12

RESPIRATION IN PLANTS

Two most important prerequisites of life are continuous supply of materials for growth of body and energy for carrying out various life processes. All systems, from a single cell to ecosystem, require energy to work. As you have already studied, light energy is converted into chemical energy by plants during photosynthesis and this energy is then stored in the bonds of complex molecules such as glucose, and starch. It is these complex molecules which are given the name 'food'.

However, the energy in the food has to be made available to the cells in a usable form. This is the role of respiration. Respiration is the process by which fats and protein's the energy stored in organic molecules is released by oxidation. This energy is thus made available to the living cells in the form of ATP (Adenosine Tri-Phosphate). The O_2 required for respiration is obtained from the atmosphere. ATP is the energy currency of the cell. This lesson covers various aspects of respiration in plants.

OBJECTIVES

After completing this lesson, you will be able to :

- *define respiration, fermentation, photorespiration and Respiratory Quotient;*
- *list the basic events of anaerobic respiration and write the chemical equation representing it;*
- *state the role of fermentation in industry;*
- *compare aerobic and anaerobic respiration;*
- *draw the flow-chart to show the basic steps in Kreb's Cycle;*
- *explain how energy is actually released and stored in the form of ATP in the cell;*
- *account for 38 ATP molecules that are released during aerobic respiration;*
- *list the factors that influence the rate of respiration and appreciate the usefulness of RQ value of different food items.*
- *to understand the Pentose Phosphate Pathway (PPP) which is the special feature of the microbes (bacteria and funagi) as well as the cells of the highly active tissues of the animals.*

12.1 RESPIRATION

Respiration is the stepwise oxidation of complex organic molecules and release of energy as ATP for various cellular metabolic activities. It involves exchange of gases between the organism and the external environment. The green as well as non-green plants obtain oxygen from their environment and return carbon dioxide and water vapour into it. This mere exchange of gases is known as **external respiration** or breathing in case of animals. It is a physical process.

The biochemical process, which occurs within cells and oxidises food to obtain energy, is known as **cellular respiration**. Various enzymes (biocatalysts) catalyze this process. The process by which cells obtain energy from complex food molecules depends upon whether or not oxygen is present in their environment and utilised. Respiration is termed **aerobic** when oxygen is utilized and **anaerobic** when oxygen is not utilized. In anaerobic respiration, organic molecules are incompletely broken down in the **cytosol** of the cell and only a small fraction of energy is captured as ATP for use by the cell. In aerobic respiration the reactions of anaerobic respiration are followed by an oxygen requiring process that releases much larger quantity of energy in the form of ATP. This occurs in the **mitochondria** of the eukaryotes and in the folded plasma membrane (mesosome) of the prokaryotes.

It is important for you to note that several common processes occur in both, anaerobic and aerobic respiration, such as,

- Oxidation reaction to release chemical energy from complex food.
- Use of coenzyme as carriers of hydrogen to remove the hydrogen from the organic molecule leading to reduction of the coenzyme and oxidation of the substrate. Most of the hydrogen carriers are NAD (nicotinamide adenine dinucleotide) and FAD (flavin adenine dinucleotide).These are later reoxidised, releasing energy for ATP synthesis
- Use of high-energy phosphate compounds like ATP for energy transfer.

The basic differences between the two forms of respiration are given in the Table 12.1.

Table 12.1 Differences between aerobic and anaerobic respiration.

Aerobic (Aero = Air)	Anaerobic (Anaero = No Air)
1. Takes place in the presece of oxygen.	1. Takes place in the complete absence of oxygen.
2. Leads to complete oxidation of organic substrate.	2. Incomplete oxidation of organic substrate takes place.
3. It is most common in higher organisms (both plants and animals).	3. Takes place in lower organisms such as bacteria, fungi, and in higher animals under limiting conditions of oxygen (e.g. in muscles when oxygen present is insufficient).

4. $C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O + 6O_2 \quad +38\ ATP$	4. $C_6H_{12}O_6 \longrightarrow$ 2Ethyl alcohol + $2CO_2$ +2 ATP (as in yeast) OR $C_6H_{12}O_6 \longrightarrow$ 2 Lactic acid + 2 ATP (as in muscles)
5. Takes place in the cytoplasm, and mitochondria in eukaryotes and plasma membrane in prokaryotes.	5. Takes place in the cytoplasm.

Coenzyme is a complex non-protein molecule which is temporarily bound to an enzyme and acts as a link between metabolic pathways, (series of biochemical reactions).

INTEXT QUESTIONS 12.1

1. How do plant and other organisms obtain energy for various activites such as growth?

   ....

2. Name the energy-rich molecule formed during respiration from food.

   ....

3. Give two differences between aerobic and anaerobic respiration.

   ....

12.2 EXTERNAL RESPIRATION/GASEOUS EXCHANGE

- In plants, the atmospheric air moves in and out by simple diffusion that takes place through,
  - (a) the general body surface of the plant (stems, roots, fruits and seeds);
  - (b) lenticels (openings in the bark of the tree trunk (Fig. 12.1);
  - (c) stomata present in the leaves and young, green parts of the stems.

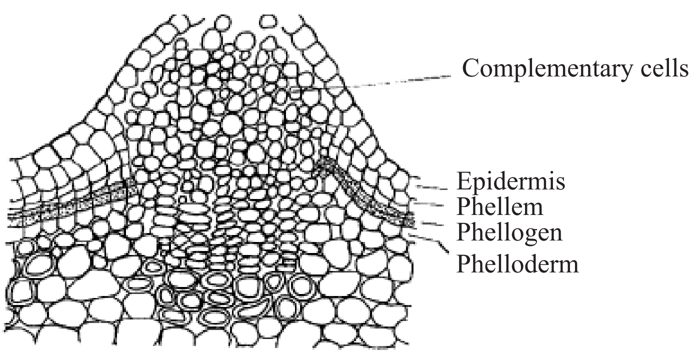


Fig. 12.1 Lenticels on the bark of a tree

- Plants do not need O_2 carrier (in contrast to animals) where O_2 is carried by blood). This is because O_2 requirement is less in plants than in animals since the plants have a large surface area (leaves) to absorb the required amount of O_2 through diffusion.
- From the atmosphere, gases enter the intercellular spaces inside the plants. As O_2 is utilized, more of it diffuses into the plant. Since CO_2 is being continuously formed, its concentration in tissue spaces becomes higher than in the surrounding air. As a result, it diffuses out of the plant, specially when it is not being used for photosynthesis.
- Can you explain as to why during the day, plants give out O_2 instead of taking it up for respiration?

