

Photosynthesis and limiting factors

Revision notes · Photosynthesis as the source of food and biomass, its equation, the limiting factors, the light intensity core practical and the inverse square law.

For Edexcel GCSE Biology 1BI0 and Combined Science 1SC0. **Triple only** is not in Combined Science. **Higher tier** is only on the Higher paper.

Photosynthesis and limiting factors Spec 6.1-6.6

Photosynthetic organisms as producers Spec 6.1

Plants and algae carry out photosynthesis. They use light energy to make glucose from simple inorganic substances, so they do not need to eat other organisms.

This makes photosynthetic organisms the **main producers of food** and therefore of **biomass**. Biomass is the mass of living material. The glucose a plant makes is used to build new cells, so it becomes part of the plant's biomass.

Every food chain starts with a producer. Animals cannot make their own food, so they get their biomass, and the energy stored in it, by eating plants or algae, or by eating other animals that have eaten them.

Producer	An organism that makes its own food. Photosynthetic organisms (plants and algae) are the main producers of food and biomass.
Biomass	The mass of living material, which in a plant is made from the glucose it produces by photosynthesis.

Common mistake: Do not write that plants 'take in food' from the soil. Plants make their own food by photosynthesis. The roots take in water and mineral ions, not food.

The photosynthesis reaction Spec 6.2

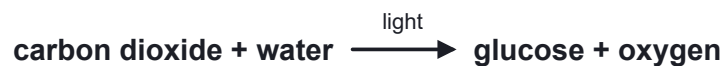
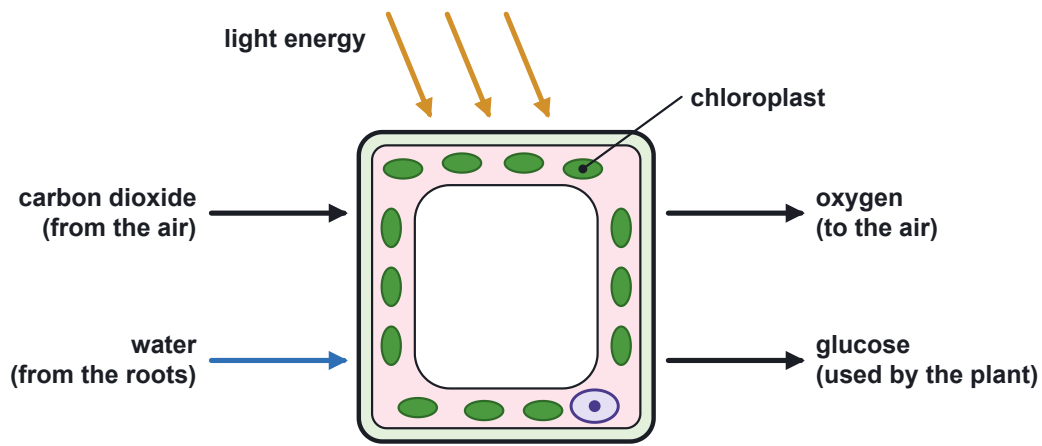
Photosynthesis in plants and algae is an **endothermic reaction**. This means it takes in energy from the surroundings. The energy comes from **light**, which is absorbed by the green pigment chlorophyll in the chloroplasts.

The light energy is used to react **carbon dioxide** and **water** to produce **glucose** and **oxygen**.

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



Where the raw materials come from and where the products go		
Substance	Reactant or product	Source or fate
Carbon dioxide	Reactant	Diffuses into the leaf from the air
Water	Reactant	Absorbed from the soil by the roots and carried to the leaf in the xylem
Glucose	Product	Used for respiration, or to build new plant material (biomass)
Oxygen	Product	Diffuses out of the leaf into the air



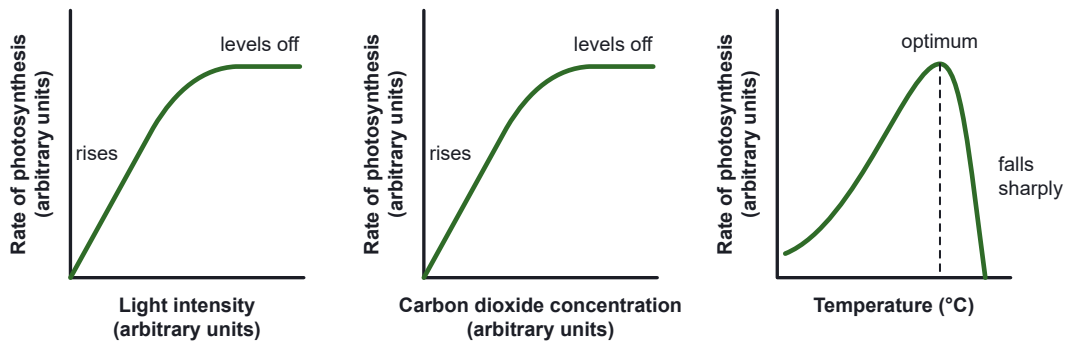
Photosynthesis in a leaf cell: **light energy** is absorbed by chlorophyll in the chloroplasts.

