CHAPTER

7

Bioenergetics

Animation 7.1: Photosynthesis
Source & Credit : 6bhaverfordgarden11.wikispaces

Chapter 4 described the structure of cell and chapter 6 mentioned the role of enzymes in cellular functions. A living cell exhibits ceaseless chemical activities.

We studied that cells are like “open systems” i.e. substances are entering and leaving the cell all the times. Inside cells, substances are broken down and new substances are formed. Energy drives all these processes in a cell. In living organisms, energy exists in two forms: kinetic energy is actively involved in doing work, and potential energy is stored for future use. Potential energy is stored in chemical bonds and is released as kinetic energy when these bonds break.

7.1 Bioenergetics And The Role Of ATP

Bioenergetics is the study of energy relationships and energy transformations (conversions) in living organisms. Organisms obtain energy by metabolizing the food they eat or prepare. Food contains potential energy in its bonds. When these bonds are broken down, a large amount of kinetic energy is usually released. Some of this energy is stored in the form of potential energy in the bonds of ATP molecules while the rest escapes as heat. The potential energy stored in ATP is again transformed into kinetic energy to carry out life activities (Fig 7.1).

Recalling

Plants and some microorganisms (e.g. photosynthetic bacteria and algae) prepare their own food from carbon dioxide and water in the presence of light by a process called photosynthesis. Whereas animals, fungi and many microorganisms (non-photosynthetic bacteria and protozoans) get the prepared food.

Animation 7.2 : Bioenergetic
Source and Credit: introbiol

Oxidation-Reduction Reaction

Various life processes in organisms involve constant flow of energy. This energy flow comprises the acquisition, transformation and use of energy for various life processes like growth, movement, reproduction etc.

For all life processes, oxidation-reduction reactions (redox reactions) are the direct source of energy. Redox reactions involve exchange of electrons between atoms. The loss of electrons is called **oxidation** while the gain of electrons is called **reduction**.

Electrons can be an energy source. It depends upon their location and arrangement in atoms. For example; when they are present in oxygen, they make stable association with oxygen atom and are not good energy source. But if electrons are dragged away from oxygen and attached to some other atom e.g. carbon or hydrogen, they make unstable association. They try to move back to oxygen and when this happens, energy is released.

In living organisms redox reactions involve the loss and gain of hydrogen atoms. We know that a hydrogen atom contains one proton and one electron. It means that when a molecule loses a hydrogen atom, it actually loses an electron (oxidation) and similarly when a molecule gains hydrogen atom, it actually gains an electron (reduction).

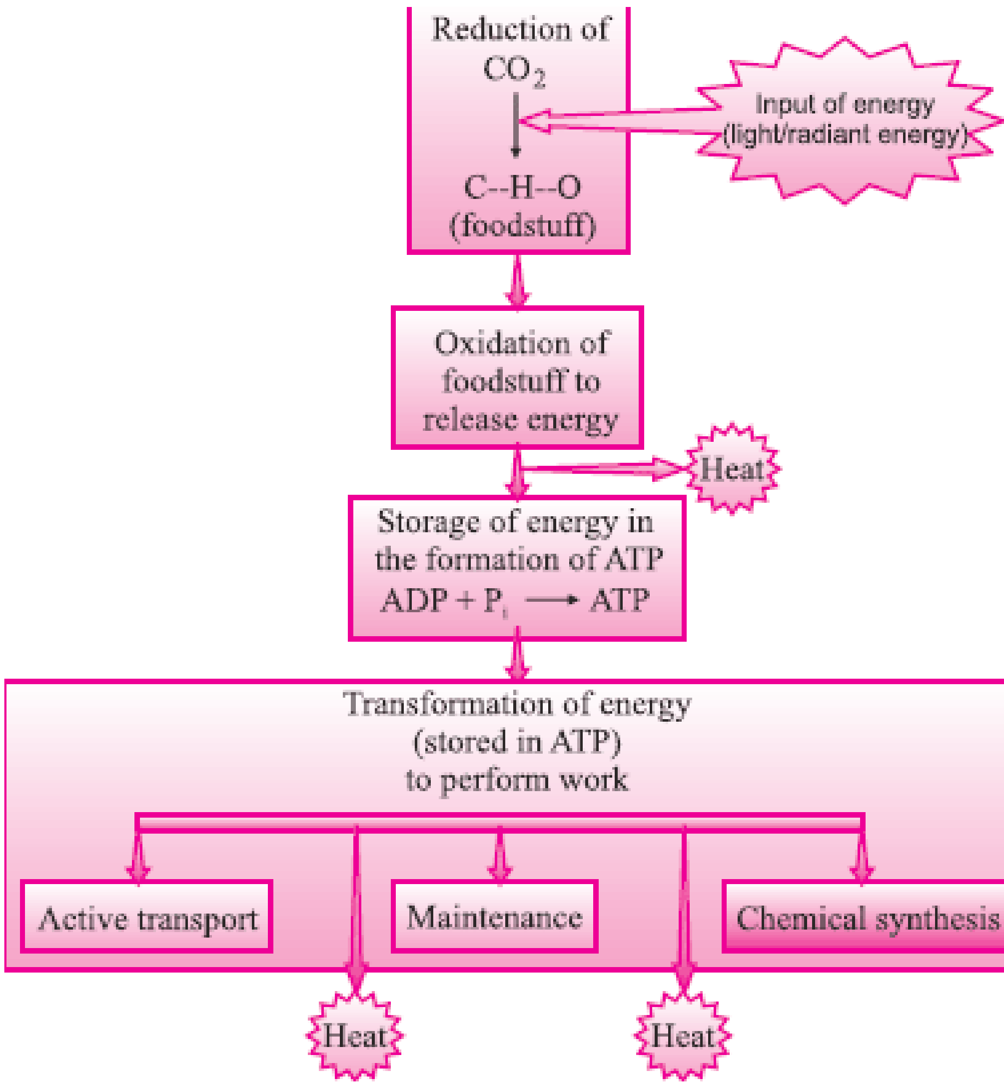

Figure 7.1: Some energy transformations in living organisms.
Note that heat is lost in every transformation

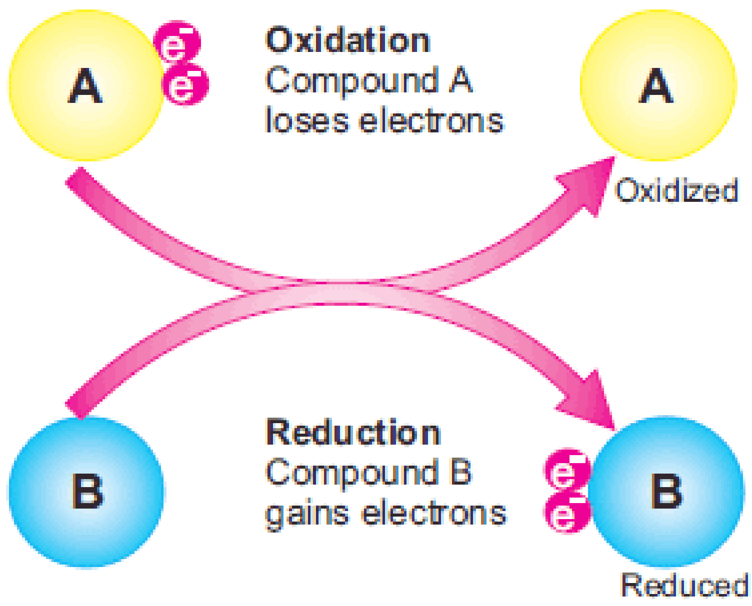

Figure 7.2: Redox reactions

ATP was discovered in 1929 by **Karl Lohmann,** and was proposed to be the main energy-transfer molecule in the cell by the Nobel prize winner, Fritz Lipmann in 1941.

ATP: The Cell's Energy Currency

The major energy currency of all cells is a nucleotide called adenosine triphosphate (ATP). It is the main energy source for majority of the cellular functions like synthesis of macromolecules (DNA, RNA, and proteins), movement, transmission of nerve impulses, active transport, exocytosis and endocytosis etc.

The ability of ATP to store and release energy is due to its molecular structure. Figure 7.3 shows a simplified diagram of ATP. Each ATP molecule has three subunits: (a) adenine - a double-ringed nitrogenous base; (b) a ribose - a five-carbon sugar; and (c) three phosphate groups in a linear chain.

The ability of ATP to store and release energy is due to its molecular structure. Figure 7.3 shows a simplified diagram of ATP. Each ATP molecule has three subunits: (a) adenine a double-ringed nitrogenous base; (b) a ribose - a five-carbon sugar; and (c) three phosphate groups in a linear chain.

