SLO 7: Bioenergetics

7.1 Introduction

7.1.1 Define Bioenergetics

The study of this conversion of free energy into different forms by living organisms is called Bioenergetics.

7.1.2 Describe The Importance Of Oxidation-Reduction Reactions For The Flow Of Energy Through Living Systems

In living organisms, the energy is transferred through gain or loss of electrons during formation and breaking of chemical bonds:

1. The oxidation reactions are those reactions in which loss of electron (e^-) or proton (H^+) occurs. These electrons or protons carry energy from the molecules from where they release to the molecules where they are added.
2. The reduction reactions are those reactions in which gain of electron (e^-) or proton (H^+) occurs. These electrons or protons bring energy from the molecules from where they release to the molecules where they are added.

In living organisms these Redox reactions occur continuously to transfer energy from one molecule to the other molecule. Without these reactions, energy transfer becomes impossible in living system.

7.1.3 Describe Adenosine Triphosphate (ATP) As The Chief Energy Currency Of All Cells

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. Each ATP molecule has three subunits:

- Adenine - a double-ringed nitrogenous base
- A ribose - a five-carbon sugar
- Three phosphate groups in a linear chain

The amount of energy stored is 7.3 Kcal/mole, this stored energy in ATP will be utilized by living organism for performing any type of work.

7.1.4 Describe Synthesis And Breaking Of ATP Through Adenosine Triphosphate-Adenosine Diphosphate (ATP-ADP) Cycle

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 (P_i) gets separated from ATP. The breaking of one phosphate bond releases about 7.3 kcal (7,300 calories) per mole of ATP as follows:

$$\text{ATP} + H_2O \rightarrow \text{ADP} + P_i + \text{energy (7.3 kcal/mole)}$$

In some cases, ADP is further broken down to AMP (adenosine monophosphate) and P_i as follows:

$$\text{ADP} + H_2O \rightarrow \text{AMP} + P_i + \text{energy (7.3 kcal/mole)}$$

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 food stuff. ATP is generated by energy-releasing (endergonic) processes and is broken down by energy-consuming (exergonic) processes. In this way ATP transfers energy between metabolic reactions.

7.2 Photosynthesis

7.2.1 Define 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.

7.2.2 State The Equation (In Words And Symbols) For Photosynthesis

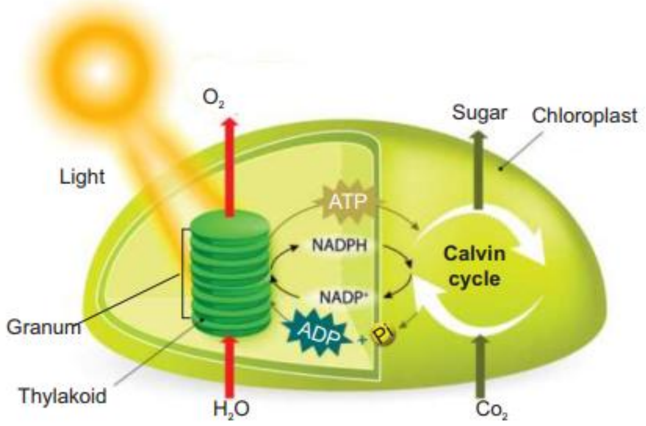
$$Carbon\ Dioxide + Water \xrightarrow{light,chlorophyll} Glucose + Oxygen$$

$$6CO_2 + \ 6H_2O \xrightarrow{light,chlorophyll} C_6H_{12}O_6 + 6O_2$$

7.2.3 Describe That Chlorophyll Traps Light Energy And Converts It Into Chemical Energy For The Formation Of Carbohydrates And Their Subsequent Storage

Chloroplast is a double membrane bounded green organelle, have semi-fluid proteins containing medium called Stroma. Another network of membrane is also embedded in it which is called Thylakoid membrane. Thylakoid are piled at one another in stack called Grana.

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.



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.

Conversion From Light to Chemical Energy

When sunlight (photons) hits the leaf, chlorophyll molecules absorb specific wavelengths (mainly blue and red). This absorption "excites" electrons in the chlorophyll molecule, raising them to a higher energy level. This is the Light-Dependent phase. The energy from these excited electrons is used to split water molecules a process called Photolysis. This trapped solar energy is then converted into temporary chemical energy in the form of two "powerhouse" molecules; ATP and $NADPH_2$.

