Photosynthesis

Limiting factors & measuring the rate of photosynthesis

Factors affecting photosynthesis

There are three factors which can affect the rate of photosynthesis: **temperature, carbon dioxide concentration and light intensity**. Each of these factors can limit the rate of photosynthesis if any are below their optimal level. If more than one factor is below their optimal level, only one factor will act as a limiting factor and directly affect the rate of photosynthesis. Usually it is the factor that is furthest away from its optimal level.

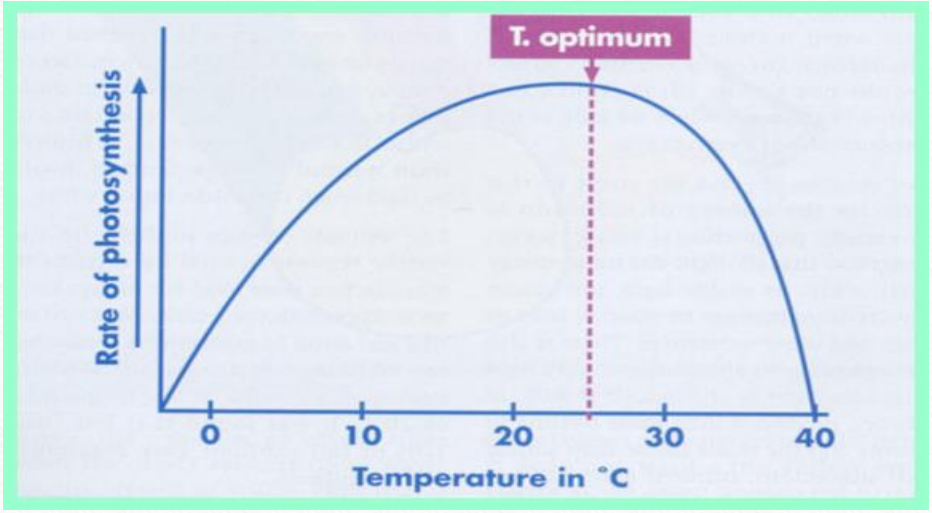
The Factors that limit the increase in the rate of photosynthesis are called limiting factors.

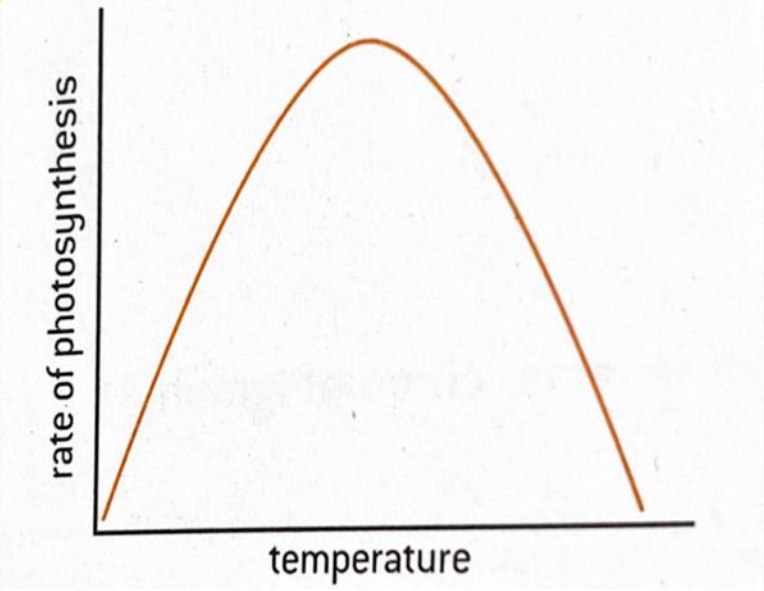
So at any point in time if one of the three factors is in short supply, this factor will be the limiting factor. Only a change to the limiting factor will increase or decrease the rate of photosynthesis. Changing the other two will have no effect.

1. Temperature

At low temperatures the rate of photosynthesis is very low. **As the temperature increases, the rate of photosynthesis increases until the maximum rate of reaction is reached at the 'optimum' temperature.**

Above the optimum temperature the rate of photosynthesis starts to decrease very rapidly as enzymes lose their shape and denature.