In plants, O_2 released during photosynthesis in day time is made available for respiration. However, the rate of photosynthesis is higher than that of respiratin. Thus, plants give out excess O_2 in the daytime. However, these release only CO_2 at night as photosynthesis stops in the absence of sunlight. Animals give out CO_2 at all times.

INTEXT QUESTIONS 12.2

1. Name the surfaces that help plants in taking up oxygen from the atmosphere.

   ....

2. Name the process by which oxygen is taken up by the plants from the atmosphere.

   ....

3. Name the gases given out by plants during daytime and night.

   ....

4. Why do plants not have any special respiratory organs like animals? Give two reasons.

   ....

12.3 CELLULAR RESPRIATION

Oxygen that is absorbed in the body, is used to oxidize the nutrients, viz., glucose, amino acids and fatty acids completely producing CO_2, water and energy. It occurs within the cells and tissues. Observe Fig. 12.2 and identify the steps of cellular (aerobic and anaerobic) respiration. Note that the first stage in all these pathways is **glycolysis**.

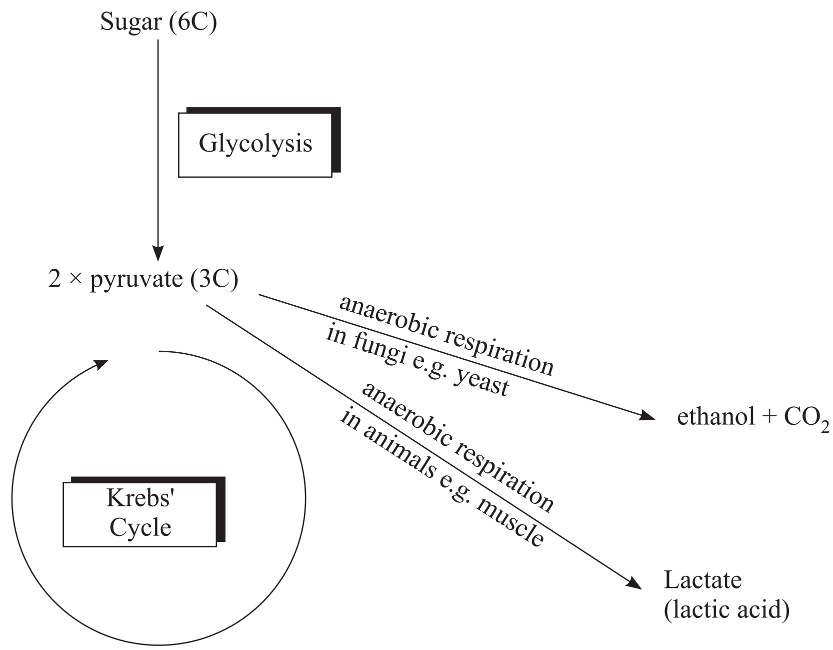


Fig. 12.2 Pathways in cellular respiration

12.3.1 Glycolysis (Also known as-Embden-Meyerhof-Parnas Pathway)

Whether or not the oxygen is available in the cells, the breakdown of glucose is initially always anaerobic. It is common to both aerobic and anaerobic respirations.

It involves oxidising **glucose** (6-carbon compound) to two molecules of **pyruvic acid** through a series of enzymatically controlled reactions occurring in the cytosol. Initial substrate is glucose (either from photosynthesis as in plants or from carbohydrate digestion as in animals).

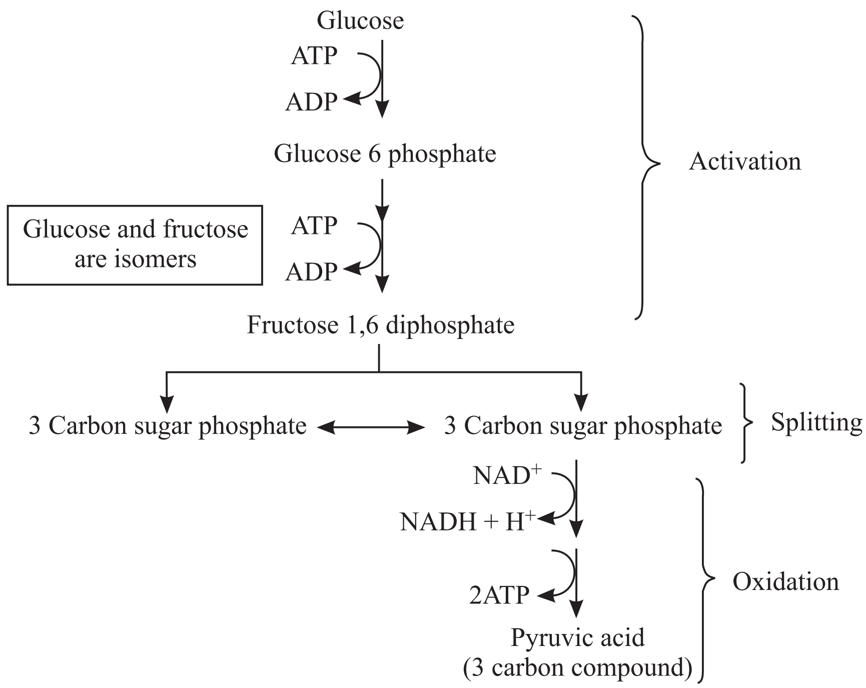
Glycolysis may be subdivided into **3 major phases:**

1. Phosphorylation of glucose to fructose 1,6 diphosphate. This is activation of glucose and 2ATPs are used.
2. Splitting of this compound into two 3- carbon sugar phosphates, which are interconvertible. Note that this is the origin of the term **glycolysis** meaning splitting of glucose.
3. Oxidation by dehydrogenation. Each 3-C sugar phosphate is oxidized by removal of hydrogen, making a reduced NAD that is NADH and production of 2ATPs.

