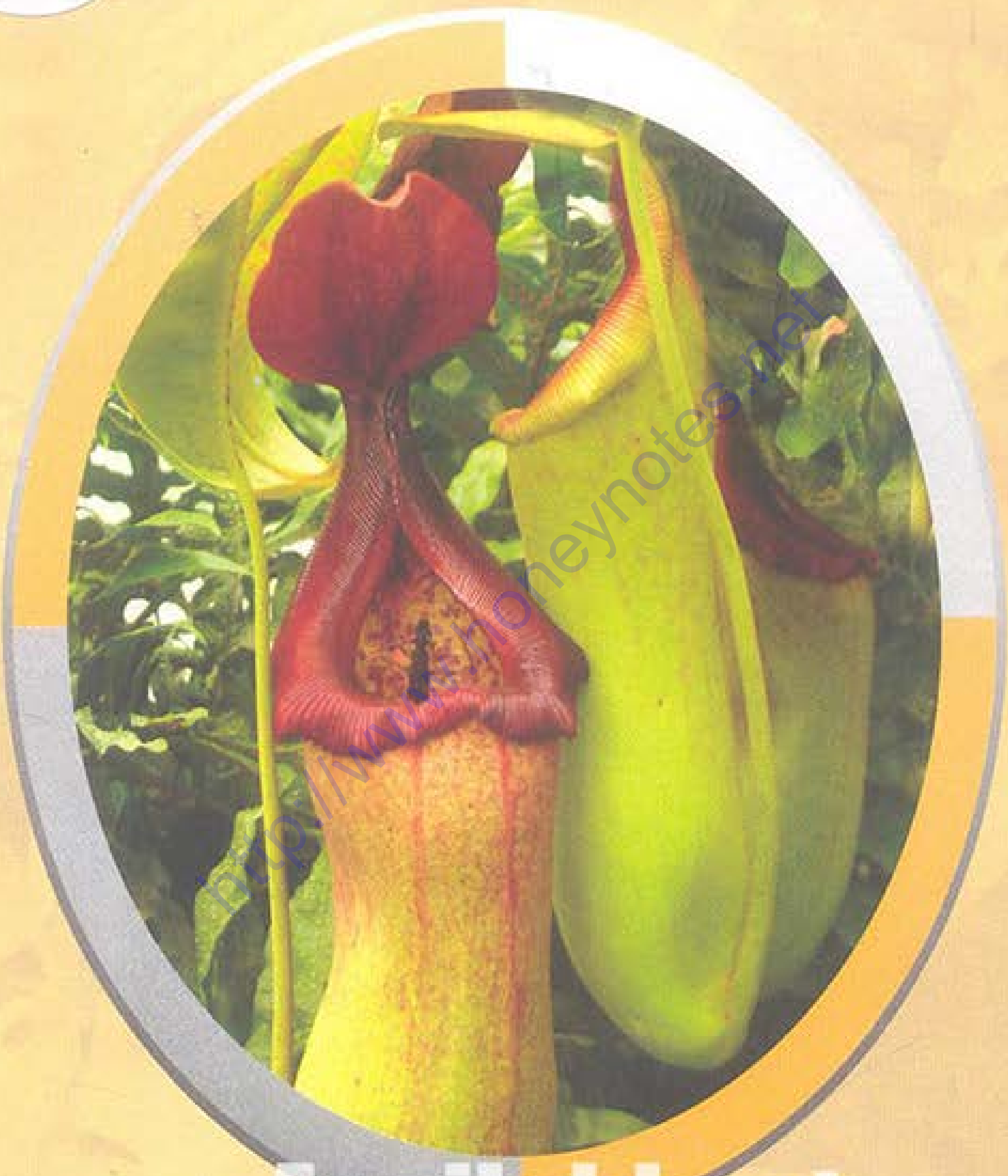
BIOLOGY

11



Bio-Energetics

CHAPTER – 11

DEFINITION

The capturing and conversion of energy from one form to another in the living system and its utilization in metabolic activities is called Bioenergetics.

