ATP:
The Primary Energy Carrier

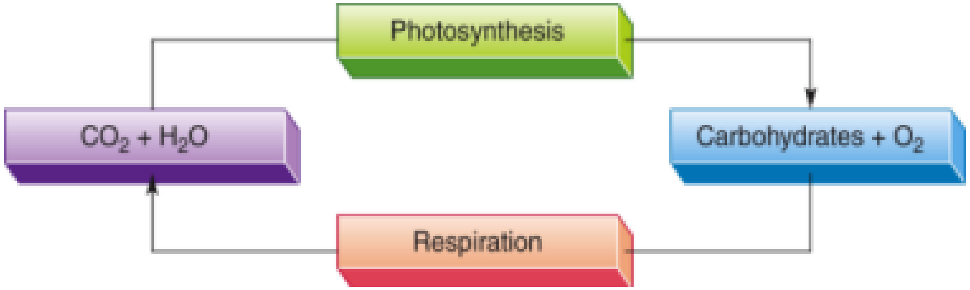
Stage 3 Biochemistry

Cellular Respiration

- During cellular respiration, plants and animals combine energy-rich compounds with oxygen from the air, producing CO_2 and releasing energy.
- Cellular respiration can be represented as:

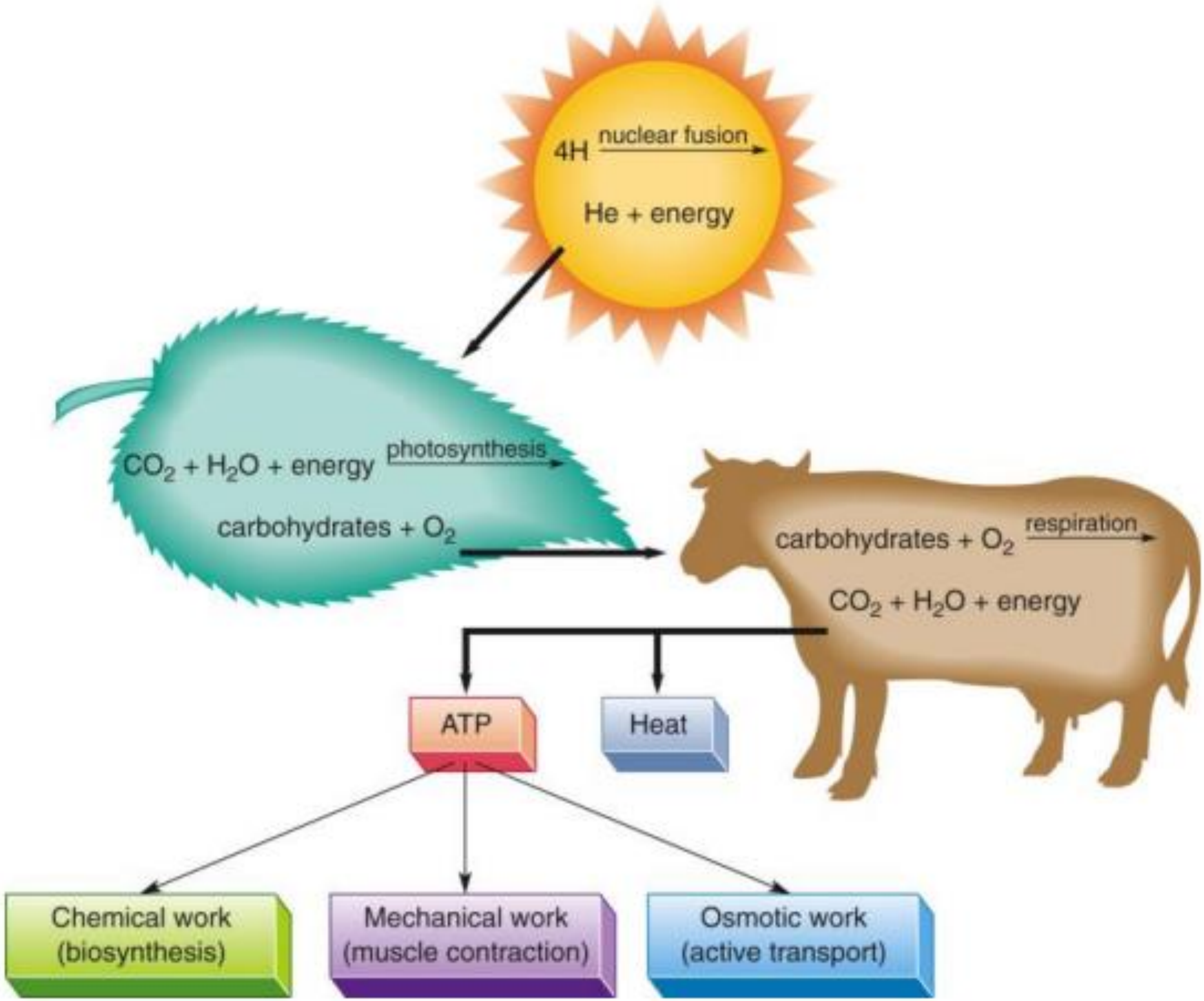
$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{respiration}} 6CO_2 + 6H_2O + \text{energy}$$

