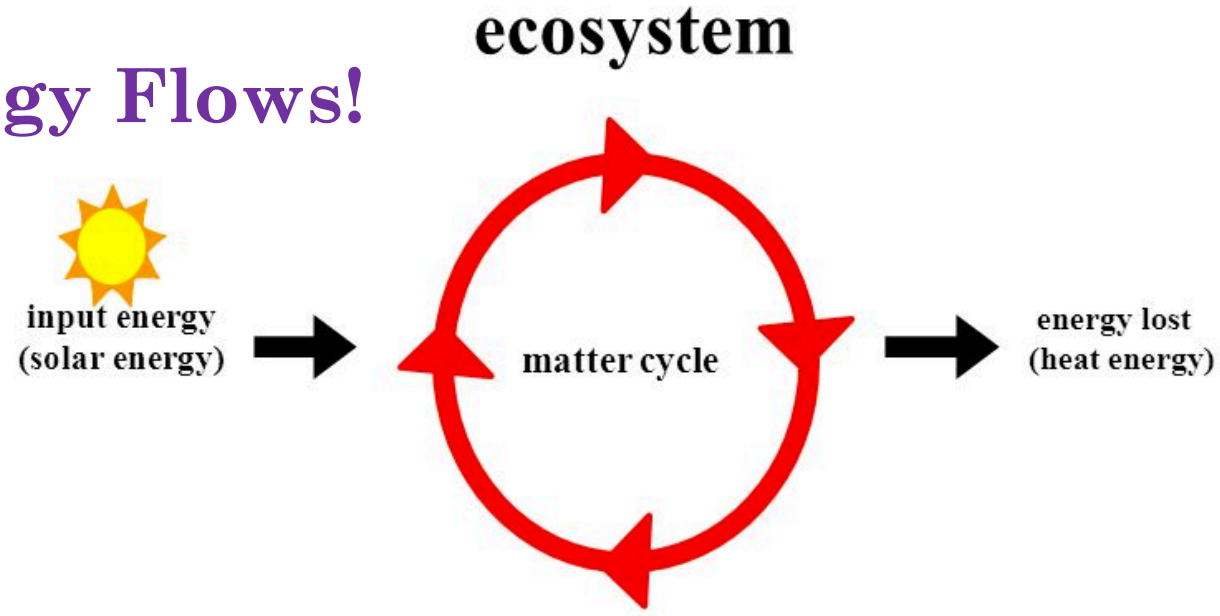
CHAPTER 6
An Introduction to Metabolism

WHAT YOU NEED TO KNOW:

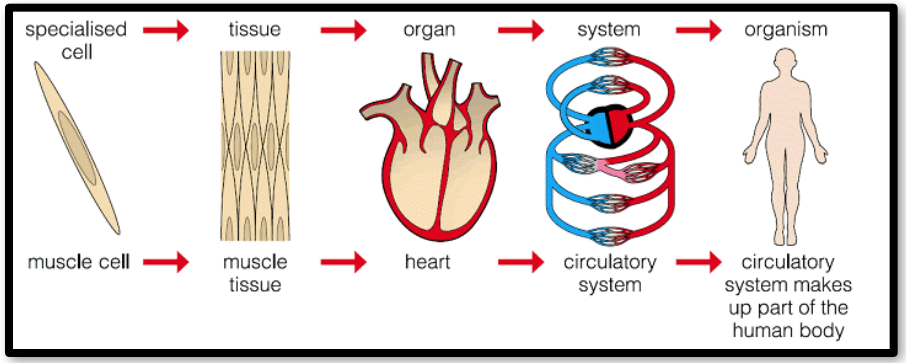
- Exergonic reactions release free energy (ΔG is negative); endergonic reactions store free energy (ΔG is positive).
- ATP powers cellular work by coupling exergonic reactions to endergonic reactions.
- Enzymes work by lowering the energy of activation.
- The catalytic cycle of an enzyme that results in the production of a final product.
- Enzymes are specific in the reactions they catalyze because of the molecular shape of their active site.
- Factors that change the shape of the active site of enzymes and how they influence enzyme activity.
- How feedback inhibition is used to maintain appropriate levels of enzymes and enzyme products in a pathway.