Bio-energetics is the quantitative study of energy relationships and conversion into biological system.

Biological energy transformation always obey the laws of thernodynamic.

ROLE OF ATP AS ENERGY CURRENCY

ATP is adenosine triphosphate. Adenosine is made of adenosine and ribose sugar. Among the three phosphate groups two are energy rich PO4 bonds. So ATP is a high energy compound it gives its PO4 groups easily. When 1 ATP is converted into ADP, 7.3 K cal/mole or 31.81 KJ/mole energy is released. ATP -> ADP + Pi + Energy

Living organisms use organic food for generation of energy. These food usually contain carbohydrates which degrade to produce CO_2, H_2O and energy. Which is usually in the form of ATPs. ATP plays role in several endergonic and exergonic reactions.

ENDERGONIC REACTIONS

Those chemical reactions which accompanied by the absorption of the energy are known as endergonic reactions. The products have a higher free energy than reactants. Examples of endergonic reaction in human are

1. Synthesis of proteins
2. Synthesis of lipids
3. Synthesis of cholestrol
4. Synthesis of glycogen

EXERGONIC REACTIONS

Those reactions which complete along with the liberation of free energy are known as Exergonic reaction. The products have a lower free energy than the reactants.

EXAMPLE

An aerobic glycolysis, Kreb's cycle, oxidative phosphoylation.

PIGMENTS

Substances in plants that absorb the visible light are called Pigments. Different pigments absorb light of different wavelength. They are involved in the conversion of light energy to chemical energy. Important plant pigments are chlorophyls, carotenoids, phycobilin, xanthophylls, phaelophytin.

PHOTOSYSTEM

Each photosystem is a highly organized unit consisting of chlorophyll accessory pigment molecules and electron carrier molecules present on the thylakoids of chloroplast. Each thylakoid contains many units of two photosystems the photosystem I and photosystem II. So chloroplast contains thousands of photosystem.

The photosystem consists of chlorophyll “a” and “b” and carotenoids. Chlorophyll having empirical formula of C55H72O5N4Mg is almost identical to “Chlorophyll b” of empirical formula C55H70O6N4Mg. But the slight structural difference between them is enough to give 2 pigments slightly different absorption spectra and hence different colours “Chlorophyll a” is blue green while “b” is yellow green.

Hundreds of chlorophyll a, chlorophyll b and carotenoids cluster together in a photosystem. But only a single molecule of chlorophyll a acts like a reaction centre the rest of others absorbs a photon, the energy is transmitted from pigment, molecules to pigment molecules until it reaches a particular chlorophyll a located in the region of reaction centre, where it gives electrons to primary electron acceptor

FIGURE 11.3 PAGE 260

Hundreds of carotenoids are admixed with 2 types of chlorophyll molecules in photosystem, giving yellow and orange shades. Carotenoids can absorb wavelength of light that chlorophyll cannot transfer to chlorophyll a. Some times excess energy can damage chlorophyll a, so carotenoids accept energy from them, thus providing a function known as Photoreceptor.

ROLE OF LIGHT

Light has a dual nature, can behave like a wave or like a particle. It is composed of packets of energy called photons (hu). Light energy captured in the light harvesting complexes is efficiently and rapidly transferred to the chlorophyll molecules present in the photosynthetic reaction centre. When a photon of light hits these chlorophyll a molecules. The energy of these photons is absorbed and results in the elevation of an e- from the ground state to an excited state, level depends upon the energy and incident photon.

A photon of red light has enough energy to raise an electron to excited state I and this energy is sufficient to carryout all

the chemical reactions of photosynthesis.
The energy transferred by blue light raise the electron to excited state –2. However the energy transmitted by red or blue photons to photosynthetic electron transport chain is exactly the same. This is because that extra energy is lost (from absorption of blue photon) by radiationless de-excitation.
The excitation energy can be used in
1. Photochemistry (i.e. it enter the photosynthetic electron transport chain)
2. Lost as heat.
3. Give fluorescence etc.