The covalent bond connecting two phosphates is indicated by the "tilde" (~) and it is a high-energy bond. The energy in this bond is released as it breaks and inorganic phosphate (Pi) gets separated from ATP. The breaking of one phosphate bond releases about 7.3 kcal (7,300 calories) per mole of ATP as follows:

ATP + H_2O → ADP + P_i + energy (7.3 kcal/mole)

In common energy reactions only the outermost of the two high-energy bonds breaks. When this happens, ATP becomes ADP (adenosine diphosphate) and one Pi is released. In some cases, ADP is further broken down to AMP (adenosine monophosphate) and P as follows:

ADP + H_2O → AMP + P_i + energy (7.3 kcal/mole)

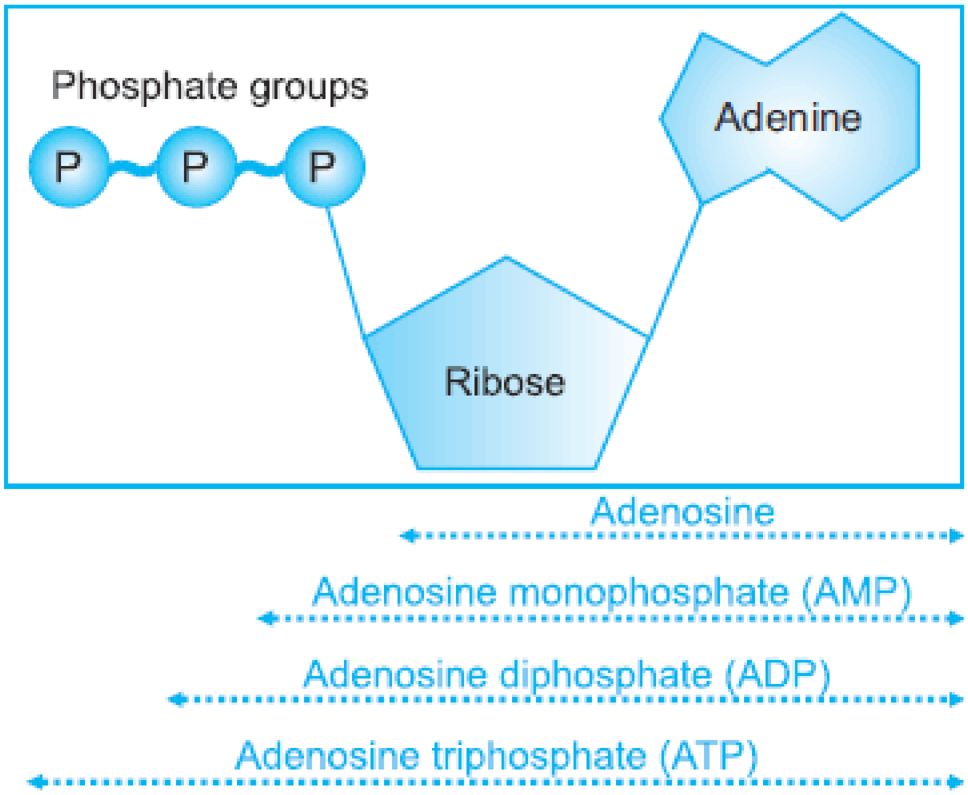

Figure 7.3: Molecular structure of ATP

Cells constantly recycle ADP by recombining it with P_i to form ATP.The synthesis of ATP from ADP and P_i requires the expenditure of 7.3 kcal of energy per mole. This energy is obtained from the oxidation of foodstuff. So we can summarize that ATP is generated by energy-releasing processes and is broken down by energy-consuming processes. In this way ATP transfers energy between metabolic reactions.

Because ATP plays a central role as energy currency in all organisms, it must have appeared in the early history of life.

7.2 Photosynthesis

Photosynthesis is the synthesis of glucose from carbon dioxide and water in the presence of sunlight and chlorophyll, with oxygen as a by-product. Photosynthesis is an anabolic (building) process and is an important component of bioenergetics in living systems.

It is the most important biochemical pathway and nearly all life depends on it. It comprises many coordinated biochemical reactions that occur in plants, some protists (algae), and some bacteria. A simple general equation for photosynthesis is as follows:

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

When cells use energy to build ATP from ADP, or ADP from AMP, they are really storing energy as we put money in a bank

Animation 7.3 : Photosynthesis
Source and Credit: agarciahawkins.weebly

Animation 7.4 : Photosynthesis
Source and Credit: mocomi

Intake of Water and Carbon dioxide

Water and carbon dioxide are the raw materials of photosynthesis. Plants have mechanisms for the intake and transport of these raw materials.

Water, present in soil, is absorbed by roots and root hairs through osmosis. This water is eventually transported to leaves through xylem vessels.

The air that enters leaf through tiny pores (stomata) reaches into the air spaces present around mesophyll cells. This air carries CO_2 , which gets absorbed in the thin layer of water surrounding mesophyll cells. From here, the carbon dioxide diffuses into mesophyll cells.

Recalling

Osmosis is the movement of water from a dilute solution to the concentrated one, through a membrane.

Animation 7.5 : Photosynthesis
Source and Credit: solpass

Animation 7.6 : Photosynthesis
Source and Credit: cas.miamioh

7.2.1 Mechanism Of Photosynthesis

Photosynthesis occurs in two phases (Fig 7.4). During first phase, light energy is captured and is used to make high-energy molecules (ATP and NADPH). These reactions, which are known as **light reactions**, take place on the thylakoid membranes of chloroplasts. During second phase, carbon dioxide is reduced to make glucose. In this phase, the energy from high energy molecules (ATP and NADPH) is utilized. Since these reactions do not use light directly, they are known as dark reactions.

The **dark reactions** take place in the stroma of the chloroplasts.

> Stomata cover only 1-2% of the leaf surface but they allow much air to pass through them.

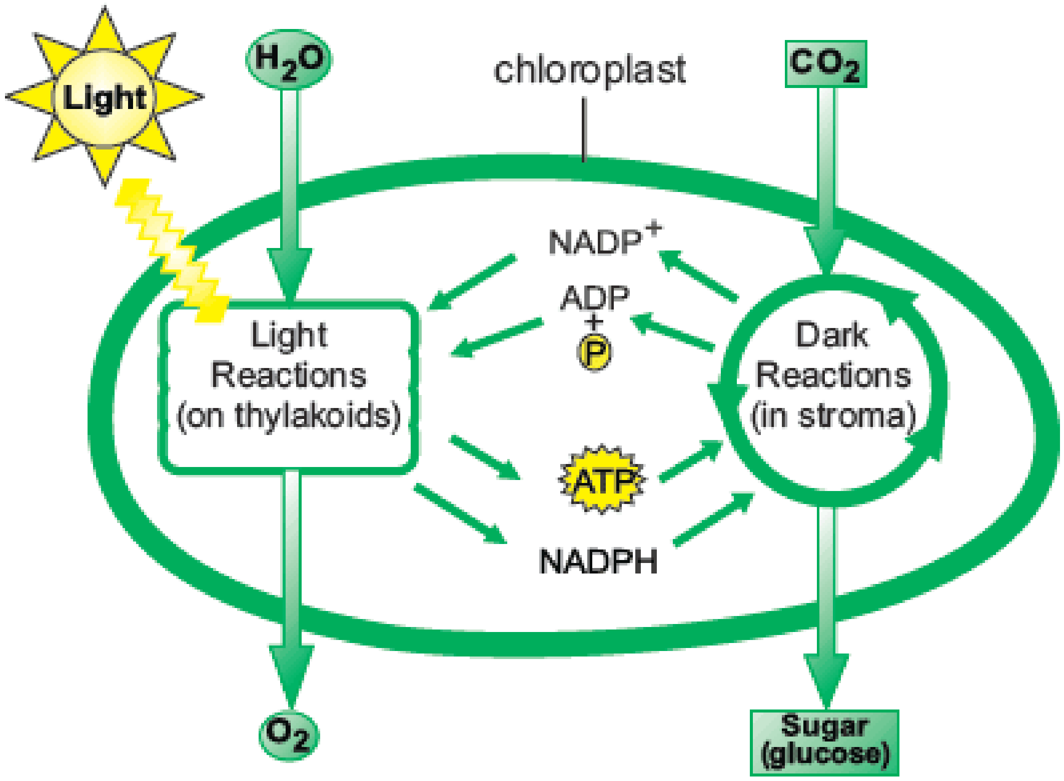

Figure 7.4: Summary of Photosynthesis

Animation 7.7 : Photosynthesis
Source and Credit: mocomi

Light Reactions

The summary of the events of light reactions is as follows;

- When chlorophyll molecules absorb light, their energy level increases and their electrons are emitted.
- Electrons are passed to electron transport chain to produce ATP.
- Light also breaks water molecule (photolysis) and oxygen is released. The hydrogen atoms of water give electrons to chlorophyll and become ions.
- The electrons of chlorophyll, after the production of ATP, and the hydrogen ions of water are used for the reduction of $NADP^+$ into NADPH.

The whole series of light reactions is called Z-scheme due to its Z-shaped flow chart.