ENERGY DYNAMICS

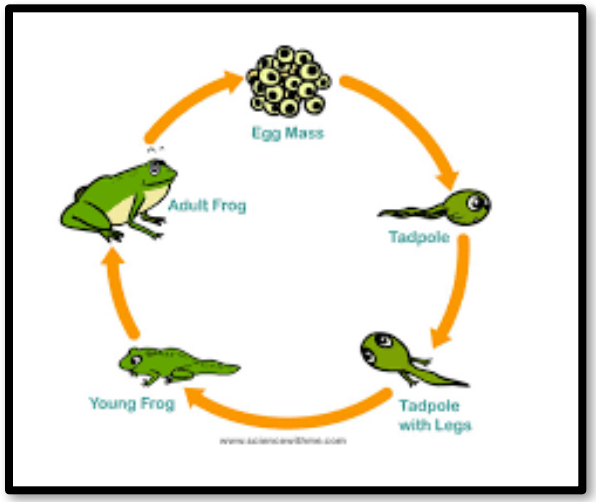
The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.



ORGANISMS USE **ENERGY** TO:

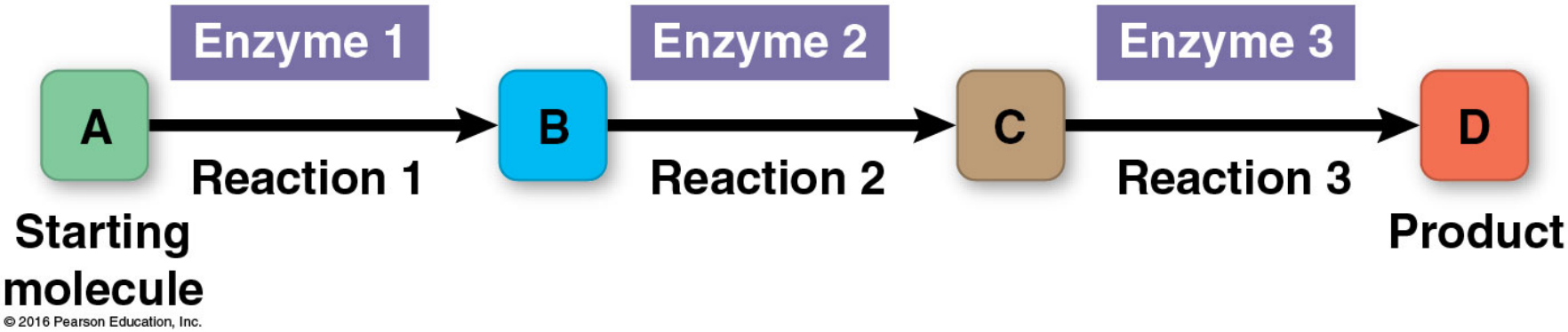


Maintain Organization



Reproduce

Grow



Metabolism is the totality of an organism's chemical reactions

- Manage the materials and energy resources of a cell
- **Metabolic rate** = total amount of energy an animal uses in a unit of time
- In general, the *smaller* the organism, the *higher* the metabolic rate

- **Catabolic pathways** release energy by breaking down complex molecules into simpler compounds
  - Eg. digestive enzymes break down food → release energy

- **Anabolic pathways** consume energy to build complex molecules from simpler ones
  - Eg. amino acids link to form muscle protein

ENERGY = CAPACITY TO DO WORK

- **Kinetic energy (KE)**: energy associated with motion
  - *Heat* (thermal energy) is KE associated with random movement of atoms or molecules
- **Potential energy (PE)**: stored energy as a result of its position or structure
  - *Chemical energy* is PE available for release in a chemical reaction
- Energy can be converted from one form to another
  - Eg. chemical → mechanical → electrical

A diver has more potential energy on the platform.

Diving converts potential energy to kinetic energy.

Climbing up converts the kinetic energy of muscle movement to potential energy.

A diver has less potential energy in the water.

Thermodynamics is the study of energy transformations that occur in matter

- Closed system: isolated from its surroundings (eg. liquid in a thermos)
- Open system: energy and matter can be transferred between the system and its surroundings
- Organisms = Open Systems
  - A **net gain in energy** results in energy storage or the growth of an organism
  - A **net loss of energy** results in loss of mass, and/or death of an organism

THE FIRST LAW OF THERMODYNAMICS (CONSERVATION OF ENERGY)

