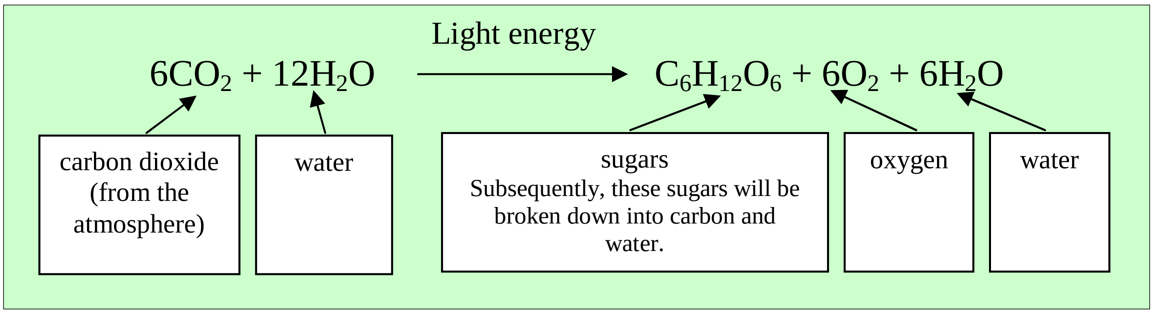
Photosynthesis: fixing carbon and making water

An introduction to photosynthesis

Photosynthesis is the process by which certain organisms—traditionally plants—convert available light energy into carbohydrate energy (i.e. sugars). This process may be conceptualised as an energetic currency converter—organisms take solar energy (an energy format that they cannot directly make use of) and convert it into carbohydrates (an energy format which these organisms can metabolise). Using this process plants, algae, bacteria and other photosynthetic organisms are able to capture light energy and store it in a chemical format, before using this energy to drive cellular processes.

The overall process of photosynthesis consists of a series of chemical reactions, which for green plants may be summarised as follows:



However, photosynthetic processes are more complex than represented above. In fact, photosynthesis occurs via three essential chemical processes. The first process occurs in two sequential parts and is light-dependent, whilst the second process is light-independent and may occur at any time, given that the necessary chemical components are available. The first parts of this process are broadly known as the “light reactions” of photosynthesis, whilst the second part is often referred to as the “dark reaction” of photosynthesis. The third stage refers to the outcomes of photosynthesis, beyond the provision of energy to the primary organism, through to the fixation of carbon within the broader environment and the release of water.

1.a) Solar energy is harvested and processed into energy storage compounds

For photosynthesis to occur, first solar energy must be harvested. In plants and algae photosynthesis takes place within the organelles known as chloroplasts, which house light-absorbing pigments such as chlorophyll. Solar energy is collected when one molecule of pigment absorbs one photon, and as a result loses one electron. Subsequently, a series of electron transfers take place such that the energy-storage protein, NADPH, is produced. Concurrently a second energy-storage protein, ATP, is synthesised.

1.b) Reaction centres are reactivated (i.e.. pigment molecules obtain their lost electron)

This process takes place within a region of the chloroplast named the “reaction centre”. Pigment molecules absorb photons by losing one electron. To continue the process of photon absorption, this electron must be replaced. The reaction centre supplies the replacement electron to each molecule of pigment. In plants, water acts as a source of these electrons and oxygen is produced as a by-product.

2) Stored energy is used to reduce carbon dioxide into carbohydrate sugars

Carbon dioxide is captured from the atmosphere. The reduction of carbon dioxide into glucose sugars (i.e. energy) is synthesised using stored energy, which was produced during the light reactions (ATP and NADPH).

3) Carbon is fixed and water is produced

As glucose is metabolised by an organism, it is broken down into carbon and water.

Summary

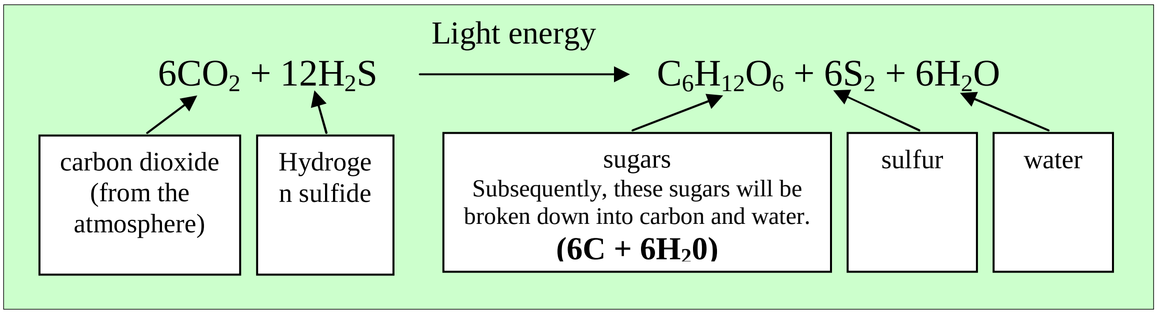
Photosynthesis is commonly understood as a process whereby the **input** of solar energy (photons), carbon dioxide ($6CO_2$) and water ($12H_2O$) results in the **output** of sugars ($C_6H_{12}O_6$), oxygen ($6O_2$) and water ($6H_20$). Ultimately the sugar energy produced by photosynthetic processes will be broken down into carbon (6C) and water ($6H_2O$). Therefore, the **ultimate output** of the photosynthetic process will be oxygen ($6O_2$), carbon (6C) and water ($12H_2O$). As such, photosynthesis results in net increases of environmental levels of oxygen and carbon. Water is necessary for chlorophyll-based photosynthesis to occur; however, the process does not consume water *per se*, the net input and output of water being equal in chlorophyll-based photosynthesis.

