Rate of photosynthesis

4.4.1.2 · Bioenergetics · revision notes

The factors that affect the rate of photosynthesis, the idea of a limiting factor, and the required practical on light intensity. Higher tier adds graphs with two or three factors, the inverse square law for light intensity, and whether it pays to add heat, light or carbon dioxide in a greenhouse. Expect graphs, calculations and practical questions, including 6-mark method answers.

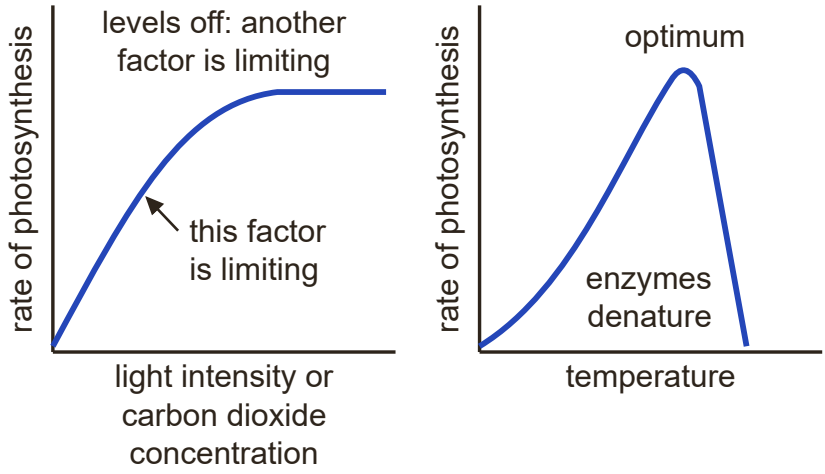
Key facts

- Factors: temperature, light intensity, carbon dioxide concentration, amount of chlorophyll
- Rate = volume of oxygen (or number of bubbles) ÷ time
- Sodium hydrogencarbonate solution supplies carbon dioxide in the pondweed practical
- Grade 7+ only Relative light intensity = 1 ÷ d^2 (arbitrary units)
- Limiting factor = the factor in shortest supply, which stops the rate increasing
- Too hot: enzymes denature, so the rate falls
- Grade 7+ only $\text{light intensity} \propto \frac{1}{d^2}$: double the distance → ¼ of the light intensity
- Grade 8+ only Extra heat, light or CO_2 is worth it only if the value of the extra crop is more than the extra cost

Notes

Factors and limiting factors

- Four factors affect the rate of photosynthesis: **temperature**, **light intensity**, **carbon dioxide concentration** and the **amount of chlorophyll**.
- A **limiting factor** is the one in shortest supply. It holds the rate back: increasing it increases the rate, but increasing the other factors does not.
- Light intensity and carbon dioxide: the rate rises as the factor increases, then levels off when a different factor becomes limiting.
- Temperature: photosynthesis is controlled by enzymes. The rate rises up to an optimum (molecules move faster and collide more), then falls steeply as the enzymes denature.

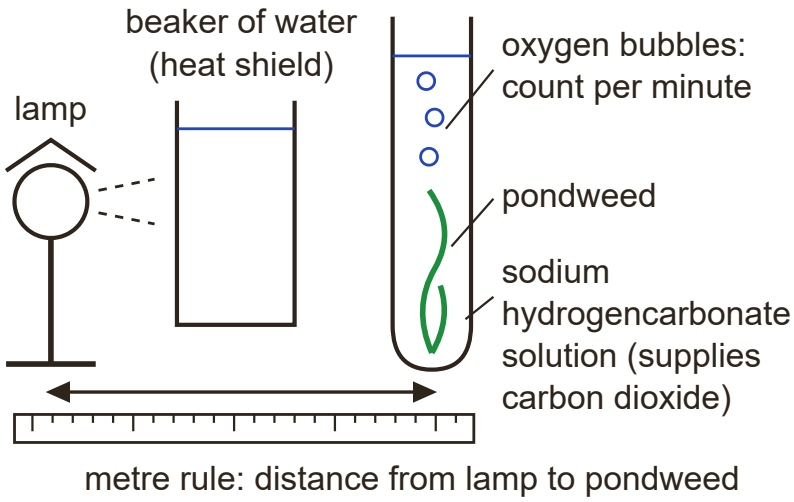


Left: the rate levels off when another factor limits it. Right: past the optimum, enzymes denature.

- Chlorophyll absorbs the light, so leaves with less chlorophyll (for example, leaves damaged by tobacco mosaic virus) photosynthesise more slowly.

