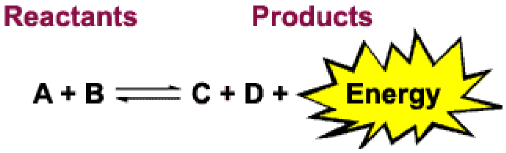
# THERMODYNAMICS OF METABOLISM

- Overall process of catabolism RELEASES energy
- Overall process of anabolism REQUIRES energy input

How do we define amount of energy?

Let's look at a hypothetical spontaneous chemical reaction:

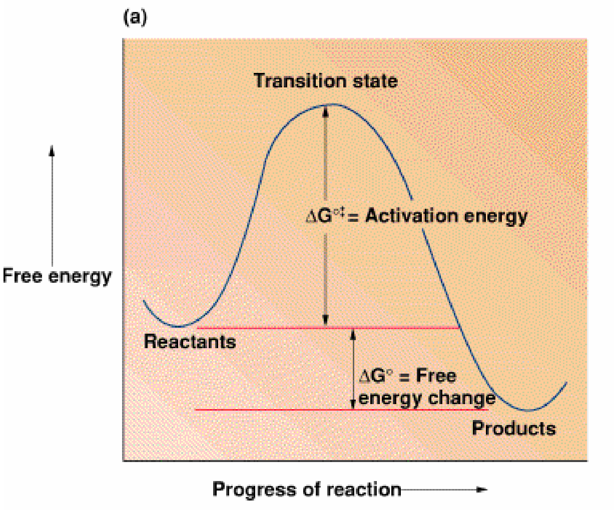


The quantity of usable energy (chemical potential) in a reaction is called the **Gibbs Free Energy (ΔG)**. ΔG is the difference between the energy contained in the products of a reaction and the reactants:

**ΔG = (energy of products) - (energy of reactants)**

Chemical reactions are classified as being either **exergonic** or **endergonic**. That just means that a reaction can either **release** energy useful for work (an **exergonic** reaction) or **requires** energy to proceed (an **endergonic** reaction).

The spontaneous reaction above is an **exergonic** reaction and **ΔG will be negative**. Thus, a negative ΔG value tells you that that reaction is possible



| Exergonic Reaction | Endergonic Reaction |
|---|---|
| Spontaneous | Not Spontaneous |
| Release Free Energy ( -ΔG) | Consume Gibbs Free Energy (+ΔG) |
| Products have less energy than reactants | Products have more energy than reactants |

- Use ΔG – Thermodynamic term
  - Measure of energy available to do useful work
  - ΔG is a constant for a reaction under a defined set of conditions

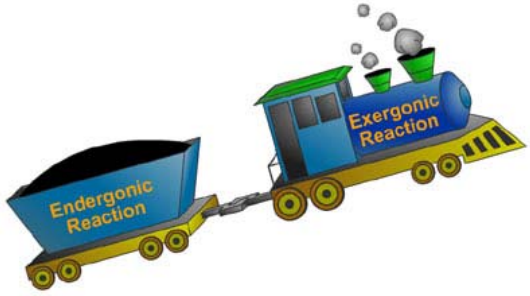
- We will use **ΔG° – The STANDARD free energy change**
  - Energy change occurring when a reaction proceeds under *standard biological conditions*
    - 1 ATM, 25°C and all reactants at 1M
  - Not really biologically relevant – so we define ΔG° as ΔG°' at pH 7.0, 1 ATM, 25°C and all reactants at 1M
  - Since standard conditions DO NOT occur in cells, absolute values of ΔG°' are not realistic. Can be used to COMPARE energy requirements.

- $\Delta G^{\circ\prime}$ defines the difference between the energy content of products and reactants
    - o $\Delta G^{\circ\prime}$ – Energy of products minus reactants

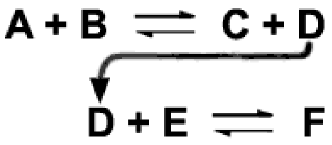
$$\mathbf{\Delta G^{\circ\prime} = G^{\circ\prime}_{products} - G^{\circ\prime}_{reactants}}$$

- Common in biological reactions to **COUPLE** unfavorable reactions with favorable ones to make the overall reaction favorable!

- We have already discussed that some reactions are, while others are endergonic. To get the energy to those endergonic reactions, they are **paired up** with energy-releasing exergonic reactions. Like a locomotive that gets the train car over the hill, an exergonic reaction can "pull" an endergonic reaction along to its destination (products). The reactions can be hooked together, or coupled, via a common intermediate.



- Thermodynamics lets us predict that the reaction will proceed if the overall ΔG of the two reactions is negative. When two reactions are coupled, the overall ΔG is the sum of the ΔGs of the component reactions.