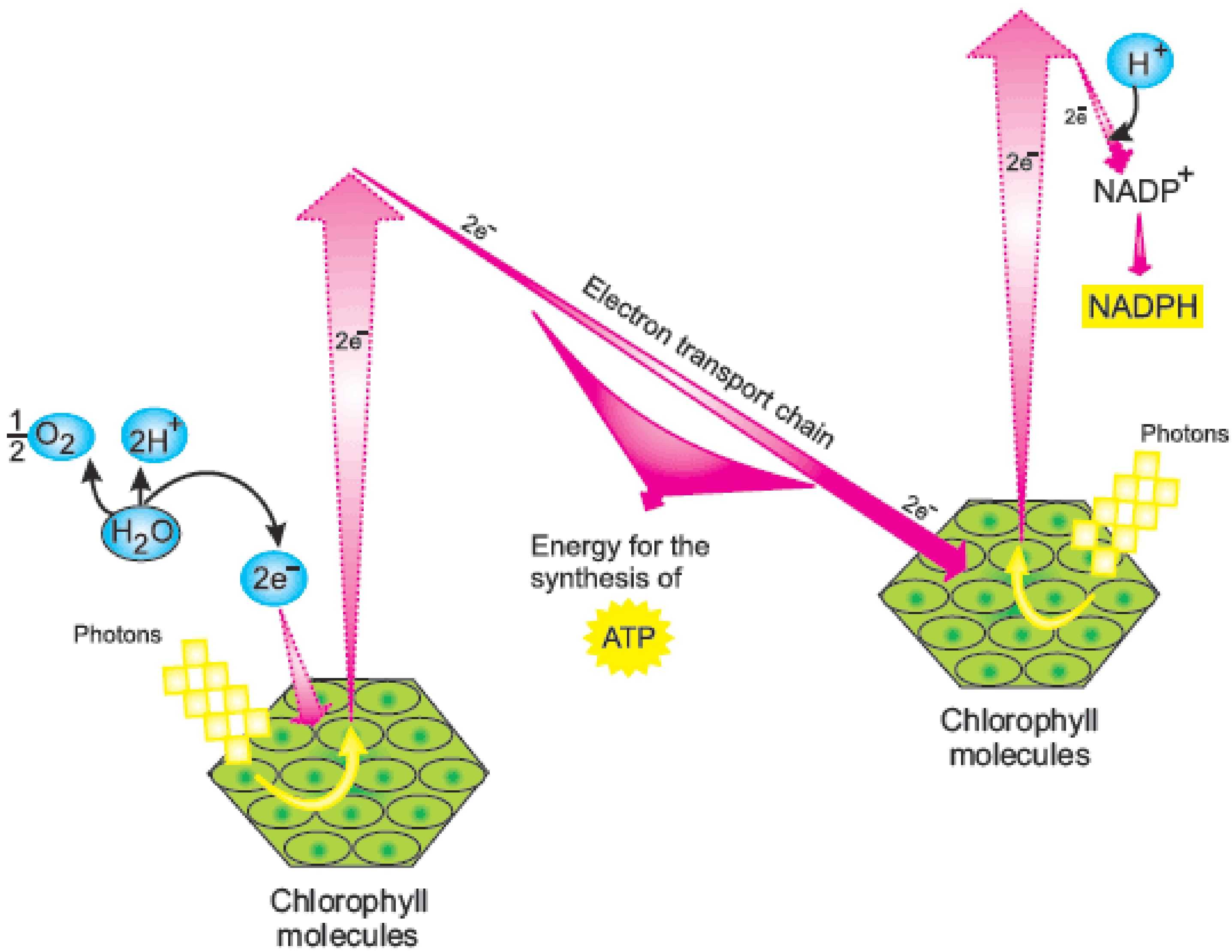

Figure 7.5: Light reactions of photosynthesis

Animation 7.8 : Photosynthesis Light Reaction
Source and Credit: makeagif

Nicotinamide adenine dinucleotide (NAD^+) is a coenzyme that takes electrons and hydrogen ions and is thus reduced to NADH. One form of this coenzyme also carries phosphate with it, so is called $NADP^+$.

Dark Reactions (Calvin Cycle)

The details of dark reactions were discovered by **Malvin Calvin** and his colleagues at the University of California. The summary of the events of dark reactions, also known as Calvin cycle (Fig 7.6) is as follows;

Animation 7.9 : Photosynthesis Light & Dark Reaction
Source and Credit: docsity

- CO_2 molecules are combined with 5-carbon compounds to form 2 temporary 6-carbon compounds, each of which splits into two 3- carbon compounds.
- The 3-carbon compounds are reduced to 3-carbon carbohydrates by using ATP and hydrogen from NADPH. The 3-carbon carbohydrates are used to manufacture glucose.
- The 3-carbon carbohydrates are also used to regenerate the original 5-carbon compounds. This step also utilizes ATP.

7.2.2 Role Of Chlorophyll And Light

Sunlight energy is absorbed by chlorophyll. It is then converted into chemical energy, which drives the photosynthetic process. Only about one percent of the light falling on the leaf surface is absorbed, the rest is reflected or transmitted. The light rays of different wavelengths are not only differently absorbed by photosynthetic pigments but are also differently effective in photosynthesis. The blue and red lights carry out more photosynthesis.

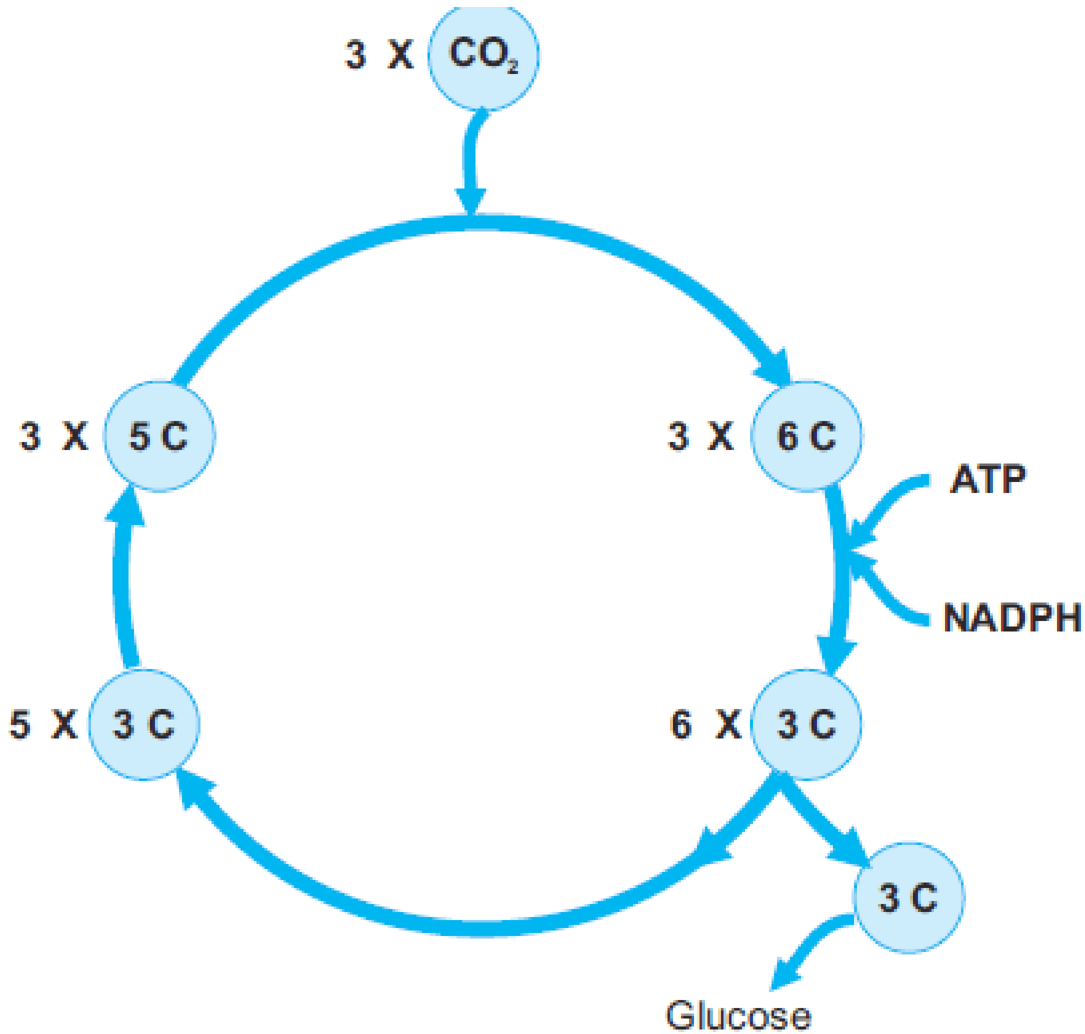

Figure 7.6: Dark reactions of photosynthesis (The Calvin cycle)

Calvin was awarded Nobel prize, in 1961, for his work on the details of photosynthesis.

Photosynthetic pigments are organized in the form of clusters, called **photosystems,** in thylakoid membranes of chloroplasts. Chlorophyll-a is the main photosynthetic pigment. Others are called accessory pigments and include chlorophyll-b and carotenoids. Chlorophylls absorb mainly blue and red lights. Some wavelengths not absorbed by chlorophyll 'a' are very effectively absorbed by accessory pigments and vice-versa.

?

In dark reactions, 3-carbon compounds are reduced to form carbohydrates. What is the ultimate source of these hydrogen for this reduction?

Water

7.2.3 Limiting Factors In Photosynthesis

Any environmental factor the absence or deficiency of which can decrease the rate of a metabolic reaction, is called limiting factor for that reaction. Many factors like light intensity, temperature, concentration of carbon dioxide and availability of water act as limiting factors for photosynthesis.

Effect of light intensity and temperature

The rate of photosynthesis varies with light intensity. It decreases as light intensity decreases and increases as intensity increases. However at much higher light intensity, the rate of photosynthesis becomes constant.

The rate of photosynthesis decreases with decrease in temperature. It increases as temperature is increased over a limited range. But if light intensity is low, increasing the temperature has little influence on the rate of photosynthesis.