Formation of Carbohydrates

This occurs in the Stroma of the chloroplast (The Light-Independent or Calvin Cycle). The plant takes CO_2 from the air and uses the "power" from the ATP and NADPH created earlier to reduce the carbon into Glucose. The kinetic energy of light is now stored as chemical energy in the covalent bonds of the carbohydrate molecule.

Storing Chemical Energy

Glucose is highly soluble in water and chemically reactive. If stored as glucose, it would affect the cell's osmotic balance. To prevent this, plants convert excess glucose into Starch (a large, insoluble polysaccharide). Starch is stored in specialized organelles called Amyloplasts within roots (tubers), seeds, and fruits for future use.

7.2.4 Describe Utilization And Storage Of Carbohydrates Produced In Photosynthesis

Starch: The Energy Reservoir (Storage)

- Form: Polysaccharide (Complex chains of glucose).
- Utilization: Excess glucose is converted into starch via dehydration synthesis.
- Function: Starch is insoluble and chemically inert. Because it doesn't dissolve, it won't cause the cell to burst by pulling in water. It is stored in tubers (potatoes), seeds, and grains.
- Exam Key: Starch is the temporary and long-term storage form.

Cellulose: The Building Material (Structure)

- Form: Polysaccharide (Long, straight fibers).
- Utilization: Glucose molecules are linked together in a specific way to form tough, insoluble fibers.
- Function: Cellulose is the main component of the Plant Cell Wall. It provides mechanical strength and prevents the cell from bursting under high turgor pressure.
- Exam Key: Cellulose is a structural carbohydrate, not a storage one.

Glucose: The Immediate Fuel (Respiration)

- Form: Monosaccharide
- Utilization: A portion of the glucose produced is used immediately by the plant cells in Cellular Respiration.
- Function: It is broken down in the mitochondria to generate ATP (energy). This energy powers the plant's active transport, mineral absorption from soil, and protein synthesis.
- Exam Key: It is the primary "currency" for metabolic energy.

Sucrose: The Transport Form (Translocation)

- Form: Disaccharide (Glucose + Fructose).
- Utilization: Glucose is converted into sucrose for travel through the Phloem.
- Function: Sucrose is highly soluble but less reactive than glucose, making it the perfect "shipping" molecule. It moves from the "Source" (leaves) to the "Sink" (roots, fruits, and growing buds).
- Exam Key: Sucrose is the standard form of carbohydrate for Translocation.

7.2.5 Describe The Events Of Light Dependent Reaction Of Photosynthesis

Location: The Thylakoid Membrane

The reaction occurs across the Thylakoid membranes of the chloroplast, where the photosynthetic pigments (chlorophyll) are embedded.

Photoactivation of Photosystem-II (PS-II)

Chlorophyll molecules in PS-II absorb light energy (photons). This energy "excites" two electrons, which leave the chlorophyll molecule and are captured by a primary electron acceptor.

Photolysis of Water and Oxygen Release

To replace the "lost" electrons in PS-II, an enzyme splits a water molecule inside the thylakoid space.

$$H_2O \rightarrow 2H^+ + 2e^- + \frac{1}{2}O_2$$

Release Of Oxygen Gas As A Byproduct

Oxygen gas is released into the atmosphere through the stomata. This is the source of the oxygen we breathe.

The Electron Transport Chain (ETC) and ATP Synthesis

The excited electrons from PS-II travel down a series of electron carriers (the ETC). As they move, they release energy. This energy is used to pump hydrogen ions across the membrane, creating a gradient. This gradient powers ATP Synthase to produce ATP from ADP and Inorganic Phosphate.

Excitation of Photosystem-I (PS-I)

Simultaneously, PS-I absorbs light, and its electrons also become excited and leave the molecule. The "empty" spot in PS-I is filled by the "tired" electrons arriving from the first ETC (coming from PS-II).

Formation of NADPH

The high-energy electrons from PS-I move through a second, shorter ETC. They are finally accepted by $NADP^+$, which combines with H^+ ions to form $NADPH_2$.