**$\Delta G^{\circ\prime}$ VALUES ARE ADDITIVE!**

- Reactions that are not spontaneous can be coupled to spontaneous reactions
- Under these conditions, the overall reaction can be spontaneous (favorable)

- $A + B \rightarrow C + D$ $\Delta G^{\circ\prime}$ reaction 1
- $\underline{D + E \rightarrow F}$ $\underline{\Delta G^{\circ\prime}\text{ reaction 2}}$
- $A + B + E \rightarrow C + F$ $\Delta G^{\circ\prime}$ overall reaction

- $\Delta G^{\circ\prime}$ overall reaction = $\Delta G^{\circ\prime}$ reaction 1 + $\Delta G^{\circ\prime}$ reaction 2

- The coupling of metabolism, particularly to ATP hydrolysis, can drive thermodynamically unfavorable reactions forward.

- An example:
    1. glucose-6-phosphate → fructose-6-phosphate
       $\Delta G^{\circ\prime}$ = +1.7 kJ mol-1
    2. fructose-6-phosphate + ATP → fructose-1,6-bisphosphate + ADP
       $\Delta G^{\circ\prime}$ = -14.2 kJ mol-1

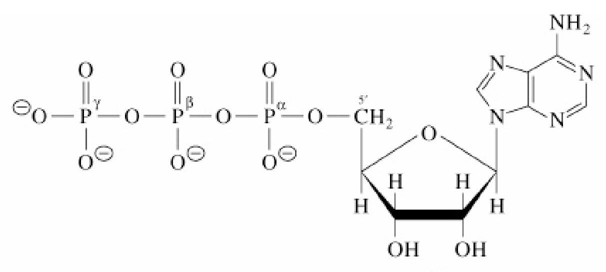
    OVERALL REACTION:
    - glucose-6-phosphate + ATP → fructose-1,6-bisphosphate + ADP
      $\Delta G^{\circ\prime}$ = -12.5 kJ mol-1

# ATP AS AN ENERGY SOURCE

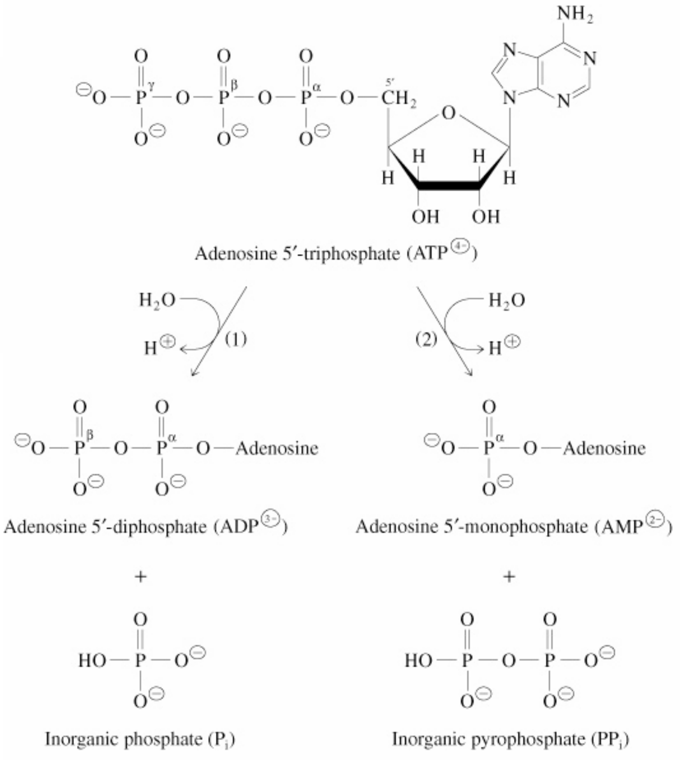
- ATP is a common form of “energy currency” within cells
- Commonly use ATP hydrolysis to drive unfavorable reactions

$$\mathbf{ATP + H_20 \rightarrow ADP + Pi + H+}$$

- ATP hydrolysis has a high $\Delta G^{\circ}$’ (-30.5 kJ mol-1)
- The equilibrium for this reaction lies heavily towards the products



Adenosine 5′-triphosphate (ATP$^{4-}$)



- **A large amount of energy is released in the hydrolysis of the <u>phosphoanhydride</u> <u>bonds</u> of ATP**

## Energy of phosphoanhydrides

(1) <u>Electrostatic</u> <u>repulsion</u> among negatively charged oxygens of phosphoanhydrides of ATP

(2) <u>Solvation</u> <u>of</u> <u>products</u> (ADP and $P_i$) or (AMP and $PP_i$) is better than solvation of reactant ATP

(3) <u>Products</u> <u>are</u> <u>more</u> <u>stable</u> <u>than</u> <u>reactants</u>
There are more delocalized electrons on ADP, $P_i$ or AMP, $PP_i$ than on ATP