PHOTOSYNTHESIS

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PHOTOSYNTHESIS

Photosynthesis is the process by which cells synthesise organic compounds from inorganic molecules in the presence of sunlight. This process requires a photosynthetic pigment (**chlorophyll**) and can only occur in certain organisms (plants, algae, cyanobacteria). In plants, photosynthesis occurs within the **chloroplast**.

$$6\,CO_2 + 12\,H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6\,O_2 + 6\,H_2O$$

Carbon dioxide + *Water* → *Glucose* + *Oxygen* + *Water*

PIGMENTS

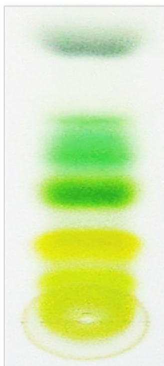
In photosynthetic organisms, the absorption of light is mediated by specific pigment molecules. Each of these pigment molecules contains electrons at discrete and specific energy levels. These electrons absorb light at **specific wavelengths** and become energised. The energy from these excited electrons is harnessed by the cell to make chemical energy (ATP). In plants, the main photosynthetic pigment is *chlorophyll*, but other pigments are also used. These pigments are clustered into photosystems to optimise light absorption.

CHROMATOGRAPHY

Chromatography is an experimental technique that allows for the separation of pigments. The pigments are dissolved in a fluid (mobile phase) and passed through a static material (stationary phase). The different pigments will travel at different speeds, causing them to separate. A retardation factor is calculated and the value is used to identify the pigment.

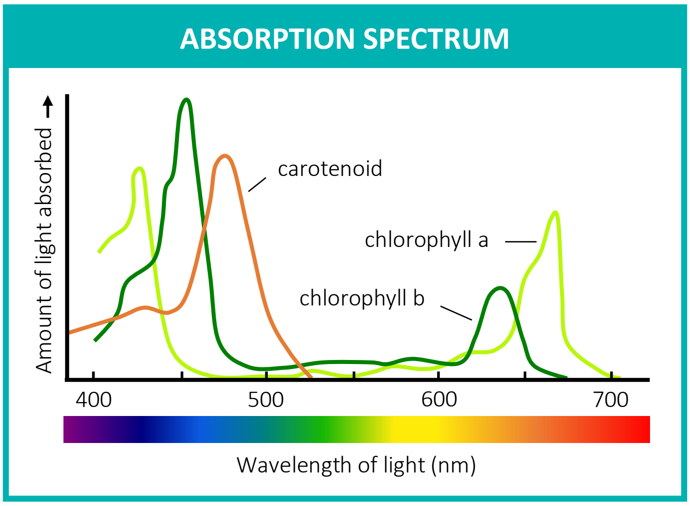
- Rf value = distance the pigment travels (mm) ÷ distance the solvent travels (mm)

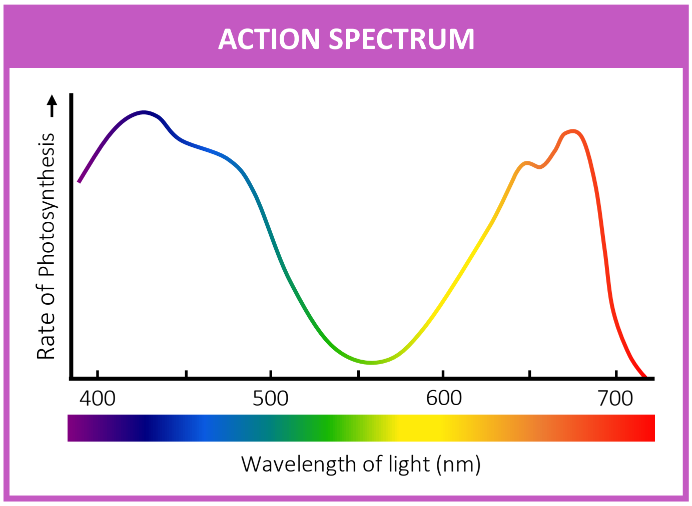
The Rf value represents a ratio and hence can never exceed a value of 1. Chromatography experiments will often use paper as the static material and acetone as an organic solvent.



