Photosynthesis

Autotrophic Nutrition in Plants

We know that all living organisms consume some form of nutrients to sustain life. Animals consume plants or other animals. Plants consume carbon dioxide and water from the environment to produce food.

Therefore, the process of taking in a source of energy (food) from outside the body of an organism to inside is known as **nutrition**.

Do you know what mode of nutrition is carried out in plants? Plants have an **autotrophic** mode of nutrition. The term 'autotrophic' is derived from the Greek word '*Auto'* meaning self and '*troph'* meaning nutrition.

In this mode of nutrition, plants prepare or synthesize their own food with the help of inorganic raw materials. Thus, they are known as **autotrophs.**

Let us explore how plants prepare their own food.

Photosynthesis

Energy is essential for all life processes. All living organisms require nutrition. What is the ultimate source of nutrition on Earth?

The **sun** is the ultimate source of energy on Earth. Energy from the sun is captured by plants and converted into usable form. Thus, the origin of all foods is the food prepared by plants. This food is also consumed by animals.

Autotrophs such as green plants and some bacteria prepare or synthesize their own food. They are capable of trapping solar energy with the help of a green pigment called **chlorophyll**. This trapped solar energy is then converted into chemical energy of food using CO_2 and H_2O.

Photosynthesis is the process by which chlorophyll-containing cells present in leaves synthesize food in the form of carbohydrates by using carbon dioxide, water and sunlight.

Therefore, the raw materials required for photosynthesis are CO_2 and H_2O and the products formed are carbohydrates and O_2.

Hence, the process can be represented as:

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

Let us discuss the raw materials required for photosynthesis.

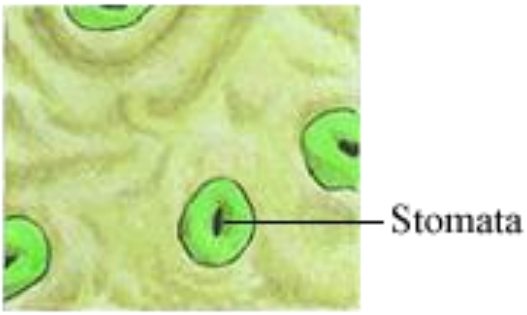
How are raw materials consumed by plants?

The raw materials required for photosynthesis are CO_2 and H_2O and the products formed are carbohydrates and O_2.