7.2.6 Describe Light Independent Reactions of Photosynthesis As A Cyclic Process

Location: The Stroma

Unlike the Light Reaction which happens in the membranes, the Calvin Cycle occurs in the Stroma (the fluid-filled space) of the chloroplast. This is because the enzymes required for this cycle are located here.

The Required Ingredients (Inputs)

To run this "sugar factory," the plant requires

- Carbon Dioxide taken from the atmosphere through stomata.
- Pentose Sugar (RuBP): A 5-carbon sugar (Ribulose Bisphosphate) that is already present in the stroma to act as the acceptor.
- ATP: Provided by the Light Reaction (acts as the power source).
- $NADPH_2$: Provided by the Light Reaction (acts as the reducing agent/hydrogen donor).

The Cyclic Process

Phase 1: Carbon Fixation

One molecule of CO_2 is attached to the 5-carbon pentose sugar (RuBP). This reaction is catalyzed by the enzyme Rubisco. This forms an unstable 6-carbon intermediate that immediately splits into two molecules of a 3-carbon compound (3-PGA).

Phase 2: Reduction (The Energy Use)

The ATP and $NADPH_2$ from the light reaction are used to convert the 3-carbon molecules into a high-energy 3-carbon sugar called G3P (Glyceraldehyde 3-phosphate). This G3P is the actual "output" of the Calvin Cycle.

Phase 3: Regeneration of RuBP

Because this is a cycle, the starting material must be remade. Some G3P molecules leave the cycle to make glucose, but most are "recycled" using more ATP to regenerate the 5-carbon pentose sugar (RuBP) so the process can start again.

The Final Product: Glucose Formation

It takes two molecules of the 3-carbon sugar (G3P) to combine and form one molecule of 6-carbon sugar (Glucose). This glucose is then utilized for respiration or stored as starch.

7.2.7 Explain The Adaptations Of Leaves

1. Large Surface Area: Broad, flat blades provide a maximum area to absorb sunlight and CO_2.
2. Thinness: Reduces the distance for CO_2 to diffuse from the surface to the inner mesophyll cells.

3. Distribution of Chloroplasts: Concentrated in the upper layers to capture the most intense sunlight.
4. Cuticle: A waxy, transparent layer on the Upper Epidermis. It prevents excessive water loss (desiccation) while allowing light to pass through.
5. Guard Cells: Specialized pairs of cells that control the opening and closing of Stomata. They regulate gas exchange and transpiration.
6. Upper & Lower Epidermis: Single layers of clear cells. The upper layer is transparent to let light reach the internal tissues, while the lower layer contains the majority of the Stomata.
7. Palisade Mesophyll: Long, cylindrical cells packed closely together directly under the upper epidermis. They contain the highest density of chloroplasts for maximum photosynthesis.
8. Spongy Mesophyll: Loosely arranged, irregular cells below the palisade layer.
9. Air Spaces: Large gaps between spongy cells that allow to circulate freely and reach every photosynthetic cell quickly.
10. Xylem: Hollow tubes that bring water and dissolved minerals from the roots to the leaf.
11. Phloem: Living tissue that carries the manufactured Sucrose from the leaf to the rest of the plant.
12. Petiole (Leaf Stalk): Holds the leaf away from the stem and adjusts its angle to prevent "shading" by other leaves, ensuring maximum light exposure.

7.2.8 Impact of Loss of Specific Leaf Adaptations on Plant’s Physiological Processes

Adaptation Lost	Primary Process Affected	Resulting Symptom
Waxy Cuticle	Water Conservation	Severe Wilting/Desiccation
Stomata/Guard Cells	Carbon Fixation	Stoppage of Glucose Synthesis
Air Spaces	Internal CO_2 Diffusion	Reduced Photosynthetic Efficiency
Palisade Chloroplasts	Light Capture	Yellowing (Chlorosis) / Low Energy
Xylem/Phloem	Resource Distribution	Nutrient Starvation / Death of Tissues

7.3 Factors Affecting Rate of Photosynthesis

7.3.1 Define Limiting Factor

Rate of biochemical reaction dependent on some factors which affect the rate are called limiting factor. For example, at low light intensity rate of photosynthesis increase continuously but at high light intensity the rate becomes constant. Light intensity, Carbon dioxide concentration and temperature can all be limiting factors for the rate of photosynthesis.

