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Topic: Bioenergetics

Photosynthesis

For us, it is a very good thing that photosynthesis evolved. The process of photosynthesis, carried out by plants and algae, is at the foot of every food chain. It captures light energy from the sun and uses it to produce chemical potential energy – we can make use of chemical potential energy: that's what our food contains! Since photosynthesis involves the transfer of light energy to chemical potential energy in cells, it is an **endothermic** reaction.

The reaction can be shown in these equations:

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$$

$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

The oxygen released by photosynthesis has built up in the atmosphere over millions of years – again, good news for us, since we require oxygen for respiration, just like all living organisms.

Photosynthesis occurs in the **chloroplasts** of plant cells. Simple molecules like carbon dioxide and water can't be used as food. However, glucose and other more complex molecules can – so you can think of photosynthesis as a reaction that produces food.

Using the glucose from photosynthesis

Obviously, plants didn't evolve simply for our benefit. They carry out photosynthesis to meet their own needs. The glucose produced in photosynthesis can be:

- Used in <u>respiration</u> in the cells of the plant/algae
- Converted into **starch** for <u>storage</u>. Starch is good for storage as it is *insoluble*, so it doesn't affect the osmosis occurring in the plant, unlike glucose.
- Used to produce **fats or oils (lipids)** for <u>storage</u>. This is particularly noticeable in seeds and nuts.
- Used to produce **cellulose**, which is a component of the cell wall. Cellulose strengthens the cell wall.
- Used to produce **amino acids**, which in turn are used to <u>synthesise proteins</u> (in the ribosomes). To produce amino acids, plants also require **nitrates** from the soil.

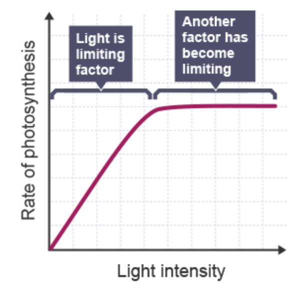
Simple lab tests can be used to identify starch, glucose and protein. Starch turns **iodine** a blue-black colour. Glucose turns **Benedict's solution** orange-red when heated with it. Proteins turn **Biuret's reagent** purple.

Key Terms	Definitions
Photosynthesis	The endothermic reaction that transfers light energy to chemical potential energy. In it, simple molecules (CO_2 and H_2O) are converted into more complex molecules (glucose) that can be used for food.
Nitrates	Ions containing nitrogen and oxygen. These are found in the soil; plants need nitrates to produce amino acids.
Rate	As always, rate means how quickly something happens.
Light intensity	The amount/strength of light. Use this term instead of 'amount of light'.
Chlorophyll	The green pigment in leaves that absorbs light for photosynthesis. Chlorophyll is found in **chloroplasts**.

The rate of photosynthesis

The following factors affect the rate of photosynthesis:

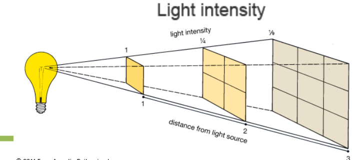
- **Temperature**: because all chemical reactions speed up as the temperature increases. However, as photosynthesis is controlled by enzymes, too high a temperature prevents photosynthesis (more on this in the metabolism section).
- **Carbon dioxide concentration**: the higher the concentration of CO_2 in the air, the more is available for photosynthesis, so the rate increases as concentration increases.
- **Light intensity**: as the equation shows, photosynthesis requires light energy. So, the higher the light intensity, the higher the rate of photosynthesis.
- **Amount of chlorophyll**: more chlorophyll means more light can be absorbed. Some leaves have pale parts, as you may have seen, due to a lack of chlorophyll. The rate of photosynthesis is obviously much lower in the pale parts compared to the deep green parts.



HT: at any given time, any one of these factors may be **limiting** the rate of photosynthesis. This can be shown on graphs – see example. When it comes to light intensity, it varies with distance according to an *inverse square law*:

$$\text{light intensity} = \frac{1}{\mathit{distance\ from\ source}^2}$$

In commercial growing of plants (e.g. tomatoes in a greenhouse), the conditions are optimised to maximise the rate of photosynthesis and obtain the highest profit.



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Respiration

Photosynthesis produces chemicals (like glucose) that can be used as food by all living organisms. In **respiration**, the chemical potential energy stored in food molecules is released through **oxidation** reactions (where oxygen from the air reacts with the food molecules). The energy released allows living cells to do **work**.

As you know, doing work means transferring energy. The kinds of work done by cells and organisms includes:

- Chemical reactions to build larger molecules from smaller ones. E.g. making proteins such as enzymes.
- Movement. E.g. movements of our body are possible due to muscle contractions. This requires energy from respiration.
- Keeping warm. This is an example of homeostasis: using energy from respiration to maintain body temperature at a set point (37^{o}C).

There are two types of respiration: **aerobic** and **anaerobic**.

Aerobic vs. anaerobic respiration

Aerobic respiration occurs when oxygen is used in the reaction. It is shown by these equations:

glucose + oxygen → carbon dioxide + water

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

This reaction releases energy that can be used by organisms, as described above. Compared to anaerobic respiration, aerobic respiration releases much more energy.

