2.8 PHOTOSYNTHESIS

Photosynthesis is the process used by plants and blue greens to produce all their own organic substances, using only light energy and simple inorganic substances. Photosynthesis makes both carbon and energy available to living organisms and produces the oxygen in the atmosphere.

- Photosynthesis involves the conversion of light energy to chemical energy (ATP)
- **White light** from the sun is composed of a range of wavelengths (colors)
- Chlorophyll is the main photosynthetic pigment (substances that absorb light)
- The structure of chlorophyll allows it to absorb some colors or wavelengths of light better than others. Red and blue light are absorbed better than green
- The green light that chlorophyll can not absorb is reflected giving the green color to the plant leaves
- Light energy absorbed by chlorophyll is used to split water molecules (**photolysis**) to give oxygen and hydrogen and to produce ATP
- ATP and hydrogen (derived from the photolysis of water) are used to fix carbon dioxide in order to make organic molecules, whereas oxygen is released as a waste product
- The conversion of carbon in a gas to carbon in solid compounds is called **carbon fixation**
- Hydrogen from photolysis and energy from ATP are involved in the carbon fixation

Equation to summarize photosynthesis:

$$CO_2 + \text{water} + \text{light energy} \rightarrow \text{glucose} + O_2$$

Photosynthesis and the atmosphere

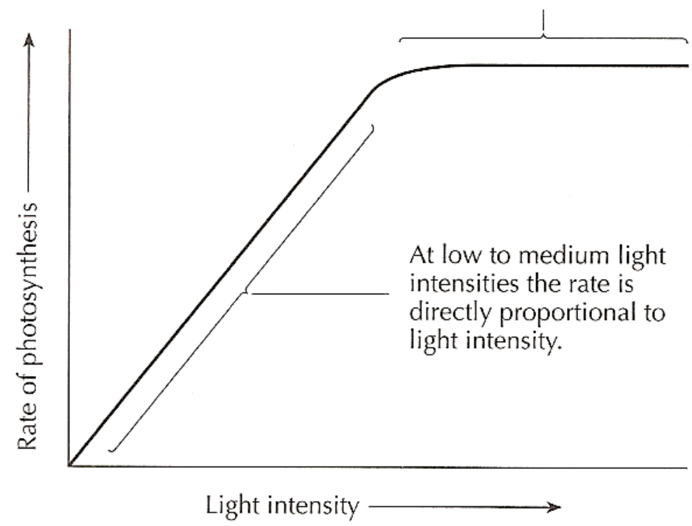
- The first organisms to release O_2 from photosynthesis were bacteria (3.5 billion years ago).
- The oxygen level started rising to 2 % between 2.4 – 2.2 billion years ago.

→ This caused dissolved iron in the oceans to precipitate as iron oxide. It sank to the oceanic benthos, forming deposits of rock called **banded iron formations.**

- With the evolution of multicellular algae and terrestrial plants, photosynthesis increased, raising O_2 levels to about 30 % (750 million years ago).
- Nowadays O_2 level is approximately 20 %.

Factors limiting the rate of photosynthesis

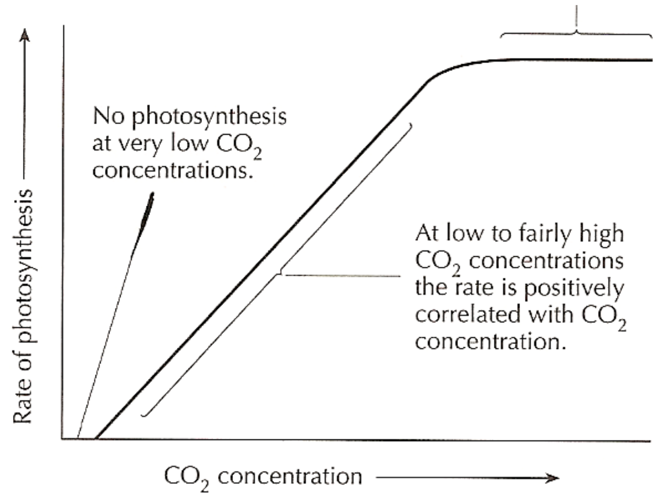
a) Effect of light intensity



At very low light intensities, the rate of photolysis, hence the production of oxygen is limited.

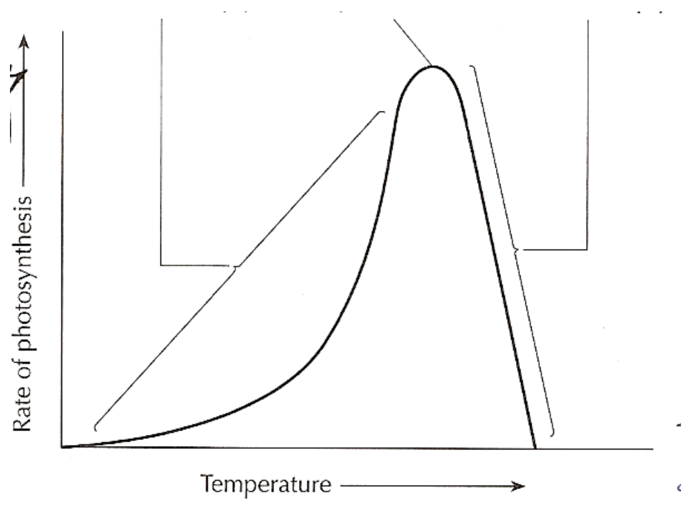
Light energy is also used for the production of ATP, which is needed for the conversion of CO_2 into glucose. Therefore, low light intensity will limit the production of sugars and other organic substances needed.