This group of reactions is believed to be one of the first energy capturing reactions which evolved about three billion years ago in ancient bacteria and today it occurs in virtually all cells of all forms of life.

$$ATP \longrightarrow ADP + Pi + 30.6\ kJ$$

The balanced equation is:



- Glucose + 4ADP + 4Pi + 2NAD $\longrightarrow$ 2Pyruvic acid + 4ATP + 2NADH
- Two molecules of ATP were used up in the initial steps of glycolysis. Thus, the net gain of ATP during glycolysis is 4 – 2 = 2 ATP. Also, 2NADH + H^+ are produced.
- Thus, we see that only a small amount of energy is released at the end of glycolsis.

12.3.2 Fermentation

Further oxidation of Pyruvic acid requires O_2 (as you will study soon). It then enters mitochondria for aerobic respiration.

Under anaerobic conditions (or insufficient supply of O_2) microbes, plants and animals carry out fermentation.

Fermentation involves **reduction** of pyruvic acid to **ethyl alcohol** and **CO_2** (as in yeast) or to **lactic acid** (as in muscle cells of animals) and oxidation of NADH to NAD^+. Thus, NAD is regenerated which can be used in glycolytic pathway and production of 2 ATPs can continue under anaerobic conditions. (Refer to the figure 12.3). Note that there is no further release of ATP during fermentation.

Although you are more familiar with the term fermentation in the context of alcoholic fermentation it is now being used for the anaerobic pathway after the production of pyruvic acid, in glycolysis in cytosol.

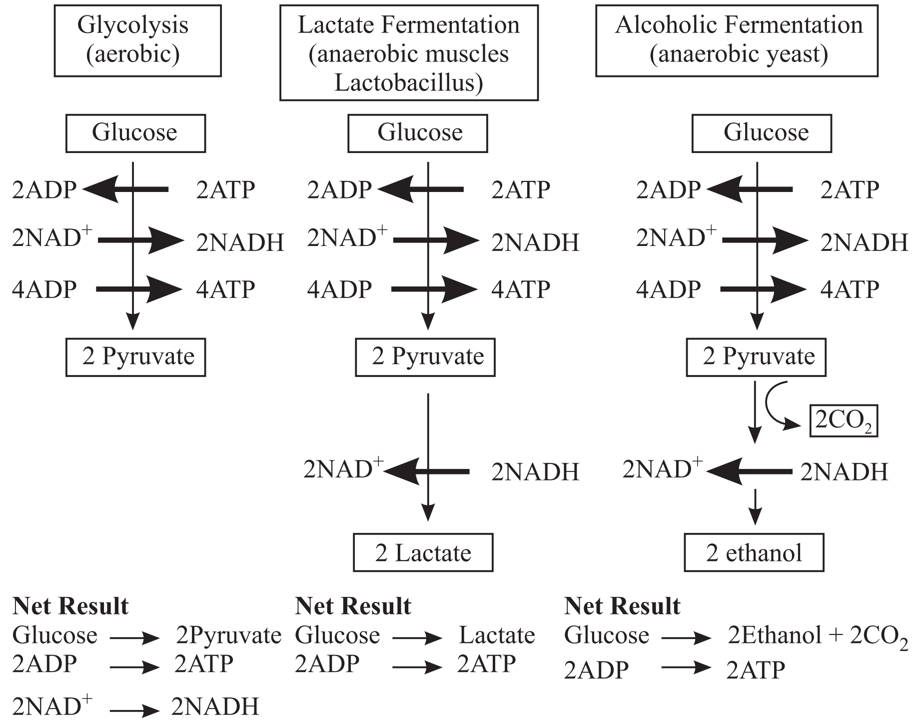


Fig. 12.3 Pathways of anaerobic respiration

Significance of fermentation

Fermentation has a number of industrial applications. It is made use of on a large scale in certain industries. Micro-organisms like the different strains of bacteria and yeast are cultured in very large numbers and used for various purposes.

1. In bakeries for preparing bread, cakes and biscuits.
2. In breweries for preparing wine and other alcoholic drinks.
3. In producing vinegar and in the tanning and curing of leather.
4. Ethanol is used to make gasohol, a fuel that is used for cars in Brazil.
5. In everyday life, fermentation is used while making *idli*, *dosa, bhatura* and *dhokla*. The kneaded flour or *maida* left for some hours in warm environment becomes somewhat spongy (leavening). This is because of fermentation by the bacteria that begin to grow in it. As carbon dioxide escapes, it causes leavening. Fermentation products give a typical flavour and taste to these items.

> Do you know why muscles pain during prolonged exercise? This is due to accumulation of lactic acid under anaerobic condition.

12.3.3 Fate of pyruvic acid in aerobic respiration

- You have already learnt how glucose is converted into 2 molecules of pyruvic acid in the cytoplasm of a cell during glycolysis.

- In the presence of oxygen, pyruvic acid enters the mitochondria and is decarboxylated (removal of CO_2) and dehydrogenated (removal of H) to acetyl CoA. **Acetyl CoA** is thus the connecting link between glycolysis and the next series of reactions that yield more energy in the form of ATP. Acetyl CoA can also be generated from fats and proteins.

