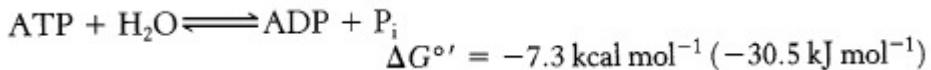
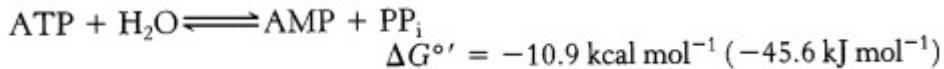


Central Role of ATP in Metabolism

Just as commerce is facilitated by the use of a common **currency**, the commerce of the **cell**—metabolism—is facilitated by the use of a common energy **currency**, **adenosine triphosphate (ATP)**. Part of the free energy derived from the oxidation of foodstuffs and from light is transformed into this highly accessible molecule, which acts as the free-energy donor in most energy-requiring processes such as motion, active transport, or biosynthesis.

ATP is a nucleotide consisting of an adenine, a ribose, and a **triphosphate** unit (Figure 1). The active form of **ATP** is usually a complex of **ATP** with Mg^{2+} or Mn^{2+} . In considering the role of **ATP** as an energy carrier, we can focus on its **triphosphate** moiety. **ATP** is an energy-rich molecule because its **triphosphate** unit contains two phosphoanhydride bonds. A large amount of free energy is liberated when **ATP** is hydrolyzed to **adenosine diphosphate (ADP)** and orthophosphate (P_i) or when **ATP** is hydrolyzed to **adenosine monophosphate (AMP)** and pyrophosphate (PP_i).



The precise $\Delta G^{\circ'}$ for these reactions depends on the ionic strength of the medium and on the concentrations of Mg^{2+} and other metal ions. Under typical cellular concentrations, the actual ΔG for these hydrolyses is approximately $-12 \text{ kcal mol}^{-1}$ (-50 kJ mol^{-1}).

The free energy liberated in the hydrolysis of **ATP** is harnessed to drive reactions that require an input of free energy, such as muscle contraction. In turn, **ATP** is formed from **ADP** and P_i when fuel molecules are oxidized in chemotrophs or when light is trapped by phototrophs. This **ATP—ADP cycle** is the fundamental mode of energy exchange in biological systems.

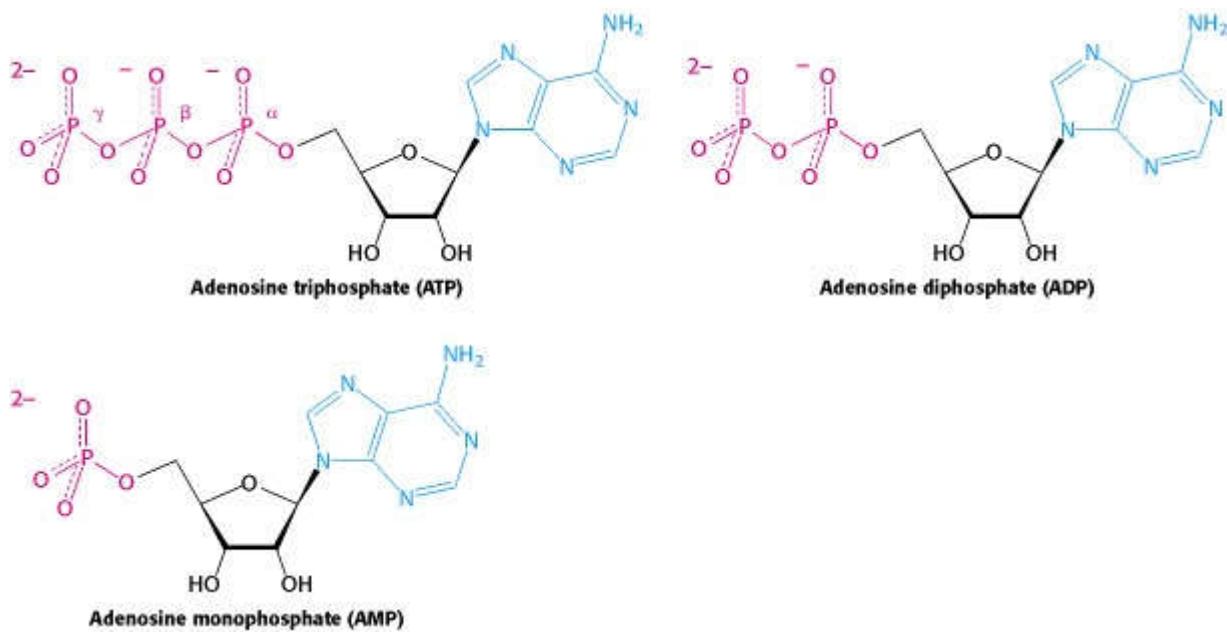


Figure 1. Structures of ATP, ADP, and AMP

These adenylates consist of adenine (blue), a ribose (black), and a tri-, di-, or monophosphate unit (red). The innermost phosphorus atom of **ATP** is designated P_α, the middle one P_β, and the outermost one P_γ.

Enzymes can catalyze the transfer of the terminal phosphoryl group from one nucleotide to another. The phosphorylation of nucleoside monophosphates is catalyzed by a family of nucleoside monophosphate kinases. The phosphorylation of nucleoside diphosphates is catalyzed by nucleoside diphosphate kinase, an enzyme with broad specificity. It is intriguing to note that, although all of the nucleotide triphosphates are energetically equivalent, **ATP** is nonetheless the primary cellular energy carrier. In addition, two important electron carriers, **NAD⁺** and **FAD**, are derivatives of **ATP**. *The role of ATP in energy metabolism is paramount.*

The high phosphoryl transfer potential of ATP enables it to serve as the energy source in muscle contraction, active transport, signal amplification, and biosyntheses. The hydrolysis of an ATP molecule changes the equilibrium ratio of products to reactants in a coupled reaction by a factor of about 10⁸. Hence, *a thermodynamically unfavorable reaction sequence can be made highly favorable by coupling it to the hydrolysis of a sufficient number of ATP molecules.*

ATP is generated by the oxidation of fuel molecules such as glucose, fatty acids, and amino acids. The common intermediate in most of these oxidations is acetyl **CoA**. The carbon atoms of the acetyl unit are completely oxidized to CO₂ by the citric acid cycle with the concomitant

formation of NADH and FADH₂. These electron carriers then transfer their high potential electrons to the respiratory chain. The subsequent flow of electrons to O₂ leads to the pumping of protons across the inner mitochondrial membrane. This proton gradient is then used to synthesize ATP. Glycolysis also generates ATP, but the amount formed is much smaller than that in oxidative phosphorylation. The oxidation of glucose to pyruvate yields only 2 molecules of ATP, whereas the complete oxidation of glucose to CO₂ yields 30 molecules of ATP.