Exam tip: Light is the energy source, not a reactant, so it does not go in the word equation as a substance. Write 'in the presence of light' or put 'light energy' above the arrow.

Limiting factors Spec 6.3

A **limiting factor** is something that is in short supply, so it stops the rate of a process from going any faster. The rate of photosynthesis can be limited by **temperature**, **light intensity** and **carbon dioxide concentration**.

How each factor limits the rate of photosynthesis		
Factor	Effect on rate	Why
Light intensity	Rate increases as light intensity increases, then levels off	Light provides the energy for the reaction. At low light, the amount of light limits the rate. At high light, another factor is limiting.
Carbon dioxide concentration	Rate increases as concentration increases, then levels off	Carbon dioxide is a reactant. At low concentration, there is not enough of it. At high concentration, another factor is limiting.
Temperature	Rate increases up to an optimum temperature, then falls sharply	Photosynthesis is controlled by enzymes. A higher temperature gives more collisions between enzymes and substrates. Above the optimum the enzymes are denatured, so the rate falls.



Light intensity and carbon dioxide: the rate **rises, then levels off**. Temperature: the rate rises to an optimum, then **falls sharply**.

On a graph, the rate rises while the factor on the x-axis is the limiting factor. Where the line goes flat, that factor is no longer limiting and something else is. Reading a graph this way is a common exam question.

Maths skill: Plot the rate on the y-axis and the factor you changed on the x-axis. To describe a graph, state the trend, then quote data from it, for example the values where the line levels off.

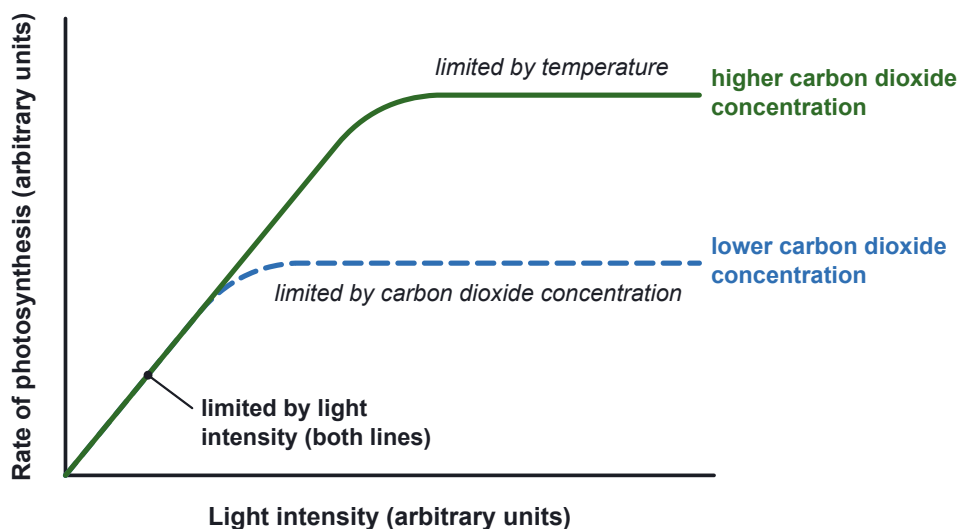
Common mistake: Do not write that the enzymes are 'killed' at high temperature. Enzymes are not alive. They are denatured, because their active site changes shape.

Interactions between limiting factors Spec 6.4 Higher tier

Temperature, light intensity and carbon dioxide concentration all act at the same time. At any moment, the rate of photosynthesis is limited by whichever factor is **in shortest supply**.

To explain a graph, find where the line levels off. At that point the factor on the x-axis is no longer limiting. Something else is, and it will be a factor that is not being increased.

- If a graph for light intensity has two lines, the line with a higher plateau has more of the other factor, for example a higher carbon dioxide concentration or a better temperature.
- The two lines are the same at low light intensity because light is the limiting factor for both.
- At the plateau, the lower line is limited by the factor that differs between the two conditions.
- If increasing one factor makes no difference to the rate, a different factor is limiting.