LIGHT ABSORPTION

The electromagnetic spectrum comprises the full range of all types of radiation energy. All photosynthetic organisms will absorb wavelengths within the visible region of this spectrum (white light: 400 – 700 nm). Chlorophyll absorbs red and blue light most effectively, while green light is reflected. This is because green light is too energetic to be used efficiently by the plant, while blue light is best able to penetrate the depths of water (reflecting the likely aquatic origins of living organisms). The amount of light absorbed by pigments at any given wavelength is represented by the absorption spectra, while the rate of photosynthesis at each wavelength is shown by the action spectra. For both spectra, the overall trend is generally comparable.



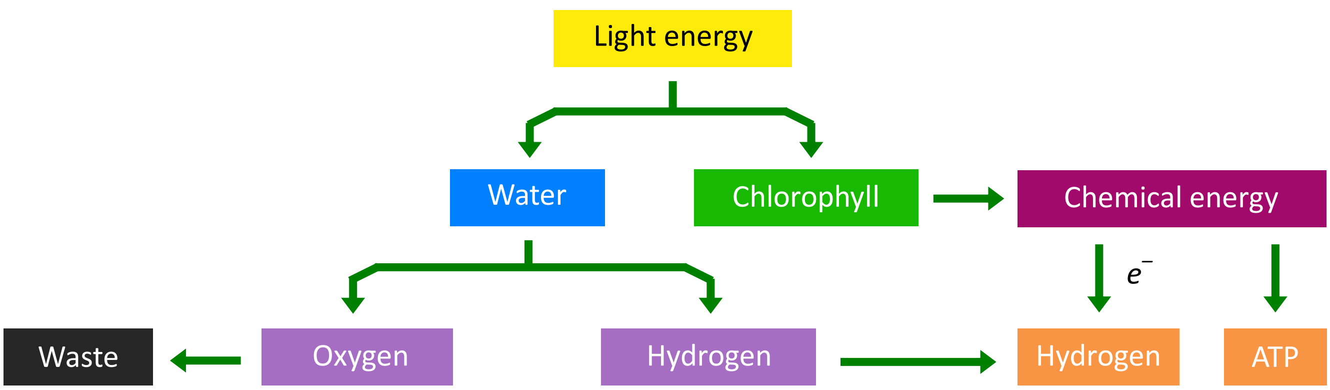


STAGES OF PHOTOSYNTHESIS

The process of photosynthesis involves two stages: the light dependent reactions and the light independent reactions (Calvin cycle). The light dependent reactions function to convert light energy into chemical energy (ATP) and the light independent reactions then use this chemical energy to synthesise organic compounds. In plants, these reactions occur within a specialised organelle called the chloroplast (found in leaf tissues).

