

Bioenergetics

- **Bioenergetics**, or **biochemical thermodynamics**, is the study of the energy changes accompanying biochemical reactions. Biologic systems are essentially isothermic and use chemical energy to power living processes.
- How an animal obtains suitable fuel from its food to provide this energy is basic to the understanding of normal nutrition and metabolism.

FREE ENERGY IS THE USEFUL ENERGY IN A SYSTEM

- Gibbs change in free energy (ΔG) is that portion of the total energy change in a system that is available for doing work—ie, the useful energy, also known as the chemical potential

Biologic Systems Conform to the General Laws of Thermodynamics

- The first law of thermodynamics states that the total energy of a system, including its surroundings, remains constant.
- It implies that within the total system, energy is neither lost nor gained during any change.
- However, energy may be transferred from one part of the system to another or may be transformed into another form of energy. In living systems, chemical energy may be transformed into heat or into electrical, radiant, or mechanical energy.

- The second law of thermodynamics states that the total entropy of a system must increase if a process is to occur spontaneously. Entropy is the extent of disorder or randomness of the system and becomes maximum as equilibrium is approached.
- Under conditions of constant temperature and pressure, the relationship between the free energy change (ΔG) of a reacting system and the change in entropy (ΔS) is expressed by the following equation, which combines the two laws of thermodynamics:

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

- where ΔH is the change in enthalpy(heat) and T is the absolute temperature. In biochemical reactions, because ΔH is approximately equal to ΔE , the total change in internal energy of the reaction, the above relationship may be expressed in the following way:

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

- If ΔG is negative, the reaction proceeds spontaneously with loss of free energy; ie, it is .If, in addition, ΔG is of great magnitude, the reaction goes virtually to completion and is essentially irreversible.
- On the other hand, if ΔG is positive, the reaction proceeds only if free energy can be gained; ie, it is endergonic. If, in addition, the magnitude of ΔG is great, the system is stable, with little or no tendency for a reaction to occur

If ΔG is zero, the system is at equilibrium and no net change takes place.

When the reactants are present in concentrations of 1.0 mol/L, ΔG^0 is the standard free-energy change. For biochemical reactions, a standard state is defined as having a pH of 7.0. The standard free-energy change at this standard state is denoted by $\Delta G^{0'}$.

The standard free-energy change can be calculated from the equilibrium constant K_{eq}

