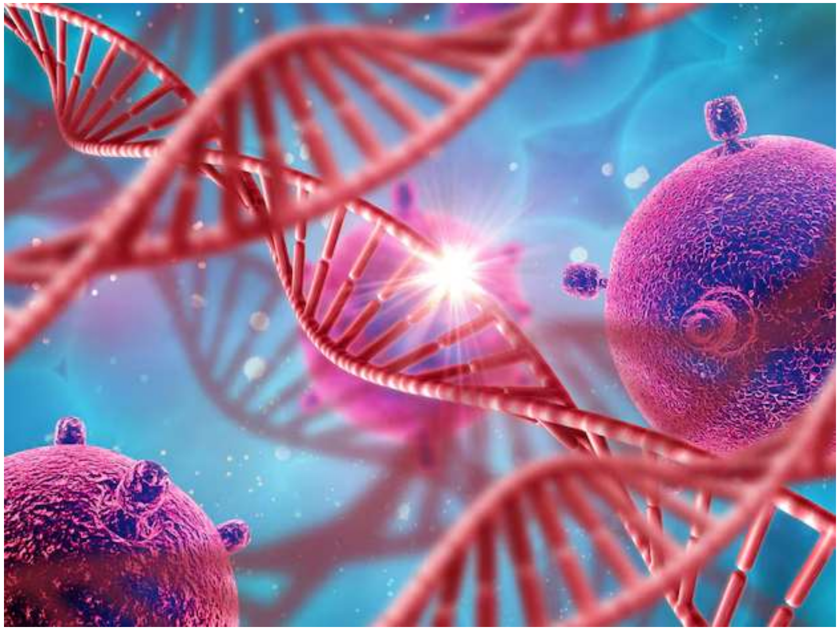
Lecture 12

General Biology & Cytology Course 2301130



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An Introduction to Metabolism

The Energy of Life

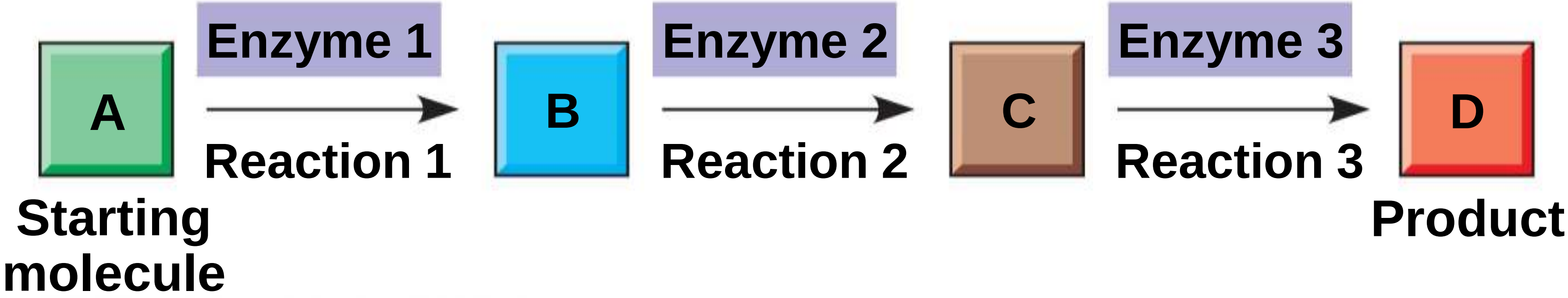
- The living cell is a miniature chemical factory where thousands of reactions occur.
- The cell extracts energy and applies energy to perform work
- Some organisms even convert energy to light, as in bioluminescence.
- E.g: Jellyfish

- **Metabolism:** Is the totality of an organism's chemical reactions.

- Metabolism is an emergent property of life that arises from interactions between molecules within the cell

- A **metabolic pathway** begins with a specific molecule and ends with a product

- Each step is catalyzed by a specific enzyme


Enzyme 1
Enzyme 2
Enzyme 3
A
B
C
D
Reaction 1
Reaction 2
Reaction 3
Starting molecule
Product

A. Catabolic pathways release energy by breaking down complex molecules into simpler compounds

- Cellular respiration, the breakdown of glucose in the presence of oxygen, is an example of a pathway of catabolism.

B. Anabolic pathways consume energy to build complex molecules from simpler ones

- The synthesis of protein from amino acids is an example of anabolism

- **Bioenergetics** is the study of how organisms manage their energy resources

Forms of Energy

- **Energy** is the capacity to cause change.
- Energy exists in various forms, some of which can perform work:

➢ **Kinetic energy** is energy associated with motion.

- E.g: Water gushing thro a dam turns a turbines.

➢ **Heat (thermal energy)** is a type of kinetic energy associated with random movement of atoms or molecules.

- (cup of coffee),thermal E in transfer from one object to another called **heat**.

➢ **Potential energy** is energy that matter possesses because of its location or structure. Molecules possess PE due to the arrangment of electrons in bonds bw atoms. And water behind a dam

➢ **Chemical energy** is potential energy available for release in a chemical reaction. glucose

- Energy can be converted from one form to another

Transformations between potential and kinetic energy

Chemical energy from food is used to perform work during climbing platform

The Laws of Energy Transformation

- **Thermodynamics** is the study of energy transformations in a collection of matter.
- An **Isolated system**, such as the liquid in a thermos, is unable to exchange energy or matter with its surroundings.
- An **open system**, energy and matter can be transferred between the system and its surroundings
- Organisms are open systems they absorb E from lightor food and release heat and waste such as CO2.