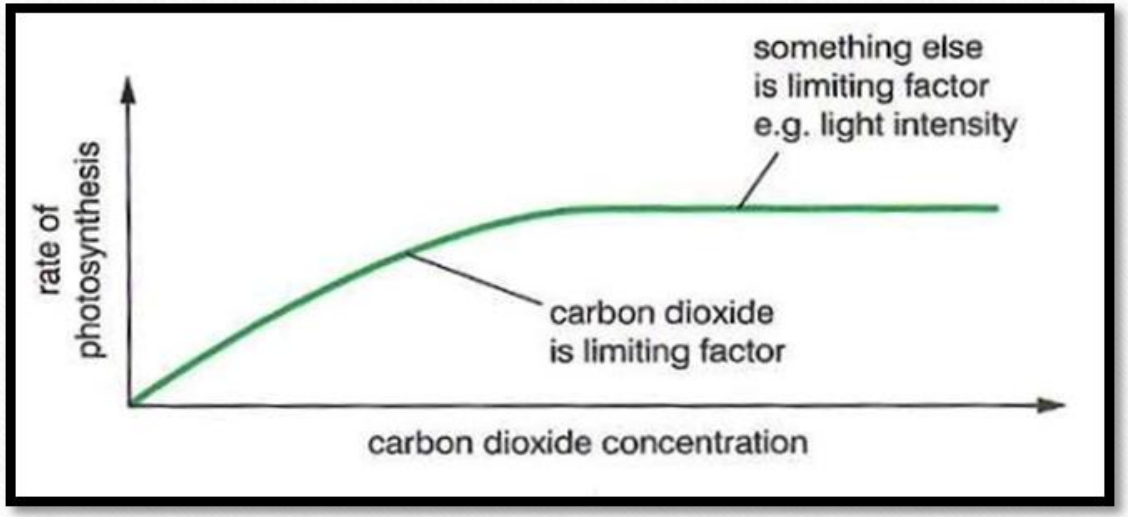


2. Carbon dioxide :

CO_2 is needed for the formation of carbon compounds in the light-independent reaction. At low CO_2 the rate of photosynthesis is low. As the CO_2 concentration increases, the rate of photosynthesis increases.

At high levels of CO_2 there is no further increase in photosynthesis and the rate reaches a plateau. **(remains constant)**

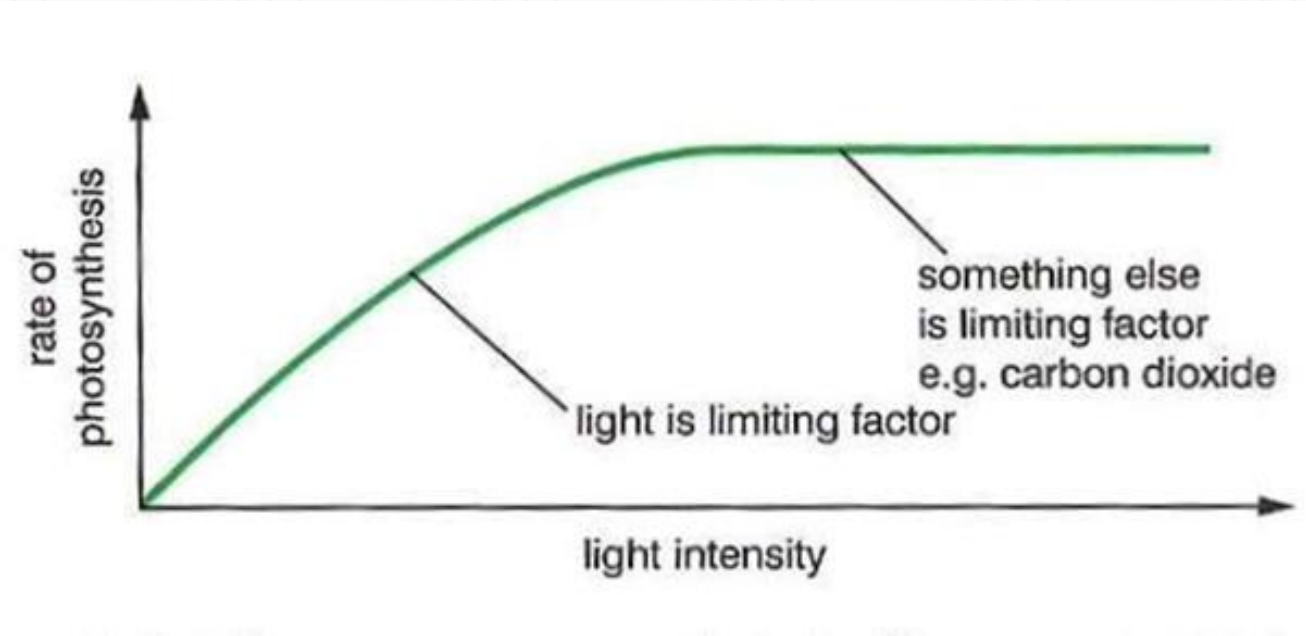
The concentration of carbon dioxide in the Earth's atmosphere varies between 0.03% and 0.04% that's why it has a major influence on the rate of photosynthesis since **it is the substrate that is in shortest supply.**



3. Light intensity :

Light is used to produce ATP and split water by photolysis to form H+ ions and oxygen. At low light intensity, the rate of photosynthesis is low. As light intensity increases the rate of photosynthesis increases until a certain point where further increase in light intensity will no longer increase the rate of photosynthesis. The rate of photosynthesis levels off and becomes constant .