Entry of raw materials

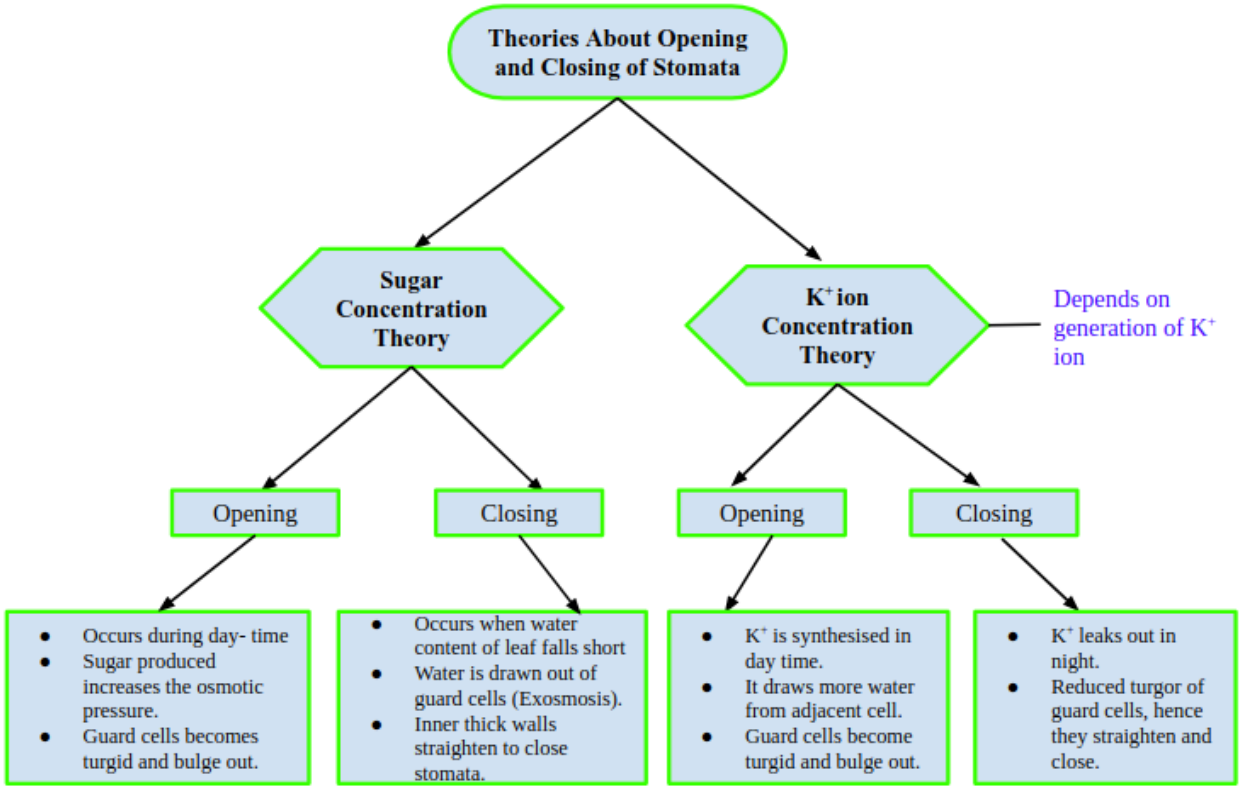
- Plants obtain water through their roots. Water is then transported to all plant parts with the help of the **xylem**.
- Exchange of gases (entry of CO_2 and release of O_2) occurs through the stomata.

Stomata are tiny pores present mainly on the surface of leaves. They are also present on the surface of young stems and roots.



Stomata consist of a stomatal opening or stoma, which is surrounded by two distinct epidermal cells known as **guard cells**. The opposing inner walls of the guard cells are thick and inelastic. The remaining walls are thin and elastic.

Theories behind Stomatal Opening and Closing



How do plants control the opening and closing of the stomata?

Two phases of photosynthesis

The process of photosynthesis occurs in two phases – **Photochemical Phase** and **Biosynthetic Phase**.

Photochemical Phase - A series of chemical reactions take place in the presence of light, as light behaves as catalyst is called as photochemical phase. The light reactions take place in **thylakoids** of the chloroplasts.

Light reactions – As the name suggests, this reaction takes place in the presence of light. Light energy is absorbed by chlorophyll molecules and is utilized for splitting water molecules into hydrogen and oxygen. Additionally in this phase, assimilatory power in the form of ATP and $NADPH_2$ are produced.

Light reactions occur in the membranes of thylakoids.

Events occurring during light reactions:

- Absorption of light energy by chlorophyll molecules
- Splitting of water molecules into hydrogen and oxygen atoms
- Formation of ATP and $NADPH_2$

Reactions involved in Photolysis:-

(i) $NADP^+ + e^- + H^+ \xrightarrow{\text{Enzyme}} NADPH$
(ii) $2O \rightarrow O_2$
(iii) $ADP + Phosphate \rightarrow ATP$ (Phosphorylation)