The First Law of Thermodynamics

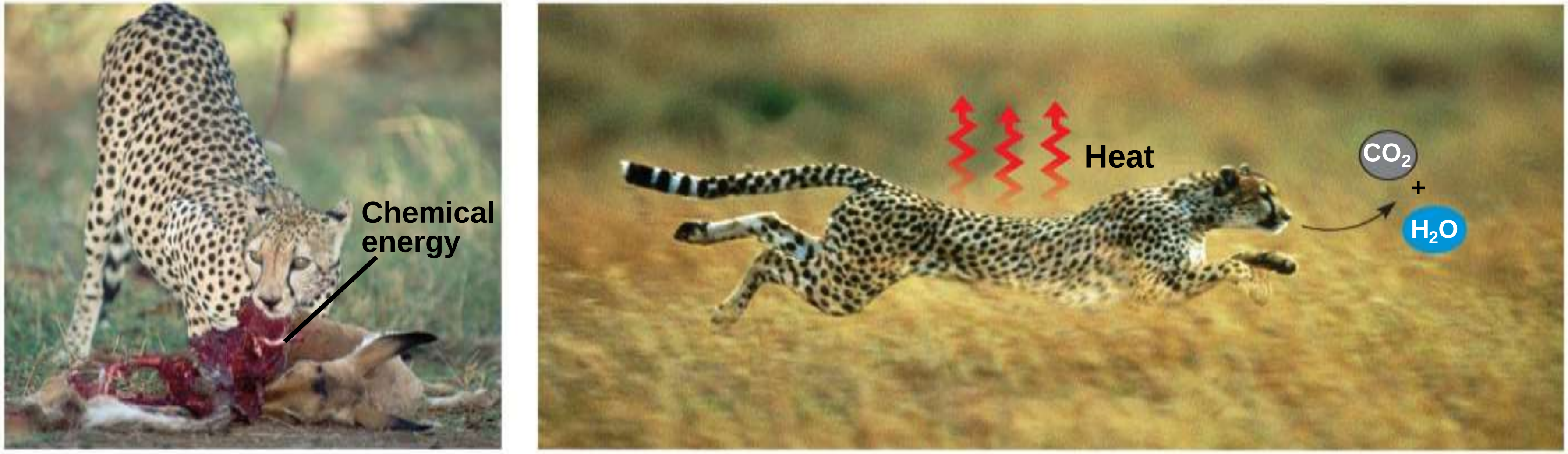
- According to the **first law of thermodynamics**, the energy of the universe is constant:
  - *Energy can be transferred and transformed, but it cannot be created or destroyed*
- The first law is also called the principle of conservation of energy

The Second Law of Thermodynamics

- During every energy transfer or transformation, some energy is unusable, and is often lost as heat
- According to the **second law of thermodynamics**:
  - ✓ *Every energy transfer or transformation increases the **entropy** (disorder) of the universe*
  - ✓ ***Entropy** is a measure of molecular disorder, or randomness.*

S= Entropy

E.g: - Break done molecules to atoms will increase Entropy (disorder, randomness), Heat is example of disorder, solid form to liquid form is disorder form.



(a) First law of thermodynamics **(b) Second law of thermodynamics**

Cheetah increase Entropy in the universe to keep itself in order

The Second Law of Thermodynamics

- Process that increase Entropy of the universe can occur spontaneous.

- Spontaneous processes occur without energy input; they can happen quickly or slowly

- Process that decrease the Entropy are nonspontaneous they required an input energy.

Biological Order and Disorder

- Cells create ordered structures from less ordered materials
- Organisms also replace ordered forms of matter and energy with less ordered forms
- Energy flows into an ecosystem in the form of light and exits in the form of heat
- The evolution of more complex organisms does not violate the second law of thermodynamics
- Entropy (disorder) may decrease in an organism, but the universe's total entropy increases

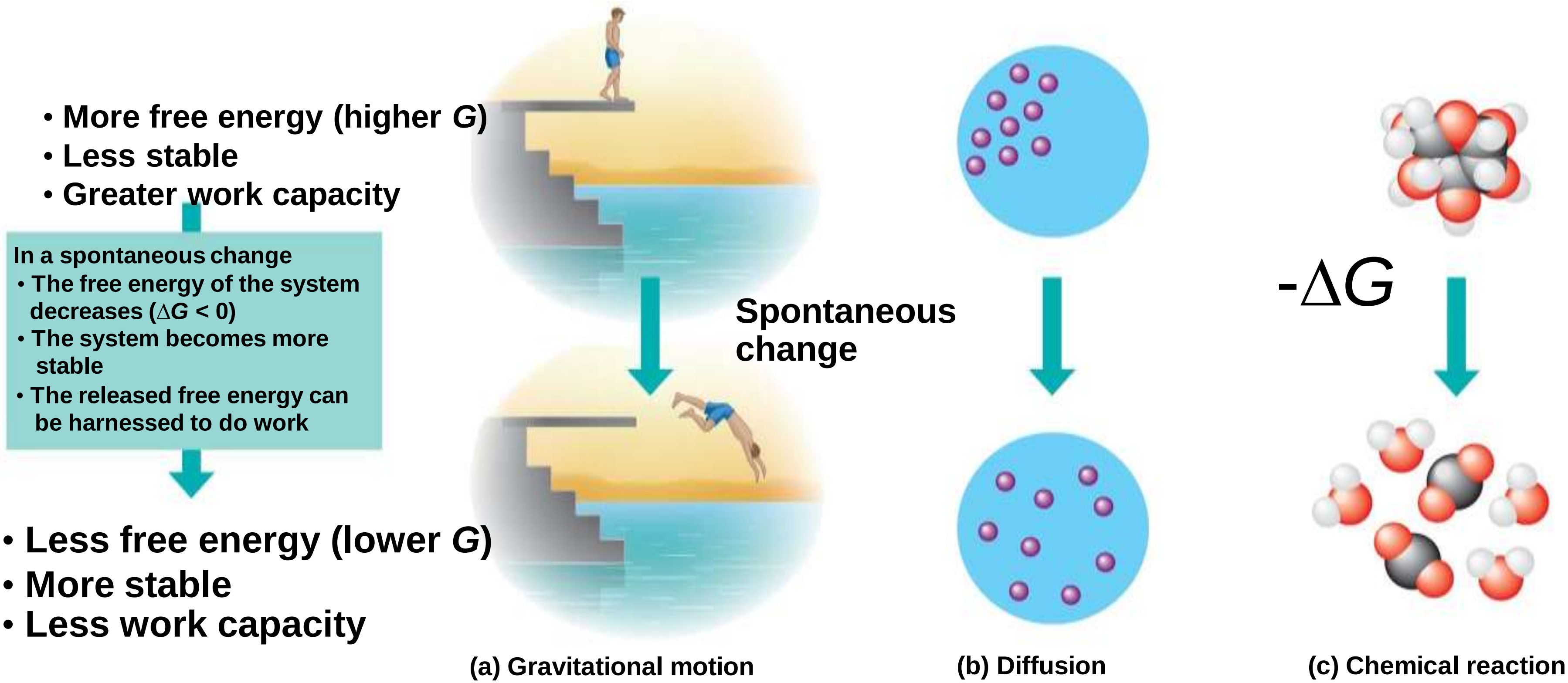
The free-energy change of a reaction tells us whether or not the reaction occurs spontaneously