Required practical: light intensity and pondweed

- Put pondweed in a boiling tube of dilute sodium hydrogencarbonate solution, which supplies carbon dioxide.
- Place a lamp 10 cm away, measured with a metre rule, and leave the pondweed a few minutes to adjust.
- Count the oxygen bubbles released in one minute, or collect the gas in an upturned measuring cylinder for a set time.
- Repeat at 20, 30, 40 and 50 cm, three times at each distance, and calculate means.
- Control the temperature (LED lamp, or a beaker of water as a heat shield), the carbon dioxide concentration and the piece of pondweed. Darken the room so the lamp is the only light.
- Rate of photosynthesis = volume of oxygen (or number of bubbles) ÷ time, for example in cm^3 per minute or bubbles per minute.
- Expected result: the closer the lamp, the faster the rate, until another factor becomes limiting.
- Graph: rate on the y-axis, distance or light intensity on the x-axis, a scale using over half the grid, and a smooth curve of best fit.



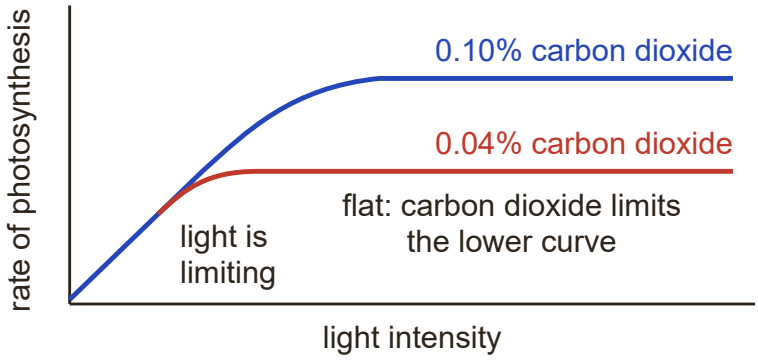
Move the lamp to change the distance, and count the bubbles each time.

Inverse square law and graphs with more than one factor Grade 7+ only

- Light intensity is inversely proportional to the square of the distance from the lamp:

$$\text{light intensity} \propto \frac{1}{d^2}$$

- Double the distance and the light intensity falls to a quarter; triple it and it falls to a ninth.
- On a graph with two or three curves, where the curves rise together the x-axis factor is limiting.
- Where a curve levels off, look at the curve above it: if a higher carbon dioxide concentration or temperature gives a higher rate, that factor was limiting the lower curve.



Where the curves overlap, light is limiting. The gap between the flat parts shows carbon dioxide was limiting the lower one.

Greenhouse economics Grade 8+ only

- Growers can add heat, light and carbon dioxide to a greenhouse to increase the rate of photosynthesis, and so the yield.
- A paraffin heater releases carbon dioxide as well as heat.
- Adding more of a factor that is not limiting wastes money, because the rate does not increase.
- It is only worth it if the value of the extra crop is greater than the extra cost: the aim is the maximum rate while still making a profit.

How to answer each type of question

Describe and explain a rate graph with one factor

2 to 3 marks | Grade 5

1. Describe the rising part, then the flat part, quoting values from the graph.
2. Explain the rising part: the factor on the x-axis is limiting.
3. Explain the flat part: name another factor that is now limiting.

Example. The graph shows how the rate of photosynthesis of a plant changes with light intensity.



Explain the shape of the graph.

Model answer. From 0 to 6 units, light intensity is the limiting factor (1), so increasing it increases the rate of photosynthesis (1). Above 6 units another factor, such as carbon dioxide concentration or temperature, is limiting, so the rate stops increasing (1).

6-mark: describe the required practical

6 marks **Grade 6**

1. Say what you change and how: the distance of the lamp, measured with a metre rule.
2. Say what you measure and how: bubbles counted, or volume of oxygen collected, in a set time.
3. Give at least two control variables and how you would control them.
4. Include repeats and a mean, and how you would turn the results into a rate.

Example. Describe a method to investigate how light intensity affects the rate of photosynthesis of pondweed. [6 marks]

Model answer. Marked by levels. A Level 3 answer (5 to 6 marks) is a clear, logical method that includes most of these points: put a piece of pondweed in a boiling tube of sodium hydrogencarbonate solution; place a lamp 10 cm away, measured with a metre rule; leave for 5 minutes to adjust; count the bubbles released in 1 minute or collect the oxygen in an upturned measuring cylinder; repeat with the lamp at 20, 30, 40 and 50 cm; do three repeats at each distance and calculate a mean; keep the temperature constant with an LED lamp or a heat shield; use the same pondweed and the same concentration of sodium hydrogencarbonate; darken the room.

Calculate using the inverse square law

2 to 3 marks **Grade 7**

1. Find how many times further away the lamp is: new distance ÷ old distance.
2. Square that number to find how many times smaller the light intensity is.
3. If the rate is proportional to light intensity, divide the rate by the same number.

Example. A lamp is moved from 12 cm to 36 cm away from some pondweed. Light intensity is inversely proportional to the square of the distance.
(a) How many times smaller is the light intensity at 36 cm?
(b) At 12 cm the rate was 45 bubbles per minute. Assume light intensity is the only limiting factor and the rate is directly proportional to it. Predict the rate at 36 cm.

Model answer.