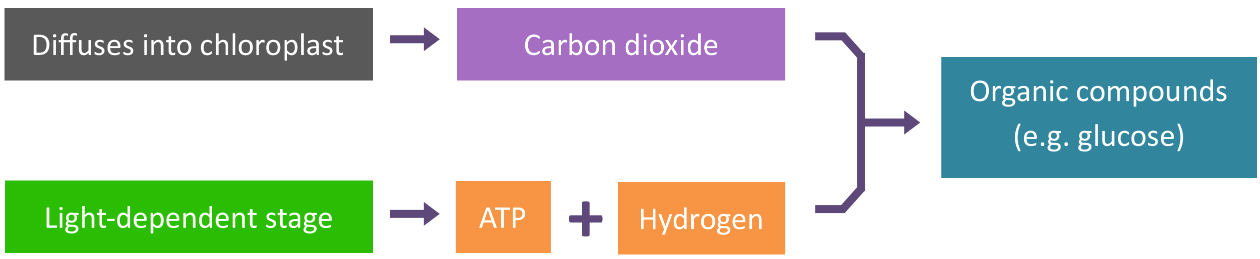
1. LIGHT DEPENDENT REACTIONS

The light dependent reactions require light and occur within the **thylakoids** (or grana) of the chloroplast. Light is absorbed by photosynthetic pigments (such as chlorophyll), resulting in the excitation of electrons. The energised electrons then transfer this energy to **ATP**. Simultaneously, light energy breaks down water molecules *(photolysis)* into **oxygen** and **hydrogen**. The oxygen gas is released as a waste product, while the hydrogen atoms will be used (along with ATP) as an input for the light independent reactions (Calvin cycle). The oxygen gas is released from tiny pores on the underside of the leaf called **stomata** (singular = stoma).



2. LIGHT INDEPENDENT REACTIONS

The second stage of photosynthesis involve the light independent reactions (also called the **Calvin cycle**). This stage uses the chemical energy (ATP) that was produced in the light dependent stage to synthesise organic compounds (carbohydrates). Molecules of **carbon dioxide** are combined with hydrogen (from the splitting of water) to form organic molecules like glucose. This anabolic process is catalysed by the enzyme **Rubisco** and uses the chemical energy from ATP to form the covalent bonds required for carbon fixation. The inputs of the Calvin cycle are carbon dioxide, ATP and hydrogen; while the product formed is **glucose**. The light independent reactions are localised to the fluid-filled region of the chloroplast (called the **stroma**).



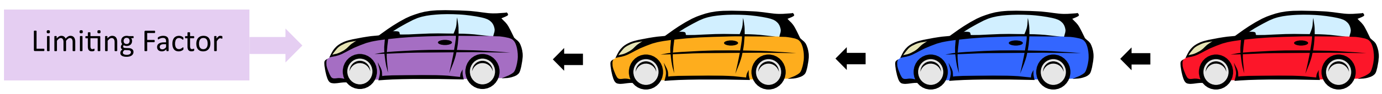
MEASURING PHOTOSYNTHESIS

Metabolic processes can be measured by the rate of input consumption or the rate of output production. In the case of photosynthesis, the process can therefore be measured by a variety of factors, including:

- **Oxygen production:** Oxygen gas is a by-product of photosynthesis and can be measured either via the rate of bubble formation (for plants in solution) or via a **pressure change** in an enclosed container
- **Carbon dioxide uptake:** Carbon dioxide interacts with water to form an acidic solution (carbonic acid) that lowers pH. Hence, the amount of CO_2 production can be measured in solution via a **pH indicator**.
- **Biomass:** Organic compounds contribute to the total dry weight of an organism. Hence, the production of glucose can be indirectly measured according to the change in **plant mass** (grams per dry weight).

LIMITING FACTORS

Photosynthesis is a complex metabolic process that involves several distinct reactions with specific inputs. The law of limiting factors states that when a chemical process depends on **multiple** essential conditions being favourable, the rate of reaction will be limited by the factor that is nearest to its minimum value. Photosynthetic rate is influenced by numerous conditions; including temperature, light and carbon dioxide.



In a convoy, the slowest car (limiting factor) sets the speed at which the cars will travel (reaction rate)

CARBON ENRICHMENT EXPERIMENTS

Human activities (such as deforestation and combustion of fossil fuels) are increasing carbon dioxide levels (~400 ppm). Higher levels of carbon dioxide typically increase plant growth and maturation, however excessive concentrations can cause plant damage. Experiments involving **enclosed** greenhouses and free air carbon dioxide enrichment (**FACE**) are being undertaken as a way of predicting rates of photosynthesis and plant growth in the future. Enclosed greenhouses allow for greater control of extraneous variables (such as sunlight and water exposure), while FACE experiments can incorporate natural conditions like heat changes.