Krebs' Cycle or the citric acid cycle

- Acetyl CoA is the molecule entering the Krebs' Cycle taking place in the matrix of the mitochondria.
- Details of this cycle were worked out by Sir Hans Krebs in the 1930s. It is also known as tricarboxylic acid cycle or TCA cycle.
- Steps of the Krebs' Cycle are as follows, (*See* Fig. 12.4)

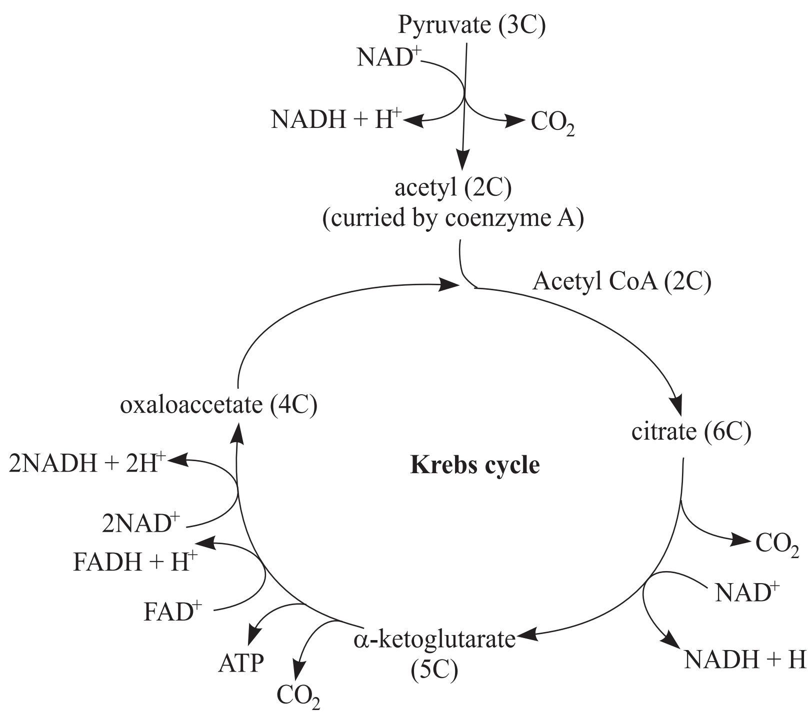


Fig. 12.4 Kreb's Cycle (simplified)

Summary of this phase in respiration is

$$2\text{Pyruvic acid} + 8\text{NAD} + 2\text{FAD} + 2\text{ADP} \longrightarrow 6CO_2 + 8\text{NADH} + 2FADH_2 + 2\text{ATP}$$

> H-carrier NAD and FAD are derived from vitamin B complex and are known as coenzymes

- Acetyl group (2 carbon) enters the cycle by combining with **oxaloacetate** (4 carbon), to form **citrate** (6 carbon). This initiates citric acid cycle.
- As acetyl group passes round the cycle, the 2 carbon atoms are lost in CO_2 in two decarboxylation reactions, and hydrogen is added to hydrogen carriers in four dehydrogenation reactions, resulting in a total of 3 $NADH_2$ and 1 $FADH_2$ molecules.

- One molecule of ATP is also made directly for every turn of the cycle. (Remember that two acetyl groups were made from one glucose molecule. As such two turns of the cycle occur per glucose molecule used). Oxaloacetate is regenerated at the end of the cycle ready to accept another acetyl group.
- Thus, at the end of the Citric Acid Cycle, there are a total of 10NADH and $2FADH_2$ (2NADH from glycolysis).
- Note that all the hydrogen atoms from the original glucose are now on hydrogen carriers, NAD and FAD.

These hydrogen carriers enter the next phase known as the respiratory chain or Electron-Transport-Chain (E.T.C.) for further release of energy.

The Respiratory Chain or Electron Transport Chain (E.T.C.) or Oxidaive-Phosphorylation

- The hydrogen carriers now move to the inner membrane of the mitochondrion. This membrane has folds called *cristae*, which increase its surface area.
- The hydrogen ions carried to the cristae undergo stepwise oxidation using molecular oxygen and energy is released in a series of small steps. Some of this energy is used to make ATP from ADP and inorganic Phosphate (P_i). This is called *oxidative phosphorylation*.
- During these reactions, the hydrogen is split into H^+ and electrons (e^{-1}), which are accepted by a series of hydrogen or electron carriers ending with oxygen. This series of carriers constitute the **respiratory chain** (Fig. 12.5).

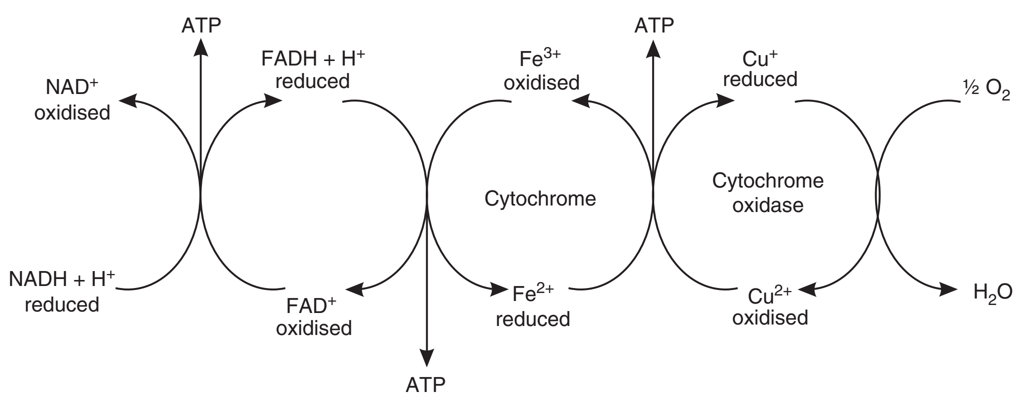


Fig 12.5 Respiratory Chain (Oxidative Phosphorylation)

- Hydrogen or electrons at a higher energy level are passed from one carrier to the next, moving downhill in energy terms, until they reach oxygen, the final acceptor of electrons which as a result is reduced to water.
- At each transfer level, some energy is released as heat and in some of the transfers this is used for the formation of ATP.
- The final step involves cytochrome oxidase enzyme, which hands over the electrons to the H^+ before being accepted by oxygen to form water.
- For each $NADH_2$ that enters the respiratory chain, 3 ATP can be made but for each $FADH_2$, only 2 ATP can be made. Can you guess why? This is owing to the facts that $FADH_2$ enters the respiratory chain at a lower energy level in the chain of reactions.

Substances like carbon monoxide and H_2S act as poisons since they block the H-transfer system and stop ATP generation.