(a) 36 ÷ 12 = 3 (1); 3^2 = 9, so 9 times smaller (1)

(b) 45 ÷ 9 = 5 bubbles per minute (1)

Identify the limiting factor from data with two factors

2 marks each | Grade 7

1. Name one factor as your answer.
2. Give a reason from the data: does increasing the x-axis factor raise the rate, and does changing the other factor make a difference?

Example. The table shows the rate of photosynthesis of a plant at 20 °C, in arbitrary units.

Light intensity (arbitrary units)	2	4	6	8
Rate at 0.04% carbon dioxide	10	18	20	20
Rate at 0.10% carbon dioxide	10	20	28	30

(a) Which factor limits the rate at a light intensity of 2? Give a reason.
(b) Which factor limits the rate at 0.04% carbon dioxide and a light intensity of 8? Give a reason.

Model answer.

(a) Light intensity (1); the rate is the same at both carbon dioxide concentrations, so carbon dioxide is not limiting (1)

(b) Carbon dioxide concentration (1); increasing light intensity from 6 to 8 does not increase the rate, but at 0.10% carbon dioxide the rate is higher (1)

Evaluate greenhouse data

3 to 4 marks | Grade 8

1. For each option, convert the extra yield into money: extra yield × price.
2. Subtract the extra cost to find the extra profit or loss.
3. Give a clear conclusion that uses your numbers, and link it to limiting factors if you can.

Example. A grower sells lettuces for £2.00 per kg. The table compares two changes with an unheated greenhouse with normal air.

Change	Extra yield (kg per week)	Extra cost (£ per week)
Heating	40	50
Adding carbon dioxide	15	35

Use the data to evaluate which, if either, the grower should use. [4 marks]

Model answer. Heating: 40 × 2.00 = £80 of extra lettuces (1), so £80 − £50 = £30 extra profit per week (1). Carbon dioxide: 15 × 2.00 = £30, so £30 − £35 = a loss of £5 per week (1). The grower should heat the greenhouse but not add carbon dioxide; carbon dioxide was probably not the main limiting factor (1).

Don’t lose marks

- Writing 'more light, so the plant grows more' without saying that light is the limiting factor and the rate of photosynthesis increases.
- Explaining a flat part of a graph with 'the plant is at its maximum'. Name another factor that is now limiting, such as carbon dioxide concentration or temperature.
- Saying high temperatures 'kill' the enzymes. Say the enzymes are denatured.
- Higher tier: halving the light intensity when the distance doubles (inverse proportion) instead of dividing it by four (inverse square).
- In the practical, forgetting that a hot lamp warms the water, so temperature changes as well as light intensity.
- Higher tier: comparing extra kilograms directly with extra pounds. Turn the extra yield into money first.

More tips

Memory tricks

- Limiting factor = the weakest link: improve it and the rate rises; improve anything else and nothing changes.
- Graph rule: rising line → the x-axis factor is limiting; flat line → something else is limiting.
- Inverse square: distance × 2 → intensity ÷ 4; distance × 3 → intensity ÷ 9; distance ÷ 2 → intensity × 4.
- Sense check: moving the lamp further away must give a lower light intensity and a lower (or equal) rate.
- The temperature curve has the same shape as an enzyme activity curve (rise, peak at the optimum, steep fall) because enzymes control photosynthesis.

Exam technique

- When asked which factor is limiting, name one factor and back it up with evidence from the graph or table.
- In 6-mark method answers, cover what you change, what you measure, at least two control variables and repeats. Write the steps in order.
- Use the full terms: 'light intensity', not just 'light', and 'carbon dioxide concentration', not 'more air'.
- Higher tier: show every step of an inverse square calculation (distance ratio, square it, then divide) so you can gain method marks.
- Higher tier: in greenhouse questions, work out profit = value of extra crop − extra cost for every option before you give your conclusion.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Name the factors affecting photosynthesis rate**
Temperature, light intensity, carbon dioxide concentration and the amount of chlorophyll.

Grade 4 — **Explain what a limiting factor is**
The factor in shortest supply, which stops the rate of photosynthesis increasing; raising it raises the rate.

Grade 4 — **Describe the light intensity required practical**
Put pondweed at different distances from a lamp and count the oxygen bubbles, or measure the volume of oxygen, in a set time.

Grade 5 — **Explain the effect of temperature**

The rate rises up to an optimum temperature, then falls quickly because the enzymes that control photosynthesis denature.

Grade 5 **Explain a one-factor rate graph**
Where the line rises the factor on the x-axis is limiting; where it levels off another factor has become limiting.

Grade 7 **Find the limiting factor on multi-factor graphs**
Compare curves: if raising the second factor raises the curve, that factor was limiting the lower curve.

Grade 7 **Use the inverse square law**
Light intensity is proportional to 1 ÷ distance^2, so doubling the distance gives a quarter of the light intensity.

Grade 8 **Evaluate greenhouse costs against extra yield**
Use data to decide whether the value of the extra crop from adding heat, light or carbon dioxide is more than the extra cost.

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