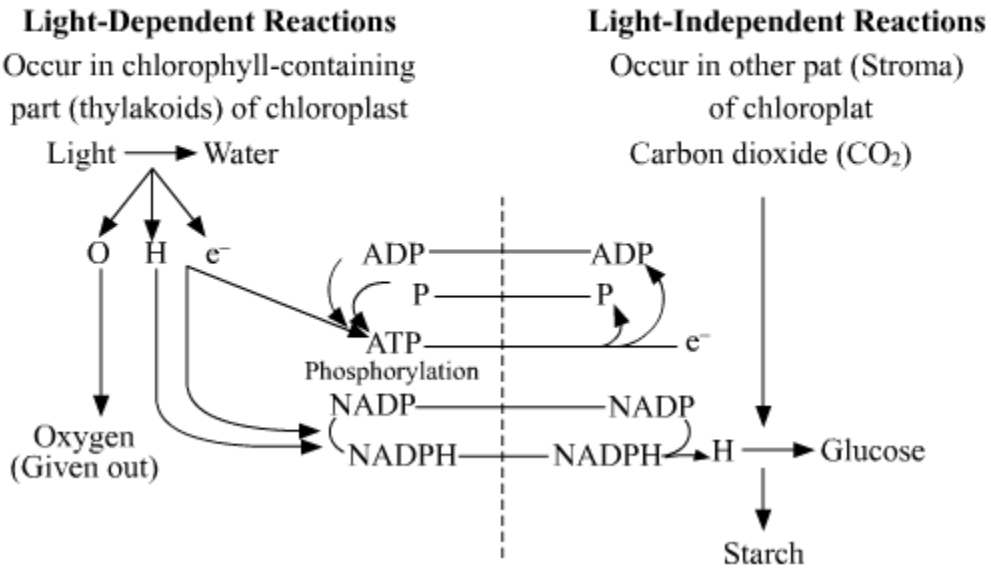
Biosynthetic Phase - It includes the reactions that are not dependent on light (but may happen during day time as well). It results in synthesis of carbohydrates, or 'food', using the energy produced through light reactions.

Dark reactions – This reaction does not require direct light and occurs in the stroma of chloroplasts. During this phase, ATP and $NADPH_2$ (formed during light reactions) are utilized for the reduction of CO_2 to carbohydrates (food).

Event occurring during dark reaction:

Reduction of CO_2 to form carbohydrates
Transformation of glucose molecules to 1 mole of Starch is called **polymerisation.**

Highly Simplified Summary of The Events in Light Reaction And Light-Independent Reaction of Photosysthesis



Some interesting facts:

- Do you know that the total amount of O_2 produced by an acre of trees per year is equal to the amount consumed by around 18 people annually!
- One tree produces nearly 260 pounds of O_2 annually.

- Hydrogen is a clean fuel. Some green algae such as *Chlamydomonas reinhardtii* are being cultured to convert water into O_2 and H_2. This mass production of hydrogen could prove to be beneficial, but is still under research.

End Results of Products Of Photosynthesis

- **Glucose:** Simple glucose is utilised by plants in the following ways:
- For consumption by plant cells
- For storage as insoluble starch
- For conversion into sucrose
- For synthesis of fats, proteins, etc
- **Water:** It can be re-utilised in the continuance of photosynthesis.
- **Oxygen:** Some of it is used in respiration of leaves and rest diffuses out.

Global warming

Do you know that global warming can be reduced by growing more plants?

Green plants, as we know, utilize CO_2 and water to produce food and in the process, release O_2 gas. Thus, green plants help in reducing the amount of CO_2 in the atmosphere. CO_2 is a green house gas, which is one of the reasons for global warming.

Chloroplast- The site of Photosynthesis

Site of Photosynthesis

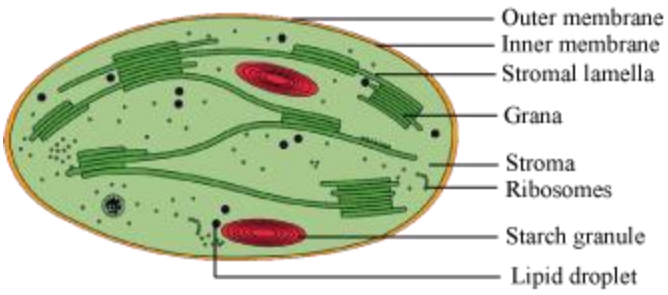
- Mesophyll cells in green leaves have large number of **chloroplasts**, which are the site of photosynthesis.