  - A portion of the energy released during respiration is captured in the form of adenosine triphosphate (ATP), which stores energy for use in other processes.
  - The remainder of the energy from respiration is released as heat.

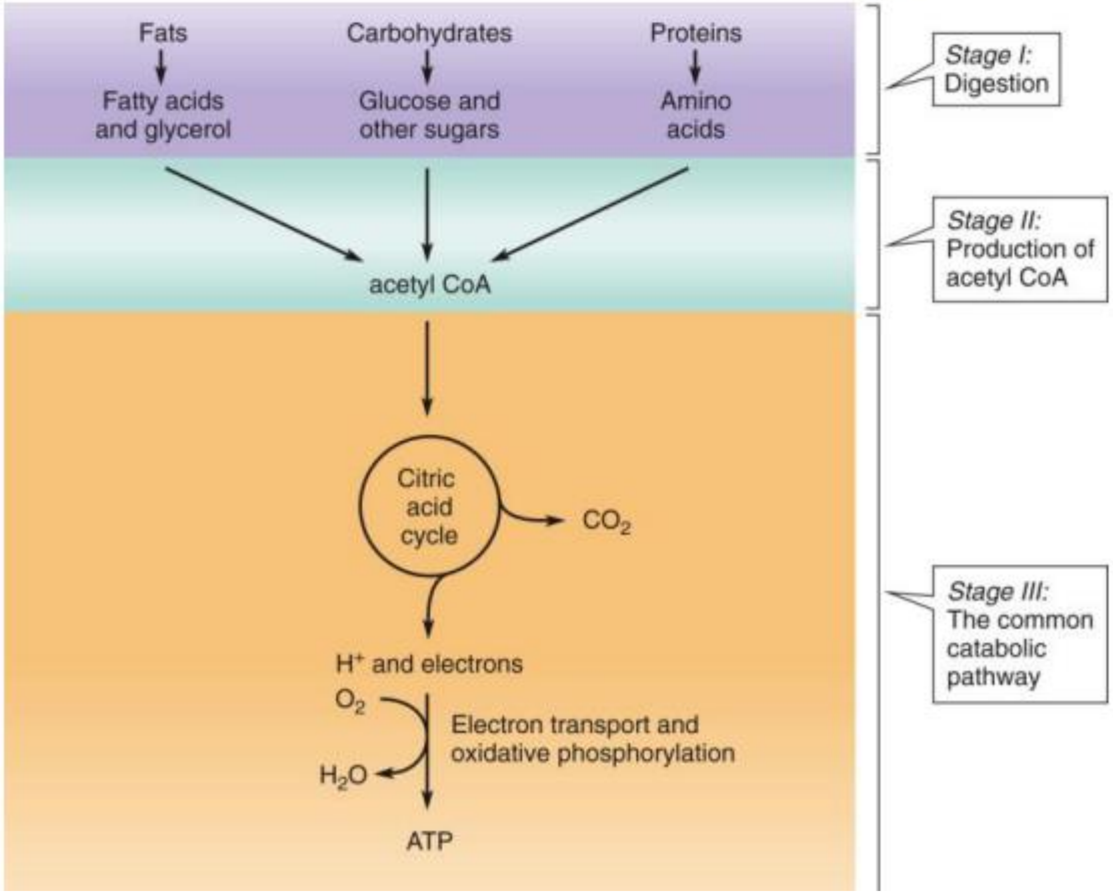


An extremely simplified carbon cycle

Energy Flow in the Biosphere



The Catabolism of Food



Metabolism

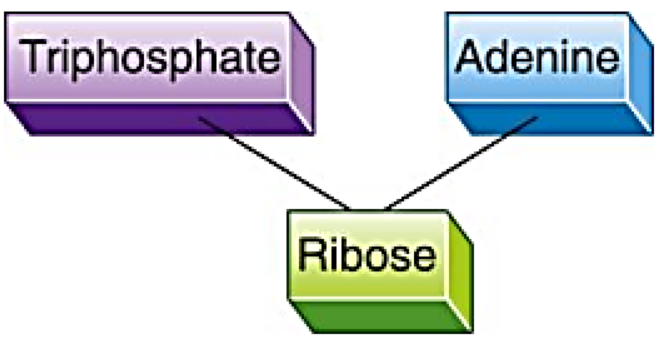
- **Metabolism** is the sum of all reactions occurring in an organism:
  - **catabolism** — the reactions involved in the *breakdown* of biomolecules.
  - **anabolism** — the reactions involved in the *synthesis* of biomolecules.
    - In general, energy is released during catabolism and required during anabolism.

The Structure of ATP

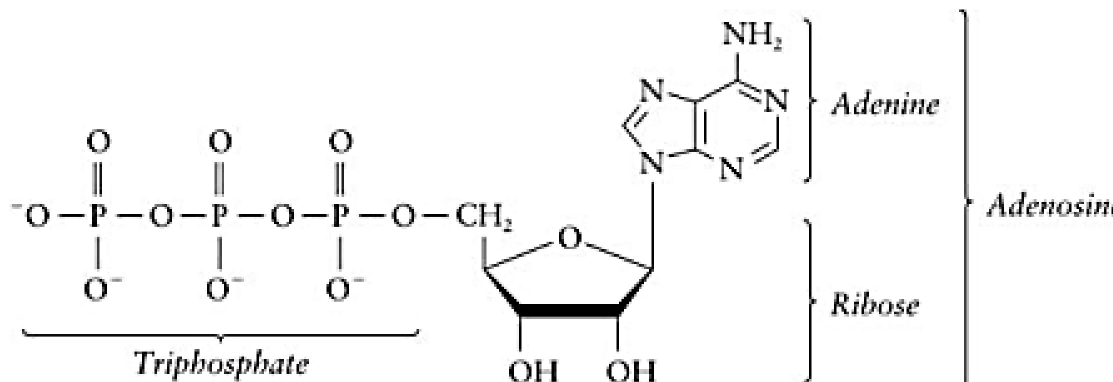
- **Adenosine triphosphate, ATP**, consists of:
  - the heterocyclic base **adenine**