PHOTOSYNTHESIS

Photosynthesis is an anabolic process in which chloroplast of the plants take up CO_2 and H_2O and using light energy to synthesize carbohydrates. In photosynthesis, the light energy is converted to chemical energy. It is an oxidation reduction process in which water is oxidized and CO_2 is reduced

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

In simple

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

This process divides into
1. Light reaction
2. Dark reaction

1. LIGHT REACTION

In the light dependent reactions, light energy is absorbed by chlorophyll and other photosynthetic pigment molecules. It is then converted into chemical energy. Due to this energy conversion, NADPH+ and ATP are produced.
Components of light reaction
1. Light capturing chlorophyll molecules.
2. Membrane bound protein complexes
3. Mobile electron carriers

CHLOROPHYLL MOLECULES AND PHOTOSYSTEM
Each photosystem consists of a light gathering "antenna complex" and a "reaction centre". The antenna complex has many molecules of chlorophyll a, chlorophyll b and carotenoids most of them channeling the energy to reaction centre. Reaction centre of photosystem I and II has one or two "chlorophyll a" molecules, primary electron acceptor, associated electron carriers of electron transport system and certain specific proteins known as chlorophyll-bound proteins which differs them from other "chlorophyll a" molecules of the same system. The "chlorophyll a" molecules at the reaction centre of photosystem I (PSI) has a maximum absorbance at 700 nm, while those of PS II absorb at 680 nm. Therefore these reaction centre are called P700 and P680 where P simply stands for pigment.

COMPLEXES
There are 4 major groups of complexes.
1. PS I
2. PS II
3. Cytochrome b/f complex
4. ATPase complex

The PS I and ATPase or ATP synthase complex are present on non-appressed region of thylakoid. While PS II and light harvesting complexes (LHC II) are present on appressed side. The cyt b/f complex is randomly distributed throughout the mambrane.

MOBILE ELECTRON CARRIERS
Transport the excited electrons between the complexes. These are plastoquinone (PQ) plastocyanin (PC), ferredoxin (FD)

ELECTRON TRANSPORT
This process occurs in several steps.

(1) EXCITATION OF PS II
When chlorophyll a of reaction centre of PS II is striked by a photon, the energy of photon absorbs in it. This results in the

elevation of an electron from the ground state to an excited state. The excited electrons produced within P680 is rapidly transferred to the primary electrons acceptors phaelophytin. So 2 electrons which are transformed has to be replaced which is done by water.

(2) PHOTOLYSIS OF WATER

In the presence of light a water splitting enzyme complex extracts 4 electrons from two water molecules. Removal of electrons splits the water into two hydrogen ions 2H+ and oxygen atoms. The extracted electrons from water are supplied to PS II (P680) while the oxygen atom immediately combines with another oxygen atom to form O2. Which is released during photosynthesis. The hydrogen ions or proton (H+) are stored in thylakoid space. The overall reaction will be

$2H_2O \rightarrow 4H^+ + 4e^- + O_2$

(3) FLOW OF ELECTRONS FROM PS II TO PS I

Photoexcited electrons accepted by phaelophytin from PS II are transferred to plastoquinone molecules QA and QB which accept two electrons and takes up two protein from the stroma. PQ carries electrons from PS II to cytochrome b/f complex containing FeS protein. This is thought to be the rate limiting step of electron transport. Electrons from PQ are taken up by Cyt b/f complex through FeS and releasing protons (2H+) to the lumen. The second mobile electron carrier plastocyanin (PC) takes the electrons and delivered to the photosystem I.