- Chloroplast consists of the grana and the stroma lamellae (forming a membranous system) and the fluid stroma.

- Membrane system of chloroplast − traps light, and synthesises ATP and NADPH (site of light-dependent reaction of photosynthesis)

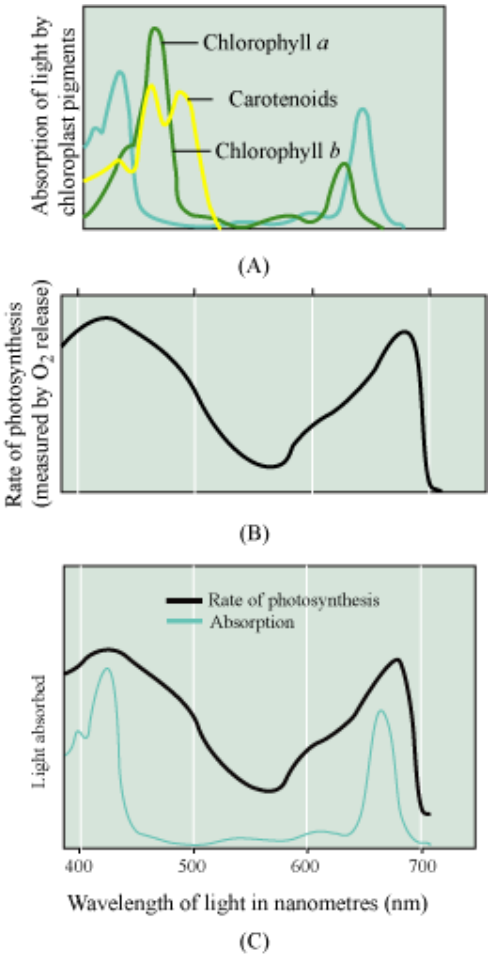
- Stroma − CO_2 is incorporated into the plant by enzymatic reactions, leading to the synthesis of sugar (site of light-independent reaction of photosynthesis)

- Chloroplasts are aligned along the walls of mesophyll cells so as to get optimum light.



Pigments Involved in Photosynthesis

- An **absorption spectrum** is the graph plotted against the fraction of light absorbed by the pigment.
- An **action spectrum** is the rate of a physiological activity plotted against the wavelength of light.
- The similarity of the action spectrum of photosynthesis and the absorption spectrum of chlorophyll tells us that chlorophylls are the most important pigments in the process.



(A) Absorption spectrum of chlorophylls *a*, *b*, and carotenoids

(B) Action spectrum of photosynthesis

(C) Action spectrum superimposed on absorption spectrum of chlorophyll a

- 4 types of pigments may be present in leaves:
- Chlorophyll *a* (blue-green)
- Chlorophyll *b* (yellow-green)
- Xanthophylls (yellow)
- Carotenoids (yellow to yellow-orange)
- Chlorophyll *a* is the main pigment in photosynthesis.
- In VIBGYOR spectra, chlorophyll *a* shows maximum absorption, and hence, the rate of photosynthesis is the highest at the blue and red regions.
- Accessory pigments: Chlorophyll *b*, xanthophylls and carotenoids
- Absorb a wider range of light, and transfer the energy to chlorophyll *a*
- Protect chlorophyll *a* from photo-oxidation

Factors Affecting Rate of Photosynthesis

- Photosynthesis is influenced by internal (plant) factors and external factors.

- **Internal factors:** Number, size and orientation of leaves, mesophyll cells and chloroplasts, internal carbon dioxide concentration and the amount of chlorophyll.

- **External factors:** Availability of sunlight, temperature, carbon dioxide concentration and water.