Effect of carbon dioxide concentration

As carbon dioxide concentration rises, the rate of photosynthesis goes on increasing until limited by other factors. Increase in carbon dioxide concentration beyond a certain level causes the closure of stomata and it decreases the rate of photosynthesis.

Practical Work:

Demonstration of photosynthesis

The phenomenon of photosynthesis can be demonstrated by using an aquatic plant, like Hydrilla. You know that in the process of photosynthesis, oxygen gas is evolved as a byproduct.So release of oxygen from a set up would provide an evidence of photosynthesis.

Problem:

Does Hydrilla carry out photosynthesis when provided by all the essential factors?

Hypothesis:

Hydrilla is an aquatic plant that carries out photosynthesis, using CO_2 and water and releases oxygen at the same time.

Deduction:

Release of O_2 from the plant body would be a proof of photosynthesis.

Material required:

Fresh Hydrilla branches, 500 ml beaker, funnel, test tube, potassium bicarbonate, match box, water tub.

Background information:

Carbon dioxide and water are the raw materials for photosynthesis. When potassium bicarbonate is dissolved in water, it is ionized into carbonate and hydrogen ions. The carbonate ions release carbon dioxide.

Procedure:

1. Fill about half of the 500-ml beaker with water.
2. Take some fresh branches of Hydrilla and place them in the broader side of a funnel and set the funnel as shown in Fig 7.7.
3. Put an inverted test tube on the tubular part of the funnel. (Perform step 1, 2 and 3 by putting all the apparatus in a water tub, so that no external air would enter the test tube. After step 3, bring the set-up out of water tub.)
4. Put some quantity of potassium bicarbonate in the water of beaker.
5. Put all the set up in light and observe.

Observation:

Bubbles would be created in test tube water and these will accumulate in the top portion of the tube.

Results: T

he branches have released oxygen gas in the form of bubbles.

Confirmation:

When enough gas bubbles have accumulated in the test tube, pick up the tube by putting thumb on its mouth. Take a burning match-stick inside the tube. It flares up when it touches gas bubbles. It confirms that the test tube contains oxygen gas.

Error analysis:

The experimental work would not give the expected results if any of the limiting factors of photosynthesis i.e. light, CO_2 , water, and chlorophyll are not present. Similarly, if gas bubbles are not observed the branches used may be dead and decayed.

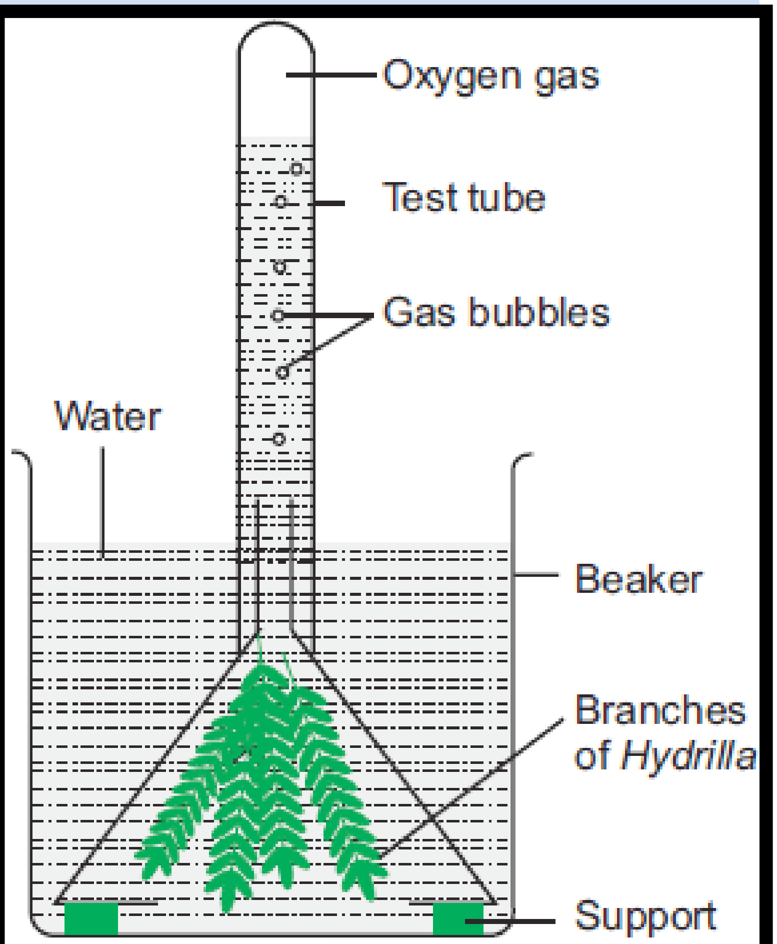

Figure 7.7: Experiment set up for the demonstration of photosynthesis

Evaluation:

1. There are two phases of photosynthesis i.e. light reactions and dark reactions.During which of these phases oxygen is produced?
2. Why was it necessary to do experiment with fresh branches of Hydrilla?
3. Why did you use a burning match-stick for confirmatory test?
4. What products (other than oxygen) are produced during photosynthesis?

Practical Work:

Investigation for the presence of starch

We know that in the process of photosynthesis, plants synthesize glucose by reducing CO_2 and for this reduction hydrogen is obtained from water. In many plants the synthesized glucose is converted into starch. So presence of starch in a leaf confirms that the plant has carried out photosynthesis. The presence of starch is investigated through starch test.

Problem:

How would it be proved that starch is present in a leaf?

Hypothesis:

A fresh leaf has carried out photosynthesis and has accumulated starch in its cell.

Deduction:

If the experimental leaf is processed for starch test, it would give positive results for starch.

Material required:

Fresh leaves, a 500 ml beaker, a forceps, a test tube, ethanol, dilute iodine solution, dropper, petri dish.

Background information:

- When a leaf is dipped in boiling water for sometime, it is killed and becomes soft.
- A soft and decolourized leaf can be tested in starch test. When soft leaf is boiled in ethanol it loses chlorophyll but retains starch in it.
- Starch turns blue when treated with dilute iodine solution (Fig 7.8).

Procedure:

1. Dip a leaf in a beaker of boiling water for about ten seconds.
2. Take the leaf out of boiling water and put it in a test tube of ethanol.
3. Put the test tube in a beaker of hot water for ten minutes. The ethanol starts boiling and the leaf in it gets decolourized.
4. Wash the leaf by moving it up and down in water in a beaker and put the washed leaf in a petri dish.
5. Perform starch test with the leaf. It is done by putting drops of iodine solution on the leaf.

Observation:
Leaf will turn blue-black.
Results:
Leaf contains starch.
Error analysis:
If leaf is retained in boiling water for long, it breaks the starch molecules present in it. Such a leaf will not give the expected results of the starch test.
Evaluation:
i. From where did the leaf get starch?
ii. Why was leaf placed in ethanol?
iii. What was the purpose of washing the leaf before performing the starch test?

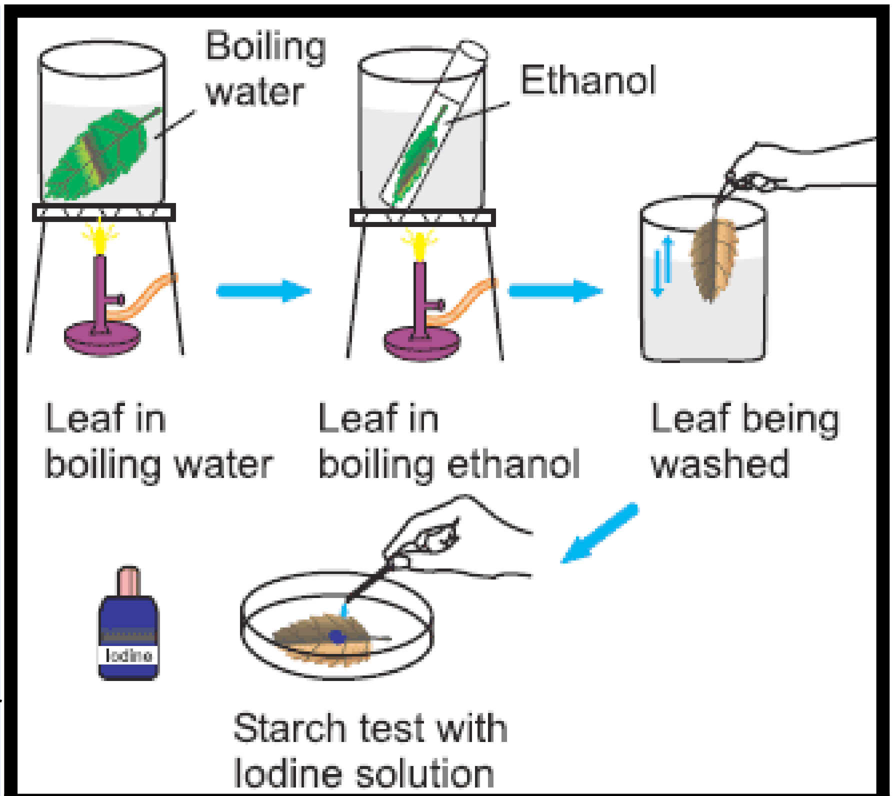

Figure 7.8: Experiment steps for starch test

Practical Work:

Investigation to find out that chlorophyll is necessary for photosynthesis
Chlorophyll is present in the chloroplasts of mesophyll cells. Leaves which lose their chlorophyll due to some diseases or salt deficiencies, fail to perform photosynthesis and eventually die.
Problem:
Is chlorophyll necessary for photosynthesis?
Hypothesis:
Chlorophyll is necessary for photosynthesis.
Deduction:
There will be no photosynthesis in the parts of the leaf that do not have chlorophyll and so there will be no starch production in these parts.
Material required:
A variegated leaf e.g. leaf of Geranium, a 500 ml beaker, a forceps, a test tube, ethanol, dilute iodine solution, dropper, petri dish.