Anaerobic respiration occurs when there is insufficient oxygen available for complete oxidation of the glucose. The reaction that happens is different in animal cells compared to plant and yeast cells.

In *animals*: glucose → lactic acid

In *plants* and *yeast*: glucose → ethanol and carbon dioxide

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Anaerobic respiration releases much less energy than aerobic respiration. In yeast, we call the anaerobic respiration **fermentation**. This is a very useful process: for making bread (the CO_2 makes it rise) and making alcoholic drinks (since ethanol is a type of alcohol).

Key Terms	Definitions
Aerobic	Using oxygen
Anaerobic	Not using oxygen
Oxidation	A reaction with oxygen. In this case, food molecules like glucose reacting with oxygen.
Fatigue	Tiredness. Fatigue in muscles is caused by a build-up of lactic acid, which is produced during anaerobic respiration (when there is insufficient oxygen).
Oxygen debt	After exercise, the lactic acid has built up and caused an **extra** need for oxygen – called the oxygen debt.
Lactic acid	Chemical produced by the incomplete oxidation of glucose (anaerobic respiration).

The response to exercise

During exercise, more energy is required by the body that when resting, due to increased muscle contractions. The body reacts to this increased **demand** for energy:

- The heart rate, breathing rate, and volume of each breath all increase. Together, these increase the amount of **oxygenated blood** reaching the muscles. The oxygenated blood provides the extra oxygen and glucose needed for respiration in muscle cells, to transfer more energy to meet demand.

However, if insufficient oxygen reaches muscles but exercise continues, the muscle cells use **anaerobic respiration** to transfer energy. From the equation, you can see that incomplete oxidation of glucose takes place and **lactic acid** is produced. The lactic acid builds up and causes an **oxygen debt**. The lactic acid building up also causes **fatigue**. Removing the lactic acid after exercise is the cause of the oxygen debt – the oxygen debt is why you breathe deeply after exercise for some time. You are 'repaying' the oxygen debt.

HT: oxygen debt, to be precise, is the amount of extra oxygen needed to react with lactic acid in muscles and remove it from cells. The blood flow through muscles removes lactic acid and transports it to the liver. In the liver, the lactic acid is converted back into glucose. This reaction requires energy, hence the extra need for oxygen (for aerobic respiration to provide that energy).

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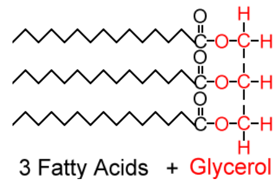
Metabolism

Metabolism is a very big term in biology. It is the name given to collectively describe ALL the chemical reactions happening in a cell or in the whole body. So, respiration in all cells is an example of metabolism, and so is photosynthesis in plants.

Many reactions that cells perform require **energy**, so metabolism relies on energy transferred by respiration. Furthermore, chemical reactions in cells are controlled by **enzymes**. As we're talking about chemical reactions, reactants are used to make products: new molecules are synthesised.

To learn: metabolism includes these reactions:

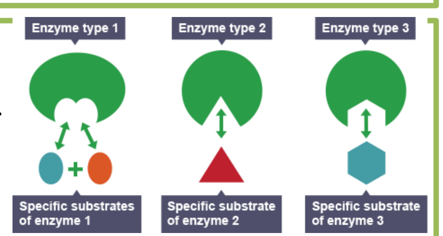
- Conversion of glucose to glycogen (in animals), or to starch or cellulose (in plants).
- Making lipid (fat) molecules from one molecule of **glycerol** and three molecules of **fatty acids** (see diagram).
- In plants, the use of glucose and nitrate ions to make amino acids. These amino acids are then used to synthesise proteins.
- Respiration, both aerobic and anaerobic.
- Breaking down excess proteins into amino acids, then into **urea** for excretion in the urine.



Key Terms	Definitions
Metabolism	The sum of all the chemical reactions in a cell or in the body of an organism.
Enzyme	Large protein molecule that acts as a biological catalyst, dramatically speeding up chemical reactions in organisms.
Synthesis	Making something new. E.g. new molecules in metabolism.
Active site	The part of an enzyme molecule into which the substrate fits – so the shape of the active site is vital.
Substrate	The molecule an enzyme 'works on' to make a product/products.
Optimum	The ideal or perfect condition . Enzymes have an optimum temperature and an optimum pH.

Factors affecting enzymes

Recap your knowledge of how enzymes work from Topic 7.



Enzymes are highly **specific**, meaning that each type of enzyme only causes a reaction by one type molecule. This comes about due to the specific shape of the active site: only one molecule (according to its shape) will fit into the active site. See diagram for an illustration.

Enzymes have an optimum temperature and pH. If the temperature is **too high** (for most enzymes, above about 45ºC), or the pH is **too acidic** OR **too alkaline**, the enzyme **denatures**. This means the active site changes shape. As a result, the substrate no longer fits into the active site, to the enzyme doesn't work any more (see diagram).

This leads to results with enzyme controlled reactions as shown in the graphs. The rate of the reaction catalysed by the enzyme is on the y-axis. The peak represents the optimum temperature/pH. Notice that different enzymes have different optimums – as shown on the pH graph with the two lines.