- Biologists want to know which reactions occur spontaneously and which require input of energy.
- To do so, they need to determine energy changes that occur in chemical reactions

Free-Energy Change, Δ*G*

- Gibbs free energy, G, refer to free energy.
- F**ree energy** is the portion of a system's energy that can do work when temperature and pressure are uniform throughout the system, as in a living cell.
- E.g: in figure

The relationship of free energy to stability, work capacity, and spontaneous change



$+\Delta G$

6Co2 + 6H2o $\xrightarrow{E}$ C6H12O6 +6O2

$+\Delta G$ **nonspontaneous**

Free Energy, Stability, and Equilibrium

- **Free energy** is a measure of a system's instability, its tendency to change to a more stable state (lower *G)*
- During a spontaneous change, free energy decreases and the stability of a system increases (- ΔG)
- **Equilibrium** is the point at which forward and reverse reaction occur at the same rate, (a state of maximum stability).
- Systems never spontaneously move away from equilibrium
- A process is spontaneous and can perform work only when it is moving toward equilibrium

- The change in free energy (ΔG) during a process is related to the change in:

- **Enthalpy, or change in total energy (ΔH)**
- **Change in entropy (ΔS),**
- **Temperature in Kelvin *(T)***

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

- Only processes with a negative ΔG are spontaneous
- Spontaneous processes can be harnessed to perform work

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

-ΔG= *Spon- (Exergonic reaction)*

+ΔG= *Non spon- (Endergonic reaction)*

-ΔH= *heat released (Exothermic)*

+ΔH= *heat absorbed (Endothermic)*

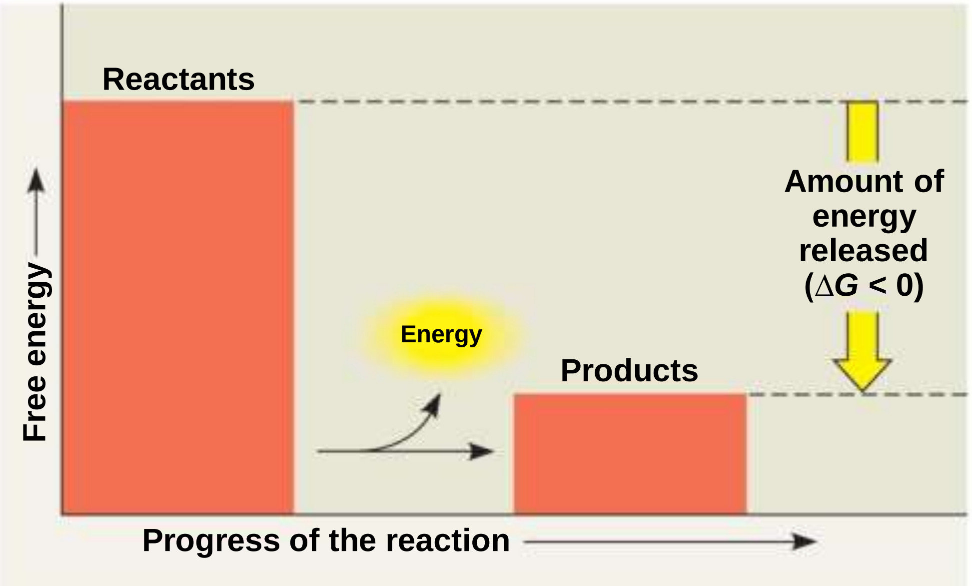
-ΔS = *less disorder*

+ΔS= *More disorder*

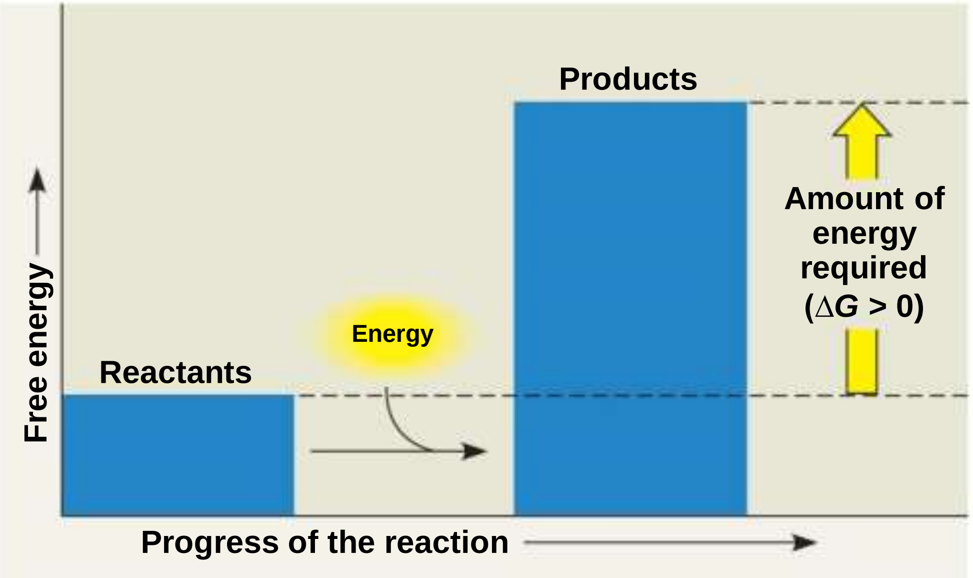
Exergonic and Endergonic Reactions in Metabolism

- The concept of free energy can be applied to the chemistry of life’s processes
- An **exergonic reaction** proceeds with a net release of free energy and is spontaneous
- An **endergonic reaction** absorbs free energy from its surroundings and is nonspontaneous