  - the sugar **ribose**
  - a **triphosphate group**

adenine + ribose is called **adenosine**

- At physiological pH, the protons on the triphosphate group are removed, giving ATP a charge of -4.
  - In the cell, it is complexed with Mg^{2+} in a 1:1 ratio, giving it a net charge of -2.



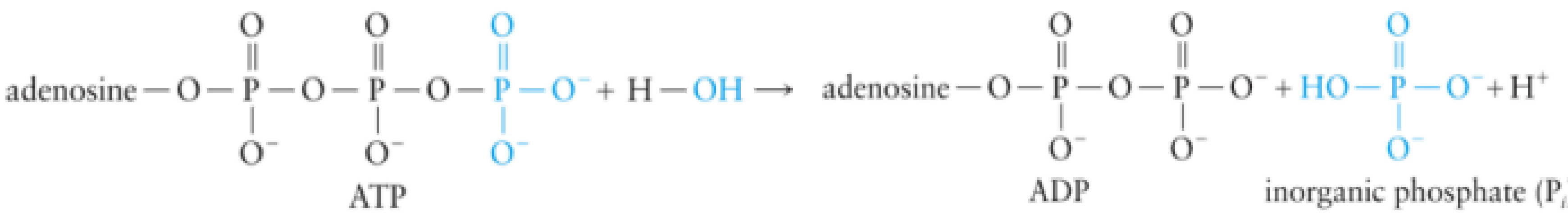
Simplified structure



Detailed structure

The Hydrolysis of ATP

- The triphosphate group is the part of the molecule that is important in the transfer of biochemical energy. The key reaction is the transfer of a **phosphoryl group**, —PO_3^{2-}, from ATP to another molecule.
  - During the hydrolysis of ATP in water, a phosphoryl group is transferred from ATP to a water molecule:



  - The products are **adenosine diphosphate (ADP)** and a **phosphate ion**, often referred to as an inorganic phosphate, P_i, or just *phosphate*.

