WELCOME

TO

This is an Education Platform

We Provide PDF Notes for Pharmacy Students

Web Site http://www.fdspharmacy.in/

You tube https://www.youtube.com/c/FDSpharmacy

Telegram https://t.me/Fdspharmacy

App https://play.google.com/store/apps/details?id=com.FDSPharmacyMedia.FDSPharmacy

E-mail fdspharmacyinfo@gmail.com

BIOCHEMISTRY

UNIT 1

TOPIC :

- **Bioenergetics**

  Concept of free energy, endergonic and exergonic reaction, Relationship between free energy, enthalpy and entropy; Redox potential. Energy rich compounds; classification; biological significances of ATP and cyclic AMP

Bioenergetics

- Bioenergetics is the study of how living organisms acquire, convert, and utilize energy to support life processes. It focuses on the transformation of energy in biological systems, particularly the chemical reactions involved in metabolism. The primary goal of bioenergetics is to understand how energy flows through biological pathways to support cellular work.
- In biological systems, energy is released when weaker chemical bonds are broken and stronger bonds are formed. This released energy is then used to perform various forms of biological work, such as muscle contraction, active transport, biosynthesis, and cell division. These processes require a constant and regulated supply of usable energy.
- ATP (Adenosine Triphosphate) serves as the universal energy currency in living cells. The central purpose of catabolic and metabolic reactions is to generate ATP from available fuel molecules such as carbohydrates, fats, and proteins. The energy stored in ATP is released when it is hydrolyzed to ADP (Adenosine Diphosphate) and inorganic phosphate (Pi), and this energy is then utilized to drive endergonic (energy-requiring) processes.
- The ATP-ADP cycle is a dynamic process in cells. ATP is constantly synthesized from ADP and Pi through energy-producing pathways such as glycolysis, the Krebs cycle, and oxidative phosphorylation. It is then broken down again to release energy for cellular functions. This constant turnover maintains a pool of usable energy in the cell.
- Cells monitor their energy status through a concept known as "energy charge", which is defined by the ratio of ATP to ADP (and AMP). When ATP levels are high, the cell is in a high-energy state and can proceed with anabolic and energy-consuming processes. Conversely, when ATP levels drop and ADP (or AMP) levels rise, it signals a low-energy state, and the cell activates energy-generating pathways to restore the balance.
- Thus, bioenergetics provides the framework for understanding how energy is managed at the cellular level, how energy production is regulated, and how it is harnessed for life-sustaining activities.

Concept of Free Energy (Gibbs Free Energy, G)

→ Free energy refers to the portion of a system's energy that is available to do useful work. In biological systems, this concept is essential for understanding whether a chemical reaction will proceed spontaneously or not.

Gibbs Free Energy (G)

- Gibbs Free Energy (G) is a thermodynamic quantity that predicts the spontaneity of a reaction at constant temperature and pressure.
- It is defined by the equation:

$$\Delta G = \Delta H - T\Delta S$$

Where:

- **ΔG** = change in free energy
- **ΔH** = change in enthalpy (total heat content)
- **T** = temperature in Kelvin
- **ΔS** = change in entropy (degree of disorder)

Exergonic Reactions

- Exergonic reactions are energy-releasing reactions in which the free energy of the products is less than that of the reactants. These reactions occur spontaneously, meaning they do not require an input of energy to proceed under standard conditions.

$$\Delta G < 0$$

(Where **ΔG** is the change in Gibbs free energy)

General Equation:

$$\text{Reactants} \rightarrow \text{Products} + \text{Energy}$$

Example:

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

(Glucose oxidation during cellular respiration)

Biological Importance

- ✓ **Provides energy for cellular processes**
  - Energy released from exergonic reactions is used to power **endergonic reactions**, such as protein synthesis, active transport, and DNA replication.
- ✓ **ATP Production**
  - The breakdown of glucose and fatty acids in **glycolysis** and the **Krebs cycle** are exergonic and drive the production of **ATP**.
- ✓ **Drives Coupled Reactions**
  - Many **non-spontaneous reactions** (endergonic) are coupled with exergonic reactions to become favorable.
- ✓ **Maintain Homeostasis**
  - Continuous energy release is essential to maintain cell structure and function.