- **Law of Limiting Factors −** If a chemical process is affected by more than one factor, then its rate will be determined by factor which is nearest to its minimal value (factor which directly affects the process if its quantity is changed).

- This law of limiting factor was given by Blackman (1905).

- **Light**

- Incident light $\propto CO_2$ fixation rate; but at higher light intensities, the rate does not increase further as other factors become limiting

- Light is rarely a limiting factor (with exception of the shade plants or plants of dense forest) because light saturation occurs at 10% of the full sunlight.

- Beyond a point, if incident light is increased, then it leads to decrease in photosynthesis due to breakdown of chlorophyll.

- **CO_2 Concentration**

- Major limiting factor
- Usually low in atmosphere (0.03 − 0.04%)
- Up to 0.05% − increases rate of CO_2 fixation
- > 0.05% − damaging effect
- Though both C_3 and C_4 show increase in rate of photosynthesis at high light intensities accompanied by high CO_2 concentration. The saturation point for C_3 is obtained at higher concentrations as compared to C_4. Therefore, CO_2 concentration is more of a limiting factor for C_3 plants.
- Increased CO_2 concentration is beneficial for greenhouse crops such as tomatoes and bell pepper.

- **Temperature**

- Dark reactions are more sensitive to an increase in temperature.
- C_4 plants respond more to an increase in temperature and show higher rate of photosynthesis as compared to C_3 plants.
- Adaptations according to habitat also affect temperature optimum for photosynthesis. Tropical plants have higher temperature optimum compared to plants growing in temperate climates.

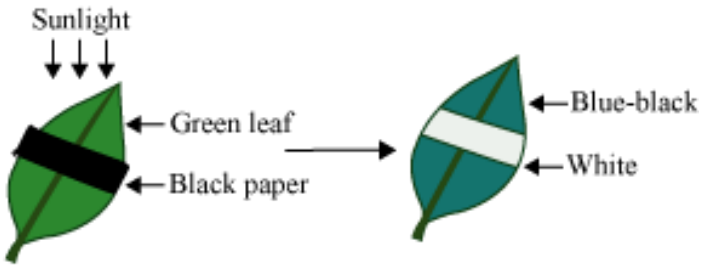
- **Water**

- Water stress causes stomata to close and hence, less CO_2 is available.
- Water stress causes the leaves to wilt, thereby reducing their surface area and metabolic activity as well.

Experiments Related to Photosynthesis

We know that raw materials are utilized by plants to prepare food. **Do plants prepare food at all times? Are there any essential conditions required for photosynthesis?**

1. **Sunlight is essential for photosynthesis**



Place a healthy green potted plant in a dark room for 1-2 days. This is done to ensure that the plant consumes all its reserve food and the leaves do not contain any starch. Then, cover a portion of a leaf of this plant on both sides with two uniform pieces of black paper, fixed in position with two paper clips.

Now, expose this plant to bright light. After a few hours, remove the leaf, decolourize it with alcohol, and test the presence of food (starch) with iodine solution.

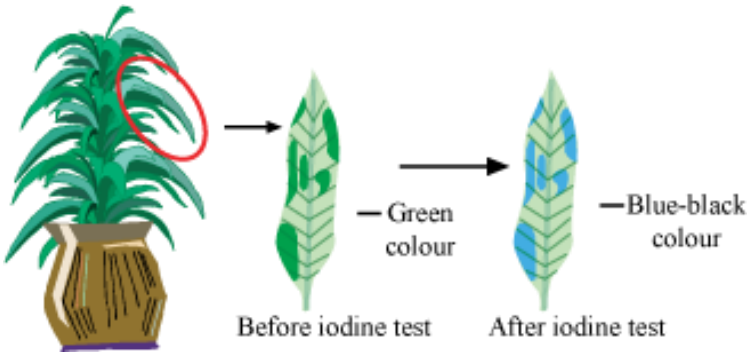
You will observe that the portion of the leaf covered with black paper does not show any presence of starch (food).