Background information:

- Some leaves have yellow areas on their green surface. These areas mark the absence of chlorophyll (chloroplasts) containing cells. Such spotted leaves are called variegated leaves.
- Occurrence of photosynthesis can be confirmed by the presence of starch, through starch test.

Procedure:

1. Take a potted plant with variegated leaves e.g. Geranium.
2. Put the potted plant in light for several days so that it carries out photosynthesis (Fig 7.9).
3. Detach one of the variegated leaves and draw its upper surface on paper. The drawing should clearly distinguish the green and non-green areas.
4. Perform starch test on whole leaf.

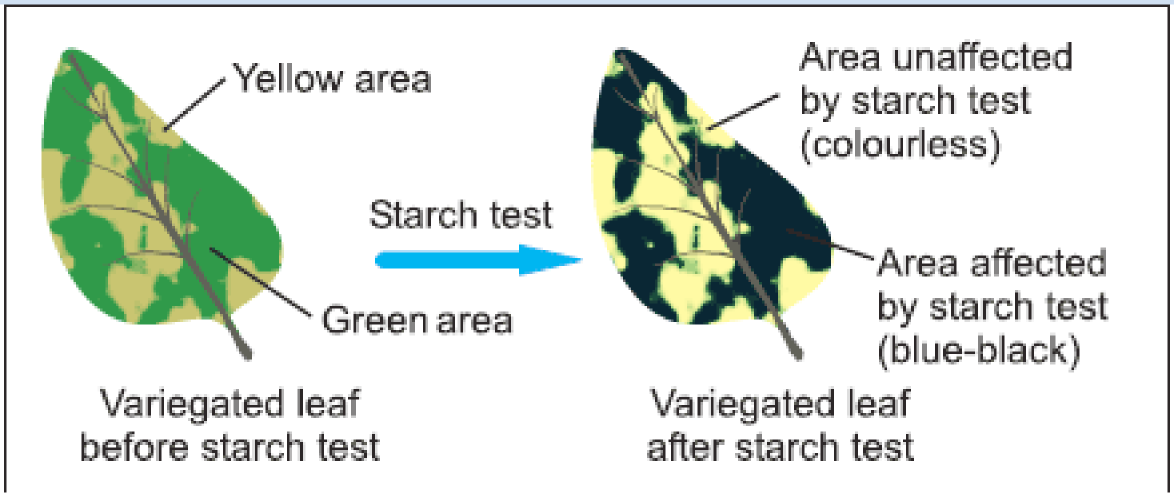

Figure 7.9: Test to prove the necessity of chlorophyll for photosynthesis

Observation:

The green parts of leaf will turn blue-black while the non-green parts will remain colourless.

Results:

There is no starch present in the non-green parts of leaf. In other words, these nongreen parts do not carry out photosynthesis.

Error analysis:

If non-green as well as green parts of leaf do not show the presence of starch, it means that the potted plant did not get any of the other required variables e.g. light, CO_2 , water etc.

Evaluation:

1. If there is no photosynthesis in the non-green parts of leaf, how they are alive?
2. In which phase of photosynthesis, chlorophyll plays its role?
3. Chlorophyll-a is the principal pigment. What are the accessory pigments?

Practical Work:

Investigation to find out that light is necessary for photosynthesis

Light energy is used for exciting the electrons of chlorophyll which in turn produce ATP and are also used for the reduction of CO_2. Thus light energy is incorporated in glucose in the form of bond energy.

Problem:

Is light necessary for photosynthesis?

Hypothesis:

Light is necessary for photosynthesis.

Deduction:

There will be no photosynthesis in the parts of leaf that do not get sufficient light and so there will be no starch production in these parts.

Apparatus required: A potted plant with healthy leaves, black paper, paper clips, a 500 ml beaker, a forceps, a test tube, ethanol, dilute iodine solution, dropper, petri dish.

Background information:

- If a plant is kept in darkness for several days, it utilizes its stored starch and is said to be de-starched.
- Black paper can check the light falling on a leaf.
- Occurrence of photosynthesis can be confirmed by the presence of starch, through starch test.

Procedure:

1. Take a potted plant and keep it in darkness for at least three days so that its leaves are de-starched.
2. Attach a strip of black paper to both the upper and lower sides of a leaf as shown in Figure 7.10.
3. Put the potted plant in a well-lit place for at least five hours.
4. Remove the experimental leaf and perform the starch test to observe the presence and/or absence of starch. Make a drawing to how the results.

Observation:

The part of the leaf having black paper strip will remain colourless while the other parts will turn blue-black.

Results:

There is no starch present in the parts of leaf, which were covered by black paper. In other words, these parts did not carry out photosynthesis.

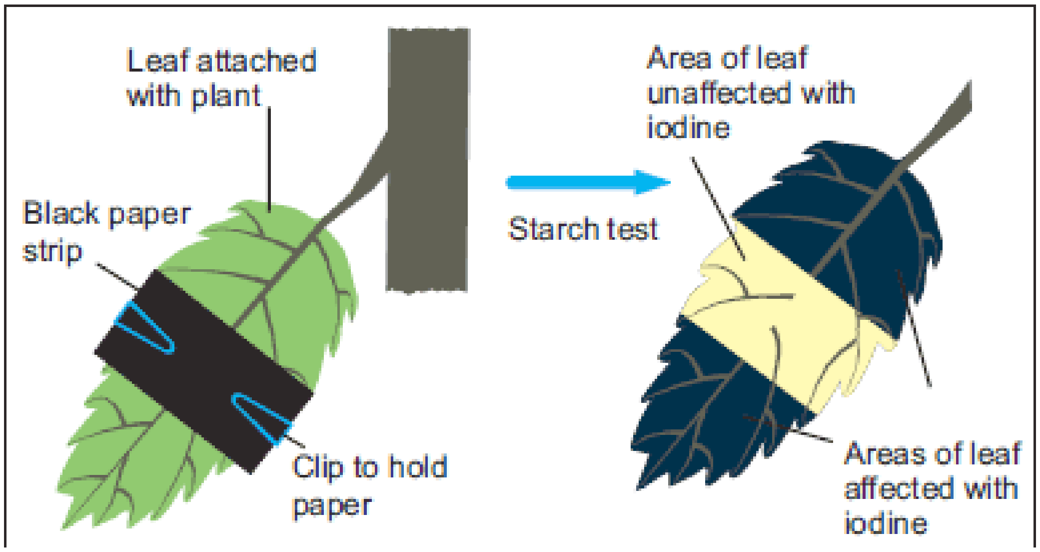

Figure 7.10: Experiment to show the necessity of light for photosynthesis

Error analysis:

If the covered parts show the presence of starch, it means that the plant could not be de-starched while it was kept in darkness. It may be due to the reason that plant was not given enough time to consume its stored starch.

Evaluation:

1. If light is necessary for photosynthesis, why the other parts of the plant do not photosynthesize, which receive light?
2. What adaptations leaves possess for maximum absorption of light?
3. Which colours of light are least absorbed by the leaves?

Practical Work:

Investigation to find out that CO_2 is necessary for photosynthesis

In photo synthesis, CO_2 is reduced to form carbohydrates (glucose). Water acts as the hydrogen source for this reduction while sunlight is the energy source for it. Plants get CO_2 from air which enters in their leaves through stomata.

Problem:

Is carbon dioxide necessary for photosynthesis?

Hypothesis:

Carbon dioxide is necessary for photosynthesis.

Deduction:

There will be no photosynthesis in the parts of leaf that do not get carbon dioxide and so there will be no starch production in these parts.

Apparatus required:

A potted plant with healthy leaves, a 500 ml beaker, a forceps, a test tube, ethanol, dilute iodine solution, dropper, petri dish, potassium hydroxide solution, a glass flask with rubber cork.

Background information:

- If a plant is kept in darkness for several days, it utilizes its stored starch and is said to be de-starched.
- Potassium hydroxide absorbs CO_2 from its surroundings.
- Occurrence of photosynthesis can be confirmed by the presence of starch, through starch test.

Procedure:

1. Take a potted plant and keep it in darkness for at least three days so that its leaves are de-starched.
2. Take potassium hydroxide solution in a glass flask and fit a cork in the mouth of the flask. The cork should be cut longitudinally before fitting.
3. Select a leaf of the de-starched plant (but do not remove it from plant). Pass half of the leaf from the cut of cork so that half portion of leaf is inside flask and other half is outside (Fig 7.11).
4. Put the potted plant in a well-lit place for at least five hours.
5. Remove the experimental leaf and perform starch test to observe the presence and/or absence of starch. Make a drawing to show the results.

Observation:

The portion of leaf present inside flask will remain colourless while the other portion that remains in fresh air will turn blue-black.