Bacterial photosynthesis: a means of water production

The most commonly understood form of photosynthesis is "chlorophyll-based photosynthesis", which occurs within plants, algae and cyanobacteria. Chlorophyll-based photosynthesis is the type of photosynthetic activity that is described by the chemical equation that is typically used to depict photosynthesis.

However, a second form of photosynthesis exists that evolved independently from chlorophyll-based photosynthesis. Bacterial rhodopsin-based photosynthesis (subsequently referred to as "bacterial photosynthesis") is exhibited by the majority of bacteria (with the exception of cyanobacteria, which engages in chlorophyll-based photosynthesis) and differs significantly from the more common form of photosynthesis. Whilst the general processes of photosynthesis are very similar between the two groups, the bacterial process differs in the means by which it replaces electrons in its pigments. Where the more commonly understood form of photosynthesis found in plants and algae requires water to provide missing electrons to photon-absorbing pigments, bacteria do not require the input of water in order to undergo photosynthesis.

Both of these photosynthetic processes result in the output of water and carbon; however, bacterial photosynthesis is unique in that this process actually produces water. Chlorophyll-based photosynthetic reactions require water as a source of the electrons that are necessary for reaction centres to be reactivated. This input of water ($12H_2O$) is balanced by an equivalent output of water, resulting in no net loss of water during photosynthesis. In contrast, bacterial photosynthetic chemical reactions do not require water to reactivate reaction centres; instead, oxidising inorganic materials to derive energy and fix carbon. Examples of the inorganic materials utilised by bacteria instead of water during photosynthesis include hydrogen sulfide (H_2S) in the case of purple and green sulfur bacteria, or hydrogen gas (H_2) in the case of purple non-sulfur bacteria. Despite the fact that bacterial photosynthesis does not require the input of water, this process still results in water production. Consequently, bacterial photosynthesis results in a net increase in water.



Photosynthetic bacteria that do not require water input to start the photosynthetic process are primarily found in soil as well as marine and freshwater environments. These bacteria operate at soil depths of up to 20 cm, accessing non-visible light spectrums such as UV and IR. The major groups of photosynthetic bacteria are: green sulfur bacteria (Family: Chlorobacteriaceae), which utilise hydrogen sulfide as the photosynthetic electron donor (e.g. Genus: *Chlorobium*); purple sulfur bacteria (Family: Thiorhodaceae), which utilise hydrogen sulfide as the photosynthetic electron donor (e.g. Genus: *Chromatium*); and purple non-sulfur bacteria (Family: Athiohodaceae), which are unable to utilise hydrogen sulfide and depend on the availability of simple organic compounds as electron donors (e.g. Genera: *Rhodomicrobium*, *Rhodopseudomonas* and *Rhodospirillum*). Each of these groups of bacteria undergo photosynthesis via the uptake of carbon dioxide and a specific inorganic or organic compound, and produce sugars, water, and a compound corresponding to their electron donor compound. After the resulting sugar energy has been metabolised, the resulting output will be carbon and more water. Consequently, bacterial photosynthesis is a means of water production.

A prerequisite for photosynthesis: phosphorus

Light energy captured during photosynthesis is temporarily stored as ATP and NADPH, which are subsequently used to reduce carbon dioxide into glucose sugars. ATP and NADPH are made available to photosynthetic organisms via two sources: first, they may have been produced by the organism undergoing photosynthesis; and second, they may be present in the environment as an outcome of photosynthesis occurring in other organisms. It is possible that bacterial photosynthesis within the soil may be a significant source of ATP and NADPH used in plants, indicating a symbiotic relationship between these photosynthesizing organisms

Both scenarios require the ready availability of an “elemental ingredient” for the production of ATP and NADPH: phosphorus. Phosphorus is a mineral that exists in solid and dissolved forms within the soil, and is a key component of both ATP and NADPH. Consequently, for photosynthesis to occur, phosphorus must be present and available.

Photosynthesis and the environment: new directions

Photosynthesis is a fundamental biological process that permits plants, algae and bacteria to capture solar energy and to subsequently convert it into a form of energy that they can metabolise. Whilst chlorophyll-based photosynthesis is well understood, the full environmental implications of bacterial photosynthetic processes have not, until now, been fully appreciated. **Bacterial photosynthesis constitutes a novel and sustainable means of water production.**

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