7.3.2 Explain The Effects In Limiting The Rate Of Photosynthesis

Effect Of Light Intensity

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.

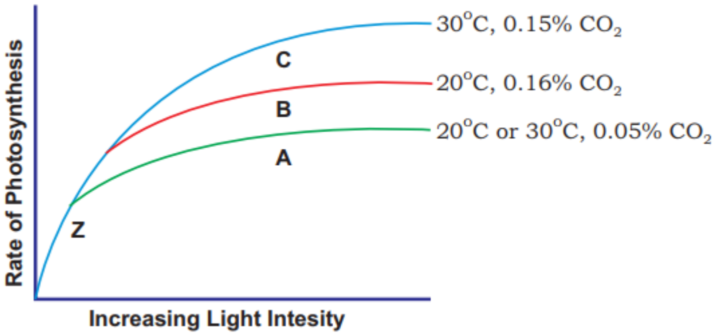
Effect Of Temperature

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.

7.3.3 Interpret Graphs Showing The Relationship Between Photosynthetic Rate And Various Limiting Factors



If light intensity increases to bright light and moderate temperature the concentration of CO2, in air becomes limiting factor. It is clearly observed that the same plant if put into air containing high CO2 then the rate of photosynthesis becomes high.

If there is high light intensity and high CO2 concentration then the temperature becomes the limiting factor but the temperature should not be very high otherwise enzymes become denatured.

7.4 Cellular Respiration

7.4.1 Define Cellular Respiration

Cells break food molecules to release their Chemical energy. The breakdown of food molecules to release energy is called respiration.

7.4.2 State Aerobic Respiration By Means Of Word And Symbolic Equation

Type of respiration where food breakdown occurs in the presence of oxygen to produce energy. It is a method of respiration found in majority of organisms. It takes place in the presence of free oxygen, oxidizing the food and releasing the maximum amount of energy i.e. 2827 kJ/mole of glucose or 36 ATP molecules/glucose. The end products of aerobic respiration are CO_2 and H_2O.

$$Glucose + oxygen \rightarrow Carbon\ dioxide + water + Energy\ (36\ ATP)$$

$$C_6H_{12}0_6 + 60_2 \rightarrow 6C0_2 + 6H_20 + 36\ ATP$$

7.4.3 Differentiate 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

7.4.4 Differentiate Between Alcoholic Fermentation And Lactic Acid Fermentation

Feature	**Alcoholic Fermentation**	**Lactic Acid Fermentation**
Organisms	Yeast (Fungi) and some Bacteria.	Human Muscle Cells and Lactic Acid Bacteria (e.g., Lactobacillus).
Pathway Steps	Glycolysis → Decarboxylation → Reduction.	Glycolysis → Direct Reduction.
End Products	Ethanol (C_2H_5OH) + 2ATP	Lactic Acid ($C_3H_6O_3$) + 2ATP
CO_2 Release	Yes (causes dough to rise).	No CO_2 is produced.
Conditions	Strictly anaerobic (absence of O_2)	Temporary O_2 debt (during extreme exercise).
Commercial Use	Baking and Brewing industries.	Yogurt/Cheese making and Pickling.

7.4.5 Identify The Three Main Stages Of Cellular Respiration

Glycolysis (Glyco = Sugar, Lysis = Break down):

First stage is that stage where a molecule of glucose (Six carbon sugar) is broken down into two molecules of pyruvic acid (three carbon acid). It does not require oxygen. It takes place in both aerobic and anaerobic respiration. This splitting of glucose releases small amount of energy of glucose which is enough to generate 2 molecules of ATP. Glycolysis is a complex sequence of reaction all occur in cytosol.

Kreb's or Citric acid Cycle:

The second stage of aerobic respiration in which pyruvic acid produced during glycolysis enters the mitochondria where O_2 available. Cellular respiration uses this O_2 to break pyruvic acid completely into CO_2 and H_2O in a cyclic manner. During Kreb's Cycle some ATP produce and some coenzymes like NAD and FAD are reduced to $NADH_2$ and $FADH_2$. It takes place in matrix of mitochondria.