(4) FLOW OF ELECTRONS FROM PS I TO NADP+ REDUCTASE

A second excitation event within PS I leads to the transfer of electrons to the primary electron acceptor. The primary e-acceptor of PS I passes the photoexcited electrons to a second electron transport chain, which transmit then to ferredoxin, an iron containing protein. An enzyme called

NADP reductase then transfer the electrons from Fd to $NADP^+$ (oxidized form)

(5) REDUCTION OF NADP+ TO NADPH+ H+

This is the redox reaction that stores the high energy electrons in $NADP^+$ to reduced it to $NADPH + H^+$.

$NADP^+ + 2H^+ \rightarrow NADPH + H^+$

Hydrogen ions are taken from stroma which is being pumped from thylakoid space to stroma by ATPase.

PHOTOPHOSPHORYLATION

Hydrogen ions are pumped into thylakoid space by cyt b/f and also $2H^+$ ions are collected there from photolysis of one water molecule. This large no. of H^+ ions in thylakoid space compared to stroma, creates an electrochemical gradient, when these hydrogen ions flow out of the thylakoid space by way of a channel protein present in membrane called the ATP synthase complex, energy is prvided to it. The transport of 3 protons (H^+ ions) through the ATPase complex are normally required to produce 1 ATP from ADP and inorganic phosphate Pi.

$ADP + Pi \rightarrow ATP$

This is called chemiosmotic ATP synthesis because chemical and osmatic events join to permit ATP synthesis. The linear flow of electrons from H_2O to $NADP^+$, coupled to ATP syntheses is non-cyclic photophosphorylation because the electrons pass on to a terminal acceptor.

In cyclic photophosphorylation the electrons are cycled from PS I back to PQ. So only ATP is produced but not $NADPH + H^+$. This occurs under following conditions to meet increased ATP demand for e.g. CO_2 fixation

1. Protein synthesis
2. Synthesis of starch

EVENTS OF LIGHT REACTION

1. Photolysis of water.
2. Reduction of $NADP^+$ to $NADPH + H^+$
3. Synthesis of ATP by photophosphorylation.

So during light reaction ATP and NADPH + H+ are produced which are used in Dark reaction, O2 is evolved as a by product.

2. DARK REACTION

The dark reaction consist of a series of light independent reactions which can proceed even in the absence of light. During dark reaction, energy is produced by ATP and NADPH+ H+ and CO2 is fixed in carbohydrates. This cyclic series of enzymatic catalyzed reaction in the stroma of the chloroplasts is called Calvin-Benson Cycle. During this cycle CO2 is reduced to triose-PO4 sugars, therefore this pathway is also known as C3 pathray (reductive pentose phosphate cycle) and the plants undergo this cycle are known as C3 plants. The calvin or C3 cycle is divided into 3 phases.

CARBOXYLATION (CARBON FIXATION)

The calvin cycle begins when a molecule of CO2 reacts with a highly reactive phosphorylated five carbon sugar named ribulase 1.5 bisphosphate (RuBP). This reaction is catalyzed by the enzyme ribulase biphosphate carboxylase or Rubisco (it is the most abundant protein in chloroplast). The product of this reaction is a highly unstable, six carbon intermediate that immediately breakdown into two molecules of three carbon compound called 3-phosphoglycerate (G3P).

3CO2 + 3RuBP -> G3P

REDUCTION

Each molecule of the PGA or G3P receives an additional phosphate from ATP of light reaction, forming 1,3-bisphosphoglycerate (G1,3P) which is then reduced to glyceraldehydes 3-phosphate (GA3P) and Dihydroxyacetone phosphate (DHAP) by NADPH+ H+GA3P and DHAP are intercovertible and the reaction don't require any energy. These products are also formed during glycolysis and links dark reaction with sugar synthesis pathway.

6G3P + 6ATP + 6NADPH + H+ -> 6GA3P + 6ADP + 6NADP+ + 6Pi

REGENERATION

Three carbon compounds are rearranged to form five carbon units ribulose 1,5-bisphosphate (RuBP), which is the primary carbon acceptors in the cycle.

5 GA3P + 3ATP -> 3 RuBP + 3 ADP + 3Pi

Again more molecules of ATP are used for phosphorylation of RuBP, which then starts the cycle again.