Overall budget for aerobic respiration of one glucose molecule

See table no: 12.2

	CO_2	ATP	$NADH+H^+$	$FADH_2$
Glucolysis	-	2	2	-
Pyruvate-> Acetyl coA	2	-	2	-
Krebs cycle	4	2	6	2
Total	$6CO_2$	4ATP	10 $NADH+H^+$ 10×3=30 ATP	2 $FADH_2$ 2×2=4 ATP

Total No. of ATP mols = 38

* Remember that two turns of the Krebs' Cycle take place per glucose molecule as at the end of glycolysis two pyruvic acid molecules are formed each of which separately enters the Krebs' Cycle.

* According to some biologists, the total numbr of ATP molecules produced in cell respiration after oxidatrion of one glucose molecule is 36 and not 38 because two $NADH_2$ molecules produced in glycolysis in cytoplasm, are theoretically oxidised through electron-transport system in mitochondrion. In the mitochondrion, on the other hand, the matrix is already having higher concentration of $NADH_2$ molecules. Thus, two $NADH_2$ molecules produced in glycolysis, have to enter the mitochondrion against the Concetration Gradient, for oxidation, and for this process, two ATP-molecules would be consumed. For this reason, the net amount of ATP molecules per glucose oxidation by aerobic respiration, should be 36. However, since bacteria do not have mitochondria; the number of ATP molecules produced per glucose molecule oxidised by prokaryotes,

should be considered as 38.

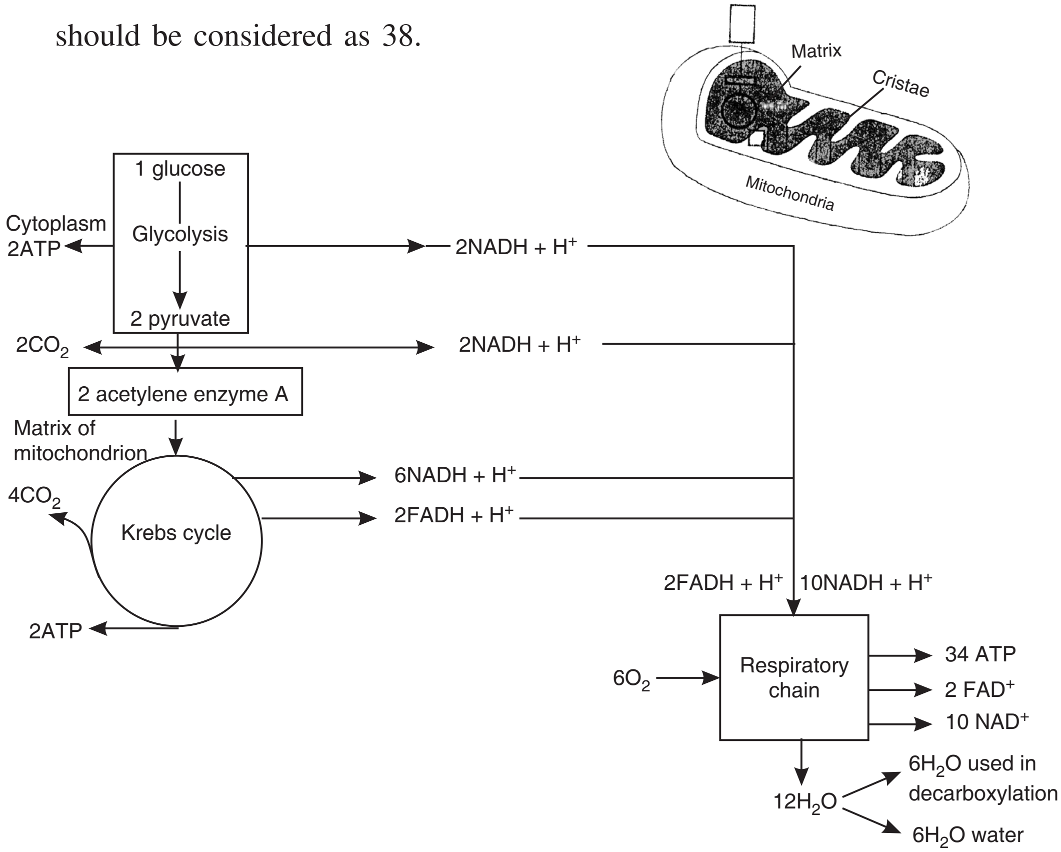


Fig 12.6 Summary of Aerobic respiration.

12.3.4. Significance of Krebs' Cycle and Acetyl CoA

1. It is the major pathway to release reduced coenzymes and energy, in a controlled manner.
2. It is the common pathway for oxidative breakdown of glucose, (carbohydrates), fatty acids and amino acids. The fatty acids undergo β oxidation to produce acetyl CoA and amino acids from proteins enter Krebs' Cycle after deamination (removal of $-NH_2$ group) of amino acids.
3. Krebs' Cycle provides series of intermediate compounds needed for the synthesis of other biomolecules like amino acids, nucleotides, chlorophyll, and fats.

12.3.5 Amphibolic Pathway

Respiration is necessary for the survival of all living beings. In respiration, oxygen is utilised and carbon dioxide given out. The green plants carry out photosynthesis during which CO_2 and H_2O are utilised in the presence of sunlight to synthesize starch and energy. As such, photosynthesis is the building up or anabolic pathway whereas respiration is a breaking down or catabolic process in which glucose is oxidised to yield CO_2, H_2O and energy. The two pathways occurring together constitute the amphibolic pathway (amphi = two).

The light intensity at which photosynthesis just compensates for respiration is called **Compensation Point**. In other words, in a green plant at the compensation point, amount of CO_2 consumed during photosynthesis is equal to the amount of CO_2 generated through respiration.