Results:

Carbon dioxide present in the air inside flask was absorbed by KOH and so the portion of leaf present here could not carry out photosynthesis and could not make starch.

Error analysis:

If the portion of leaf inside flask shows the presence of starch, it means that the cut in the rubber cork was wide to allow some air to enter the flask.

Evaluation:

1. Why the portion inside the flask could not make starch?
2. Where had the CO_2 gone that was present in the air inside flask?

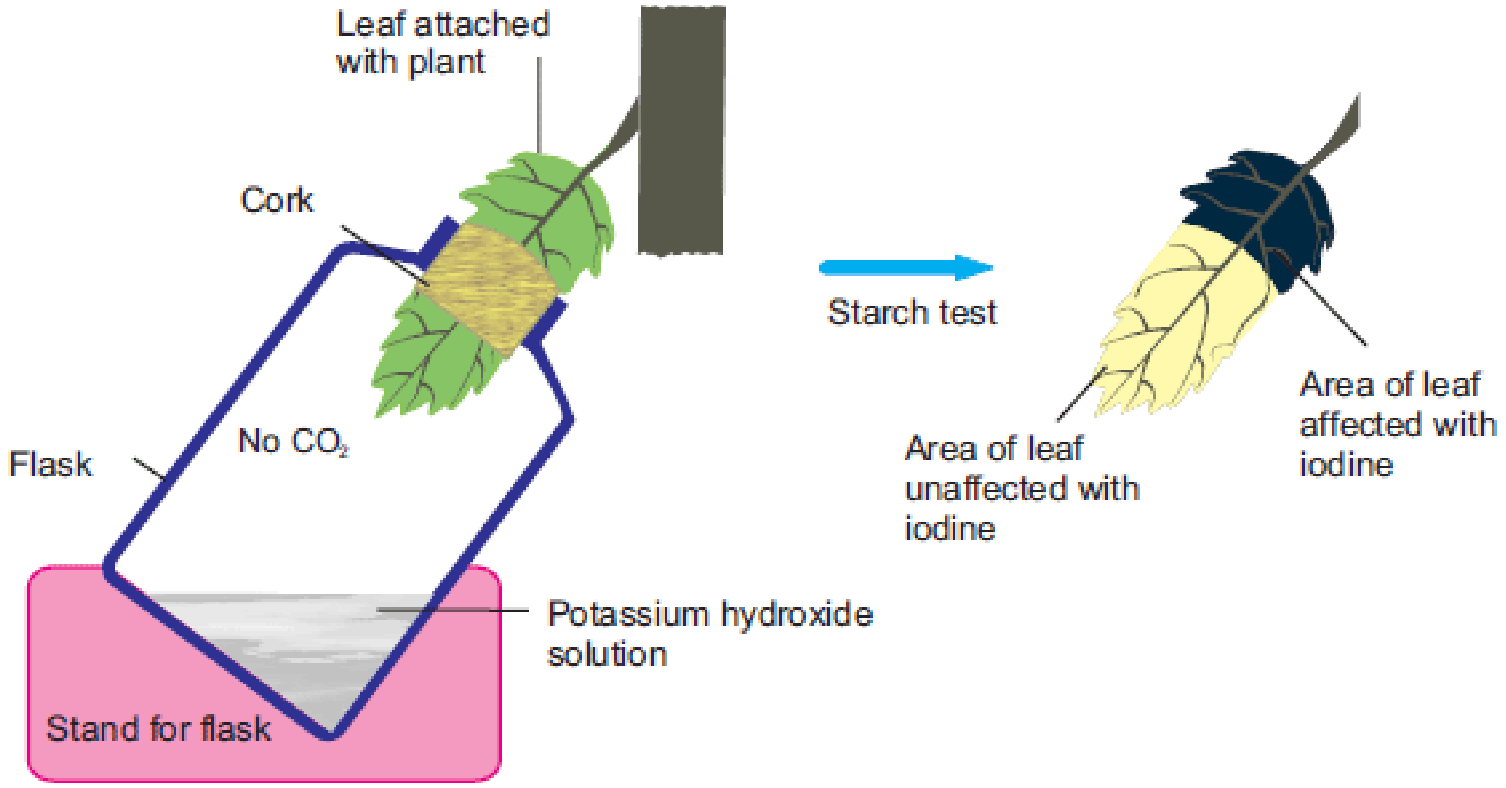

Figure 7.11: Experiment to show the necessity of CO_2 in Photosynthesis

? There are more chloroplasts in the palisade mesophyll than in the spongy mesophyll. Why?

Because the palisade cells are on the upper surface and receive more light. So they should be able to absorb more light.

7.3 Respiration

When we burn a fuel, it utilizes oxygen and yields energy in the form of light, heat, etc. In this burning process, oxygen is used to break the C-H bonds present in fuel molecules. In the same way, organisms utilize oxygen for the breakdown of C-H bonds present in the food in their cells. This break down yields energy which is transformed into ATP. During this process the C-H bonds are broken by oxidation-reduction reaction and so carbon dioxide and water are also produced. The cellular energy-yielding process is called **cellular respiration.**

In cellular respiration, food is oxidized to CO_2 while O_2 is reduced into H_2O.

7.3.1 Aerobic And Anaerobic Respiration

The most common fuel used by cell to get energy by cellular resp ration is glucose. The way glucose is oxidized depends on the availability of oxygen. The cellular respiration occurring in the presence of oxygen is called aerobic respiration while the one that occurs in the absence of oxygen is called anaerobic respiration.

i. Aerobic Respiration

In the presence of oxygen, complete oxidation of glucose occurs with maximum release of energy. In the first phase of aerobic respiration, a molecule of glucose (6-C) is broken down into two molecules of pyruvic acid (3-C).

In the second phase, molecules of pyruvic acid are completely oxidized (all C-H bonds are broken) to CO_2 and water and all energy is released.The overall reaction is as follows.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

ii. Anaerobic Respiration (Fermentation)

In the absence of oxygen, glucose is incompletely oxidized with less amount of energy released. In anaerobic respiration, the first phase is exactly similar to that of aerobic respiration. A molecule of glucose is broken down into two molecules of pyruvic acid. But in the second phase, pyruvic acid is not completely oxidized (due to the absence of oxygen).

Animation 7.10 : Anaerobic Respiration
Source and Credit: biobook.kuensting

It is transformed into ethyl alcohol or lactic acid. In this way many of the C-H bonds are left unbroken in the products. Anaerobic respiration is further classified as alcoholic fermentation and lactic acid fermentation.

A- Alcoholic fermentation:

It occurs in bacteria, yeast etc. In this type of anaerobic respiration, pyruvic acid is further broken down into alcohol (C_2H_5OH) and CO_2 .

Pyruvic acid → Ethyl Alcohol + Carbon dioxide

B- Lactic acid fermentation:

It occurs in skeletal muscles of humans and other animals during extreme physical activities. This also happens in the bacteria present in milk. In this type of anaerobic respiration, each pyruvic acid molecule is converted into lactic acid ($C_2H_6O_3$).

Pyruvic acid → Lactic acid

Importance of Fermentation

When life evolved on the Earth, the early land or water habitats did not have any supply of free oxygen (O_2). In these anaerobic conditions, early organisms respired anaerobically and got energy for their life activities. Even today when free oxygen is available, some organisms including some bacteria and some fungi get energy from anaerobic respiration and are called **anaerobes**. Humans can also provide energy to their skeletal muscle cells through anaerobic respiration. It happens when skeletal muscles have to work hard (during exercise etc.) but oxygen supply cannot be increased to fulfil the demand.

Scientists have used the fermenting abilities of fungi and bacteria for the benefit of mankind. For example, the fermenting powers of bacteria are used for making cheese and yogurt. Fermentation in yeasts is used in brewing and baking industries. Similarly, the soy sauce is made through the fermentation by a fungus Aspergillus.

7.3.2 Mechanism Of Respiration

The process of respiration involves complex series of reactions. For the study of all the reactions of glucose oxidation, we will go into the mechanism of aerobic respiration. Aerobic respiration is a continuous process, but for convenience we can divide it into three main stages; 1- glycolysis, 2- Krebs cycle and 3- electron transport chain.

Glycolysis occurs in cytoplasm and oxygen is not involved in this stage. That is why, it occurs in both types of respiration i.e. aerobic and anaerobic. In glycolysis, glucose (6C) molecule is broken into two molecules of pyruvic acid (3C).

In Krebs cycle, the pyruvic acid molecules are completely oxidized, along with the formation of ATP, NADH and $FADH_2$. Before entering in Krebs cycle, pyruvic acid is changed into a 2-carbon compound called acetyl-CoA.

Electron transport chain is the final step of cellular respiration. It is the transfer of electron on an electron transport chain. In this step, NADH and $FADH_2$ release electrons and hydrogen ions. These electrons are taken up by a series of electron carriers. When electrons move through the series of electron carriers they lose energy, which is used to synthesize ATP. At the end of chain, electrons and hydrogen ions combine with molecular oxygen and form water.

? Why it is incorrect to say that the energy releasing step of respiration is electron transport chain?

Energy released in glycolysis and kerbs cycle in the form of NADH and $FADH_2$. Electron transport chain transforms the energy present in these components to ATP.

