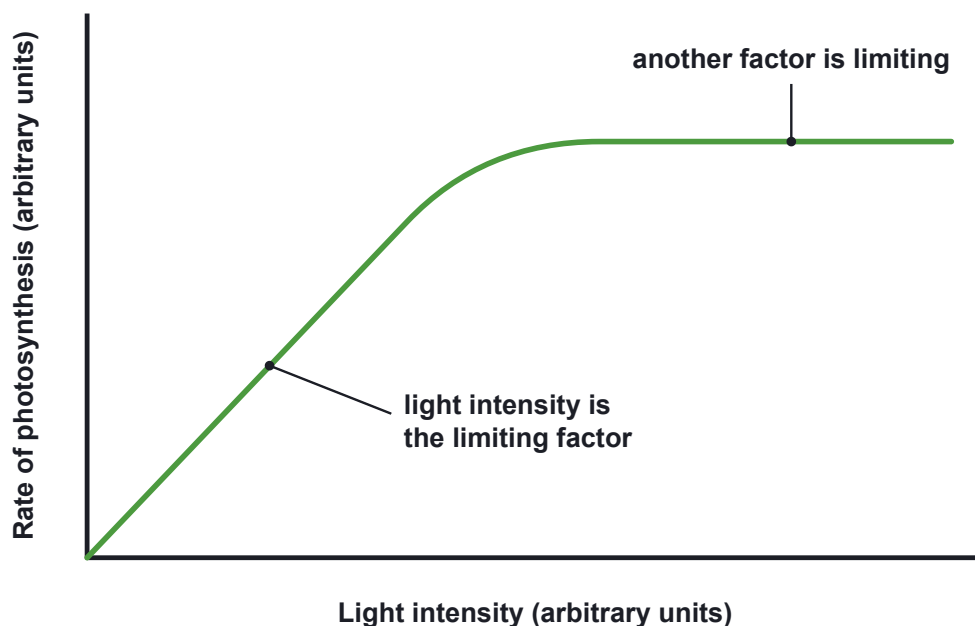
Answer: 6 minutes

Maths skill: Always include units in a rate. Here the unit is cm^3 per minute (cm^3/min).

Plotting and reading graphs

- Put the factor you change (the independent variable) on the x-axis and the rate on the y-axis.
- Choose a scale that uses more than half of the grid, with equal steps on each axis.
- Label both axes with the quantity and the unit.
- Plot the points accurately and draw a smooth line or curve of best fit.
- To read a graph, find the value on one axis and follow it across to the line, then down or across to the other axis. You can then write the values in a table, or draw a graph from a table.

For a graph with one limiting factor, the rate rises steeply, then curves over and becomes flat. In the rising part the factor on the x-axis is limiting. In the flat part another factor is limiting.



Rate rises while **light intensity is limiting**, then levels off when another factor limits it.

Interacting factors and the inverse square law Spec 4.4.1.2 Higher tier

These factors **interact**, and **any one of them may be the factor that limits photosynthesis**. Which one is limiting can change with conditions, for example from the middle of a summer day to a winter morning.

To explain a graph with two or three factors, follow these steps:

1. Look at the lines (or curves) for each set of conditions.
2. Find the part where a curve is still rising. The factor on the x-axis is limiting there.
3. Find the part where a curve is flat. A factor that is not on the x-axis is limiting there.
4. If a line is higher because another factor was increased (for example a higher carbon dioxide concentration or temperature), that other factor was limiting the lower line.
5. Where two lines are on top of each other, the factor on the x-axis is limiting both, so changing the other factor has no effect there.

Exam tip: To find the limiting factor, ask which factor would raise the rate if it were increased. That factor is the limiting one.

Light intensity and the inverse square law

Light intensity is **inversely proportional** to the **square** of the distance from the light source. This is the **inverse square law**. If you move a lamp twice as far away, the light intensity is one quarter as much, not one half.

$$\text{light intensity} \propto 1 \div \text{distance}^2$$

Using the inverse square law

A lamp 10 cm from a plant gives a light intensity of 64 units. What is the light intensity when the lamp is moved to 40 cm?

1. Distance has increased by a factor of $40 \div 10 = 4$
2. Light intensity falls by a factor of $4^2 = 16$
3. New intensity = $64 \div 16$

Answer: 4 units

If light is the limiting factor, the rate of photosynthesis is roughly proportional to light intensity. So halving the distance gives four times the light intensity, and four times the rate (provided nothing else becomes limiting).