The Hydrolysis of ATP

- The transfer of a phosphoryl group from ATP to water is accompanied by a release of energy.
- **Free energy**, ΔG, is used as a measure of the energy change.
  - When energy is released, ΔG is negative.
  - When energy is absorbed, ΔG is positive.
  - When ΔG is measured under standard conditions, it is represented by ΔG^{o}.
  - When ΔG^{o} is measured under body conditions, it is represented by $\Delta G^{o\prime}$.

Table 22.5 Free Energy Changes for the Hydrolysis of Some Phosphate Compounds

Reaction			$\Delta G^{\circ\prime}$ (kcal/mol)
Phosphoenolpyruvate + H_2O	→	pyruvate + phosphate	−14.8
Carbamoyl phosphate + H_2O	→	ammonia + CO_2 + phosphate	−12.3
1,3-bisphosphoglycerate + H_2O	→	3-phosphoglycerate + phosphate	−11.8
Phosphocreatine + H_2O	→	creatine + phosphate	−10.3
ATP + H_2O	→	ADP + phosphate	−7.3
ADP + H_2O	→	AMP + phosphate	−7.3
Glucose-1-phosphate + H_2O	→	glucose + phosphate	−5.0
AMP + H_2O	→	adenosine + phosphate	−3.4
Glucose-6-phosphate + H_2O	→	glucose + phosphate	−3.3
Glycerol-3-phosphate + H_2O	→	glycerol + phosphate	−2.2

The Hydrolysis of ATP

- Compounds that liberate a large amount of free energy on hydrolysis are called **high-energy compounds**.
- The hydrolysis of ATP to ADP is the principal energy-releasing reaction for ATP. Some other hydrolysis reaction occur under some conditions, such as the hydrolysis of ATP to adenosine monophosphate, AMP, and pyrophosphate, PP_i:

ATP

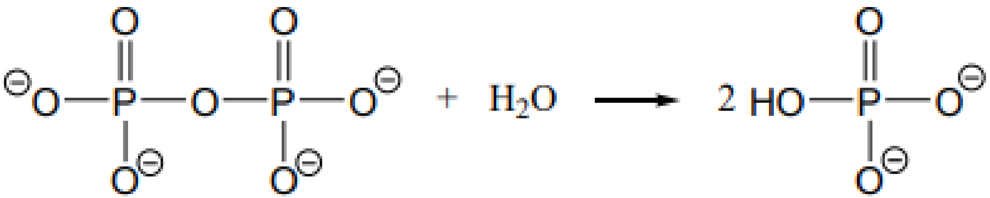
AMP adenosine monophosphate

PP_i pyrophosphate

$$ATP + H_2O \rightarrow AMP + PP_i + 2H^+, \Delta G^{o\prime} = -8.0 \text{ kcal/mol}$$

The Hydrolysis of ATP

– This is usually followed by immediate hydrolysis of the pyrophosphate, which releases even more energy:



PP$_i$ P$_i$

$\Delta G°' = -6.5$ kcal/mol

- The hydrolyses of ATP and related compounds are summarized below:

Table 22.6 Hydrolyses of Some ATP-Related Compounds

Reaction			$\Delta G°'$ (kcal/mol)
ATP + H_2O	→	ADP + P_i + H^+	−7.3
ATP + H_2O	→	AMP + PP_i + $2H^+$	−8.0
PP_i + H_2O	→	$2P_i$	−6.5
ADP + H_2O	→	AMP + P_i + H^+	−7.3

The ATP-ADP Cycle

- ATP functions as an immediate donor of free energy rather than as an energy storage medium.
  - The turnover rate of ATP is very high: typically, an ATP molecule is hydrolyzed within 1 minute after its formation.
  - At rest, a human body hydrolyzes ATP at the rate of about 40 kg every 24 hours.
  - During strenuous exertion, this rate may be as high as 0.5 kg per minute.
- ATP must be continuously regenerated from ADP if cellular work is to occur.