No more light can be absorbed by the available chloroplasts which are filled already.



Experiments for measuring the rate of photosynthesis:

Factors Affecting the rate of photosynthesis		
Light Intensity	Concentration of Carbon dioxide	Temperature

If you want to study effect of changing one Factor you must ensure that the other factors are kept CONSTANT→ Fair Test

Note :

When designing an experiment it is essential to control the relevant variables. Consider the following variables (and how they relate to photosynthesis experiments :

- ***Independent variable- this is the variable that you change (I change).***
- ***Dependent variable-this is the variable that you measure.***
- ***Control variables--these are the variables that you must control so they do not impact the result of your experiment.***

Remember that you need to identify which limiting factor you plan to investigate--this will be your independent variable. The other limiting factors must be controlled and kept constant.

Procedure:

https://scratch.mit.edu/projects/133475453/embed

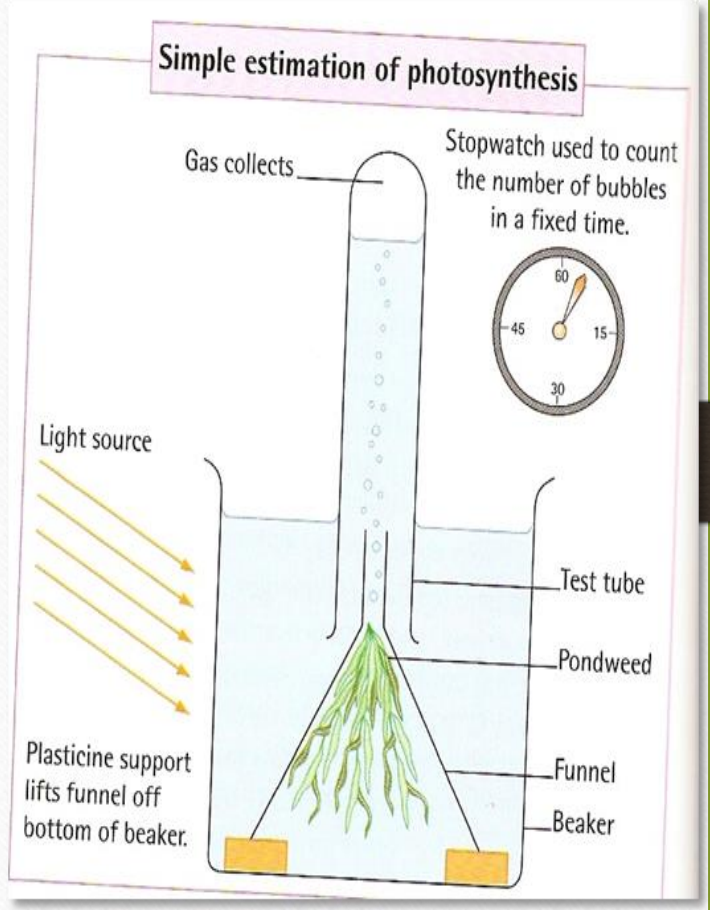
1) Fill a beaker with water and add about 5cm^3 saturated hydrogencarbonate solution (this is added to maintain a good supply of carbon dioxide)

2) Select a pondweed and place it as shown in the apparatus below.

3) Switch on a bench lamp and bring it close to the beaker, after two or three minutes, bubbles should appear from the cut end of the stem.

4) When the bubbles appear steadily, switch off the lamp and observe the change in the bubble production (it will decrease).

5) Now place the lamp about 25 cm away from the beaker. Switch on the lamp and move the lamp 10 cm from the jar and count the bubbles again.



Practical skills: Investigating the limiting factors of photosynthesis

You can use the apparatus in figure 11 to measure the effect of temperature on the rate of photosynthesis. You can place this apparatus in water baths of varying different temperatures, and calculate the rate of reaction by measuring the volume of oxygen gas produced in a period of time. Keep in mind the control variables that must be kept constant such as the light intensity in the room, carbon dioxide concentration and the volume of water used. Remember that you can investigate one factor at one time.