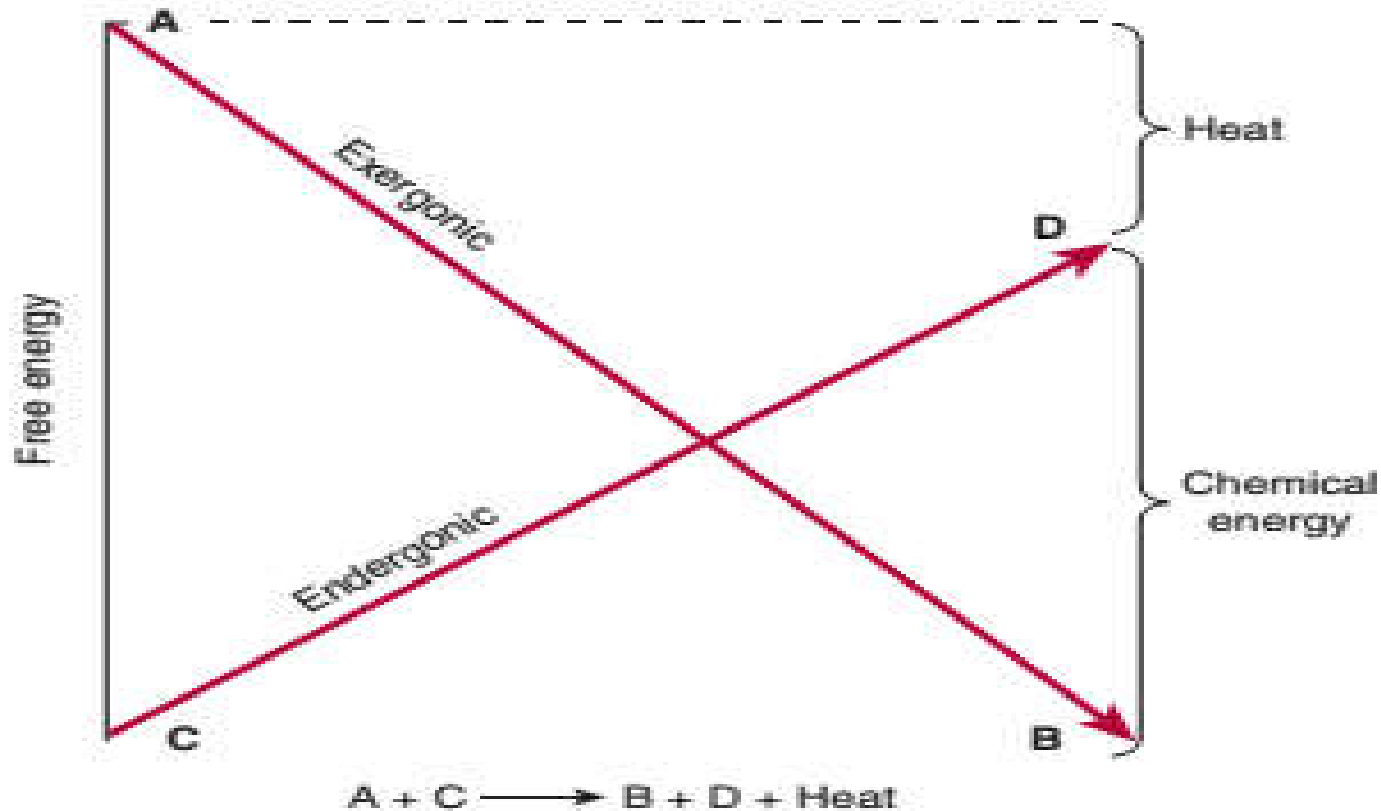
$$\Delta G^{0'} = -RT \ln K'_{eq}$$

ENDERGONIC PROCESSES PROCEED BY COUPLING TO EXERGONIC PROCESSES

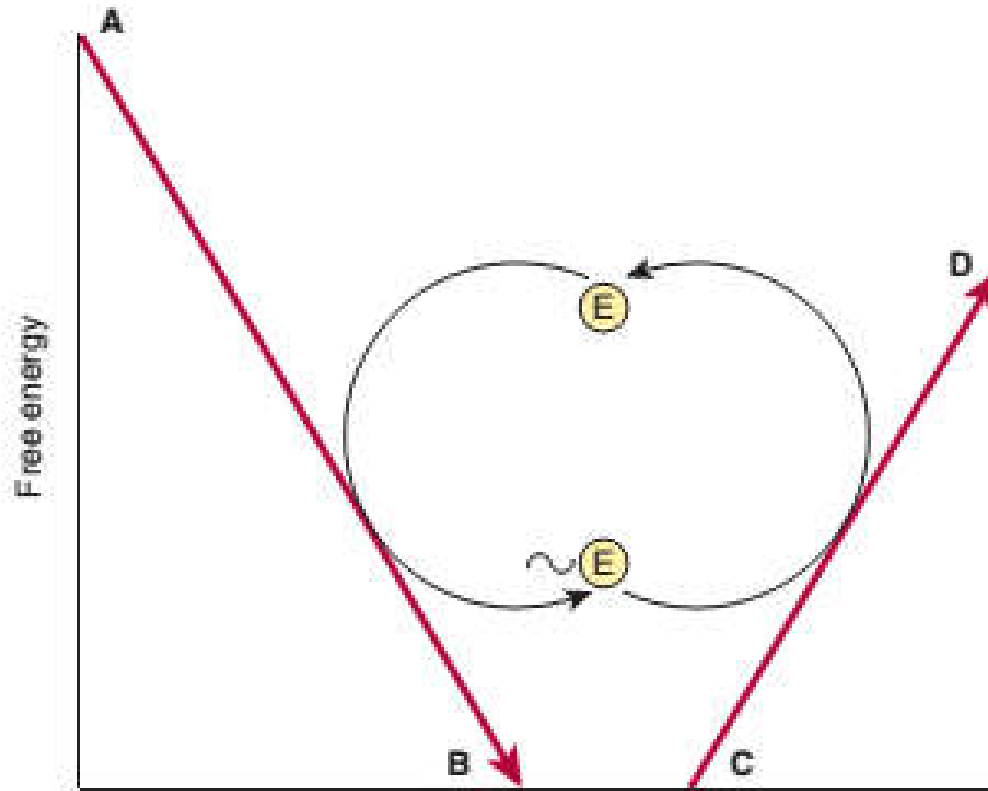
The vital processes—eg, synthetic reactions, muscular contraction, nerve impulse conduction, and active transport—obtain energy by chemical linkage, or coupling, to oxidative reactions. In its simplest form, this type of coupling may be represented .

