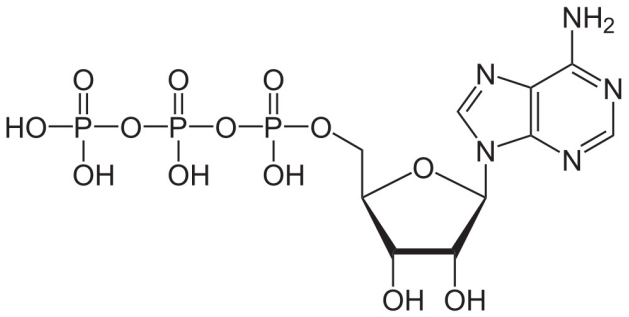
Bioenergetics, ATP & Enzymes

Some Important Compounds Involved in Energy Transfer and Metabolism

Bioenergetics can be defined as all the energy transfer mechanisms occurring within living organisms. Energy transfer is necessary because energy cannot be created and it cannot be destroyed (1st law of thermodynamics). Organisms can acquire energy from **chemicals (chemotrophs)** or they can acquire it from **light (phototrophs)**, but they cannot make it. Thermal energy (heat) from the environment can influence the rate of chemical reactions, but is not generally considered an energy source organisms can "capture" and put to specific uses.

Metabolism, all the chemical reactions occurring within living organisms, is linked to bioenergetics because **catabolic reactions** release energy (are **exergonic**) and **anabolic reactions** require energy (are **endergonic**).

Various types of high-energy compounds can "donate" the energy required to drive endergonic reactions, but the most commonly used energy source within cells is **adenosine triphosphate (ATP**), a type of coenzyme. When this molecule is catabolized (broken down), the energy released can be used to drive a wide variety of synthesis reactions. Endergonic reactions required for the synthesis of **nucleic acids** (DNA and RNA) are exceptions because all the nucleotides incorporated into these molecules are initially high-energy molecules as described below.



The nitrogenous base here is **adenine**, the sugar is the pentose monosaccharide **ribose** and there are three phosphate groups attached. The sugar and the base form a molecule called a **nucleoside**, and the number of phosphate groups bound to the nucleoside is variable; thus alternative forms of this molecule occur as **adenosine monophosphate (AMP)** and **adenosine diphosphate (ADP).**

ATP can also be called a **nucleoside triphosphate** or **NTP**, and as illustrated here is **r-NTP**, because the sugar is ribose (found in RNA). Alternative sugars can be incorporated in place of ribose; if the sugar is **deoxyribose** (found in DNA and missing the hydroxyl group on the #2 carbon), the molecule is designated as **d-NTP**, and if the sugar is **dideoxyribose** (missing both hydroxyl groups), the molecule is **dd-NTP** (a type of molecule used in chain termination nucleotide sequencing – as described in lab).

Alternate bases can be incorporated into nucleoside triphosphate molecules, so alternative high-energy forms exist as **GTP, CTP, UTP**, etc. Some of these molecules can also exist in cyclic forms as mentioned earlier, e.g., **cyclic-AMP** and **cyclic-GMP**.

Other types of molecules can "donate" the energy needed to drive synthesis reactions, including **acetyl coenzyme A** (acetyl-CoA) and **succinyl coenzyme A** (succinyl-CoA). Coenzyme A molecules contain the base adenine, a sugar similar to ribose and three phosphate groups but the configuration differs from NTPs. Phosphocreatine (creatine phosphate) is a phosphorylated creatine molecule that can be used to provide high-energy phosphate within eukaryotic muscle cells and neurons. The role of this molecule in microorganisms is much less significant than is the role of ATP.

The various types of chemical reactions occurring within living organisms require the assistance of **biochemical catalysts**, molecules that can increase reaction rates hundreds or thousands of times. Two types of catalysts are **enzymes** (proteins) and **ribozymes** (RNA molecules). These are typically very specific in action (interact only with certain types of substrate molecules), and are not changed by the reactions they catalyze, so can be used over and over again.

Enzymes can be categorized as: **endoenzymes** (active inside cells) or **exoenzymes** (active outside cells); **simple enzymes** (active as protein alone) or **conjugated enzymes** (inactive **apoenzymes** that require the "help" of **coenzymes**, **cofactors** or **prosthetic groups** in order to become active **holoenzymes**); **constitutive enzymes** (essential to cell function so always being made), **inducible enzymes** and **repressible enzymes**.

Factors that influence enzyme activity include **temperature**, **pH**, **concentration** (of enzyme or substrate), **light** and a variety of substances that can either enhance or inhibit enzyme activity. Enzyme inhibition can be categorized as **competitive inhibition** (if the inhibitor binds to the enzyme active site in place of the normal substrate) or **allosteric inhibition** (if the inhibitor binds to a site other than the enzyme active site and thereby changes the enzyme configuration so that the active site can no longer bind the substrate).

Coenzymes are non-protein organic compounds that can assist enzymes. They are much less specific in action than are enzymes, and are changed by the reactions being catalyzed. Some coenzymes function primarily as **oxidizing agents** (hydrogen and electron acceptors). These include nicotinamide adenine dinucleotide (**NAD**), nicotinamide adenine dinucleotide phosphate (**NADP**), and flavin adenine dinucleotide (**FAD**). These coenzymes are derived from the B complex vitamins **niacin** and **riboflavin** respectively. $NADH + H^+$, $NADPH + H^+$ and $FADH_2$ are the reduced forms of these coenzymes, and have a higher energy potential than do the oxidized forms. The reduced forms of coenzymes can serve as electron and hydrogen donors (reducing agents).

Coenzyme A (CoA) is similar in structure to ATP (as described above), and plays a significant role within respiratory organisms. It binds with acetic acid forming acetyl-CoA at the start of the Krebs cycle and with succinic acid (forming succinyl-CoA) toward the middle of the Krebs cycle. **Coenzyme Q** (CoQ) or ubiquinone is a compound involved in the transport of electrons and hydrogen protons in association with both cellular respiration and photophosphorylation.

Cytochromes (cyto = cell, chrome = color) are pigmented **enzymes with iron prosthetic groups** that can be alternately oxidized and reduced. These enzymes transport electrons in association with electron transport chains (during both cellular respiration and photophosphorylation), and move hydrogen protons across cellular membranes (cristae, thylakoids and cell membranes) creating a type of concentration and electrical gradient known as the **proton motive force**. The potential energy associated with this gradient is used to make ATP (from ADP plus PO_4), when the hydrogen protons flow back across the membranes through **ATP-synthase** enzymes.

Cytochrome C (the enzyme being tested for in the **oxidase test**) is a peripheral protein capable of catalyzing a variety of chemical reactions. The iron prosthetic group (heme) of cytochrome C accepts electrons from the cytochrome b-c1 complex, and transfers electrons to the cytochrome oxidase complex. **Cytochrome c oxidase** is a large transmembrane protein complex (containing both iron and copper prosthetic groups) that receives electrons (and H^+) from four cytochrome C molecules, and passes them to **molecular oxygen** (O_2), generating two molecules of **water**. Oxygen is typically the final electron acceptor in the respiratory chain.