Limiting factors and greenhouses

Limiting factors are important in the **economics** of enhancing the conditions in greenhouses. Growers can add heat, light or carbon dioxide to gain the maximum rate of photosynthesis, so that plants grow faster and yield more.

But each addition costs money for fuel, electricity or carbon dioxide. The grower must still maintain a profit. It is only worth adding a factor if it is the limiting factor, and if the extra crop is worth more than the cost of adding it. Increasing a factor that is not limiting is a waste of money.

Exam tip: For an evaluation question, use data to compare the extra rate gained with the cost, and say whether the factor was actually limiting.

Required practical: light intensity and the rate of photosynthesis Spec 4.4.1.2

Required practical: Investigate the effect of light intensity on the rate of photosynthesis using an aquatic organism such as pondweed. This is Required Practical 6 in Biology (Triple) and Required Practical 5 in Combined Science: Trilogy.

Aim: to find how the distance of a lamp from pondweed affects the rate at which it photosynthesises.

1. Set up a beaker of water with a piece of pondweed and a lamp.
2. Use a ruler to place the lamp a set distance from the pondweed, for example 10 cm.
3. Leave the pondweed for a short time to adjust to the new light.
4. Count the number of bubbles of oxygen released from the cut end of the stem in a set time (for example one minute), or collect the gas in a gas syringe or upside-down measuring tube and measure its volume.
5. Repeat the count at least twice more at the same distance and calculate a mean.
6. Move the lamp to a new distance (for example 20, 30, 40 and 50 cm) and repeat.
7. Calculate the rate at each distance and plot a graph.

Variables	
Type	Variable
Independent (changed)	Distance of the lamp from the pondweed, which changes the light intensity
Dependent (measured)	Number of bubbles, or volume of oxygen, in a set time
Control (kept the same)	Temperature of the water, carbon dioxide concentration, the same piece of pondweed, the same lamp, time period

- Control temperature by placing the beaker inside a larger beaker of water that acts as a heat shield, or by using a water bath. A cool LED lamp also keeps the water temperature steady.
- Control carbon dioxide by dissolving sodium hydrogencarbonate in the water.
- Do the experiment in a dim room so that light from the lamp is the main light source.

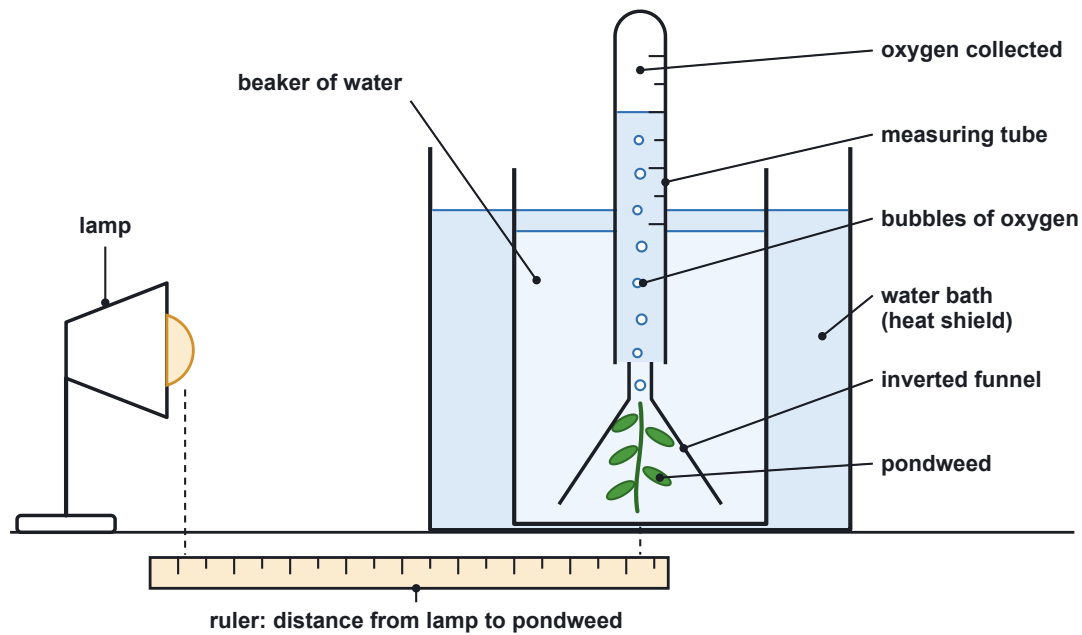
Typical results: the closer the lamp, the higher the light intensity and the more bubbles are produced. At first the rate rises steeply as the lamp moves closer. At high light intensity, the rate levels off because another factor (such as carbon dioxide concentration or temperature) becomes limiting.