The **exergonic** reactions are termed **catabolism** (generally, the breakdown or oxidation of fuel molecules), whereas the **synthetic** reactions that build up substances are termed **anabolism**. The combined catabolic and anabolic processes constitute metabolism.

Coupling of an exergonic to an endergonic reaction.



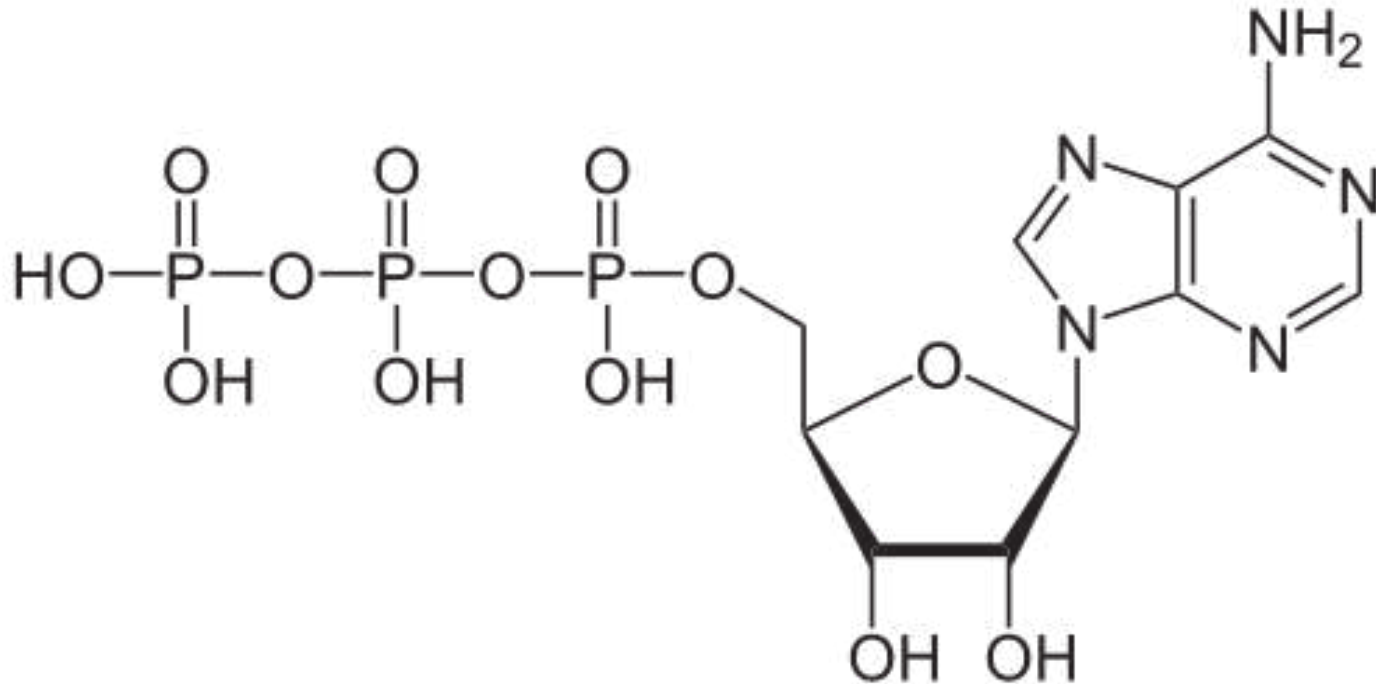
Transfer of free energy from an exergonic to an endergonic reaction via a high-energy intermediate compound



HIGH-ENERGY PHOSPHATES PLAY A CENTRAL ROLE IN ENERGY CAPTURE AND TRANSFER

- **Autotrophic** organisms utilize **simple exergonic** processes; eg, the energy of sunlight (green plants), the reaction $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$ (some bacteria).
- **Heterotrophic** organisms obtain free energy by coupling their metabolism to the **breakdown of complex organic molecules in their environment**. In all these organisms, **ATP** plays a central role in the transference of free energy from the exergonic to the endergonic processes

ATP is a nucleotide consisting of the nucleoside adenosine (adenine linked to ribose), and three phosphate groups. In its reactions in the cell, it functions as the Mg^{2+} complex.