Endergonic Reactions

- Endergonic reactions are chemical reactions that require an input of energy to proceed. In these reactions, the free energy of the products is greater than that of the reactants, meaning energy must be absorbed from the surroundings.

$$\Delta G > 0$$

(Where **ΔG** is Gibbs Free Energy)

General Reaction :

$$\text{Reactants} + \text{Energy} \rightarrow \text{Products}$$

Example:

$$\text{Glucose} + \text{Phosphate} \rightarrow \text{Glucose-6-phosphate} \quad (\Delta G > 0)$$

This reaction is **non-spontaneous** and requires ATP input to occur in cells.

Biological Importance

Endergonic reactions are essential for:

- ✓ Biosynthesis (e.g., protein, nucleic acid, lipid synthesis)
- ✓ Active transport (e.g., pumping ions against gradients)
- ✓ Muscle contraction
- ✓ Cell growth and division

Relationship between Free Energy, Enthalpy, and Entropy

- Every living organism must perform biological work—like cell movement, growth, biosynthesis, and reproduction.
- This work requires energy, which is obtained from food (nutrients) or light, and is transformed and used efficiently, following the laws of thermodynamics.

Fundamental Laws of Thermodynamics

1. First Law of Thermodynamics:

"Energy can neither be created nor destroyed; it can only change forms."

- The total energy of the universe remains constant.
- Biological systems **convert** energy (e.g., chemical → kinetic or thermal) without losing it.

2. Second Law of Thermodynamics:

"All spontaneous processes increase the total entropy (disorder) of the universe."

- Biological reactions are directed in a way that increases overall disorder.
- Organisms **maintain order** internally by increasing disorder externally (e.g., heat release).

Key Thermodynamic Terms in Bioenergetics:

1. Gibbs Free Energy (G):

- It is the amount of **energy available to do work** at constant **temperature and pressure**.
- **Symbol:** ΔG
- **Equation:**

$$\Delta G = \Delta H - T\Delta S$$

Where:

- **ΔG** = change in free energy
- **ΔH** = change in enthalpy (heat content)
- **T** = temperature in Kelvin
- **ΔS** = change in entropy (disorder)

2. Enthalpy (H):

- Represents the **heat content** of a system.
- It tells us whether a reaction **releases** or **absorbs** heat.

ΔH Value	Meaning	Type of Reaction
$\Delta H < 0$	Heat is released	**Exothermic**
$\Delta H > 0$	Heat is absorbed	**Endothermic**

3. Entropy (S):

- Entropy measures the **degree of randomness or disorder** in a system.

ΔS Value	Meaning
$\Delta S > 0$	Disorder has **increased**
$\Delta S < 0$	Disorder has **decreased**

The Relationship Equation:

$$\Delta G = \Delta H - T\Delta S$$

This equation helps predict whether a biological reaction will occur **spontaneously** under constant temperature and pressure.

Redox Potential (E°)

Redox potential, also known as **standard reduction potential (E°)**, is a measure of the **tendency of a chemical species to accept electrons** (i.e., to be **reduced**) under standard conditions.

- It indicates how easily a molecule **gains electrons**.
- The higher the redox potential, the **greater the tendency to get reduced**.
- Units: **Volts (V)**

Basic Concept:

- A **redox reaction** involves both:
  - **Oxidation** (loss of electrons)
  - **Reduction** (gain of electrons)

$$\text{Oxidation: } A \rightarrow A^{+} + e^{-}$$
$$\text{Reduction: } B + e^{-} \rightarrow B^{-}$$

The redox potential tells us which species will act as an oxidizing or reducing agent in a redox pair.

Energy-Rich Compounds

Energy-rich compounds are molecules that contain **high-energy bonds**, which, when broken, release a **large amount of free energy (ΔG)** that the cell can use for biological work.

- These compounds are **critical in energy transfer and storage**.
- Most energy-rich compounds contain **phosphate bonds**, **thioester bonds**, or **reduced coenzymes**.

Classification of Energy-Rich Compounds

Class	Example(s)	Type of Bond Involved
Nucleoside triphosphates	ATP, GTP, UTP	Phosphoanhydride bonds
Enol phosphates	Phosphoenolpyruvate (PEP)	Enol phosphate bond
Acyl phosphates	1,3-Bisphosphoglycerate (1,3-BPG)	Acyl phosphate bond
Thioesters	Acetyl-CoA, Succinyl-CoA	Thioester bond
Phosphagens	Creatine phosphate	Phosphoamide bond
Reduced coenzymes	NADH, $FADH_2$, Ubiquinol	Energy stored in electrons
Cyclic nucleotides	cAMP, cGMP	Regulatory energy-signaling roles

Biological Significance

1. **ATP synthesis and hydrolysis**:
   - Acts as an energy shuttle between catabolic and anabolic reactions.
2. **Driving non-spontaneous reactions**:
   - Endergonic reactions are coupled with hydrolysis of energy-rich compounds.
3. **Metabolic regulation**:
   - Levels of ATP, NADH, etc., indicate cellular energy status.

