Energy Change in Chemical Reaction

Energy

- **Energy is defined as the capacity to do work, and is derived by animals through the catabolism of dietary carbohydrates, lipid and protein within the body.**
- Many forms of energy exist in nature i.e. radiant, chemical, mechanical, heat, and electrical energy.
- Energy is essential for the maintenance of life processes such as cellular metabolism, growth, reproduction, and physical activity.
- **Life on earth is dependent on radiant solar energy and its subsequent fixation and conversion by green plants during photosynthesis into stored chemical energy (ie. carbohydrates) for use as an energy source by plants and animals**

Laws of thermodynamics

- All forms of energy are inter-convertible and obey the laws of thermodynamics. The first law of thermodynamics states that energy may be transformed from one form into another, but can never be created or destroyed.

Solar energy $\xrightarrow{\text{photosynthesis}}$ Chemical energy + Heat energy

- The second law of thermodynamics states that no transformation of energy will occur unless energy is degraded from a concentrated form to a less concentrated or more dispersed form, and further that no transformation is 100% efficient.

Solar energy (high energy form) $\xrightarrow{\text{photosynthesis}}$ Chemical energy (low energy form)

Energy units

- Energy is usually expressed in terms of heat units, since all forms of energy are convertible into heat energy.

- The basic heat unit normally used is the **calorie**. One calorie is defined as the amount of heat required to raise the temperature of one gram of water by one degree centigrade.

- Since for many purposes the calorie (cal) is too small a unit of measurement, the kilocalorie (kcal) is often used; 1 kcal = 1000 cal.

- In many scientific studies the calorie is now being replaced by the joule (J) as the unit of energy; 4.184 J = 1 cal.

Dietary energy sources

- The major dietary source of energy for living organism are carbohydrates, fats and proteins.

- **Carbohydrates** are the cheapest and most abundant source of energy for animals.

- **Fats** are the principal form of energy storage in plants and in animals. Fat contains more energy per unit weight than any other biological product.

- **Protein**: In nature, carnivorous fish consume diets which are about 50 percent protein. Fish have a very efficient system for excretion of waste nitrogen from protein which is catabolised for energy

Energy Status of food

- **Carbohydrates** give average gross energy values of **4.2** kcal or 17.6 kJ per gram

- **Fat** gives **9.4 kcal**, or 39.4 kJ per gram

- **Protein** gives **5.65** kcal or 23.7 kJ per gram

Energy metabolism

- Metabolism is usually the largest part of energy budget and it has central role to play in physiological traits like growth and energy storage.

Anabolism (synthesis)

- **Metabolism**

Catabolism (breakdown)

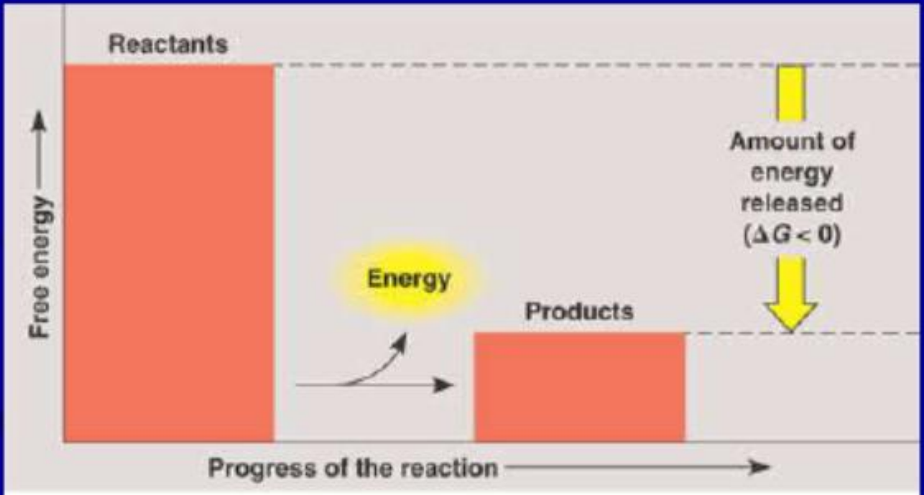
- **Energy metabolism** is concerned with the catabolism and oxidation of carbohydrates, lipid and protein within the animal body, and the consequent release and use of the liberated energy as work for the maintenance of the life process.