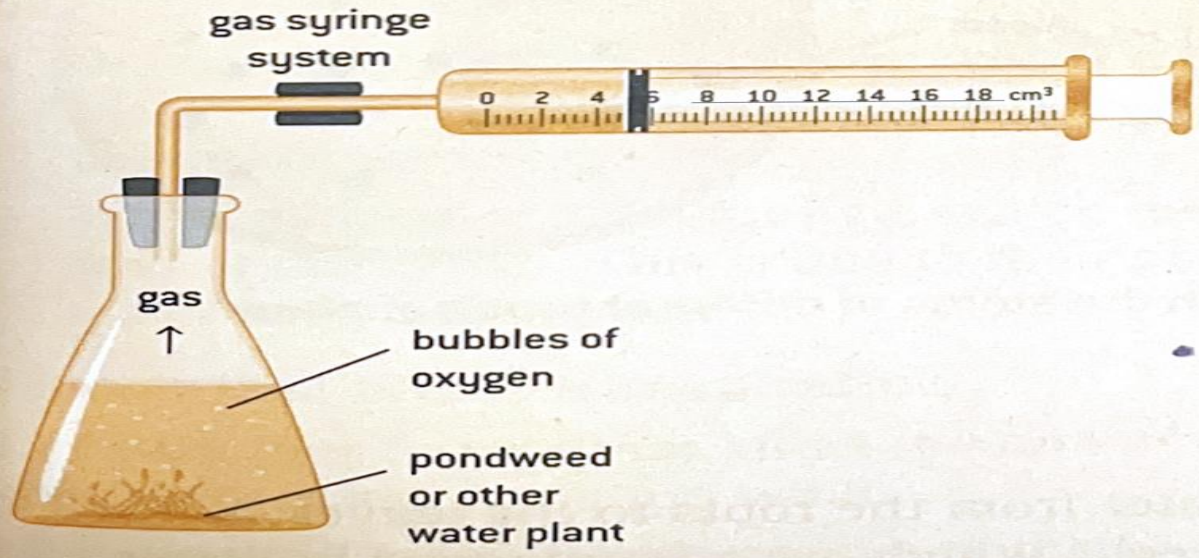


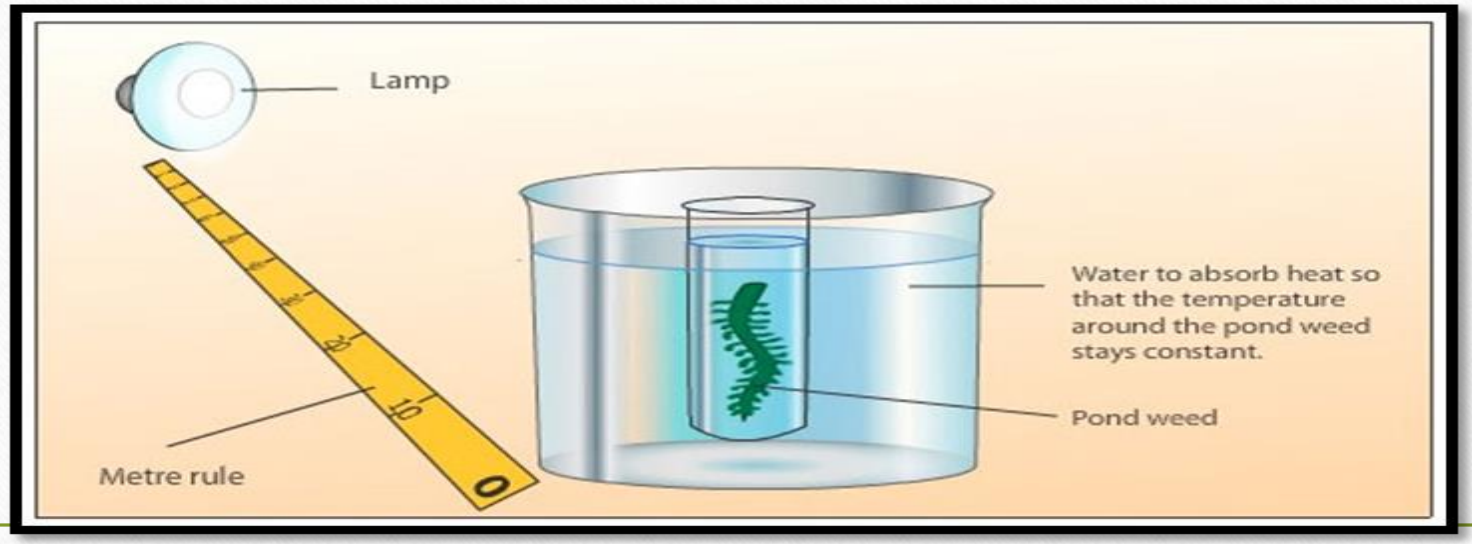
Figure 11. Measuring the effect of temperature on the rate of photosynthesis