Examples of Energy-Rich Compounds

1. ATP (Adenosine Triphosphate)

- Most important energy currency of the cell.
- Contains **two high-energy phosphate bonds (phosphoanhydride bonds).**
- Hydrolysis releases ~ **–7.3 kcal/mol:**

$$\text{ATP} \rightarrow \text{ADP} + \text{Pi} \quad (\Delta G^\circ = -7.3\ \text{kcal/mol})$$

Biological Significance of ATP (Adenosine Triphosphate)

ATP, or **Adenosine Triphosphate**, is often referred to as the "**energy currency of the cell**". It stores and supplies energy necessary for many biochemical cellular processes.

- It is a **nucleoside triphosphate** composed of:
  - **Adenine** (nitrogenous base)
  - **Ribose** (5-carbon sugar)
  - **Three phosphate groups**

Biological Functions & Importance of ATP:

✓ **Energy Supply for Metabolism:**

- ATP provides usable energy for anabolic reactions like:
  - Protein synthesis
  - DNA and RNA synthesis
  - Lipid and carbohydrate synthesis

✓ **Muscle Contraction:**

- ATP is required for actin-myosin interactions in muscle fibers.
- Enables muscle relaxation and contraction cycles.

✓ **Active Transport:**

- Powers transport proteins in cell membranes, including:
  - Na^+/K^+-ATPase pump
  - Ca^{2+} and H^+ pumps
- Maintains ionic balance and cell homeostasis.

✓ **Signal Transduction:**

- ATP donates phosphate groups in phosphorylation reactions.
- Protein phosphorylation regulates:
  - Enzyme activity

- Signal transduction pathways
- Cellular communication

✓ **Nerve Impulse Transmission:**

- ATP supports the repolarization of neurons by powering ion pumps.
- Also acts as a neurotransmitter in purinergic signaling.

✓ **Substrate in Biosynthetic Reactions:**

- Acts as a substrate for synthesis of:
  - cAMP (second messenger)
  - Coenzymes like NAD^+ and FAD
  - Nucleic acids (ATP is one of the four nucleotides in RNA)

Biological Significance of Cyclic AMP (cAMP)

Cyclic AMP (cAMP), or **cyclic adenosine monophosphate**, is a **secondary messenger** that plays a vital role in **cellular communication and regulation of metabolism**.

- It is a **derivative of ATP**.
- Synthesized from ATP by the enzyme **adenylate cyclase**.
- Broken down by the enzyme **phosphodiesterase**.

Structure:

- cAMP consists of:
  - Adenine (nitrogenous base)
  - Ribose (sugar)
  - One phosphate group, forming a cyclic bond between the 3′ and 5′ hydroxyl groups of ribose.

Biological Functions & Importance of cAMP:

✓ **Second Messenger in Hormonal Signaling:**

- cAMP acts as a second messenger in pathways involving hormones like:
  - Adrenaline (epinephrine)
  - Glucagon
  - ACTH
- These hormones bind to G-protein-coupled receptors (GPCRs) and activate adenylate cyclase, which increases cAMP levels.

✓ **Activation of Protein Kinase A (PKA):**

- cAMP activates Protein Kinase A (PKA) by binding to its regulatory subunits.
- PKA then phosphorylates various enzymes, altering their activity.

- This regulates metabolic pathways, gene expression, and ion channels.

✓ **Regulation of Metabolism:**

- In the liver:
  - cAMP promotes glycogen breakdown (glycogenolysis).
  - Inhibits glycogen synthesis.
- Stimulates lipolysis in adipose tissue (fat breakdown).

✓ **Gene Expression Regulation:**

- PKA can enter the nucleus and phosphorylate transcription factors like CREB (cAMP response element-binding protein).
- This leads to gene transcription and synthesis of proteins involved in cell growth, memory, and differentiation.

✓ **Neural Signaling and Brain Function:**

- Involved in learning and memory by modulating neurotransmitter release.
- Plays a role in long-term potentiation (LTP) in neurons.

✓ **Cardiac Function:**

- cAMP increases heart rate and force of contraction by enhancing calcium ion influx in heart cells.
- Mediated by β-adrenergic receptors.