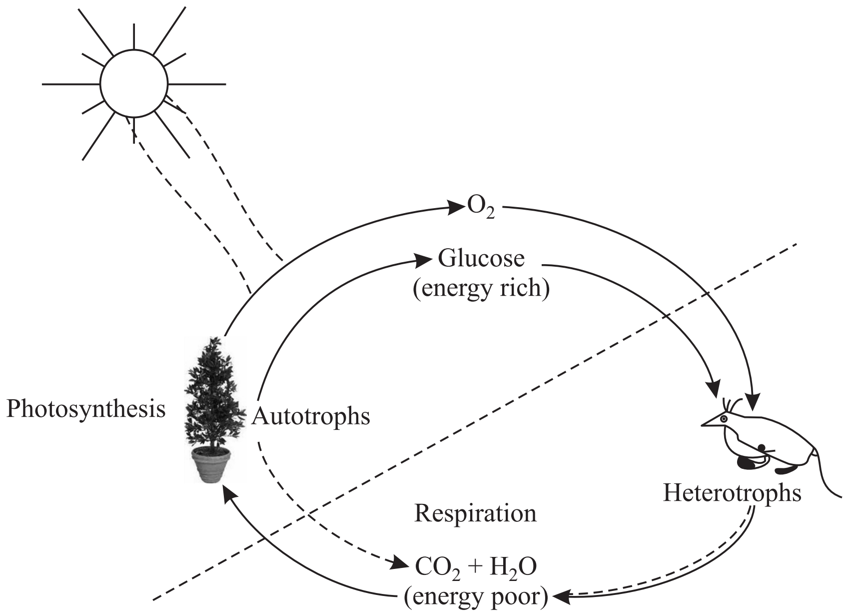


Fig. 12.7 Anaerobic respiration in germinating seeds

INTEXT QUESTIONS 12.3

1. Why is pyruvic acid converted into alcohol or lactic acid during fermentation?

   ....

2. Why is there less release of energy during anaerobic respiration?

   ....

3. List the three phases of aerobic respiration of glucose. Where in the cell do these reactions take place?

   ....

4. What is the role of O_2 in aerobic respiration?

   ....

5. Name the substrate and products of Krebs' Cycle.

   ....

6. How do fatty acids enter Krebs' Cycle?

   ....

7. When the amount of CO_2 uptake during photosysthesis is equal to the amount of CO_2 generated through respiration, it is called ....

8. What is amphibolic pathway?

....

12.4 RATE OF RESPIRATION AND FACTORS AFFECTING IT

The rate of respiration can be measured by the amount of CO_2 released per unit time. As expected, it varies in different organs and with age.

In general the factors which affect respiration include **internal factors** such as minerals, structure of respiratory tissue or organ, the activity of the respiratory enzymes and the type of substrate; and **external factors** such as oxygen, water, and temperature.

(a) **Type of substrate**-Respiratory substrate may be carbohydrate, protein or fats. The kind of substrate being oxidized can be determined by measuring the **Respiratory Quotient** of the respiratory tissue or oxygen. What is respiratory quotient or R.Q?

$$R.Q = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

> For carbohydrates, $CO_2/O_2 = 1$ as in the stem and roots.
>
> For protein, $CO_2/O_2 < 1$ as in protein-rich seeds like pulses.
>
> For fat and oils $CO_2/O_2 > 1$ as in the oil-containing seeds e.g. mustard.
>
> As for fats RQ > 1 since more energy is released per mol of fat than per mol of glucose.

(b) **Temperature -** The temperature between 30-35°C is most suitable for respiration. Can you guess why? This is because the enzymes can work best in this range. Respiration is reduced beyond 50°C and also at very low temperatures (0-10°C).

(c) **Oxygen**-the rate of respiration increases with rise in oxygen concentration. As O_2 concentration increases from zero, the rate of respiration increases. However, beyond a limit the rate of increase falls.

(d) **Carbon dioxide**–rate of respiration decreases if CO_2 is allowed to accumulate surrounding the respiratory tissue.

(e) **Water**–respiration is very slow if the water content of the protoplasm is low as in dry, matured seeds. Dormant seeds show very low rate of respiration. It water is supplied to dry seeds, respiration starts immediately.

INTEXT QUESTIONS 12.4

1. What is the R.Q. for carbohydrates and fats?

....

2. What is the effect of high concentration of O_2 on respiration?

....

3. What is the ideal temperature for the process of respiration ?

....

4. Define R.Q.

....

5. What is the limiting factor of respiration in dry seeds?

....

12.5 PHOTORESPIRATION

- Your have aready studied that during dark reaction of photosynthesis, the enzyme RUBISCO catalyses the carboxylation of RUBP :

$$RUBP + CO_2 \xrightarrow{RUBISCO} 2PGA \text{ (Phosphoglyceraldehyde)} \longrightarrow \text{Calvin Cycle}$$

- This enzyme also has very high affinity for O_2. It can therefore, catalyze the reaction of O_2 with RUBP (oxygenation).
- The respiration that is initiated in chloroplast and occurs in the presence of light and high concentration of O_2 (and low CO_2) is called photorespiration :

$$RUBP + O_2 \xrightarrow{RUBISCO} 2PGA + 1 \text{ Phosphoglycolate}$$

$$\downarrow$$

$$\text{Calvin Cycle}$$

Thereafter, the phosphoglycolate undergoes series of reactions in **mitochondria and peroxisomes.** 2 molecules of phosphoglycolate ultimately produce 1 molecule of PGA and 1 molecule of CO_2. Note that there is no ATP production here, unlike respiration.

- This occurs because RUBISCO anzyme has the same active site for both CO_2 and O_2.
- Oxygenation of RUBP in presence of oxygen leads to a loss of about 25% carbon fixed by plants during the dark reaction.
- Use: Protects the plants from photo-oxidative damage by utilising part of the solar energy which would otherwise damage the plant pigments.

INTEXT QUESTIONS 12.5

1. Name the products that are formed when RUBP combines with O_2. Name the enzyme that is responsible for this reaction.

   ....

2. Give one point of difference between respiration and photorespiration.?

   ....

3. State the conditions under which photorespiration occurs?

   ....

12.6. PENTOSE PHOSPHATE PATHWAY OR HMP-PATHWAY

In microbes (bacteria and some fungi) used for Industrial production of commercial products such as antibiotics and in highly metabolically active tissues of animals, most efficient respiratory pathway has been discovered. It is called **PPP or Pentose Phosphate Pathway or Hexose-Monophosphate Shunt Pathway** or **Direct Oxidation of Glucose-pathway**. The site of this respiratory pathway is cytosol and it does not require ETC (electron transport chain) or the mitochondrion.