The Intermediate Value for the Free Energy of Hydrolysis of ATP Has Important Bioenergetic Significance

Compound	ΔG°	
	kJ/mol	kcal/mol
Phosphoenolpyruvate	-61.9	-14.8
Carbamoyl phosphate	-51.4	-12.3
1,3-Bisphosphoglycerate (to 3-phosphoglycerate)	-49.3	-11.8
Creatine phosphate	-43.1	-10.3
ATP \rightarrow ADP + P_i	-30.5	-7.3
ADP \rightarrow AMP + P _i	-27.6	-6.6
Pyrophosphate	-27.6	-6.6
Glucose 1-phosphate	-20.9	-5.0
Fructose 6-phosphate	-15.9	-3.8
AMP	-14.2	-3.4
Glucose 6-phosphate	-13.8	-3.3
Glycerol 3-phosphate	-9.2	-2.2

¹P_i, inorganic orthophosphate.

²Values for ATP and most others taken from Krebs and Kornberg (1957). They differ between investigators depending on the precise conditions under which the measurements are made.

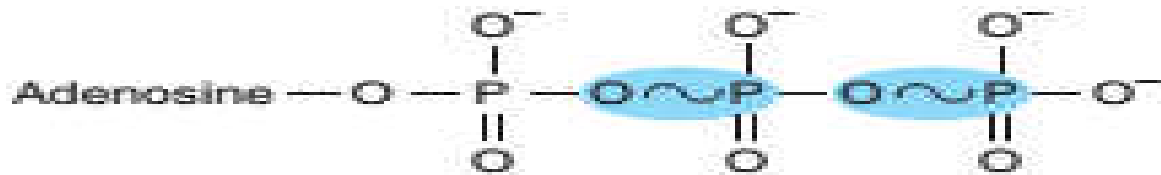
- **Low-energy phosphates**, exemplified by the ester phosphates found in the intermediates of glycolysis, have G° values smaller than that of ATP, while **in high-energy phosphates** the value is higher than that of ATP.

- The symbol $\sim \textcircled{\text{P}}$ indicates that **larger quantity of free energy**. For this reason, the term **group transfer potential**, rather than “high-energy bond”. Thus, **ATP** contains **two** high-energy phosphate groups and **ADP** contains **one**, whereas the phosphate in AMP is of the **low-energy** type since it is a normal ester link

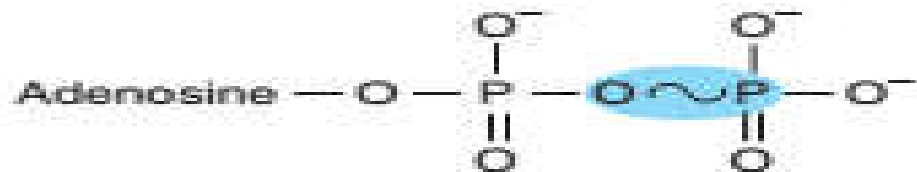
The Intermediate Value for the Free Energy of hydrolysis of aTp has Important Bioenergetic Significance

- The high free-energy change on hydrolysis of ATP is due to relief of charge repulsion of adjacent negatively charged oxygen atoms and to stabilization of the reaction products, especially phosphate, as resonance hybrids

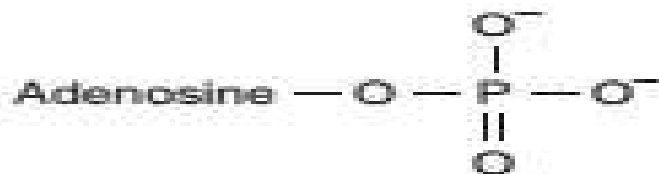
Structure of ATP, ADP, and AMP showing the position and the number of high-energy phosphates ($\sim\text{P}$)



Adenosine triphosphate (ATP)