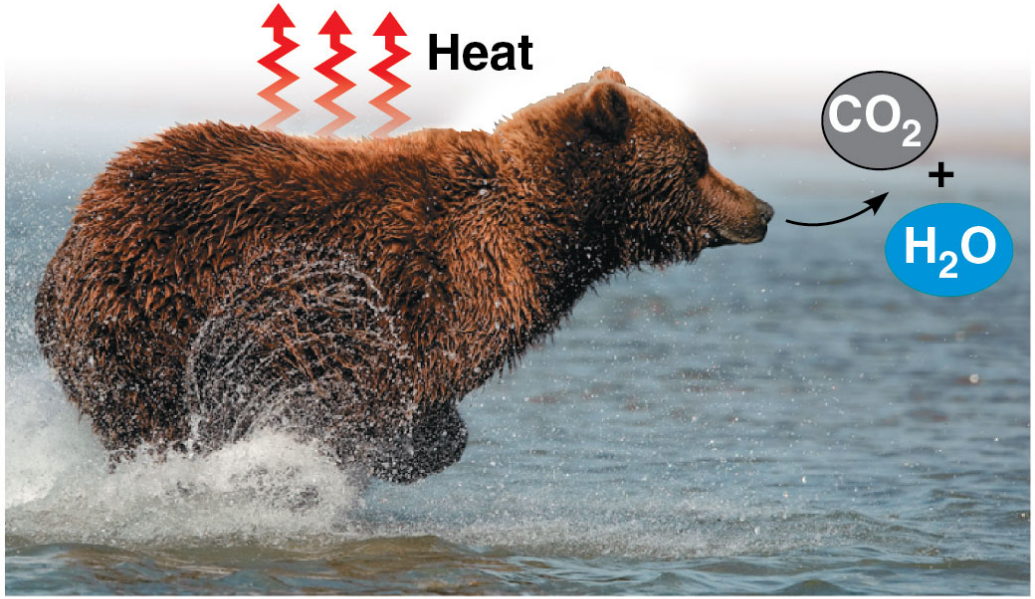
- The energy of the universe is constant
  - Energy **can** be transferred and transformed
  - Energy **cannot** be created or destroyed

(a) First law of thermodynamics

THE SECOND LAW OF THERMODYNAMICS

- Every energy transfer or transformation increases the entropy (disorder) of the universe

- During every energy transfer or transformation, some energy is *unusable*, often lost as **heat**