CONCLUSION

For every 3 molecules of CO_2 entering the cycle and combining with 3 mole of RuBP (5C), six molecules of three carbon G3P is produced. Out of six G3P only one G3P molecule leaves the cycle and can be used for synthesis of glucose, starch, cellulose, sucrose or other compounds. The other 5 molecules are recycled to regenerate 5C RuBP's three molecules, the CO_2 acceptor.

CONSUMPTION

For the net synthesis of one G3P molecule, the calvin cycle consumes a total of nine ATP's and six NADPH + H^+

PHOTORESPIRATION

In presence of light (photon), oxygen is taken up by RuBP and CO_2 is evolved.

RuBP + O_2 -> PGA + Phosphoglycolate ® CO_2

It occurs when CO_2 is deficient, Rubisco works like an oxygenase rather than carboxylase in presence of O_2, produce phosphoglycerate (phosphoglyceric acid-PGA) and Phosphoglycolate, where phosphoglycolate rapidly breaks down to release CO_2. Alternative mechanisms of carbon fixation in hot, arid climate.

In hot temperature the concentration of CO_2 begins to fall in leaves due to closing of stomata, increase yield of photosynthesis etc. These conditions in leaves may cause a wasteful process called photorespiration in which precious products are lost and less energy is generated. In certain plant species alternate mode of CO_2 fixation have evolved

even in very hot and arid environment.
These two photosynthetic adaptations are

1. C4 PHOTOSYNTHESIS (C4 PATHWAY)

This process occurs in C4 plants. Those which prefer calvin cycle with an alternate mode of carbon fixation are known as C4 plants. CO_2 reacts with PEP in presence of PEP carboxylase to produce oxaloacetate, a four carbon compound which converts into malate. Malate transfers from mesophyll cell to bundle sheath cell where it breaks down to pyruvate and releases CO_2. This CO_2 is fixed in calvin cycle by Rubsico and so the cycle continues.
E.g. Family poaceae especially sugar cane, corn.

2. CAM

Plants of hot, arid environment, open their stomata during the night and close them during the day. Closing stomata during the day helps deserts plants to conserve water but it also prevents CO_2 from entering the leaves. During the night, when their stomata are open, these plants take up CO_2 and incorporate it into a variety of organic acids because of lack of energy (ATPs and NADPH+ H+). This mode of carbon fixation is called crassulacean acid metabolism (CAM). They store these organic acids in vacuoles. During day time organic acids release CO_2 for dark reaction because light reaction can supply ATP and NADPH+ H+ on which the calvin cycle depends.
E.g. Cactus, Pinapple, Succulent plants.

CELLULAR RESPIRATION

Aerobic breakdown of glucose molecules into CO_2 and water with synthesis of ATP is called Cellular Respiration.
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 673$ Kcal/mole
Respiration is an oxidation reduction process because the carbon of substrate, mostly glucose is oxidized to form CO_2, while the atmospheric O_2 is reduced to form the water.
There are two types of cellular respiration.

(A) AEROBIC RESPIRATION

The breakdown of sugar, in presence of oxygen [molecular O2] and release of carbondioxide and water with sufficient amount of energy. This type of respiration is known as Aerobic respiration, and the organisms performed this are known as Aerobes.

(B) ANAEROBIC RESPIRATION

The break down of sugar in absence of oxygen is known as Anaerobic respiration, and this type of respiration is performed by Anaerobs.

E.g. Yeast, some bacteria, gut parasites (e.g. tapeworm). Some species of annelids, roots of plants growing in water logged area. Anaerobes are of two types. Those which never need of O2 at all are Obligate anaerobes. Those which respire aerobically but can also respire in absence of O2 are known as Facultative aerobes.

CATEGORIES OF AEROBIC RESPIRATION

The process of aerobic respiration is divided into three main categories.