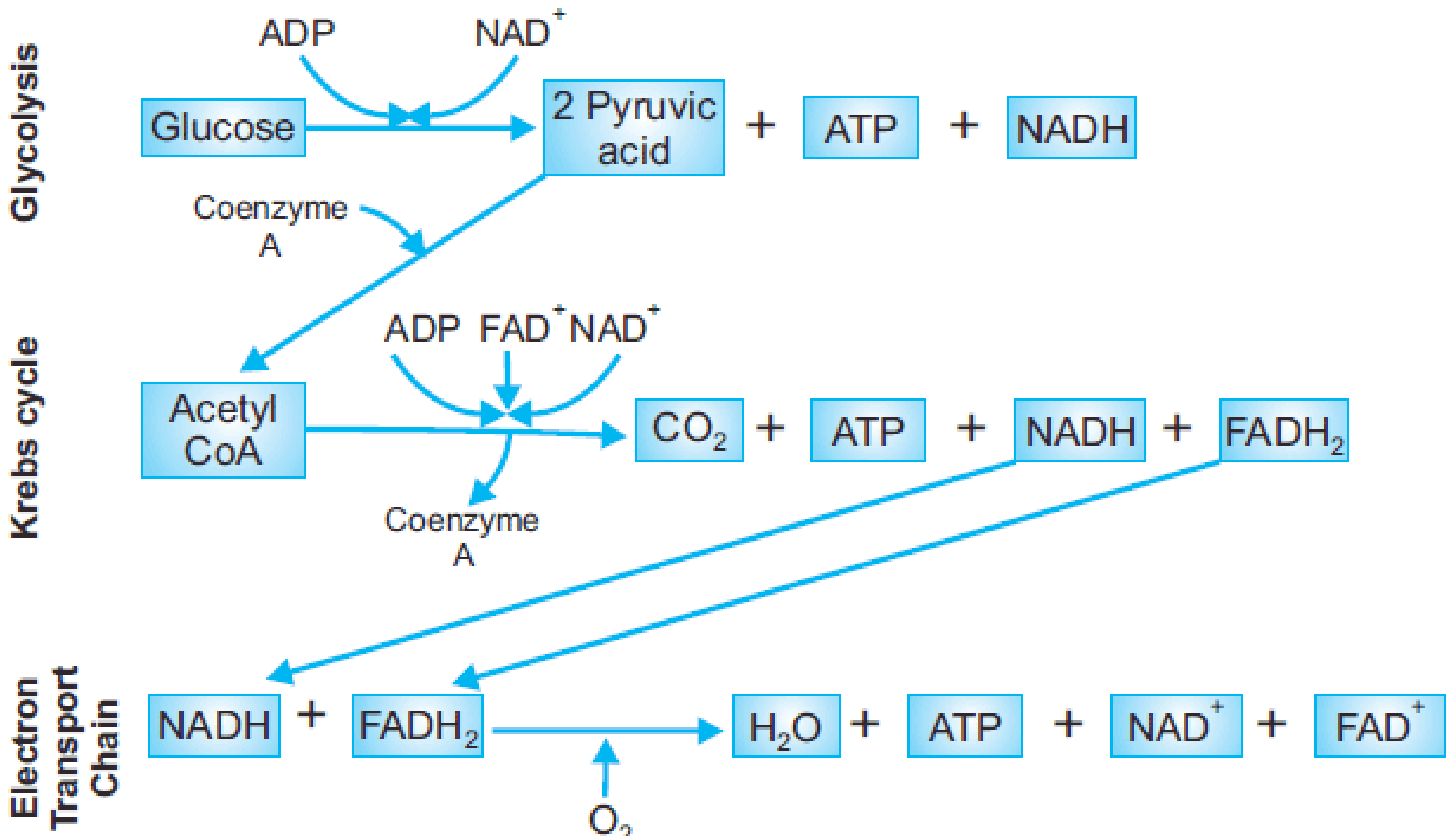

Figure 7.12: Mechanism of respiration

7.3.3 The Energy Budget Of Respiration

Each NADH produces 3 ATP in electron transport chain. The NADH generated in glycolysis gives 2 ATP because 1 ATP is spent to transport it across the mitochondrial membrane. Each $FADH_2$ produces 2 ATP. The total output of ATPs can be calculated from the following data (Fig 7.13). Note that during anaerobic oxidation of a glucose molecule only 2 ATP molecules are gained as the net profit. It is because there is no Krebs cycle and electron transport chain in anaerobic respiration.

A British biochemist, **Sir Hans Krebs** discovered this series of reactions that is why it is called the Krebs cycle.

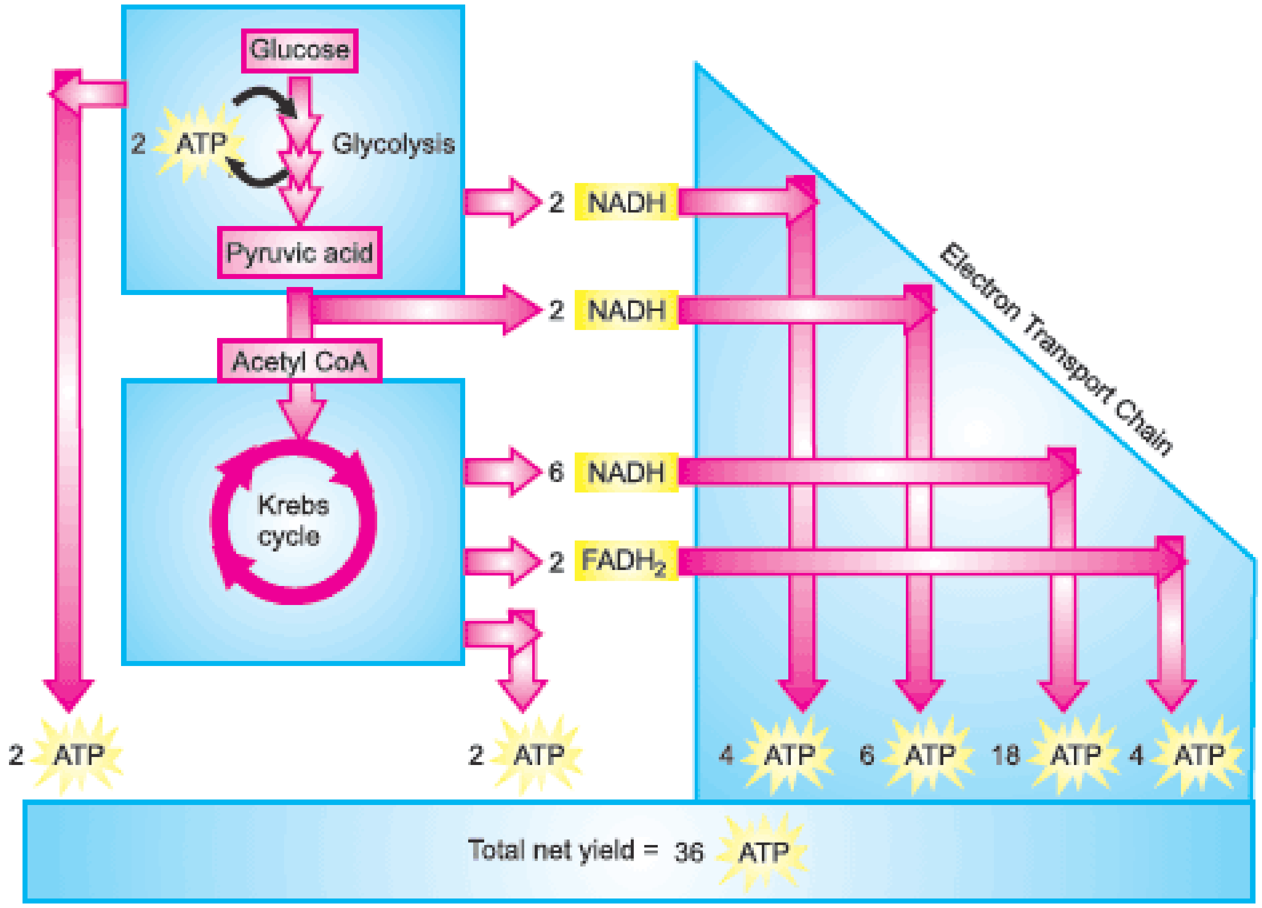

Figure 7.13: Energy chart of Respiration

Practical Work:

Investigation to find out that carbon dioxide is released during aerobic respiration

In aerobic respiration, the C-H bonds of glucose are broken. The hydrogen released in this breakage is taken by oxygen to produce water and CO_2 is left behind.

Problem:

Does the process of respiration produce CO_2 ?

Hypothesis:

CO_2 is produced as one of the end products of aerobic respiration.

Deduction:

An organism carrying out aerobic respiration will release CO_2

Apparatus required:

Flasks, potassium hydroxide, lime water, an animal.

Background information:

- Lime water readily absorbs CO_2 .

Procedure:

Set the apparatus as Figure 7.14 and observe the changes in lime water.

Observation:

Color changes would be observed in lime water.

Results:

CO_2 is produced during respiration.

Evaluation:

i. What color changes occurred in lime water?

ii. Why did we use potassium hydroxide and lime water?