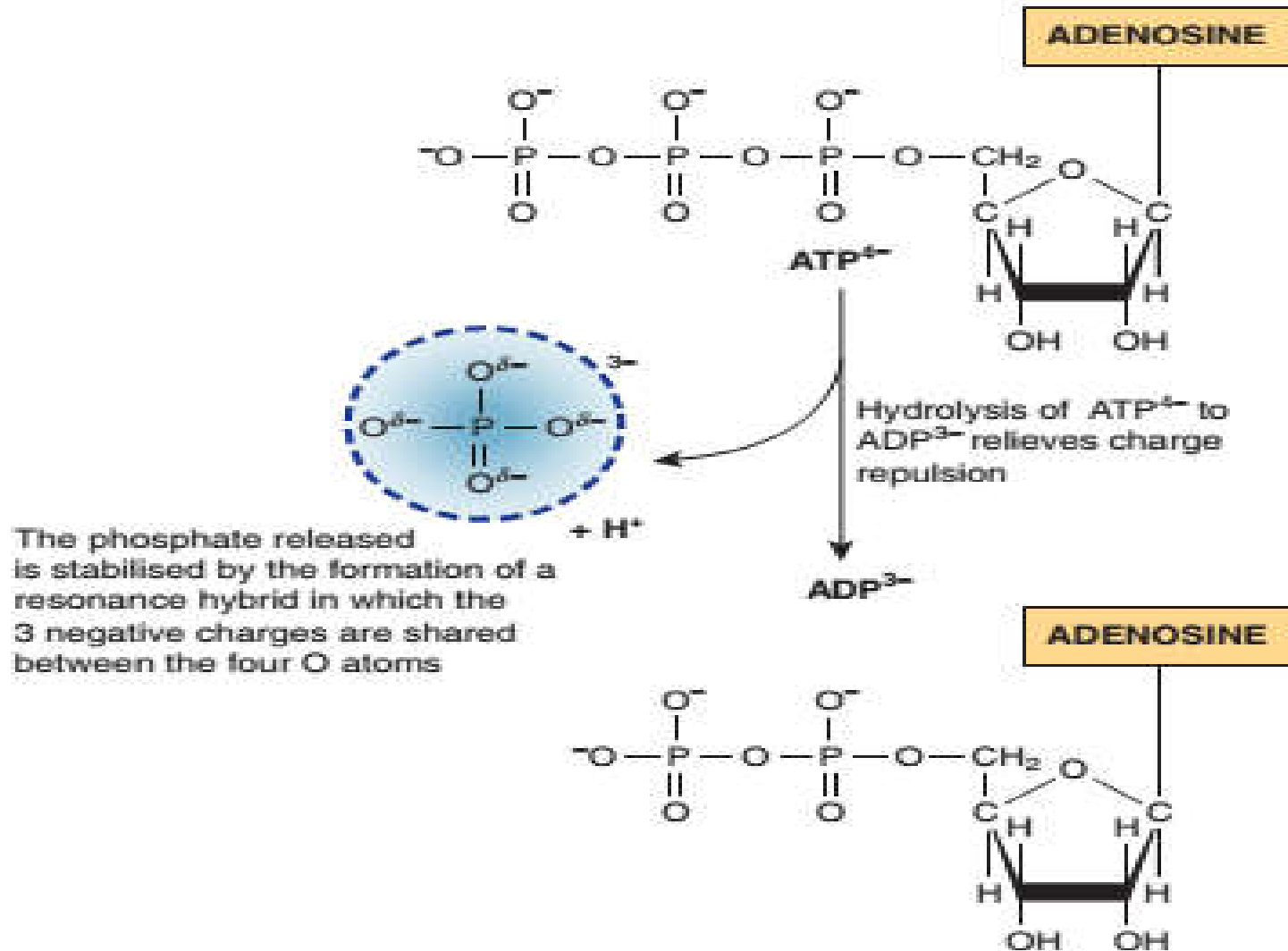


Adenosine diphosphate (ADP)



Adenosine monophosphate (AMP)