Higher tier

Because the light intensity is proportional to $1 \div \text{distance}^2$, you can plot rate against $1 \div \text{distance}^2$ to get a straight line through the origin while light is limiting.

Common mistake: Counting bubbles is not very accurate, because bubbles may be different sizes. Say this in an evaluation, and say that measuring the volume of gas collected is more accurate.

- Safety: keep electrical equipment (the lamp) away from water and wipe up any spills.
- Safety: lamps get hot, so do not touch them, and handle glassware carefully.



Investigating light intensity: change the **distance** of the lamp and measure the **oxygen** produced.

Uses of glucose from photosynthesis Spec 4.4.1.3

The glucose produced in photosynthesis may be:

- used for respiration
- converted into insoluble **starch** for storage
- used to produce **fat or oil** for storage
- used to produce **cellulose**, which strengthens the cell wall
- used to produce **amino acids** for protein synthesis.

To produce proteins, plants also use **nitrate ions** that are absorbed from the soil. Glucose alone contains only carbon, hydrogen and oxygen, so plants need nitrate ions as a source of nitrogen to make amino acids.

Uses of glucose		
Use	Product	Purpose
Respiration	Energy transferred	Supplies the energy for living processes
Storage	Starch	Insoluble, so suitable for storage
Storage	Fat or oil	Stored for later use
Cell walls	Cellulose	Strengthens the cell wall
Protein synthesis	Amino acids (with nitrate ions)	Used to build proteins

Exam tip: Starch is stored because it is insoluble. You can test a leaf for starch with iodine solution, which turns from orange-brown to blue-black if starch is present.

Quick check

1. Write the word equation for photosynthesis.
2. Name the four factors that affect the rate of photosynthesis.
3. In the pondweed practical, what is the independent variable?
4. Why do plants need nitrate ions?
5. Why is photosynthesis described as endothermic?

2 Respiration Spec 4.4.2

Aerobic and anaerobic respiration Spec 4.4.2.1

Cellular respiration is an **exothermic** reaction which is continuously occurring in living cells. In an exothermic reaction, energy is transferred to the surroundings. The energy transferred supplies all the energy needed for living processes.

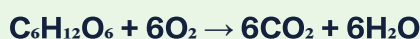
Organisms need energy for:

- chemical reactions to build larger molecules
- movement
- keeping warm.

Respiration in cells can take place **aerobically** (using oxygen) or **anaerobically** (without oxygen), to transfer energy.

Aerobic respiration

glucose + oxygen → carbon dioxide + water



Anaerobic respiration in muscles

glucose → lactic acid

As the oxidation of glucose is **incomplete** in anaerobic respiration, much less energy is transferred than in aerobic respiration.

Anaerobic respiration in plant and yeast cells

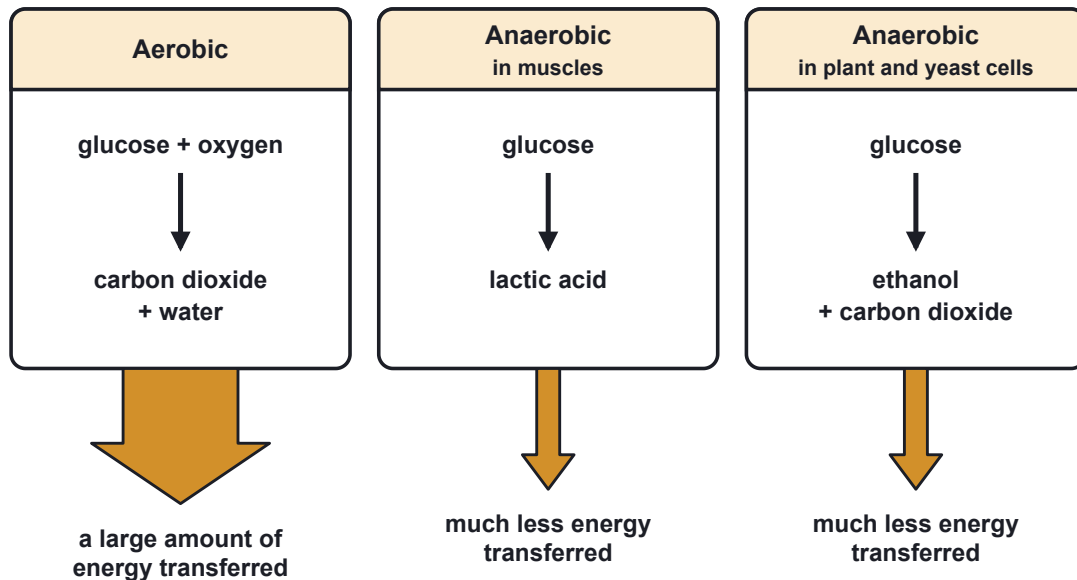
glucose → ethanol + carbon dioxide

Anaerobic respiration in yeast cells is called **fermentation**. It has economic importance in the manufacture of bread and alcoholic drinks.