Free energy changes (ΔG) in exergonic and endergonic reactions



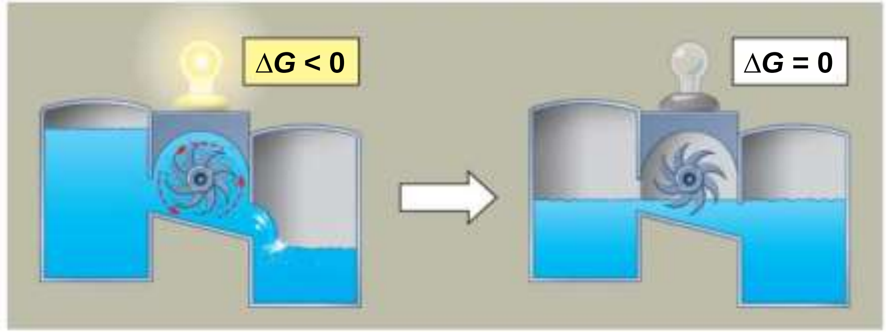
(a) Exergonic reaction: energy released



(b) Endergonic reaction: energy required

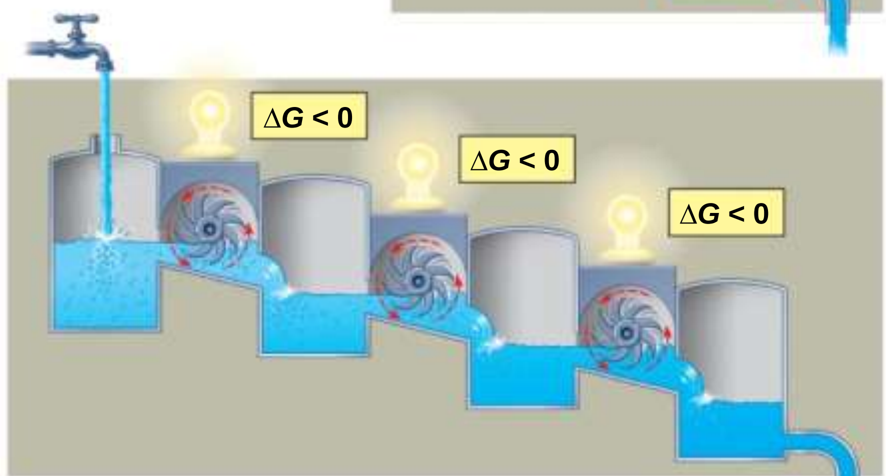
Equilibrium and Metabolism

- Reactions in a closed system eventually reach equilibrium and then do no work
- Cells are not in equilibrium; they are open systems experiencing a constant flow of materials
- A defining feature of life is that metabolism is never at equilibrium
- A catabolic pathway in a cell releases free energy in a series of reactions
- Closed and open hydroelectric systems can serve as analogies



(a) An isolated hydroelectric system

(b) An open hydroelectric system



(c) A multistep open hydroelectric system

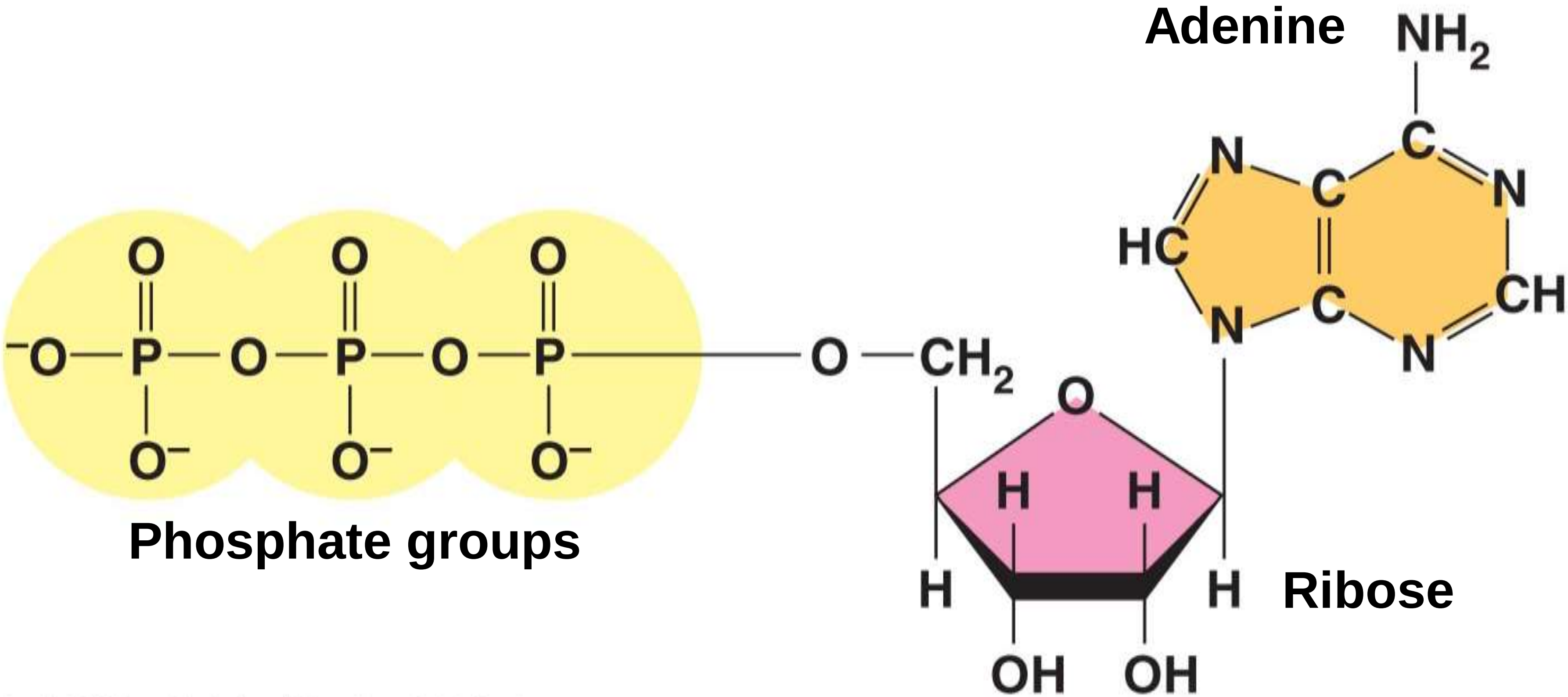
ATP powers cellular work by coupling exergonic reactions to endergonic reactions

- A cell does three main kinds of work:
  - Chemical work, pushing endergonic reactions
  - Transport work, pump substance across membrane.
  - Mechanical work, contacting muscle cells
- To do work, cells manage energy resources by **energy coupling**, the use of an exergonic process to drive an endergonic one
- Most energy coupling in cells is mediated by ATP