Electron Transport Chain:

The last stage of aerobic respiration in which $NADH_2$ (Nicotinamide Adenosine Di-nucleotide) and $FADH_2$ (Flavin amide Adenosine Dinucleotide) are oxidized to produce ATP and H_2O. It takes place at the cristae of mitochondria.

7.4.6 Describe The Process Of Glycolysis

The word literally means "Sugar-splitting" (Glyco = Sugar, Lysis = Breaking). It is the initial stage of cellular respiration where a glucose molecule is broken down. It occurs in the Cytoplasm (Cytosol) of the cell and oxygen is not involved in this stage.

A stable 6C Glucose molecule is activated by the addition of phosphate groups. Glucose is phosphorylated and then split into two 3-carbon intermediate molecules (PGAL/G3P).

The 3C intermediates are oxidized (hydrogen is removed). High-energy electrons and hydrogens are picked up by NAD^+ to form NADH. Simultaneously, 4 ATP molecules are produced. Final product; two molecules of Pyruvic Acid (a 3-carbon compound) $C_3H_4O_3$.

7.4.7 Describe Decarboxylation And Dehydrogenation Of Pyruvate In Link Reaction

The conversion of Pyruvate to Acetyl-CoA involves two simultaneous processes:

Decarboxylation (Removal of Carbon)

A carboxyl group is removed from the 3-carbon Pyruvate molecule. This carbon is released in the form of a Carbon Dioxide molecule. This is the first time in respiration that CO_2 is produced. The 3C chain becomes a 2C Acetyl group.

Dehydrogenation (Removal of Hydrogen)

Oxidation occurs as hydrogen atoms (and high-energy electrons) are stripped away from the Pyruvate. These hydrogens are picked up by the electron carrier NAD^+. NAD^+ is reduced to form NADH. This NADH will later be used in the Electron Transport Chain to generate ATP.

Attachment of Co-Enzyme A

The remaining 2-carbon Acetyl group is highly unstable. To stabilize it and deliver it to the Kreb's Cycle, a carrier called Co-Enzyme A (CoA) attaches to it. Final product is Acetyl-CoA.

7.4.8 Describe The Krebs Cycle (Citric Acid Or TCA Cycle)

Krebs cycle occurs in the Mitochondrial Matrix (the innermost fluid-filled space of the mitochondria). The cycle begins when the 2-carbon Acetyl-CoA (from the Link Reaction) enters the matrix. This Acetyl group combines with a 4C molecule already present in the matrix called Oxaloacetate. This forms a 6C Citric Acid molecule.

The 6-carbon Citrate loses one carbon as CO_2 to become a 5-carbon compound. The 5-carbon compound loses another carbon as CO_2 to become a 4-carbon compound. During these steps, Dehydrogenation occurs, and NADH is produced. At one point in the cycle, enough energy is released to directly synthesize one molecule of ATP. The remaining 4-carbon molecule undergoes further oxidation. $FADH_2$ and another NADH are produced, and the molecule is converted back into Oxaloacetate, ready to pick up a new Acetyl-CoA.

7.4.9 Describe The Process Of The Electron Transport Chain (ETC)

It occurs in the Inner Mitochondrial Membrane (Cristae). The folds of the cristae provide a large surface area for thousands of ETC stations. The goal is to use the energy from high-energy electrons to pump protons and create a gradient that drives ATP Synthesis.

NADH and $FADH_2$ arrive from the previous stages. They drop off their high-energy electrons and hydrogen ions at protein complexes in the membrane, becoming NAD^+ and FAD again. Electrons are passed from one protein carrier to the next in a series of redox reactions. As the electrons move, they lose a little bit of energy at each step. The energy released by the electrons is used to pump H^+ ions from the matrix into the Intermembrane Space. This creates a high concentration of protons (an electrochemical gradient).

H^+ ions want to move back into the matrix but can only pass through a special protein channel called ATP Synthase. This process is called Chemiosmosis. As H^+ ions rush through ATP Synthase like water through a turbine, the protein spins and attaches an inorganic phosphate (P_i) to ADP, creating ATP. At the end of chain, the tired electrons and H^+ ions are picked up by Oxygen to form Water.