Chemical Reactions and Free Energy

- Chemical reactions involve
  - changes in chemical bonds
  - changes in substance concentrations
  - changes in free energy
    - **free energy** = energy available to do work in a chemical reaction (such as: create a chemical bond)
      - free energy changes depend on bond energies and concentrations of reactants and products
      - **bond energy** = energy required to break a bond; value depends on the bond

Chemical Reactions and Free Energy

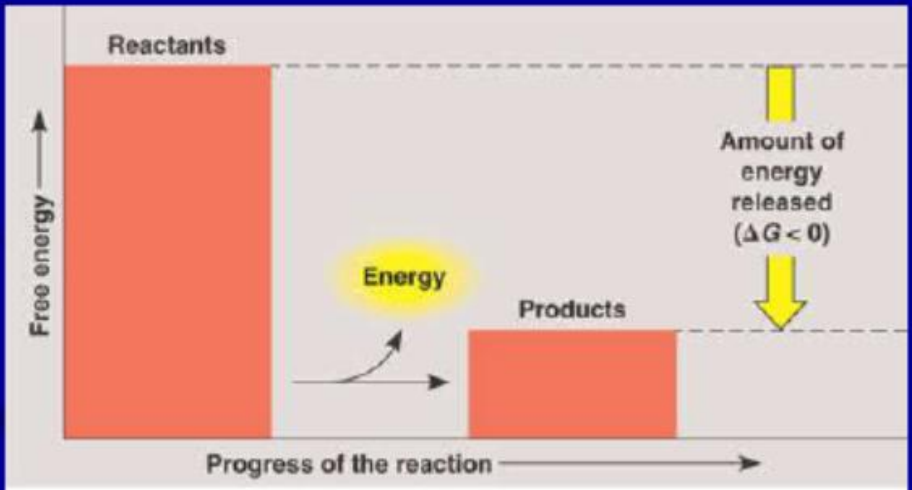
- **exergonic reactions** – the products have less free energy than reactants
  - the difference in ***energy is released*** and is ***available to do work***
  - exergonic reactions are thermodynamically favored; thus, they are ***spontaneous***, but not necessarily fast (more on ***activation energy*** later)



(a) Exergonic reaction: energy released

Chemical Reactions and Free Energy

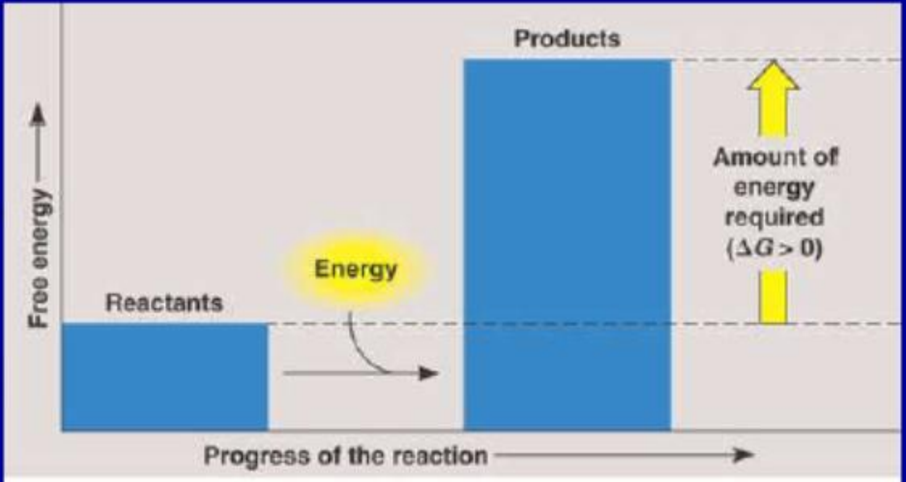
- catabolic reactions are usually exergonic
- $ATP + H_2O \rightarrow ADP + P_i$ is highly exergonic