1. Glycolysis
2. Kreb's cycle
3. ETC

(1) GLYCOLYSIS

Glycolysis is the first and common step in both aerobic and anaerobic respiration. It consists of a complex series of enzymatically catalyzed reactions in which a 6 carbon molecule "Glucose" breaks down into 3 carbon "Pyruvic acid". These reactions occur in Cytoplasm and doesn't require oxygen. Following are the different steps of Glycolysis.

(I) PHOSPHORYLATION

Phosphorylation is the addition of phosphate groups to the sugar molecules. Glucose is phosphorylated by a molecule of ATP to form an activated molecule, the glucose 6 phosphate. ATP is converted to ADP.

(II) ISOMERIZATION

Glucose -6-phosphate is converted to fructose -6-phosphate, an isomer of it by an enzyme.

(III) SECOND PHOSPHORYLATION

Another molecules of ATP is invested which transfers its phosphate group to carbon no.1 of fructose –6-phosphate, forming fructose 1,6-bisphosphate and ADP.

(IV) CLEAVAGE

The 6-carbon, fructose 1,6 bisphosphate molecule is break down into 2; three carbon molecules, 3-phosphoglyceraldehyde PGAL and dihydroxyacetone phosphate (DHAP). These two sugar molecules are isomers and are interconvertible. This is the reaction from which glycolysis derives its name. DHAP is converted to its isomer PGAL and then 2 PGAL will be converted to 2 pyruvic acid molecules. Since at this stage 2 ATPs are used, therefore this phase is known as Energy investment phase.

In the subsequent reactions, energy is produced therefore this half is also known as Energy yielding phase

(V) DEHYDROGENATION (OXIDATION)

In the next step, PGAL is acted upon by an enzyme dehydrogenase along with a co-enzyme nicotine amide adenine dinucleotide (NAD+), which convert PGAL into phosphoglyceric acid PGA or phosphoglycerate by the loss of two hydrogen atoms (2e- + 2H+). These H atoms are captured by NAD+. This is a redox reaction in which PGAL oxidized by removal of electrons and NAD is reduced by the gaining of electrons. Now phosphoglyceric acid PGA picks up phosphate group (Pi) present in cytoplasm and becomes 1,3-bisphosphoglyceric acid (DPGA)

(VI) PHOSPHORYL TRANSFER

1,3-bisphosphoglyceric acid loses its phosphate group to ADP forming ATP and 3-phosphoglyceric acid.

(VII) ISOMERIZATION

The PO4 group of PGA, attaches with carbon no,3 changes its position to carbon no.2 forming an isomer 1-phosphoglyceric acid.

(VIII) DEHYDRATION

A water molecule is removed from the substrate and forming phosphoenal pyruvate (PEP)

(IX) PHOSPHORYL TRANSFER

ADP removes the high energy PO4 from PEP producing ATP and Pyruvic acid. OVERALL REACTION of glycolysis can be summarized as Glucose + 2ADP + 2NAD+ -> 2 Pyruvic acid + 2ATP + 2NADH+ H+ + 2H2O

ENERGY YIELD

Since when PGAL is produced, the cycle is counted twice because DHAP also converts into PGAL and enter the same cycle. 4ATP molecules are produced at Substrate level phosphorylation because PO4 groups are transferred directly to ADP from another molecule. 2 ATP are used in the first phase. Thus there is a net gain of 2 ATPs. 2 NADH+ H+ are produced and each gives 2 ATPs (a total of 6 ATPs). Therefore net production of ATP during glycolysis is 8 ATPs

FATE OF PYRUVIC ACID

There are 3 major pathways by which it is further processed under anaerobic conditions, pyruvic acid either forms, ethyl alcohol or lactic acid or produces CO2 and H2O from kreb's cycle under aerobic conditions.

FERMENTATION

Fermentation the alternative term for Anaerobic respiration was used by W.Pasteur and defined as respiration in absence of oxygen (air). The production of ethyl alcohol from glucose is alcoholic fermentation and that of lactic acid is lactic acid fermentation.