7.4.10 Describe That Lactic Acid Builds Up In The Muscles And Blood During Vigorous Exercise Causing An Oxygen Debt

Oxygen Debt (or EPOC - Excess Post-exercise Oxygen Consumption) is the amount of extra oxygen required by the body after exercise to neutralize the accumulated Lactic Acid and restore energy reserves.

During intense physical activity (like sprinting or heavy lifting), the demand for ATP in muscle cells exceeds the rate at which the heart and lungs can supply Oxygen. To keep the muscles moving, cells switch from aerobic respiration to Lactic Acid Fermentation. Glucose is partially broken down into Lactic Acid. Since oxygen is absent, the pyruvate cannot enter the mitochondria; instead, it is converted into Lactic Acid in the cytoplasm.

As Lactic Acid accumulates, it lowers the pH of the muscle tissue (making it more acidic). This interferes with muscle contraction and enzyme function, leading to muscle fatigue and a "burning" sensation. Lactic Acid eventually diffuses out of the muscle cells and into the bloodstream, where it is transported to the Liver.

7.4.11 Explain The Removal Of Oxygen Debt After Exercise, With Respect To:

Continuation Of Fast Heart Rate To Transport Lactic Acid In The Blood From Muscles To Liver

After exercise, the heart continues to beat rapidly for several minutes. This high cardiac output is necessary to flush Lactic Acid out of the muscle tissues where it was produced. The blood carries this Lactic Acid specifically to the Liver, which acts as the primary processing center for neutralizing metabolic waste.

Continuation of Deep And Fast Breathing To Supply Oxygen For Aerobic Respiration Of Lactic Acid

Hyperventilation continuous even while resting. This provides the "extra" oxygen required to settle the debt. This oxygen is used for the Aerobic Respiration of Lactic Acid. It ensures that the mitochondria have enough O_2 to resume full-scale aerobic metabolism, which was bypassed during the anaerobic sprint.

Aerobic Respiration Of Lactic Acid In The Liver

Once Lactic Acid reaches the liver, it undergoes aerobic respiration.

The "1/5th and 4/5ths" Rule: About 20% (1/5th) of the Lactic Acid is completely broken down (oxidized) using the incoming oxygen to produce ATP, CO_2 and Water.

ATP generated from that 20% is then used to convert the remaining 80% (4/5ths) of the Lactic Acid back into Glucose or Glycogen. The "debt" is paid, the blood pH returns to normal, and energy stores are replenished.

7.4.12 Compare Aerobic And Anaerobic Respiration

Feature	Aerobic Respiration	Anaerobic Respiration
Conditions	Occurs in the presence of O_2	Occurs in the absence of O_2
Location	Cytoplasm and Mitochondria.	Cytoplasm only.
Breakdown	Complete oxidation of glucose.	Incomplete breakdown of glucose.
Reactants	Glucose + Oxygen.	Glucose only.
End Products	Co_2 + H_2O + Energy.	Animals: Lactic Acid + Energy Plants/Yeast: Ethanol + CO_2 + Energy.
Energy Yield	High (Approx. 36–38 ATP).	Low (Only 2 ATP).
Efficiency	Highly efficient (~39–40%).	Very inefficient (~2%).

7.4.13 Describe The Various Functions Of Respiratory Energy (ATP) In The Body

Muscle Contraction (Mechanical Work)

Movement of muscle requires energy which is produced from chemical energy, chemical energy converted into kinetic energy.

Active Transport (Transport Work)

Movement of ions and molecules from low concentration to high concentration requires energy.

Biochemical Reactions (Chemical Work)

ATP drives virtually all anabolic pathways by transferring its terminal phosphate group or by being hydrolyzed to provide free energy.

- Protein Synthesis: Amino acid activation, initiation, elongation, and termination steps on the ribosome, protein folds
- Nucleic Acid Synthesis: DNA replication, powers RNA polymerases, DNA repair and recombination.

Maintaining Homeostasis (Integrated Role)

Homeostatic Process	How ATP is used	Consequence if ATP fails
Body temperature	Shivering	Hypothermia
Blood pH	H^+ pumps in kidney tubules	Acidosis/alkalosis
Blood glucose	Gluconeogenesis in liver	Hypoglycemia
Osmotic balance	Na^+/K^+ pumps in kidney	Edema
blood pressure	Vascular smooth muscle	Hypertension
Immune function	Antibody production	Increased infections