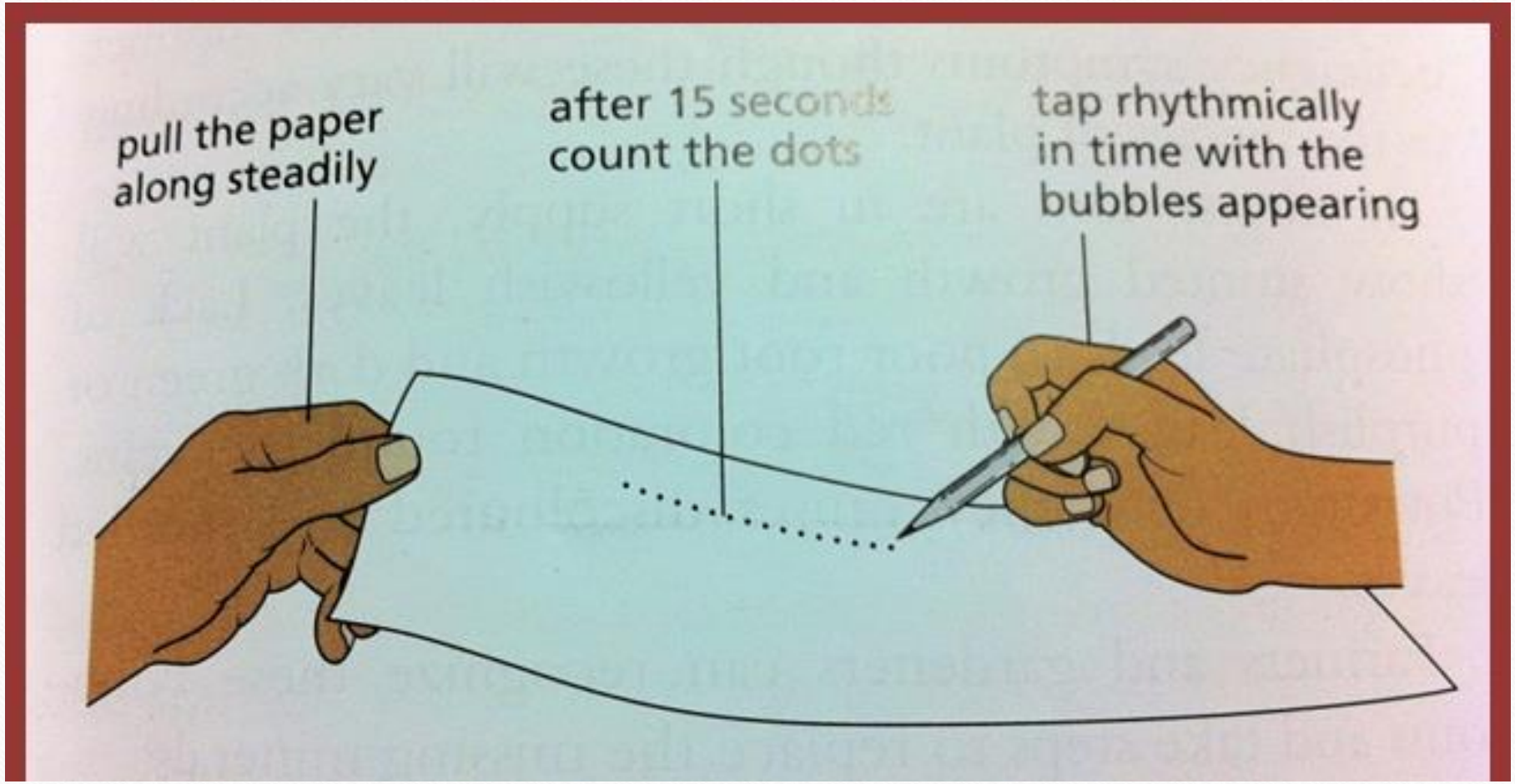
If the bubbles appear too rapidly, try tapping a pencil on a sheet of paper every time you see a bubble appearing in the jar for 15 seconds just as described in the figure below:

The bubbles appear because the plant is photosynthesizing and producing oxygen gas, the gas bubbles in water, so the appearance of bubbles indicate that photosynthesis is taking place.

Every time you get the lamp closer to the plant, light intensity increases, the rate of photosynthesis increase and the rate of oxygen production increases as well.

As the light intensity increases photosynthesis increases, BUT up to a certain point, beyond this point the rate will remain steady (constant) due to the influence of limiting factors.




pull the paper
along steadily
after 15 seconds
count the dots
tap rhythmically
in time with the
bubbles appearing