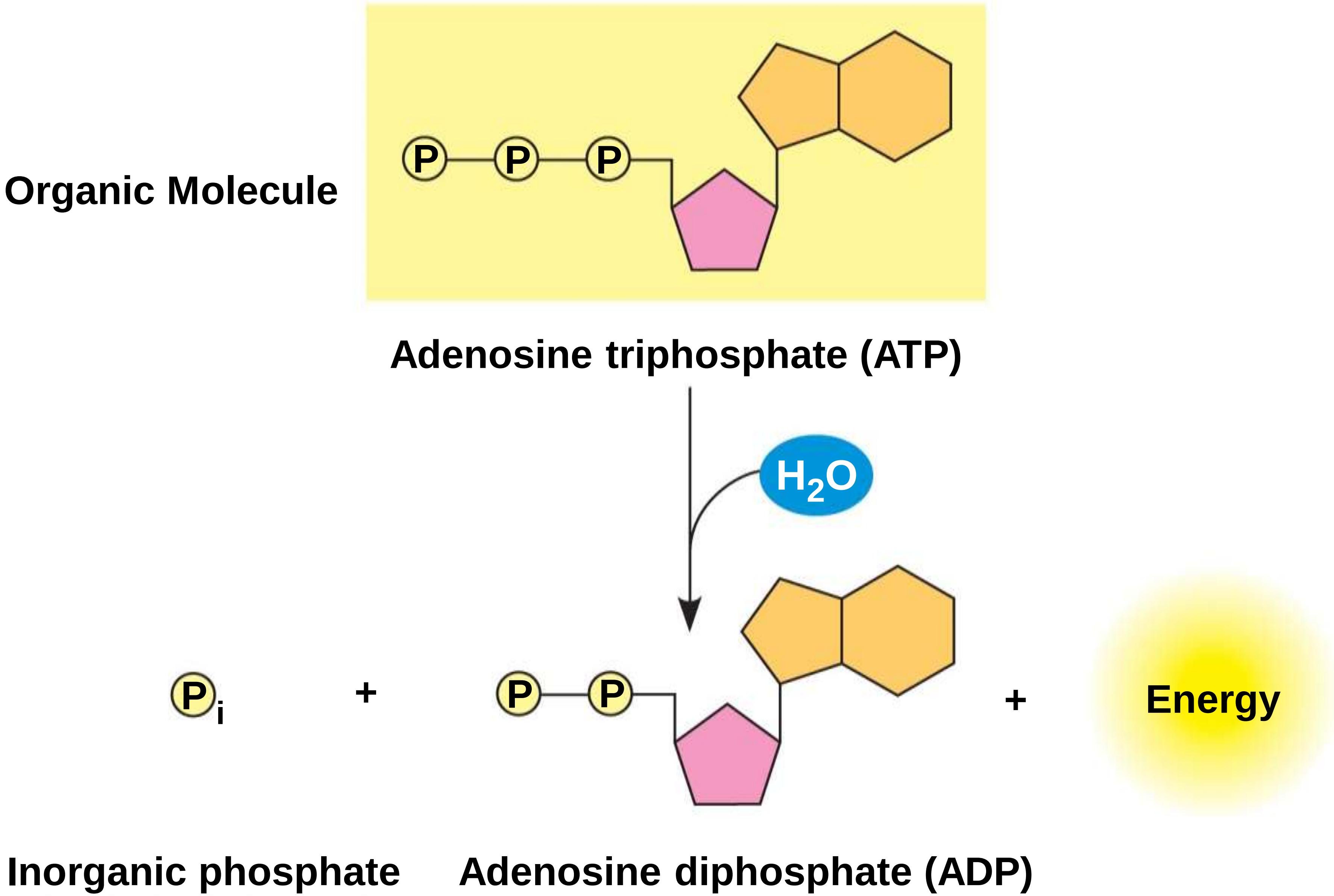
The Structure and Hydrolysis of ATP

- **ATP (adenosine triphosphate)** is the cell's energy shuttle
- ATP is composed of ribose (a sugar), adenine (a nitrogenous base), and three phosphate groups
- Other function of ATP as one of the nucleoside triphosphate used to make RNA

- **ATP is a chemical Energy form.**
- **The potential Energy is high based on the structure**



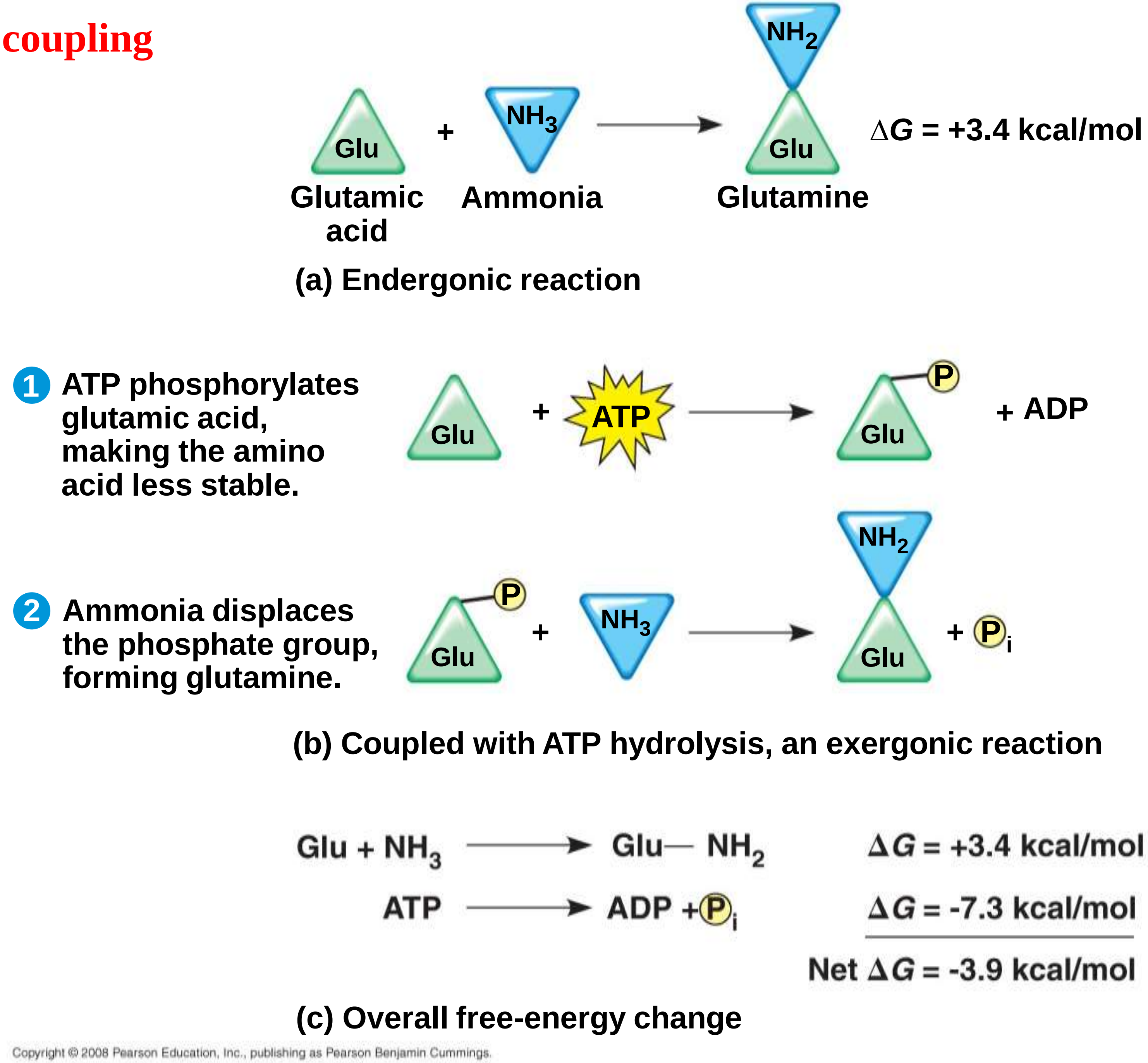
- The bonds between the phosphate groups of ATP’s tail can be broken by hydrolysis (added water).
- Energy is released from ATP when the terminal phosphate bond is broken
- This release of energy comes from the chemical change to a state of lower free energy in the products, not from the phosphate bonds themselves.