ALCOHOL FERMENTATION

Each pyruvic acid molecule is converted to ethyl alcohol also known as Ethanol in two steps. In the first pyruvic acid is decarboxylated to acetaldehyde under the action of enzyme. Pyruvic acid CH3.CO.COOH -> CH3CHO + CO2

In the next step NADH+ H+ reduces acetaldehyde to ethyl alcohol

$CH_3.CHO + NADH + H^+ \rightarrow CH_3.CH_2OH + NAD^+$

Ethyl alcohol is toxic, plants can never use it because it cannot be converted to carbohydrates or breaks up in presence of O_2. When accumulation is more than tolerable limits, plants will be poisoned and subsequently they died.

LACTIC ACID FERMENTATION

When NADH+ H+ transfer its hydrogen directly to pyruvic acid, it results in formation of lactic acid.

Pyruvic acid + $NADH + H^+ \rightarrow CH_3.CH.OH.COOH$

During extensive exercise such as fast running muscle cells of animals and man respire anaerobically. Due to inadequate supply of O_2, pyruvic acid is converted to lactic acid. Blood circulation removes lactic acid from muscle cells. When lactic acid accumulates inside cells, it causes Muscle futigue. This forces person to stop work, until normal O_2 levels are restored.

ECONOMIC IMPORTANCE OF FERMENTATION

1. It is the source of ethyl alcohol in wines and beers Wines are produced by fermenting fruits like grapes, dates etc. Beers are produced by fermenting malted cereals such as Barley.
2. Yeast is used to prepare bread from wheat.
3. Milk is converted to curd (yoghurt) by bacteria.
4. Preparation of cheese and other dairy products.
5. Production of lactic acid, propionic acid, and butanol.
6. Flavour of pickles is due to lactic and acetic acid.
7. Addition of lactic and acetic acids prevent foods from spoilage and also give sour flavours to yoghurt and cheese.
8. Acetone is also formed as a by-product.

(2) KREB'S CYCLE

FORMATION OF ACETYL-COA

Before entering the Kreb's cycle, each molecule of pyruvic acid undergoes oxidative decarboxylation. During this

process one of the three carbons of pyruvic acid molecule is removed to form CO2 by enzymatic reactions.
Simultaneously pyruvic acid is oxidized and a pair of energy rich Hydrogen atoms are passed on to a H acceptor NAD+ to form NADH+H+. The remaining 2-carbon component is called acetyle which combines with coenzyme A to form an activated two carbon compound called acetyle CoA. "Acetyle CoA connects Kreb's cycle with glycolysis." For each molecule of glucose that enters glycoilysis, two molecules of acetyle CoA produced, which enter in a cyclic series of enzymatically catalyzed reactions known as Kreb's Cycle, which occurs in Mitochondria.
Pyruvic acid (3C) + CoA + NAD+ -> Acetyle CoA + CO2 + NADH+H+

SERIES OF REACTIONS IN KREB'S CYCLE

Sir Hans Kreb was working over these cyclical series of reactions therefore the cycle was given the name as Kreb's cycle. The first molecule formed during the cycle is citric acid, so it is also called as "Citric Acid cycle." This cycle is a multi step process and the steps are given below:

1. FORMATION OF CITRIC ACID

In this first step of the Kreb's cycle, bond between acetyl and CoA is broken by the addition of water molecule. The acetyl (2C) reacts with 4 carbon compound (oxalo acetic) acid to form 6-carbon compound, citric acid, and the CoA is set free. This citric acid possess 3 carboxyl groups, therefore the cycle is also recommended as Tricarboxylic Acid Cycle (TCA cycle).

2. ISOMERIZATION

A molecule of water is removed and another added back so that cirtic acid is isomerized to isocitric acid through an intermediate, Cis-aconitic acid.