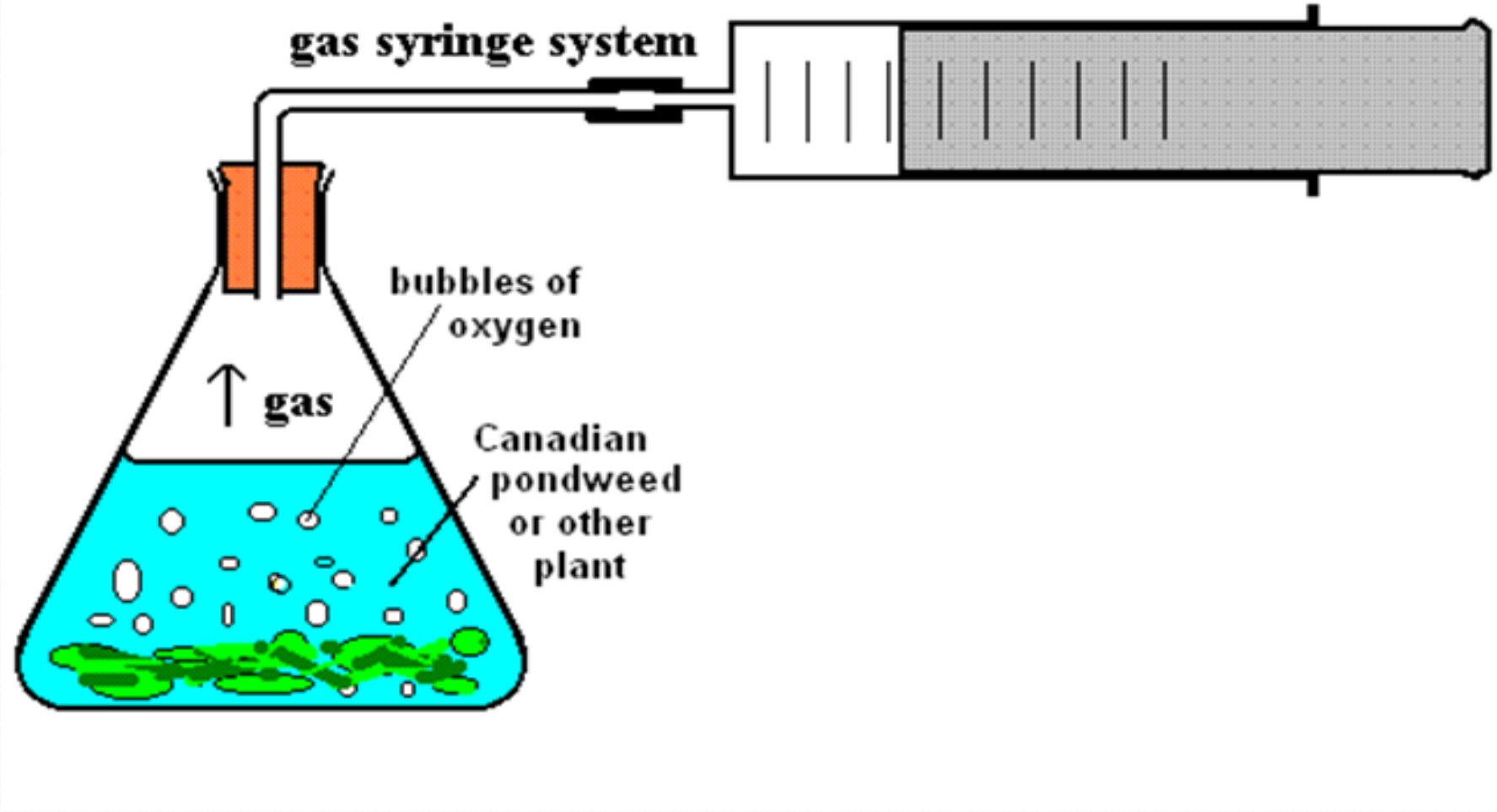
How to estimate rate of bubbling?

Assuming that the bubbles do not increase in size (they all have the same size) → some bubbles might be larger (they contain more oxygen) than other bubbles.

Rate of Photosyntheis = Rate of bubbling equals:

$$\frac{\text{Number of dots counted on the paper}}{\text{Time}}$$

A more accurate method , using a gas syringe → Measuring the Volume of Oxygen gas produced per unit of time instead of estimating number of bubbles :


gas syringe system
bubbles of oxygen
gas
Canadian pondweed or other plant

Experiment 2 : The effect of carbon dioxide concentration on the rate of photosynthesis https://scratch.mit.edu/projects/133475453/embed

This apparatus is set up to investigate the effect of carbon dioxide concentration on the rate of photosynthesis of a pond plant

Five similar pieces of pond plant and **five different concentrations** of sodium hydrogen carbonate solution which provides carbon dioxide.