Organic Molecule
P
P
P
Adenosine triphosphate (ATP)
H_2O
P_i
+
P
P
+
Energy
Inorganic phosphate
Adenosine diphosphate (ADP)

How ATP Performs Work

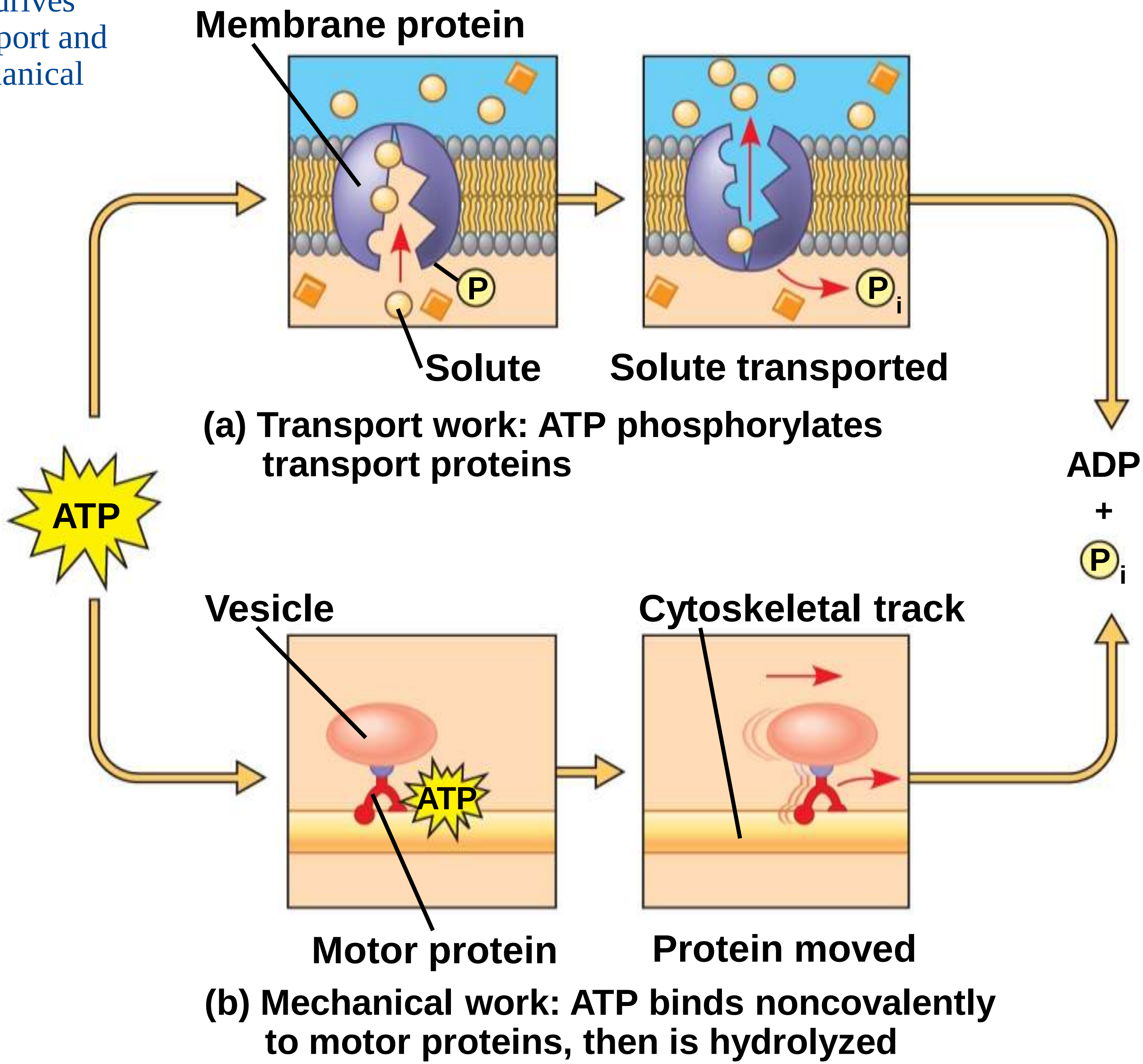
- The three types of cellular work (mechanical, transport, and chemical) are powered by the hydrolysis of ATP
- In the cell, the energy from the exergonic reaction of ATP hydrolysis can be used to drive an endergonic reaction
- Overall, the coupled reactions are exergonic

Energy coupling



- ATP drives endergonic reactions by phosphorylation, transferring a phosphate group to some other molecule, such as a reactant
- The recipient molecule is now **phosphorylated**