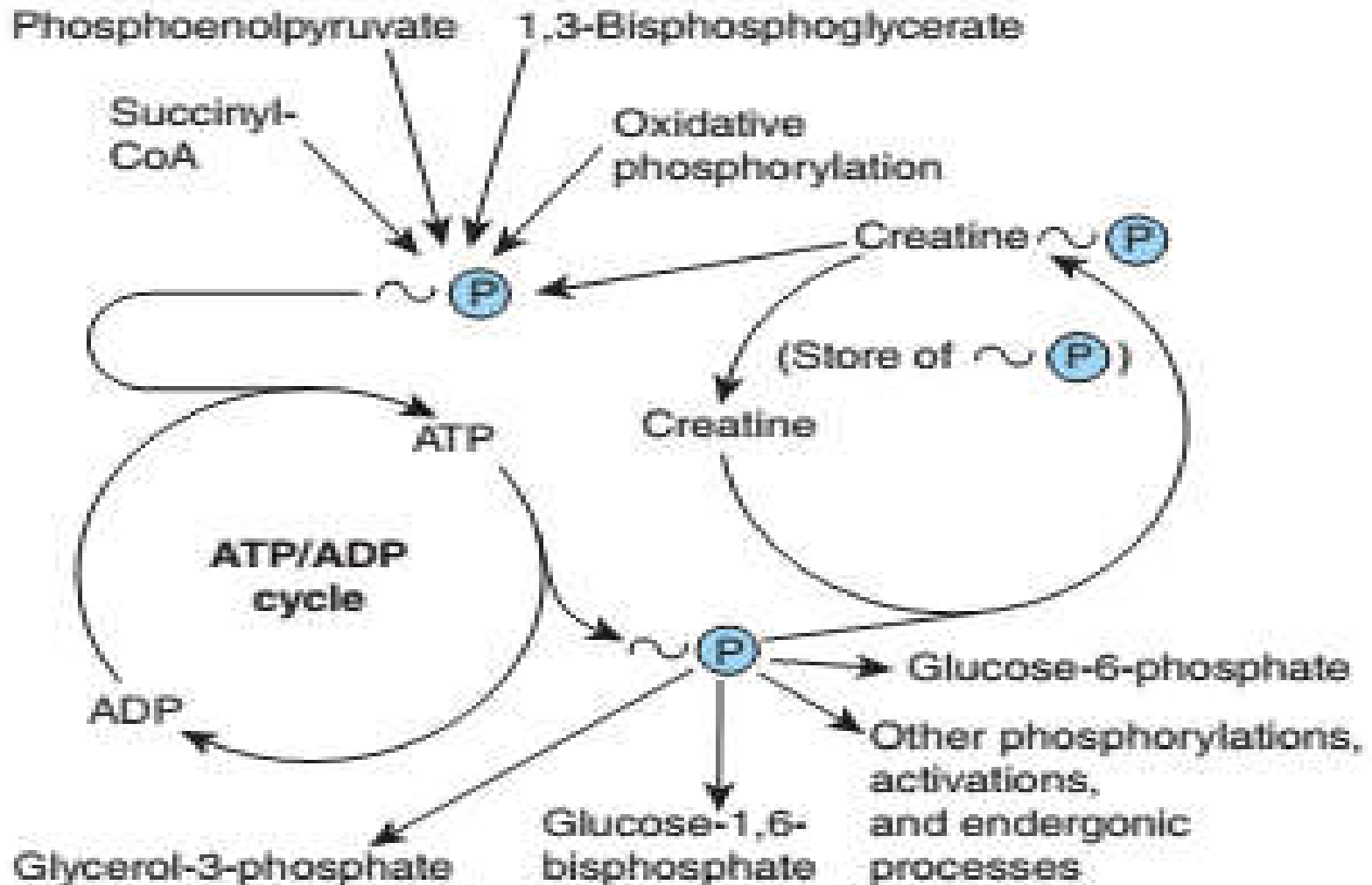
The free-energy change on hydrolysis of ATP to ADP.



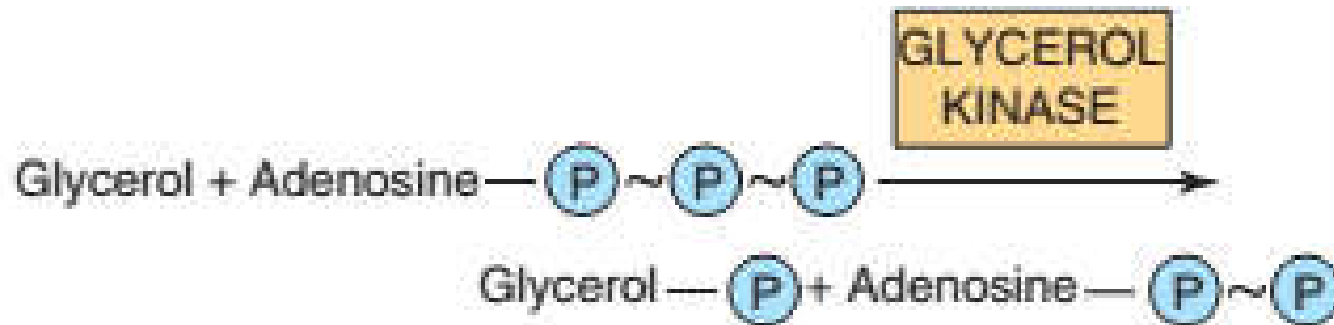
HIGH-ENERGY PHOSPHATES ACT AS THE “ENERGY CURRENCY” OF THE CELL

- There are three major sources of $\sim P$ taking part in energy conservation or energy capture:
 - 1. Oxidative phosphorylation
 - 2. Glycolysis.
 - 3. The citric acid cycle.