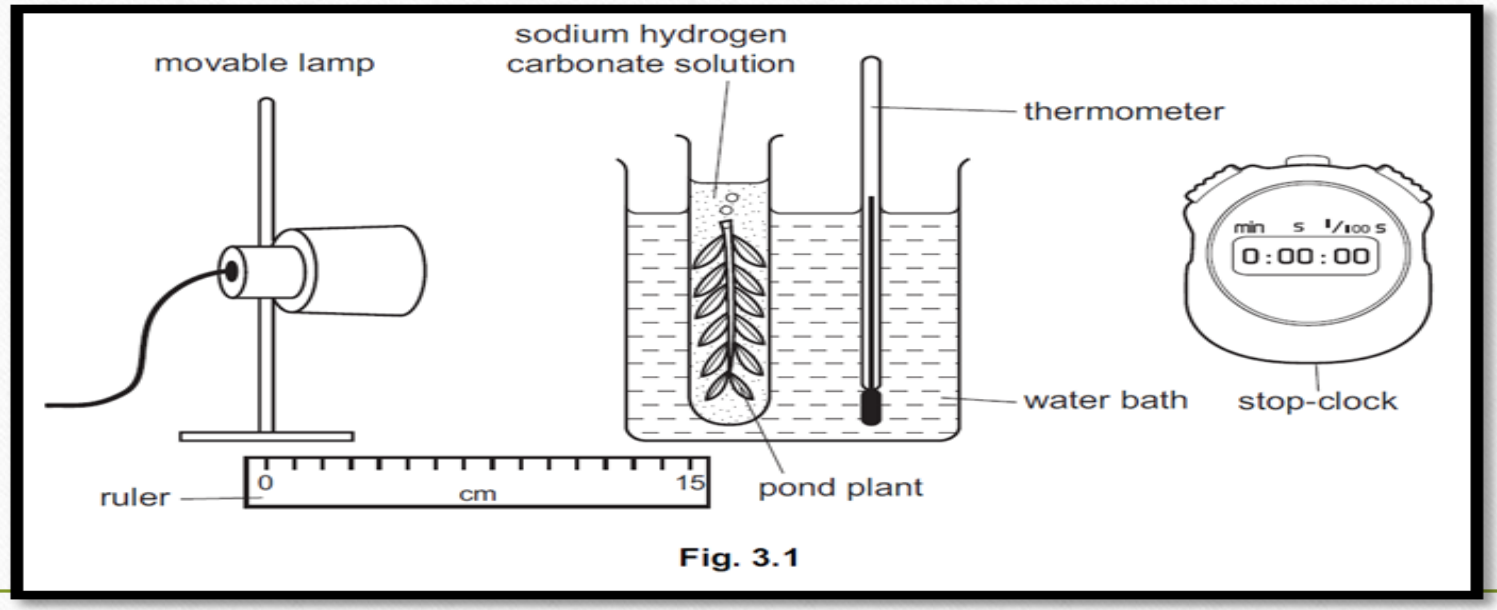


Fig. 3.1

The number of bubbles produced by the plant over a period of five minutes were counted and recorded as shown below:

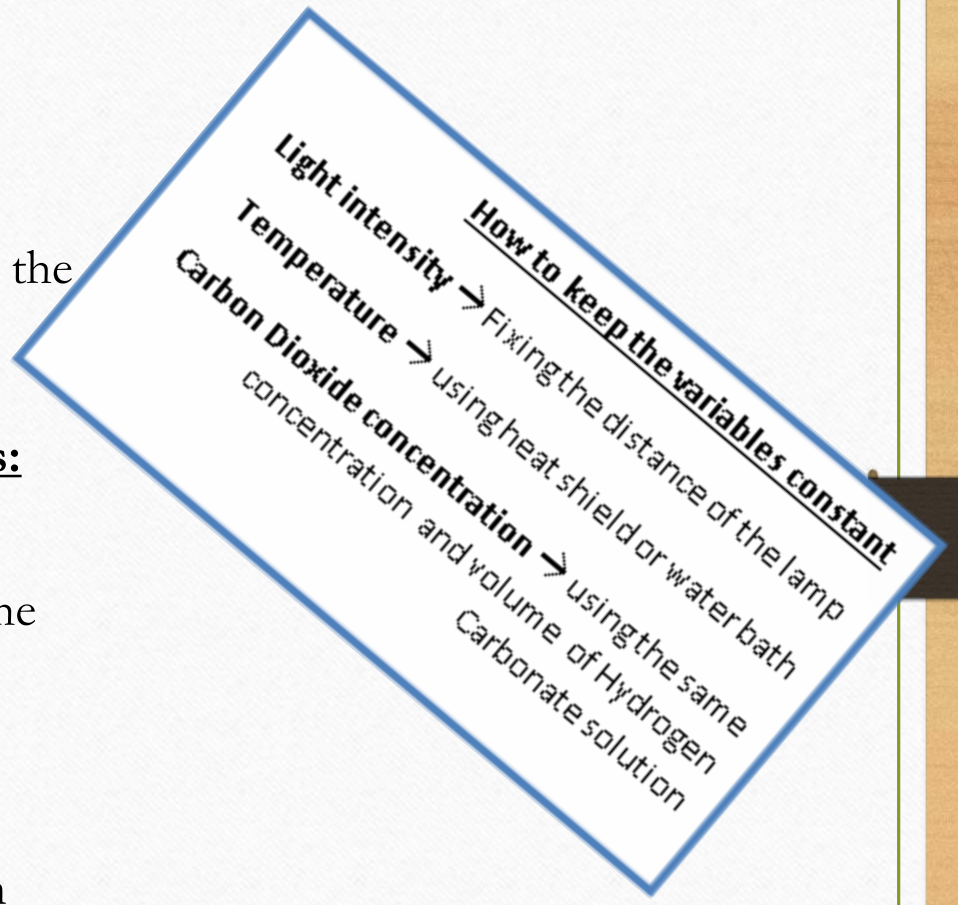
carbon dioxide concentration / %	rate of photosynthesis / number of bubbles per minute			
	1st	2nd	3rd	mean
0	3	2	4	3
0.1	6	4	5	5
0.2	12	7	11	
0.3	14	15	16	15
0.4	18	22	21	20
0.5	19	23	21	21