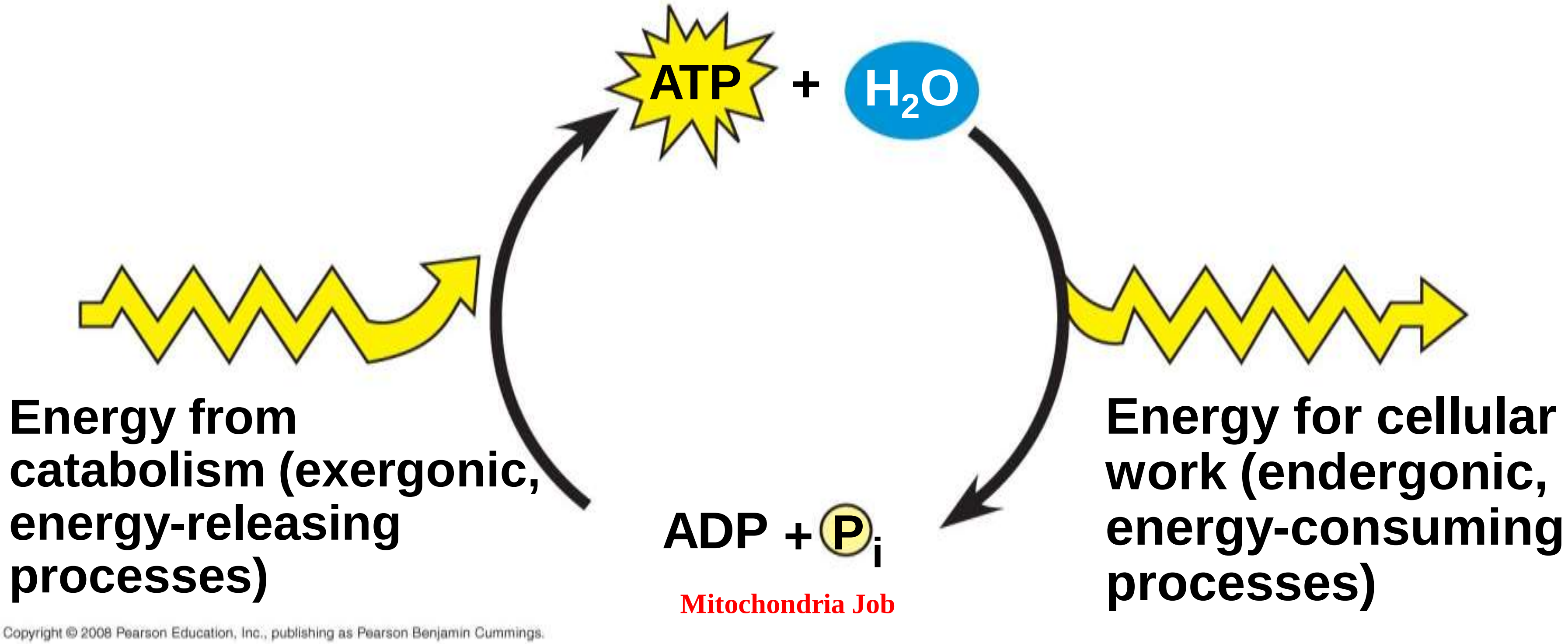
How ATP drives transport and mechanical work



The Regeneration of ATP

- ATP is a renewable resource that is regenerated by addition of a phosphate group to adenosine diphosphate (ADP)
- The energy to phosphorylate ADP comes from exergonic reaction (catabolic reactions) in the cell
- The chemical potential energy temporarily stored in ATP drives most cellular work

The ATP cycle



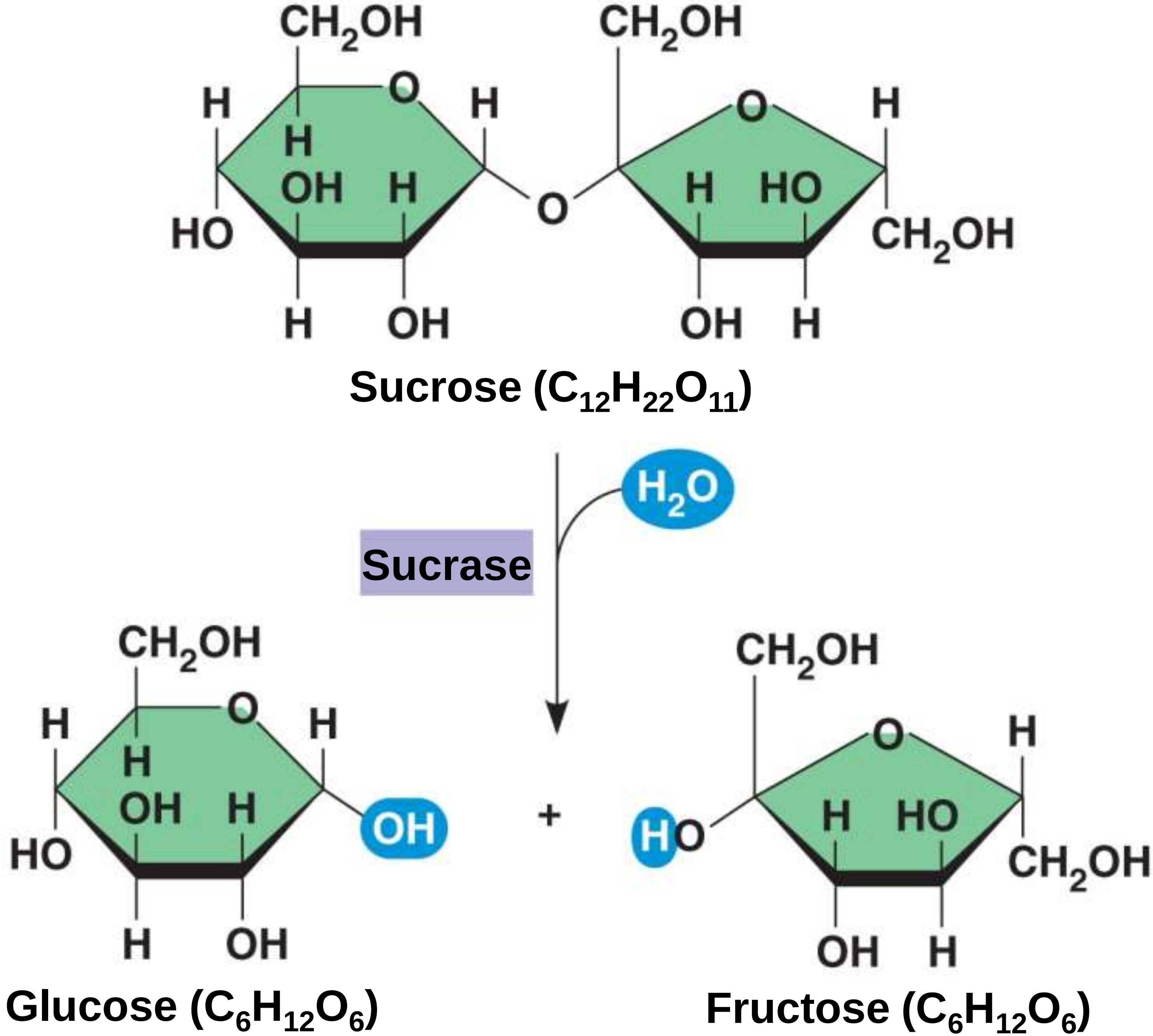
Enzymes speed up metabolic reactions by lowering energy barriers

- Spontaneous reactions no need E, but they can slow enough.