b) Effect of CO_2 concentration



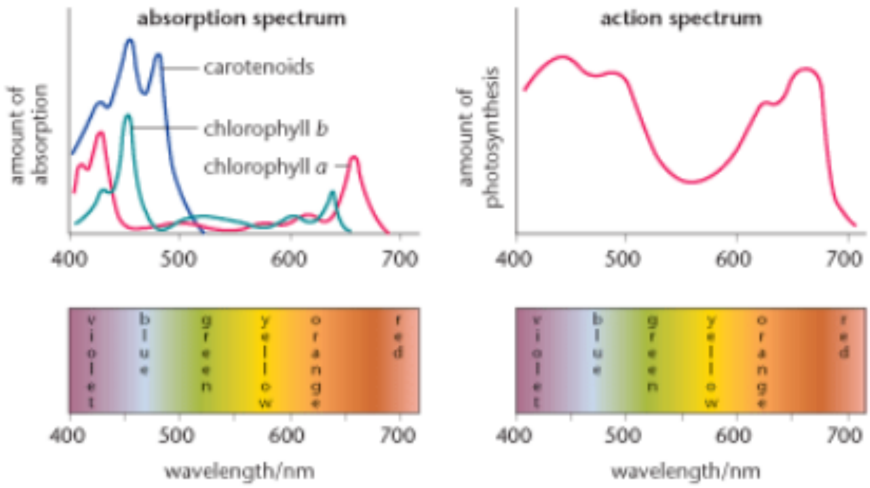
Below 0.1 % CO_2 the enzyme rubisco used to fix CO_2 is not effective, so there is no net photosynthesis. More CO_2 is required to successfully bind to the active site of rubisco. If the concentration increases, then more ATP can be used to increase photolysis and therefore oxygen production.

c) Effect of temperature



At temperatures below 5 ^{0}C, the enzymatic activity drops. At temperatures above 30 ^{0}C rubisco becomes more and more ineffective. Hence, temperature can become a limiting factor with a low rate use of ATP, low photolysis and low O_2 production

<u>Absorption</u> spectrum of chlorophyll and <u>Action</u> spectrum in photosynthesis:



a) A **spectrum** is a range of wavelengths of electromagnetic radiation. The spectrum of <u>visible light</u> is the range of wavelengths from 400 nm to 700 nm.

The same range of wavelengths is used in photosynthesis, because photosynthetic pigments do not absorb other wavelengths.

Chlorophyll (a and b) which is the main photosynthetic pigment, absorbs red and blue light more effectively, whereas green is reflected.

b) The **action spectrum** shows the maximum photosynthetic rate, which is in blue light (highest) and red light (a bit lower). The efficiency is the percentage of light of a wavelength that is used in photosynthesis.

In class activity:

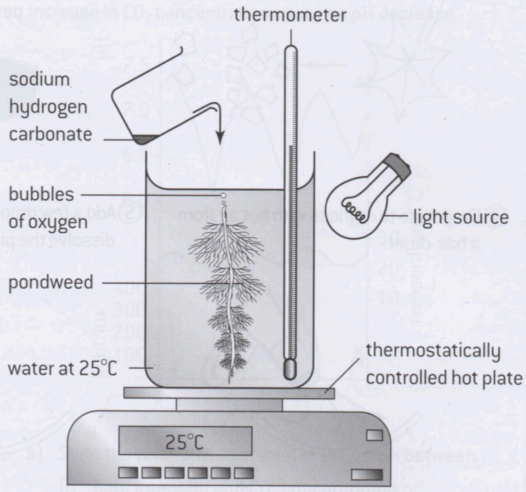
Investigating limiting factors

DESIGNING EXPERIMENTS TO INVESTIGATE LIMITING FACTORS

Processes such as photosynthesis are affected by various factors, but usually just one of these factors is actually limiting the rate at a particular time. This is the factor that is nearest to its minimum and is called the **limiting factor**. The three possible limiting factors for photosynthesis are **temperature**, **light intensity** and **carbon dioxide concentration**.

These principles should be remembered when designing an experiment to investigate the effect of a limiting factor on photosynthesis:

1. Only one limiting factor should be investigated at a time – this is the **independent variable**.
2. A suitable range for the independent variable should be chosen, from the lowest possible level, to a level at which the factor is no longer limiting.
3. An accurate method should be chosen for measuring the rate of photosynthesis. This is the **dependent variable** and is usually a measure of oxygen production per unit time.
4. Methods must be devised for keeping all factors constant, apart from the independent variable. These are the **control variables**. This part of experimental design is essential so it is certain that changes in the rate of photosynthesis are due only to the factor being investigated (the independent variable). Of the three factors temperature, light intensity and carbon dioxide concentration one will be the independent variable in the experiment and the other two will be control variables.



Limiting factor	Method of varying the factor	Suggested range	Controlling the factor
Temperature	Place pondweed in water in a thermostatically controlled water bath or on a hot plate to vary the temperature	5°C to 45°C in 5 or 10°C intervals	Set the thermostat at 25°C and keep it there throughout the experiment
Light intensity	Move light source to different distances and measure light intensity with a lux meter (light intensity = 1/(distance^2))	4, 5, 7, 10 and 14 cm and no light gives a good range of intensities	Keep the light source at a constant distance, such as 5 cm
Carbon dioxide concentration	Start with boiled, cooled water (no CO_2) then add measured quantities of $NaHCO_3$ to increase the CO_2 concentration	0 to 50 mmol dm^{-3} in 10 mmol dm^{-3} intervals	Add enough $NaHCO_3$ to give a high CO_2 concentration (50 mmol dm^{-3})