Aerobic and anaerobic respiration compared			
	Aerobic	Anaerobic (muscles)	Anaerobic (plant and yeast cells)
Oxygen needed?	Yes	No	No
Products	Carbon dioxide and water	Lactic acid	Ethanol and carbon dioxide
Energy transferred	A large amount, as glucose is completely oxidised	Much less, as glucose is only partly oxidised	Much less, as glucose is only partly oxidised

Common mistake: Plants respire all the time, not only at night, and so do all other living cells.
Respiration is not breathing; it happens inside cells.

Exam tip: In a comparison, give both sides: aerobic needs oxygen, and anaerobic does not. Say anaerobic respiration transfers much less energy (never 'makes energy') because the oxidation of glucose is incomplete.



Aerobic respiration transfers **much more energy** than either type of anaerobic respiration.

Response to exercise Spec 4.4.2.2

During exercise the human body reacts to the increased demand for energy. The **heart rate, breathing rate and breath volume** increase during exercise to supply the muscles with more oxygenated blood. This brings more oxygen and glucose to the muscles for respiration.

If insufficient oxygen is supplied, anaerobic respiration takes place in muscles. The incomplete oxidation of glucose causes a build-up of **lactic acid** and creates an **oxygen debt**. During long periods of vigorous activity, muscles become **fatigued** and stop contracting efficiently.

1. Exercise increases the demand for energy in the muscles.
2. Heart rate, breathing rate and breath volume increase, so more oxygenated blood reaches the muscles.
3. If the oxygen supply is still not enough, muscles respire anaerobically.
4. Glucose is only partly oxidised, so lactic acid builds up and an oxygen debt is created.
5. After long vigorous activity, muscles become fatigued and stop contracting efficiently.

Higher tier

Removing lactic acid and the oxygen debt

Higher tier

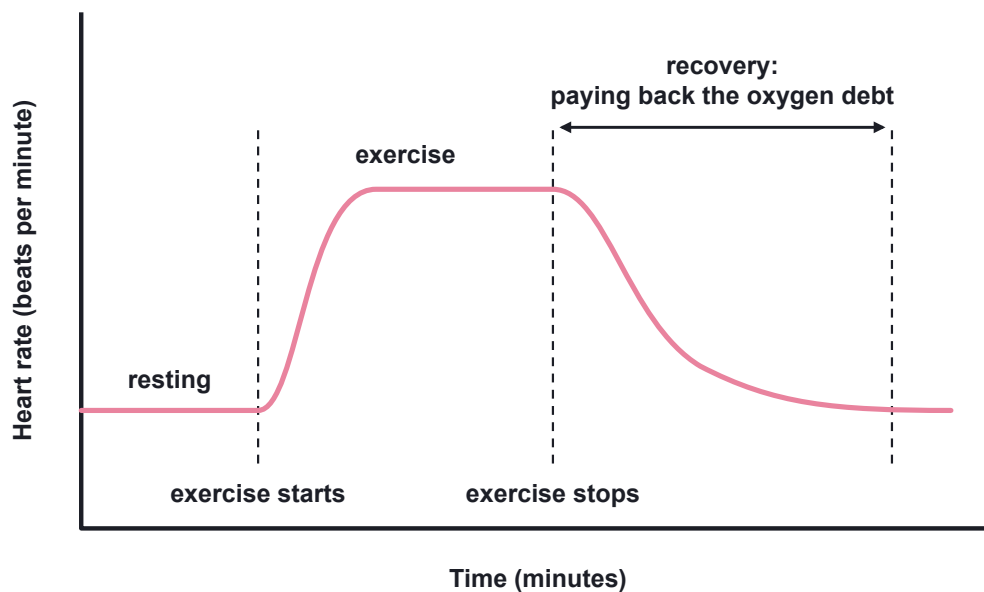
Blood flowing through the muscles transports the lactic acid to the liver, where it is converted back into glucose.

Higher tier

Oxygen debt is the amount of extra oxygen the body needs after exercise to react with the accumulated lactic acid and remove it from the cells. This is why you keep breathing hard, and your heart rate stays high, for a while after you stop.