  -Hydrolysis of sucrose to G+F is spont-

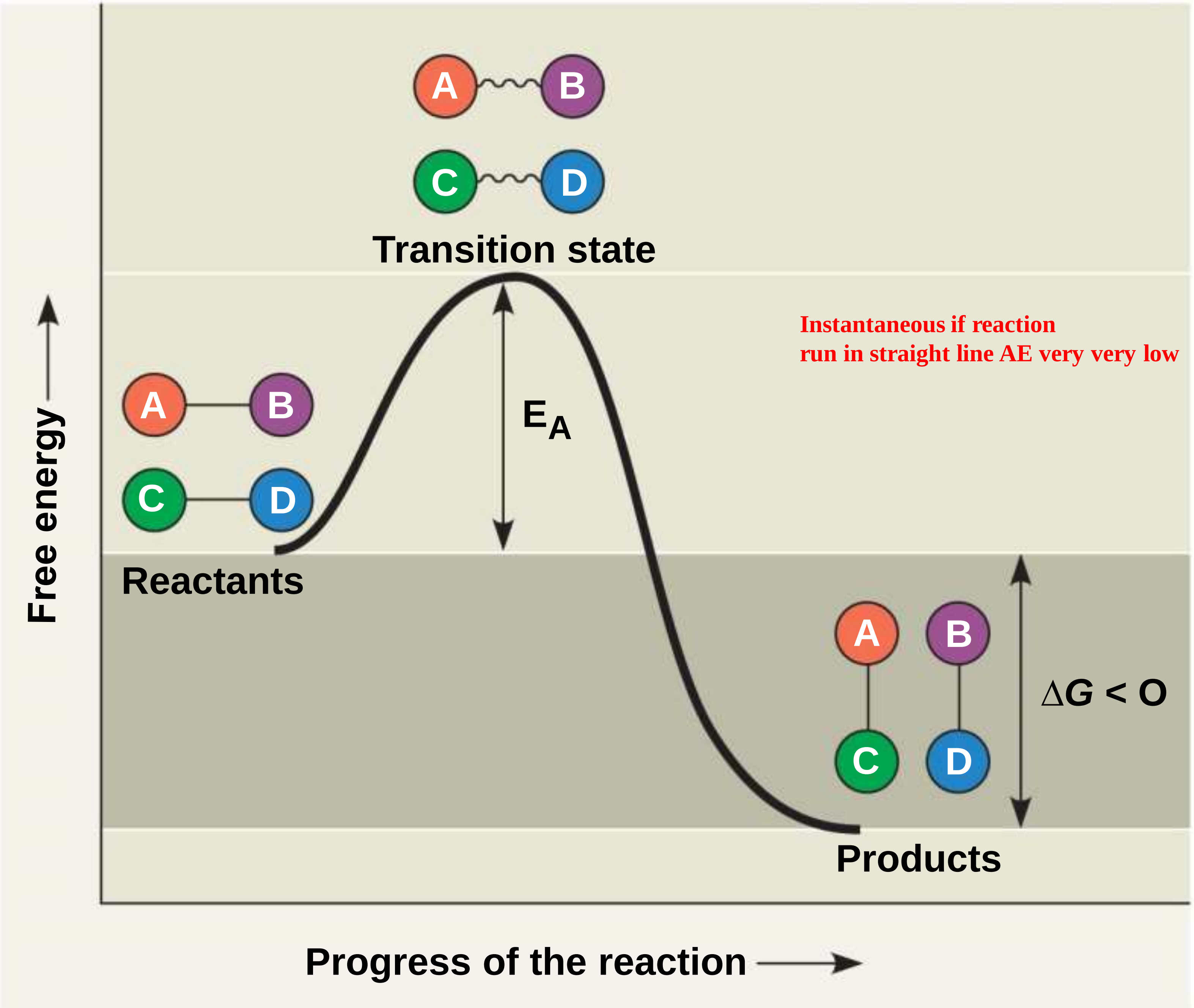
  - At room Temp, sucrose solution to be hydrolysis in water to G+F need set of years.

- A **catalyst** is a chemical agent that speeds up a reaction without being consumed by the reaction
- An **enzyme** is a catalytic protein
- Hydrolysis of sucrose solution by the enzyme sucrase is an example of an enzyme-catalyzed reaction, within seconds


Sucrose ($C_{12}H_{22}O_{11}$)
H_2O
Sucrase
Glucose ($C_6H_{12}O_6$)
Fructose ($C_6H_{12}O_6$)

The Activation Energy Barrier

- Every chemical reaction between molecules involves bond breaking and bond forming
- The initial energy needed to start a chemical reaction is called the **free energy of activation**, or **activation energy (E_A)**
- Activation energy is often supplied in the form of heat from the surroundings
- Molecules becomes unstable when enough energy absorbed to break bonds, this is transition state.



Instantaneous if reaction
run in straight line AE very very low

Activation Energy barrier

- The activation E provides a barrier that determines the rate of spontaneous reactions.

- Some of reactions, E_A is <u>low</u> enough that thermal E at room temp. is sufficient to overcome the activation E barrier.

- Most reactions have <u>high</u> E_A, and need addition energy as heat (thermal energy) to reach the transition state.

- But adding heat is not useful way to speed the reactions in cells because it can cause denaturation of proteins.

- Heat is also impractical because it would speed up all reactions, not those needed.

- So, living cells used catalysts to overcome these obstacles.

How Enzymes Lower the E_A Barrier

- Enzymes catalyze reactions by lowering the E_A barrier

- Enzymes do not affect the change in free energy (ΔG); instead, they hasten reactions that would occur eventually.

The effect of an enzyme on activation energy