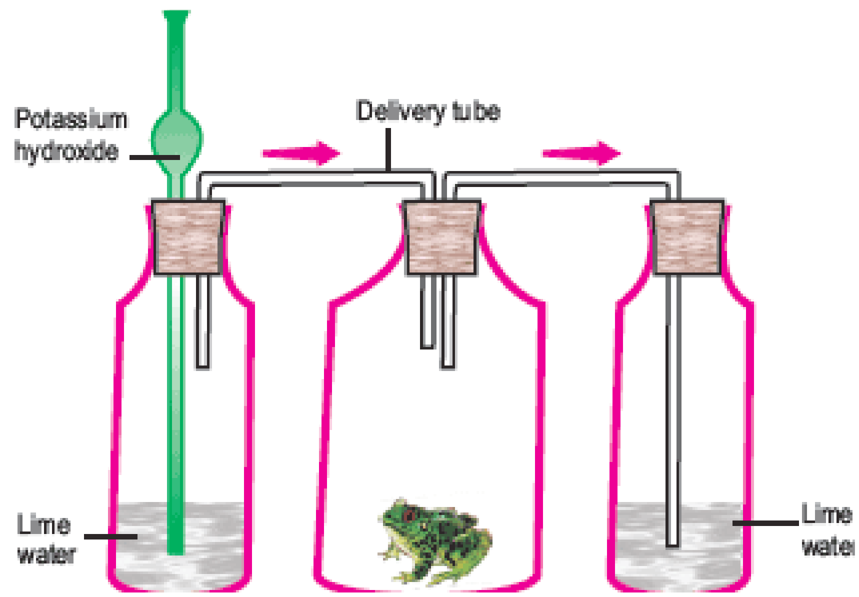

Figure 7.14: Experiment set up to investigate the release of carbon dioxide during aerobic respiration

Practical Work:

Investigation to find out that heat is given out during aerobic respiration

In respiration, lot of energy is released and some of this is stored in the form of ATP while the rest evolves out in the form of heat energy.

Problem:

Is there any production of heat energy during respiration?

Hypothesis:

Heat is produced during respiration.

Deduction:

A thermometer placed in the apparatus where respiration is being carried out,would show a rise in temperature.

Apparatus required:

Pea seeds, 01% chlorine or sodium hypochlorite solution, 02 beaker,02 flasks, 02 thermometers, cotton.

Background information:

- Seeds contain embryos of plants which consist of many cells.
- Boiling of seeds kills their cells.
- High temperature causes decay of dead cells.

Procedure:

1. Take pea seeds and keep them in water for 24 hours.
2. Wash the seeds with some germicide (e.g. 01% chlorine or sodium hypochlorite solution)to kill the bacteria present on their surface.
3. Boil some seeds for ten minutes so that their cells die. Cool these seeds so that these should not decay.
4. Put both sets of seeds (alive and dead) in separate flasks and label them as 'a and 'b'respectively. (Do not fill the flask up to their mouths.)
5. Insert a thermometer in the mouth of each flask and seal the mouth with cotton as in Figure 7.15.
6. Invert the flasks and fix them with stands and note the temperatures on both thermometers.
7. Keep the apparatus for about 4 hours.

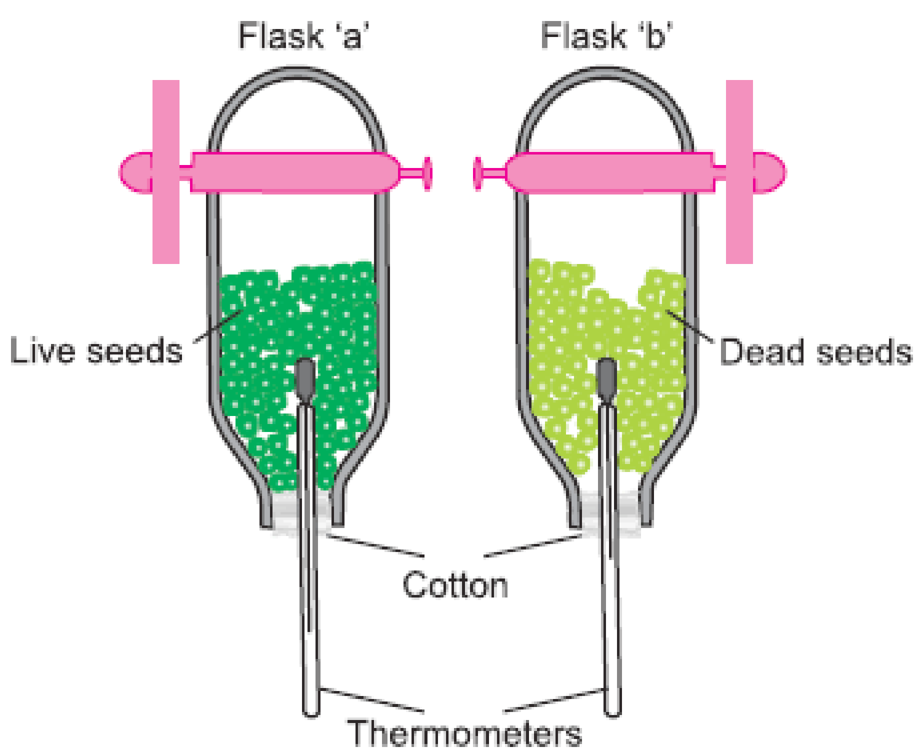

Figure 7.15: Experiment set up to investigate the release of heat during respiration

Observation:

The temperature reading in the thermometer put in flask 'a' rises but there is no rise in the temperature reading in the second thermometer.

Results:

Respiration in the live cells of seeds in flask 'a' results in the release of heat.

Error analysis:

If there is rise in temperature in the apparatus flask 'b'', it may be due to some rise in room temperature. In such conditions, the temperature in flasks 'a' will raise more than the temperature in flask 'b'.

Evaluation:

i. Why were the flasks not filled up to their mouths?
ii. Why did the temperature in flask 'a' rise and why did not in flask 'b'?
iii. Is there any heat released during respiration in our bodies?

TABLE 7.1: Difference between photosynthesis and respiration

Characteristics	Photosynthesis	Respiration
Metabolism	Anabolism	Catabolism
Energy investment / production	Investment of light energy to store it in the form of bond energy	Bond energy transformed into chemical energy of ATP
Organisms capable of;	Some bacteria, all algae all plants	All organisms
Site of occurrence	Chloroplasts	In cytoplasm and mitochondria
Time of occurrence	In daytime only, in the presence of light	All the time

TABLE 7.2: Difference between Aerobic and Anaerobic Respiration

Properties	Aerobic respiration	Anaerobic respiration
Presence of Oxygen	Yes	No
Number of ATP as net profit	36	2
Final products	CO_2 , H_2 O	Lactic acid or Ethanol + CO_2
Site of occurrence	Gycolysis in cytoplasm and Krebs cycle and electron transport chain in mitochondria	In cytoplasm
Importance	Major source of energy for most organisms	• Source of energy for anaerobic organisms • Source of energy for aerobic organisms in short supply of O_2 • Source of many products (ethanol, cheese etc)

UNDERSTANDING THE CONCEPTS

1. How would you define bioenergetics while relating it to the oxidation reduction reactions in living systems?
2. Interpret that ATP is the chief energy currency of all cells.
3. What is the role of chlorophyll and light in photosynthesis?
4. Outline the processes involved in photosynthesis?
5. State how the varying light intensity carbon dioxide concentration and temperature affect the rate of photosynthesis?
6. Outline the mechanism of respiration while defining glycolysis, Krebs cycle and electron transport chain.
7. Draw a comparison of aerobic and anaerobic respiration.
8. How will you compare respiration and photosynthesis?

SHORT QUESTIONS

1. Why is it said that all life forms are dependent on photosynthesis?
2. What structures and phenomena are involved in the intake of carbon dioxide and water by plants?
3. In what ways the respiratory energy is used in the body of organisms?
4. What is the importance of anaerobic respiration?

TERMS TO KNOW

Acetyl-CoA	Chlorophyll	NADPH
Adenine	Coenzyme-A	Oxidation
ADP	Electron transport chain	Photolysis
Aerobic respiration	FAD	Photosynthesis
Alcoholic fermentation	Glycolysis	Photosystem
AMP	Krebs cycle	Pigments
Anabolism	Lactic acid fermentation	Pyruvic acid
Anaerobic respiration	Light-dependent reactions	Reduction
ATP	Limiting factors	Respiration
Autotrophic	Mesophyll	Stroma
Bioenergetics	Metabolism	Thylakoid
Calvin cycle	Chlorophyll	Z-scheme

Initiating And Planning

1. Design the molecular model of ATP using low-cost no-cost materials.
2. Design a model of light and dark reactions by low-cost no-cost materials.

Activities

1. Demonstrate the process of photosynthesis using an aquatic plant, like Hydrilla.
2. Identify and label the cellular and tissue structures in the CS of a leaf through observation under the microscope.
3. Investigate the necessity of chlorophyll, light, carbon dioxide, using appropriate controls.
4. Demonstrate the process of respiration in germinating seeds by using limewater.
5. Investigate the release of carbon dioxide and heat during aerobic respiration in germinating seeds.

ON-LINE LEARNING

1. en.wikipedia.org/wiki/Bioenergetics
2. photoscience.la.asu.edu/
3. www.sambal.co.uk/respiration.html
4. www.fi.edu/learn/heart/systems/respiration.html