(a) Exergonic reaction: energy released

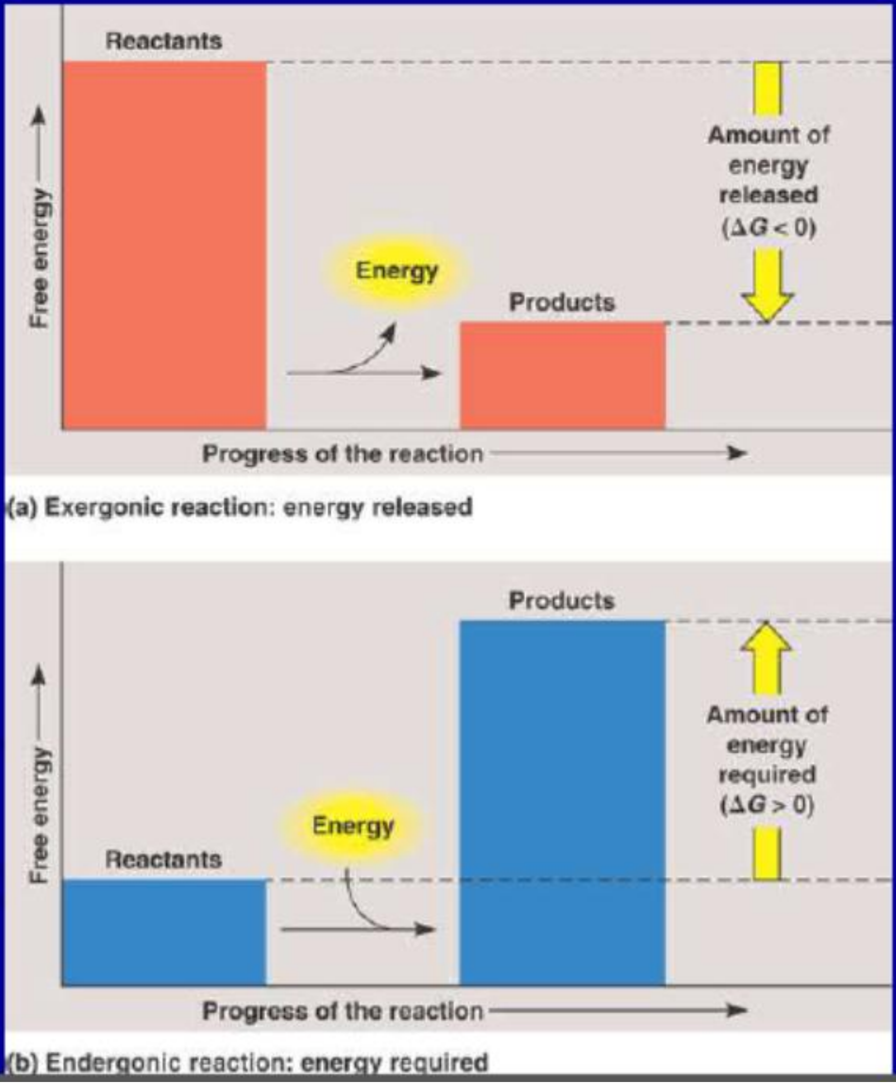
Chemical Reactions and Free Energy

- **endergonic reactions** – the products have more free energy than the reactants
  - the difference in free ***energy must be supplied*** (stored in chemical bonds)
  - endergonic reactions are not thermodynamically favored, so they are ***not spontaneous***



(b) Endergonic reaction: energy required

Chemical Reactions and Free Energy



(a) Exergonic reaction: energy released

(b) Endergonic reaction: energy required

Chemical Reactions and Free Energy

- How to get energy for an endergonic reaction?
  - couple with an exergonic one!
  - together, the **coupled reactions** must have a ***net exergonic nature***
  - reaction coupling requires that the reactions share a common intermediate(s)

Chemical Reactions and Free Energy

EXAMPLE:

A → B (exergonic)

C → D (endergonic)

Coupled: A + C → B + D (overall exergonic)

Actually: A + C → I → B + D

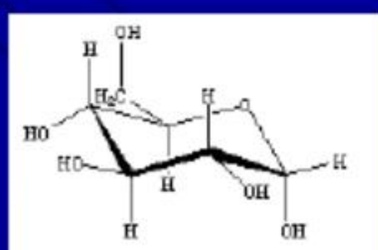
- typically, the exergonic reaction in the couple is

  $ATP + H_2O \rightarrow ADP + P_i$

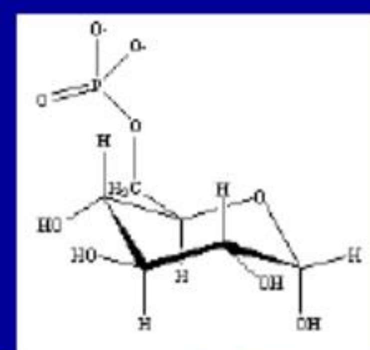
- anabolic reactions are usually endergonic

ATP is the main energy currency in cells

- **Intermediates when ATP hydrolysis is coupled to a reaction to provide energy**
  - **often phosphorylated compounds**
  - **the inorganic phosphate is transferred onto another compound rather than being immediately released**
  - **a phosphorylated compound is in a higher energy state**



glucose



glucose-6-phosphate

ATP is the main energy currency in cells

EXAMPLE of a coupled reaction:

glucose + fructose → sucrose + H_2O (endergonic; requires ~27 kJ/mol)

ATP + H_2O → ADP + P_i (exergonic; provides ~30 kJ/mol)

coupled:

glucose + fructose + ATP + H_2O → sucrose + H_2O + ADP + P_i

simplified:

glucose + fructose + ATP → sucrose +ADP + P_i

with intermediates:

glucose + fructose + ATP + H_2O → glucose-P + fructose + ADP → sucrose + H_2O + ADP + P_i (net exergonic, releases ~3 kJ/mol)