Explanation of the activity:

The food prepared by plants (carbohydrates) through the process of photosynthesis is stored as starch. This starch reacts with the iodine solution to change to blue-black colour. Only those portions of the leaf that were exposed to sunlight could photosynthesise and hence, change to blue-black colour when tested with iodine.

2. Chlorophyll is essential for photosynthesis

Place a variegated plant (i.e., a plant which has both green and non-green areas, for e.g., croton or money plant) in a dark room for 2 – 3 days. This is done to ensure that all the reserve food (starch) is utilized.



Place this plant in sunlight for six hours to allow photosynthesis to take place.

Then, pluck a leaf from this plant and trace the green areas on a sheet of paper.

Now, decolourize the leaf using alcohol and dip it in a dilute solution of iodine for a few minutes. Wash this leaf with water and compare it with the tracings of the leaf done earlier.

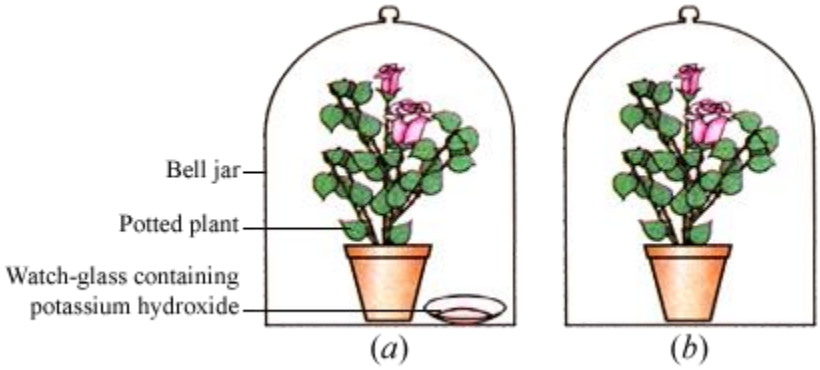
It will be observed that only the green areas of the leaf could photosynthesize.

Explanation:

The leaf is treated with alcohol so that it loses its green colour (chlorophyll pigment) and blue-black colour (in presence of starch) obtained after treatment with iodine.

The green parts of a variegated leaf contain chlorophyll. Therefore, only these parts could photosynthesize and manufacture food. Thus, the change in colour was observed only in these parts.

3. CO_2 is essential for photosynthesis



Select two healthy potted plants of nearly the same size and label them as **A** and **B.** Place them in a dark room for 2-3 days. Then, place two glass plates under both the plants. Place a watch-glass containing potassium hydroxide besides pot **A**. Cover both the plants by inverting separate bell jars over them. Potassium hydroxide, as we know, is used to absorb CO_2. Therefore, CO_2 is not available for plant **A**.

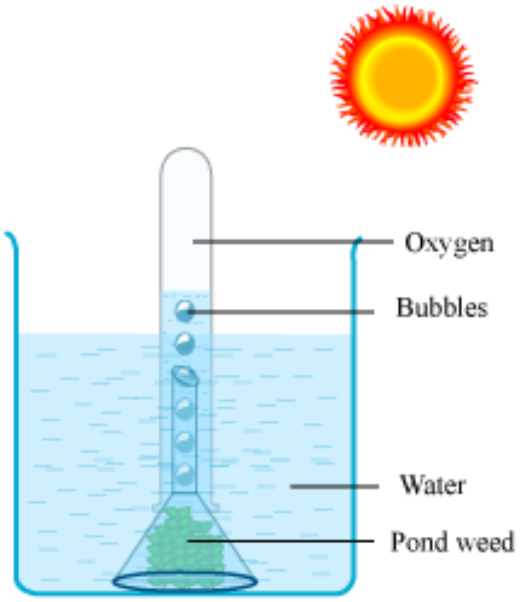
Now, seal the bottom of the jars to the glass plates with the help of Vaseline. This prevents the entry of CO_2 into the set up. Then, place the plants under sunlight for 2 – 3 hours. Test one leaf each from both plants for the presence of starch, using alcohol and iodine (as explained in the previous activity). It will be observed that plant **B** has a higher amount of starch as compared to plant **A**.