Exam tip: To investigate exercise, measure pulse or breathing rate at rest, straight after exercise and at regular intervals during recovery. Keep the type and duration of exercise the same, and repeat to find a mean.

Exam tip: Say that anaerobic respiration happens because the oxygen supply is not enough, that lactic acid builds up, and that the muscles become fatigued. Do not say that muscles run out of energy completely.



Heart rate stays high after exercise while the **oxygen debt** is paid back.

Metabolism Spec 4.4.2.3

Metabolism is the sum of all the reactions in a cell or the body.

The energy transferred by respiration in cells is used by the organism for the continual **enzyme controlled** processes of metabolism that synthesise new molecules.

Metabolism includes:

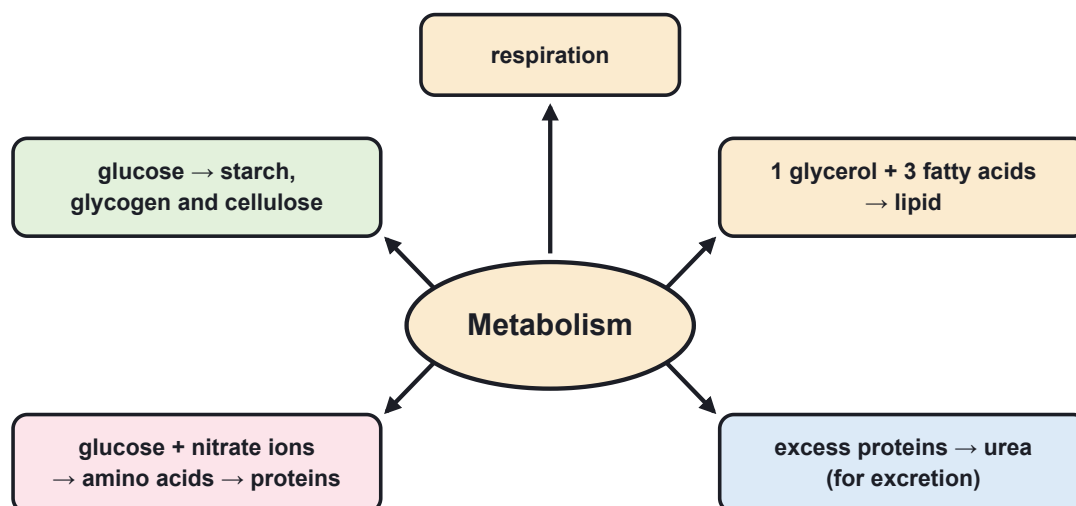
- conversion of glucose to starch, glycogen and cellulose
- the formation of lipid molecules from a molecule of **glycerol** and **three molecules of fatty acids**
- the use of glucose and nitrate ions to form amino acids, which in turn are used to synthesise proteins
- respiration
- breakdown of excess proteins to form **urea** for excretion.

Synthesis and breakdown of large molecules		
Large molecule	Made from (synthesis)	Broken down into (breakdown)
Carbohydrates (starch, glycogen, cellulose)	Sugars such as glucose	Sugars
Proteins	Amino acids	Amino acids
Lipids	One glycerol and three fatty acids	Fatty acids and glycerol

So sugars, amino acids, fatty acids and glycerol are the building blocks used to make carbohydrates, proteins and lipids, and the molecules that those large molecules are broken down into.

Exam tip: A lipid is made from one glycerol and three fatty acids. Learn the numbers 1 and 3.

All of these aspects are covered in more detail in the relevant specification sections but are linked together here.



Metabolism is the sum of all the reactions in a cell or the body.

Quick check

1. Write the word equation for aerobic respiration.
2. What are the products of anaerobic respiration in yeast?
3. Why does anaerobic respiration transfer much less energy than aerobic respiration?
4. Name the three things that increase during exercise to supply muscles with more oxygenated blood.
5. What is metabolism?

Quick check answers

Photosynthesis

1. carbon dioxide + water → glucose + oxygen (in the presence of light)
2. Temperature, light intensity, carbon dioxide concentration and the amount of chlorophyll.
3. The distance of the lamp from the pondweed (which changes the light intensity).
4. To make proteins, as nitrate ions are used with glucose to make amino acids.
5. It takes in energy from the environment, transferred to the chloroplasts by light.

Respiration

1. glucose + oxygen → carbon dioxide + water
2. Ethanol and carbon dioxide.
3. Because the oxidation of glucose is incomplete.
4. Heart rate, breathing rate and breath volume.
5. The sum of all the reactions in a cell or the body.