(b) Second law of thermodynamics

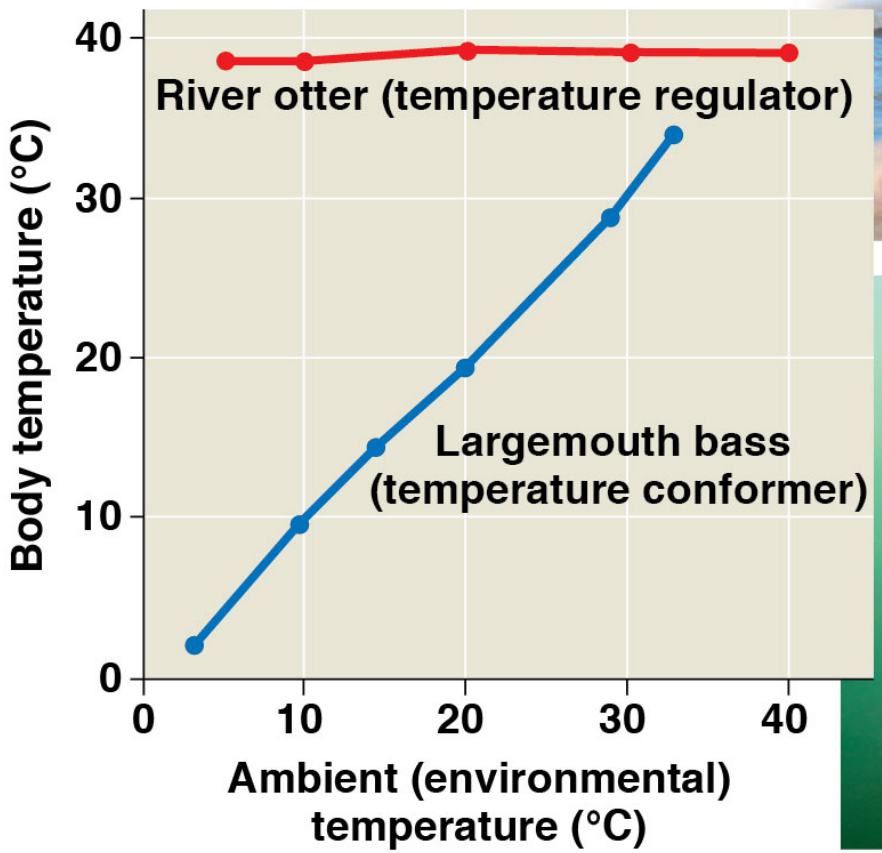
THERMOREGULATION

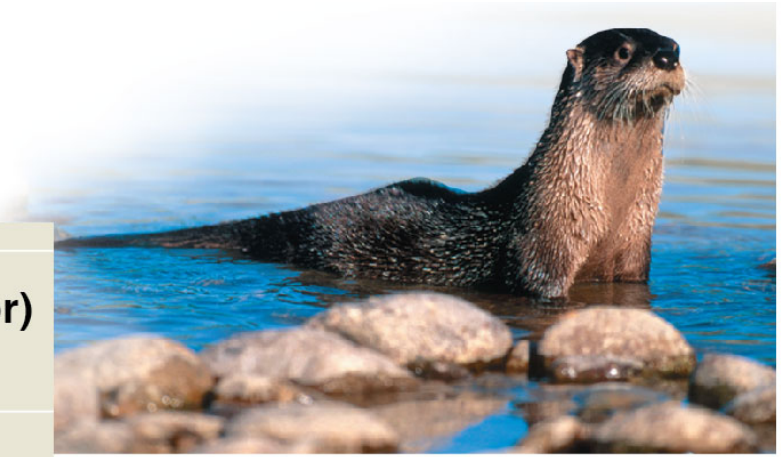
- Maintain an internal temperature within a tolerable range
- **Endothermic** animals use thermal energy generated by metabolism to maintain homeostatic body temperatures (birds and mammals)
- **Ectothermic** animals gain heat from external sources (invertebrates, fishes, amphibians, and nonavian reptiles)

(a) A walrus, an endotherm

(b) A lizard, an ectotherm

ENDOTHERMS VS. ECTOTHERMS



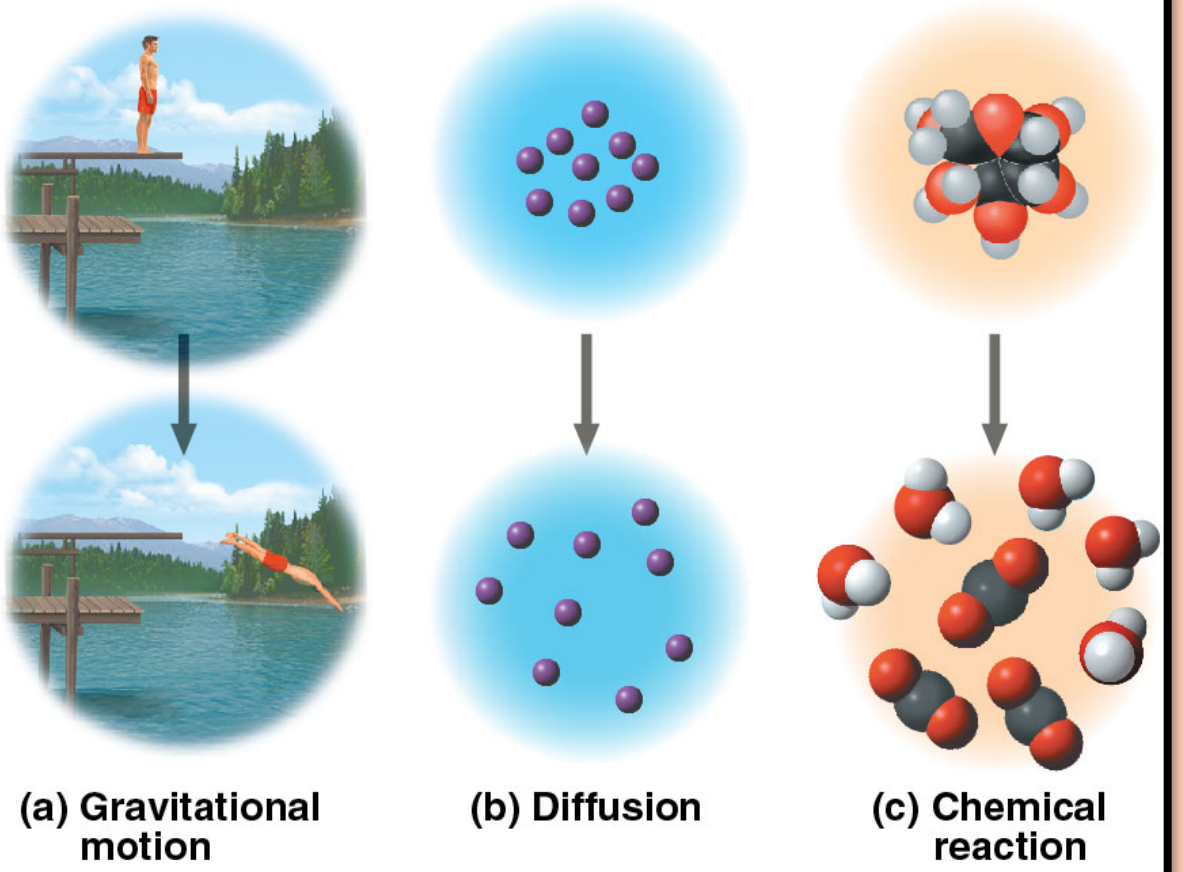


- **Free energy**: part of a system's energy available to perform work
  - ΔG = change in free energy
- **Exergonic reaction**: energy is released
  - Spontaneous reaction
  - $\Delta G < 0$
- **Endergonic reaction**: energy is required
  - Absorb free energy
  - $\Delta G > 0$