Explanation of the activity:

This happens because potassium hydroxide present besides plant **A** absorbs all the CO_2. Therefore, plant **A** is not able to photosynthesize and manufacture food. Hence, the amount of starch present in plant **B** is higher than plant **A**.

Photosynthesis in a laboratory

Place an aquatic plant (hydrilla) in a beaker filled with water. Cover the plant with a transparent funnel. Then, invert a test tube over the open end of the funnel.



While inverting the test tube, make sure it does not contain any air bubbles. Place this apparatus in sunlight and observe the changes.

It will be observed that after sometime, air bubbles (O_2) emerge in the test tube.

Importance of Photosynthesis and Carbon Cycle

Adaptations in Leaves for Photosynthesis

Leaves often exhibit a number of adaptations to increase the rate of photosynthesis. Some of them are as follows:

- Large surface area for maximum sunlight absorption
- Leaf arrangement at correct angle for maximum light
- Transparent cuticle and upper epidermis to allow free entry of light
- Large number of stomata for maximum exchange of gases
- Thin leaves to reduce the distance between cells involved in rapid transportation
- Chloroplasts concentrated at the upper layer to absorb light quickly
- Extensive vein system for rapid transportation

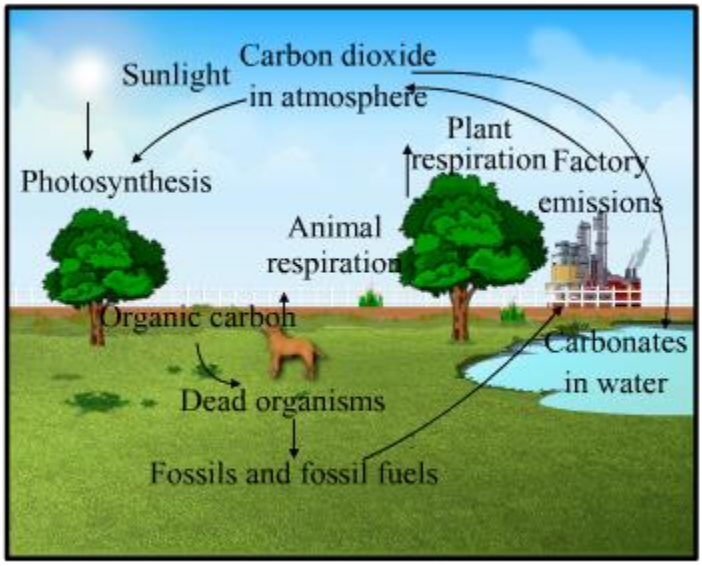
Importance of Photosynthesis

- **Provides food**- Photosynthesis is the basis for production of food by the autotrophs, i.e. plants. All other organisms are directly or indirectly dependent on the food produced by plants for their survival.

- **Provides oxygen**- Oxygen is produced during photosynthesis which is the life supporting gas. All organisms are dependent on the oxygen to sustain their life.

Carbon Cycle

Carbon cycle is a series of chemical reactions in which carbon as a chemical element gets consumed by living organisms and again gets restored in the atmosphere by various means.



The steps involved in carbon cycle are:

- Autotrophs use carbon dioxide to produce carbohydrates through photosynthesis.
- These carbohydrates keep travelling from one to another organism through food chain.
- Plants and animals respire by oxidising carbohydrates to produce energy.
- In the process of decomposition, the bacteria break down the inorganic matter to release carbon dioxide back into atmosphere.
- Combustion also releases the carbon dioxide stored in fuels back to the atmosphere.