Where each line levels off, light is no longer limiting. The **factor in shortest supply** sets the plateau.

Exam tip: Name the factor in your answer. 'Another factor is limiting' will not get the mark. Say which one and give the reason, for example 'carbon dioxide concentration is limiting because the rate rises when it is increased'.

Core practical: light intensity and photosynthesis Spec 6.5

You can investigate how **light intensity** affects the rate of photosynthesis using an aquatic plant such as pondweed. The light intensity is changed by moving a lamp to different distances from the plant.

1. Cut a piece of pondweed and place it in a boiling tube or beaker of water with a little sodium hydrogencarbonate, which supplies carbon dioxide. Place a heat shield (a clear container of water) between the lamp and the plant, or use an LED lamp, to keep the temperature constant.
2. Place a lamp a measured distance from the pondweed, for example 10 cm, using a ruler. Switch off or block other light sources.
3. Leave the pondweed for a couple of minutes to adjust to the new light level.
4. Count the number of bubbles of oxygen released from the cut end of the stem in one minute. (You can instead collect the gas and measure its volume.)
5. Repeat at different distances, for example 20, 30, 40 and 50 cm.
6. Repeat each distance at least three times and calculate a mean rate.

Variables		
Type	Variable	How it is controlled or measured
Independent	Light intensity	Changed by changing the distance between the lamp and the plant
Dependent	Rate of photosynthesis	Measured as the number of bubbles per minute, or the volume of gas collected per minute
Control	Temperature	Heat shield or water bath, and a lamp that gives out little heat
Control	Carbon dioxide concentration	Same amount of sodium hydrogencarbonate in the water each time
Control	The plant	Same piece of pondweed, with the same length of stem, for every distance

Typical results: the further the lamp is from the plant, the lower the light intensity, so fewer bubbles are released per minute. Plot the mean rate (y-axis) against the distance or light intensity (x-axis).

Higher tier

Because light intensity is inversely proportional to the square of the distance, plotting the rate against $1 \div \text{distance}^2$ should give a straight line while light is the limiting factor.

Counting bubbles is not very accurate because bubbles can be different sizes. Collecting the gas and measuring its volume gives better data.

Core practical: Safety: keep the mains lamp and its cable away from the water, and do not touch a hot lamp. Controlling temperature matters because a lamp placed close to the plant also warms the water, which would change the rate.

Exam tip: 'Light intensity' is the independent variable, not 'the distance'. Say that the distance is how you change the light intensity.

Light intensity, distance and the inverse square law Spec 6.6 Higher tier

When light is the limiting factor, the rate of photosynthesis is **directly proportional** to light intensity. If the light intensity doubles, the rate doubles.

The light intensity falls as the distance from the light source increases. So the rate of photosynthesis is **inversely proportional** to the distance from the light source. The exact relationship is the **inverse square law**: light intensity is proportional to $1 \div \text{distance}^2$, so the rate is too.

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

- Double the distance: the intensity becomes $1 \div 2^2 =$ one quarter.
- Treble the distance: the intensity becomes $1 \div 3^2 =$ one ninth.
- Halve the distance: the intensity becomes $1 \div (\frac{1}{2})^2 =$ four times as much.

Using the inverse square law

A pondweed 10 cm from a lamp releases 36 bubbles per minute. Light is the limiting factor. Predict the number of bubbles per minute when the lamp is moved to 30 cm.

1. The distance has increased by a factor of $30 \div 10 = 3$.
2. Light intensity is proportional to $1 \div \text{distance}^2$, so the intensity falls by a factor of $3^2 = 9$.
3. The rate is directly proportional to light intensity, so the rate also falls by a factor of 9.
4. New rate = $36 \div 9 = 4$ bubbles per minute.

Answer: 4 bubbles per minute

Maths skill: The rule only works while light is the limiting factor. Very close to the lamp, another factor such as carbon dioxide concentration or temperature takes over, and the rate stops increasing.

Quick check

1. Why are photosynthetic organisms called the main producers of biomass?
2. Why is photosynthesis described as endothermic?
3. Name the three limiting factors of photosynthesis.
4. In the light intensity core practical, how is the light intensity changed?

Quick check answers

Photosynthesis and limiting factors

- 1 . They make their own food (glucose) by photosynthesis, which builds biomass that other organisms feed on.
- 2 . It takes in energy from the surroundings, in the form of light.
- 3 . Temperature, light intensity and carbon dioxide concentration.
- 4 . By changing the distance between the lamp and the pondweed.