It this pathway, when a molecule of glucose enters the respiratory process, it is phosphorylated to Glucose-6-Phosphate by consumption of one ATP-molecule. This Glucose-6-P molecule, meets a group of 5 glucose-6-P molecules in the cytoplasm, which in the presence of dehydrogenase and 6 NADP get oxidized to 6 Phosphoglucomutase molecules, producing 6 $NADPH_2$ molecules. In the next reaction catalyzed by dehydrogenase and decarboxylase, six-phosphogluconate molecules, get oxidised to six molecules of pentose sugar, Ribulose-5P; producing $6CO_2$ (that diffuse in air) and 6 more NADP get reduced to 6 $NADPH_2$. Thus, in this respiratory pathway a glucose molecule is broken down to 6 CO_2 + $12H_2$ (as part of 12 $NADPH_2$), side by side producing 6 molecules of pentose sugar (Ribulose-5 phosphate) which is utilized for regeneration of 5 molecules of Glucose-6-P through a long chain of intermediate compounds produced in Calvin Cycle of photosynthesis to restart another cycle of glucose-oxidation.

You would observe that in this pathway if 12 $NADPH_2$ molecules produced within two steps of glucose-oxidation, are allowed to enter oxidative phosphorylation (ETC), 36 ATP molecules would be produced. If we deduct one ATP, consumed in first step of conversion of Glucose to Glucose-6P, a net amount of 35ATP molecules would be available as respiratory energy produced by complete oxidation of one glucose molecule within two chemical reactions to $12H_2$ and $6CO_2\uparrow$

PPP is so-called because after complete oxidation of one glucose molecule to $6CO_2$ + $12NADPH_2$; a side product is a pentose phosphate sugar i.e., ribulose-5-Phosphate. If glucose molecules keep entering this pathway, a large number of pentose sugars would be formed. This sugar, on conversion to ribose-5-P, would act as raw material for RNA synthesis. If ribose-5-P loses one O-atom, it would change to deoxyribose-5P, that can act as raw material for DNA-synthesis. However, in general, 6 molecules of ribulose-5P, through large number of intermediate compounds (such as erythrose, sedoheptulose, and hexoses), regenerate 5 molecules of Glucose-6-P, responsible for new cycle of Pentose Phosphate Pathway.

PPP is also called HMP-pathway because the raw material for glucose oxidation is Glucose-6-P which is a hexose sugar produced after consuming only one ATP in contrast to Glycolytic pathway, where two ATP-molecules are consumed during the respiratory-oxidation of Glucose under aerobic condition.

ACTIVITY I

To demonstrate anaerobic respiration in germinating seeds

Take eight or ten water-soaked pea seeds with the seed coats removed and push them into the mouth of a test tube filled with mercury and invert it in a beaker of mercury. The pea seeds float on the top and are completely surrounded by mercury. After about two days there is a fall in the level of the mercury because of gas liberation. If potassium hydroxide (KOH) is introduced into the test tube then it is found that KOH floats up through the mercury and on coming in contact with the gas, makes the level of mercury to rise up again. Now can you say why does this happen? KOH absorbs the carbon dioxide gas liberated by the seeds. Therefore this experiment demonstrates the anaerobic respiration (See Fig. 12.8) wherein, CO_2 is process of evolved due to anaerobic respiration of seeds soaked in water.

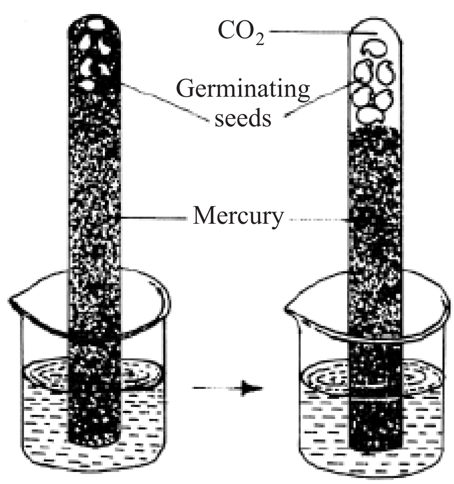


Fig. 12.8 Anaerobic respiration in germinating seeds

ACTIVITY II

Anaerobic respiration in yeast

Procedure : Take a pinch of dry baker's yeast (in water) or few ml of yeast suspension used in a bakery. Add this to 10 ml of 10% glucose solution in test tube A. Cover the surface of the liquid in the tube with oil to prevent contact with air. Close the test-tube tightly with a cork. Take a double bent glass delivery tube with one end small and other end long (See Fig. 12.9).

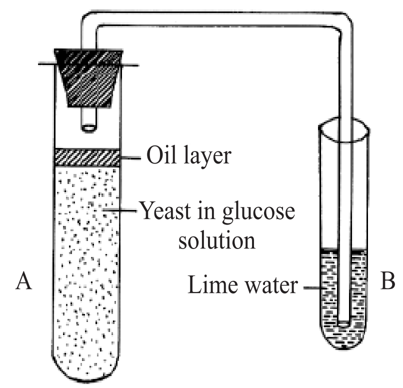


Fig. 12.9 Anaerobic respiration in yeast.

Insert the short end of the glass tube through the rubber-cork stopper so that it remains exposed to the air inside the tube A. Insert the other end of the tube into the limewater containing test tube B, as shown in the figure.

Place test tube A in warm water 37-38°C in a beaker. Observe that lime water gradually turns milky indicating evolution of CO_2 from yeast preparation. Also note that the level of the limewater in the delivery tube does not rise, showing that there is no fall in volume of gas in test tube A and therefore no utilization of O_2 by yeast. Keep the experimental set up for one day. Open the stopper of tube A and smell. Do you notice the smell of alcohol? Can you name the alcohol and write the equation for the alcoholic fermentation

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + 2ATP$$

ACTIVITY I

You can use similar set-up as in activity II to demonstrate aerobic respiration in yeast. Make the following changes :

1. Replace the test tube A with a large conical flask so that it has sufficient space left above the glucose solution with yeast.
2. The surface of the solution should not be covered with oil to permit easy contact with air.