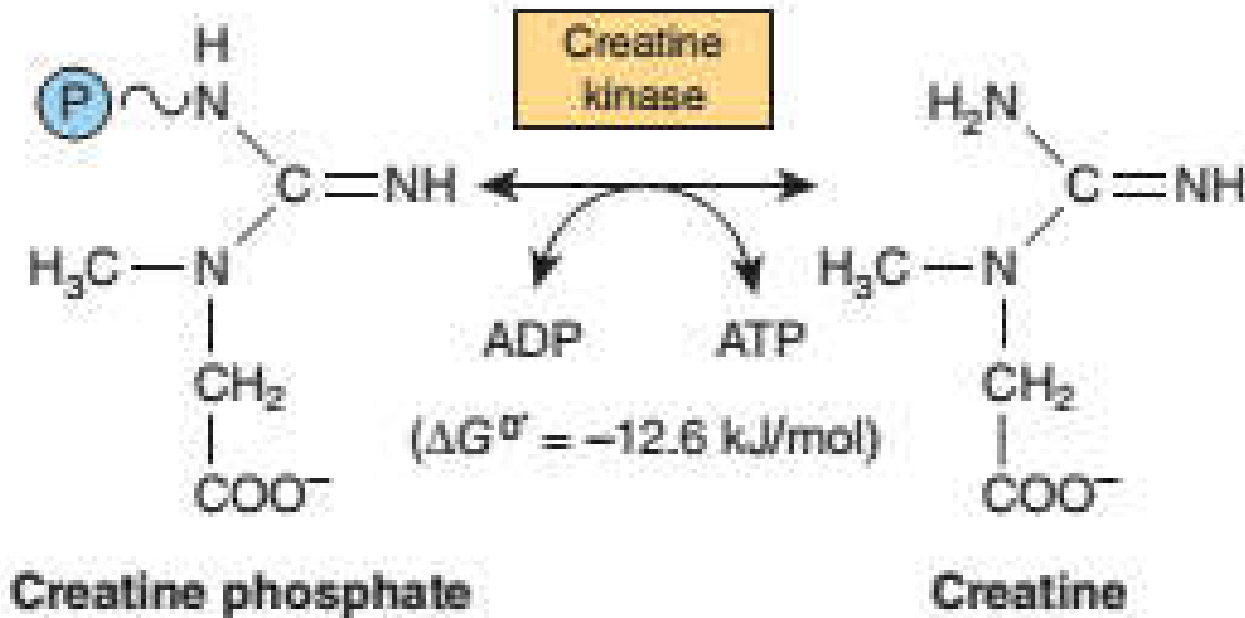
role of ATP/ADP cycle in transfer of high-energy phosphate



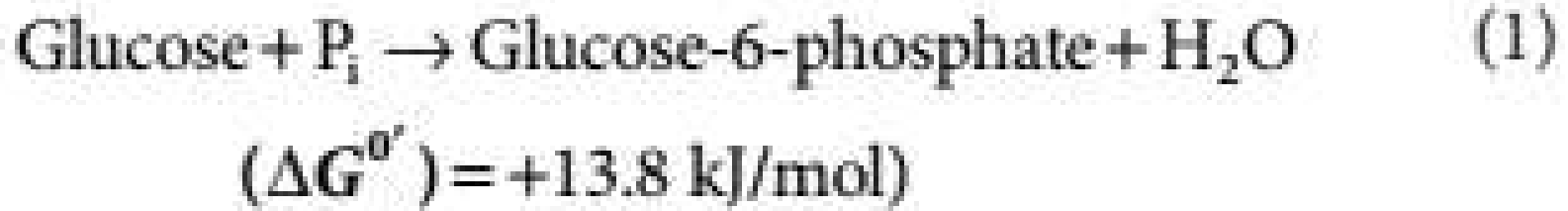
When ATP acts as a phosphate donor to form compounds of lower free energy of hydrolysis, the phosphate group is invariably converted to one of low energy. For example, the phosphorylation of glycerol to form glycerol-3-phosphate



ATP allows the Coupling of thermodynamically Unfavorable reactions to Favorable Ones



transfer of high-energy phosphate between ATP and creatine.



adenylate Kinase (Myokinase)

Interconverts adenine Nucleotides



Adenylate kinase is important for the maintenance of energy homeostasis in cells because it allows:

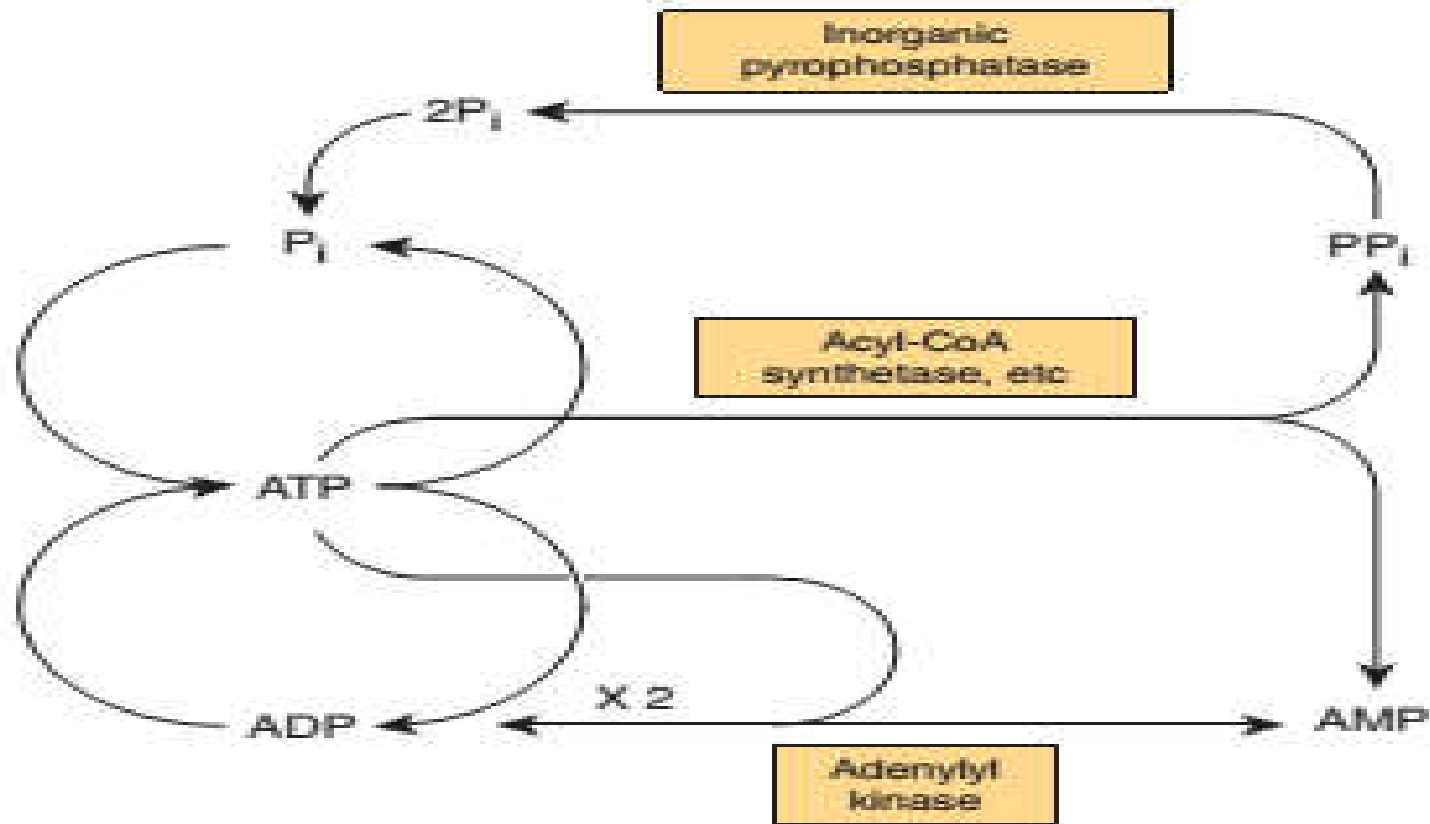
1. High-energy phosphate in ADP to be used in the synthesis of ATP.
2. The AMP formed as a consequence of activating reactions involving ATP to be rephosphorylated to ADP.
3. AMP to increase in concentration when ATP becomes depleted so that it is able to act as a metabolic (allosteric) signal to increase the rate of catabolic reactions, which in turn lead to the generation of more ATP

When ATP Forms AMP, Inorganic pyrophosphate (ppi) Is produced



This reaction is accompanied by loss of free energy as heat, which ensures that the activation reaction will go to the right, and is further aided by the hydrolytic splitting of Ppi catalyzed by inorganic pyrophosphatase, a reaction that itself has a large ΔG^0 of - 19.2 kJ/mol

phosphate cycles and interchange of adenine nucleotides.



**INORGANIC
PYROPHOSPHATASE**



Other nucleoside Triphosphates participate in the Transfer of high-Energy phosphate

By means of the nucleoside diphosphate (NDP) kinases, UTP, GTP, and CTP can be synthesized from their diphosphates, for example, UDP reacts with ATP to form UTP.