3.FIRST OXIDATIVE DECARBOXYLATION

First time the sugar molecules are oxidized, therefore it is also called first oxidation of the cycle. Isocitric acid is oxidized yielding a pair of electrons (2H+) that reduces a molecule of NAD+ to NADH+H+. The reduced sugar molecule is decarboxylated with the removal of CO_2. It now converts into a 5 carbon compound α-Ketoglutaric acid (αKG).

4. SECOND OXIDATIVE DECARBOXYLATION

αKG is oxidatively decarboxylated. A CO_2 molecule is lost. The remaining 4-C compound is oxidized by transfer of a pair of electrons (2H+) reducing NAD+ to NADH+H+. This 4-C compound accepts CoA forming succinyl CoA.

5. SUBSTRATE LEVEL PHOSPHORYLATION

Bond between succinyl and CoA is broken. CoA is replaced by PO_4 group, which is then transferred to Guanosine diphosphate (GDP) to form Guanosine Triphosphate (GTP). GTP then transfers its phosphate group to ADP, forming ATP and with addition of 1 water molecule, succinic acid is formed.

6. THIRD OXIDATION

With loss of two electrons (2H+)succinic acid is oxidized to fumaric acid and FAD+ is reduced to $FADH_2$.

7. HYDRATION

One water molecule is added to fumaric acid to convert it to Malic acid.

8. FOURTH OXIDATION AND REGENERATION OF OXALO-ACETIC ACID

Oxidation of malic acid leads to the production of 1 more NADH+H+ and oxaloacetic acid is regenerated.

ENERGY YIELD

Glucose molecule breaks down into 2 pyruvic acid molecules and each will enter the Kreb's cycle.

For each pyruvic acid molecule, $3CO_2$ molecules are produced, four NADH+H+ are produced and 1 $FADH_2$.

Pyruvic Acid + $3H_2O$ + 4NAD+ + FAD+ -> $3CO_2$ + 4NADH+H+ + $1FADH_2$

Four calculation of energy (ATPs) we will multiply the

products with 2 as 2 acetyle CoA enters the Kreb's cycle.
Pyruvic Acid to Acetyl CoA……………1NADH2 -> 3ATP x 2 = 6 ATP
Kreb's Cycle…………………………………..3NADH+H+ -> 9ATP x 2 = 18 ATP
……………………………………………………1FADH2 -> 2ATP x 2 = 4 ATP
…………………………………………….Substrate Level Phosphorylation -> 1ATP x 2 = 2ATP
Total…………………………………. = 30 ATP

<u>OVERALL ENERGY YIELD OF AEROBIC RESPIRATION</u>

Glycolysis……………………………8ATP
Pyruvic Acid to Acetyl CoA……………6ATP
Kreb's Cycle…………………………24 ATP
Total……………………………….38 ATP

But actually 2 ATPs are utilizing in transporting cytoplasmic NADH+H+ to Mitochondria, which are produced during Glycolysis, so overall energy yield is only 36 ATPs.

3. ELECTRON TRANSPORT CHAIN/ ETC OR ET SYSTEM

The last of all steps is ETC. It consists of a series of electron acceptors which are located in the cristae of mitochondria. In respiration there are 6 steps at which hydrogen atoms are released (one in glycolysis, 5 in Kreb's cycle). A pair of hydrogen atoms are dissociated into a pair of electrons and a pair of protons.

2H -> 2H+ + 2e

These electrons are accepted by Nicotinamide adenine dinucleotide (NAD) and Flavin Adenine Dinucleotide (FAD) from where they are passed along a chain of electron carriers such as cytochrome b, cytochrome c; cytochrome a, cytochrome a3.While passing from one carrier to another, these cytochromes are alternatively reduced and oxidized. During this, the energy released is used in the formation of ATP (adenosine triphosphate) from ADP and Pi. The final electron acceptor is atmospheric oxygen, which also picks up protons, and form the water molecule. The formation of ATP in mitochondria is called Oxidative Phosphorylation. From every NAD, 3ATPs and from 1 FADH2, 2 ATPs are produced.