3. Observe that lime water turns milky in this experiment too, indicating evolution of CO_2. Also note that the level of H_2O in the delivery tube B also rises indicating a fall in gas volume in tube A. How do you explain this? Oxygen is utilized by the yeast, and you will not smell alcohol after the reaction in the test tube A

Note that the yeast grows both in aerobic and anaerobic conditions but better under aerobic conditions. The secret of brewing is to regulate the conditions very strictly.

WHAT YOU HAVE LEARNT

- All living organisms require energy. Oxidation of food molecules provides this energy.
- Respiration involves (i) external respiration or gaseous exchange, and (ii) cellular respiration.
- Anaerobic respiration is the process of incomplete oxidation and produces only 2 molecules of ATP whereas the aerobic respiration is a process of complete oxidatin with production of 38 molecules of ATP, per molecule of glucose-oxidised.
- Aerobic respiration occurs in three main steps viz. Glycolsis; Krebs' Cycle; and electron trasport chains (or oxidative phosphorylation).
- Steps of glycolysis are common between aerobic and anaerobic respiration.
- Glycolysis occurs in cytoplasm and Krebs' Cycle and ETC in mitochondria.
- Alcoholic fermentation has many industrial applications.
- Young parts of the plants show higher rate of respiration.
- Factors like type of substrate, temperature, oxygen and amount of available water influence the rate of respiration.
- RQ value is important in identifying the kind of substrate used in respiration.
- Photorespiration occurs in plants during intense light and low level of carbon dioxide. There is no net gain of ATP. It protects the chlorophyll pigments from photo-oxidation, when light intensity is very high.

TERMINAL EXERCISES

1. Define respiration
2. What is the role of O_2 in electron transport chain (ETC)?
3. How many molecules of ATP are released when a molecule of glucose is oxidised to
   (a) CO_2 and H_2O?
   (b) Ethyl alcohol and CO_2?

4. Write the equation for aerobic respiration.
5. Name the end products of electron transport chains.
6. Respiration is a continuous process in green plants. Then why is it that they give out O_2 and not CO_2 during the day?
7. What is the site for
   (a) Glycolysis,
   (b) Krebs Cycle,
   (c) ATP generation by oxidative phosphorylation?
8. What is the fate of pyruvic acid in the (a) presence, and (b) absence of oxygen? Write the equations representing the processes, that take place in (a) & (b).
9. What is the significance of stepwise oxidation of organic molecules instead of one step reaction?
10. What is the significance of photorespiration?
11. List the substrates that enter and the products produced in
    (a) Glycolysis
    (b) Krebs Cycle
12. How is yeast useful in industry? Give any three examples.
13. How does exchange of respiratory gases take place in plants
14. Define RQ. What is its significance?
15. Mention the significance of TCA cycle.
16. Why does fermentation yield less energy than aerobic respiration?
17. List any 2 important contributions of PPP in a cell.
18. What are the three major phases of glycolysis?
19. What is the importance of Krebs' Cycle?
20. Differentiate between aerobic and anaerobic respiration
21. Why is photorespiration a wasteful reaction?
22. What is respiratory chain or ETC? What is its significance?
23. Discuss the site of Pentose Phosphate Pathway in a cell.

ANSWERS TO INTEXT QUESTIONS

12.1 1. The green Plants convert solar energy to chemical energy and store it in the form of complex organic molecules. During respiration, they are oxidised and large amount of energy is released. This is stored as ATP. Plants use this ATP for metabolic activities.

2. In the form of ATP

3. Please see text.

12.2 1. Gaseous exchange takes place through the general body surface of the plants; through the stomata; and the lenticels.

2. Diffusion

3. Oxygen; carbon dioxide

4. (a) They have a large surface area to allow exchange of gases from and (b) their requirement of oxygen is much less.

12.3 1. In the presence of O_2, it is completely broken down to simple forms such as CO_2 and H_2O.

$$2\text{Pyruvic acid} + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 30\text{ATP}$$

(8ATP are obtained from glycolysis)

In the absence of O_2 they carry out alcoholic fermentation.

$$2\text{Pyruvic acid} \longrightarrow 2\text{Ethyl alcohol} + 2CO_2$$

2. This is becausse organic molecules are only partially oxidised in anaerobic respiration and much of the energy remains in the end products such as alcohol or lactic acid.

3. Glycolysis-in cytosol

Krebs' Cycle-matrix of mitochondria

E.T.C.-inner membrane of mitochondria

4. O_2 acts as the terminal acceptor of electrons and H_2, removed from the glucose molecule and gets reduced to H_2O.

5. Substrate- Acetyl CoA

Product-2 CO_2, 3 $NADH_2$, 1 $FADH_2$, 1 ATP

6. Fatty Acid undergoes β oxidation and produces acetyl CoA. This can enter the Kreb's Cycle

12.4 1. R.Q. is 1

2. Rate of respiration increases up to a point and beyond this point its rate of increase falls.

3. 30-35°C

4. It is the ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration. It gives us an idea of the kind of substrate used for respiration.

5. Water for hydration of respiratory enzymes.

12.5 1. Products are1 P.G.A. and 1 Phosphoglycolate

2.

Respiration	Photorespiration
1. Occurs in cytoplasm and mitochondria	1. It involves 3 organelles chloroplast, mitochondria peroxisome
2. Substrate is glucose	2. Substrate is RUBP
3. ATP, CO_2 and H_2O are given out as products	3. The products are only CO_2 and P.G.A. and no ATP is generated
4. Takes place in C_3 as well as C_4-plants	4. Takes place in green plants (C_3-plants)
5. Occurs at both day and night	5. Takes place under high O_2 and low CO_2 and high temperature. Therefore occurs only during the day.
6. Makes energy available for metabolic activities.	6. It is a wasteful reaction. Its only use is that it prevents photo-oxidative damage of photosynthetic pigments in the green-C_3-plants. (any one)

3. (a) Light
   (b) High concentration of O_2
   (c) Low concentration of CO_2