Results and conclusions:

As the concentration of carbon dioxide increases, the rate of photosynthesis increases because carbon dioxide is needed for photosynthesis, the increase in the rate then becomes constant due to the effect of LIMITING **FACTORS**

Since we are studying the effect of one factor on the rate of photosynthesis we MUST keep the other factors constant that is:

- Temperature must be **kept constant**
- Light intensity should be kept constant by **fixing the distance** of the light source from the plant
- Same volume of **hydrogen carbonate** solution
- Same type (species) of plant used
- Same number , mass and size of leaves used during the investigation
- Every time you add a different concentration of hydrogen carbonate it **should be kept for the same time**



Maths skills: Measuring the rate of reaction

You can measure the rate of any reaction in two ways.

1. Measuring the rate at which a product is formed. For example, to measure the rate of photosynthesis, you can measure the rate at which oxygen is produced. This can be done in several ways, such as:

- Count bubbles of oxygen produced from a pondweed.
- Collect oxygen produced and measure its volume.
- Use an oxygen probe to find the oxygen concentration.

2. Measuring the rate at which a reactant is used up. For example, to measure the rate of photosynthesis, you can measure the rate at which carbon dioxide is being used up. This can be done in several ways:

- When carbon dioxide is absorbed from water, the pH of the water rises and this can be measured with pH indicators or pH meters.
- Use a carbon dioxide probe to find the carbon dioxide concentration.

Once the amount of product or reactant is measured in a specific time, the rate can be calculated using one of the two methods:

a) $$\text{Rate} = \frac{\text{amount* of product}}{\text{time}}$$

*where amount refers to volume, concentration or number of bubbles.

b) from a graph (figure 10):

$$\text{Rate} = \text{slope} = \frac{\text{change in amount of product (change in } y\text{)}}{\text{change in time (change in } x\text{)}}$$

Worked example: Calculating the rate of reaction

1. Calculate the rate of reaction using the graph in figure 10.

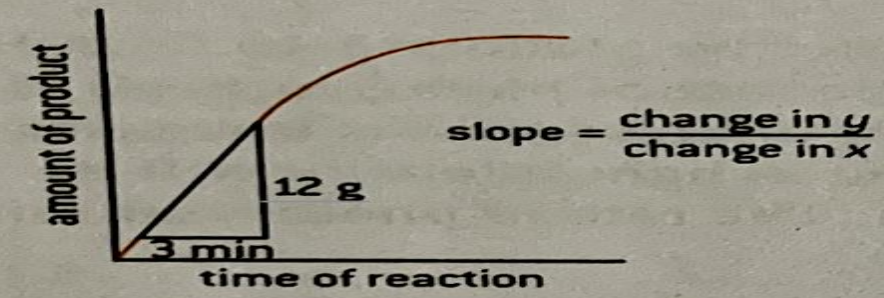


Figure 10. Calculating the rate of reaction

Solution

Use the formula below to find the value of the slope:

$$\text{Rate of reaction} = \text{Slope} = \frac{\text{change in } y}{\text{change in } x}$$

$$\text{Rate of reaction} = \text{Slope} = \frac{12\text{ g}}{3\text{ min}} = 4\text{ g min}^{-1}$$

2. Calculate the rate of photosynthesis knowing that 10 cm^3 of oxygen gas was collected in a syringe in 4 minutes.

Solution

Use the formula below to calculate rate of photosynthesis:

$$\text{Rate of photosynthesis} = \frac{\text{volume of } O_2 \text{ produced}}{\text{time}}$$

$$\text{Rate of photosynthesis} = \frac{10\text{ cm}^3}{4\text{ min}} = 2.5\text{ cm}^3\text{ min}^{-1}$$

Extra example ; Discs
https://www.youtube.com/watch?v=3bOMR5Zaw3Q

Question

Calculate the rate of photosynthesis knowing that 15 oxygen gas bubbles were collected in three minutes..

15 / 3 = 5 bubbles per minute