- More free energy (higher *G*)
- Less stable
- Greater work capacity

In a spontaneous change
- The free energy of the system decreases ($\Delta G < 0$)
- The system becomes more stable
- The released free energy can be harnessed to do work

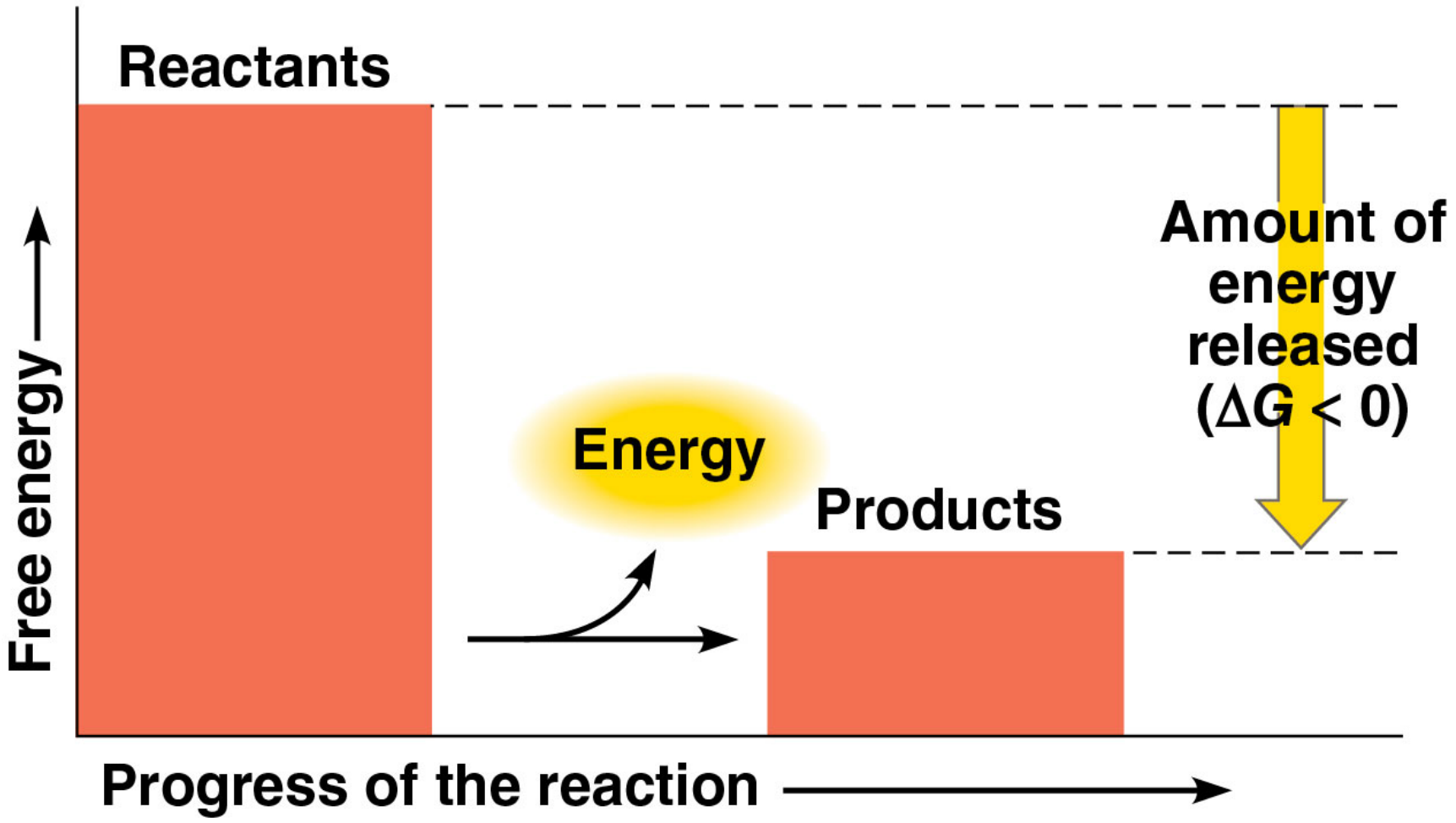
- Less free energy (lower *G*)
- More stable
- Less work capacity

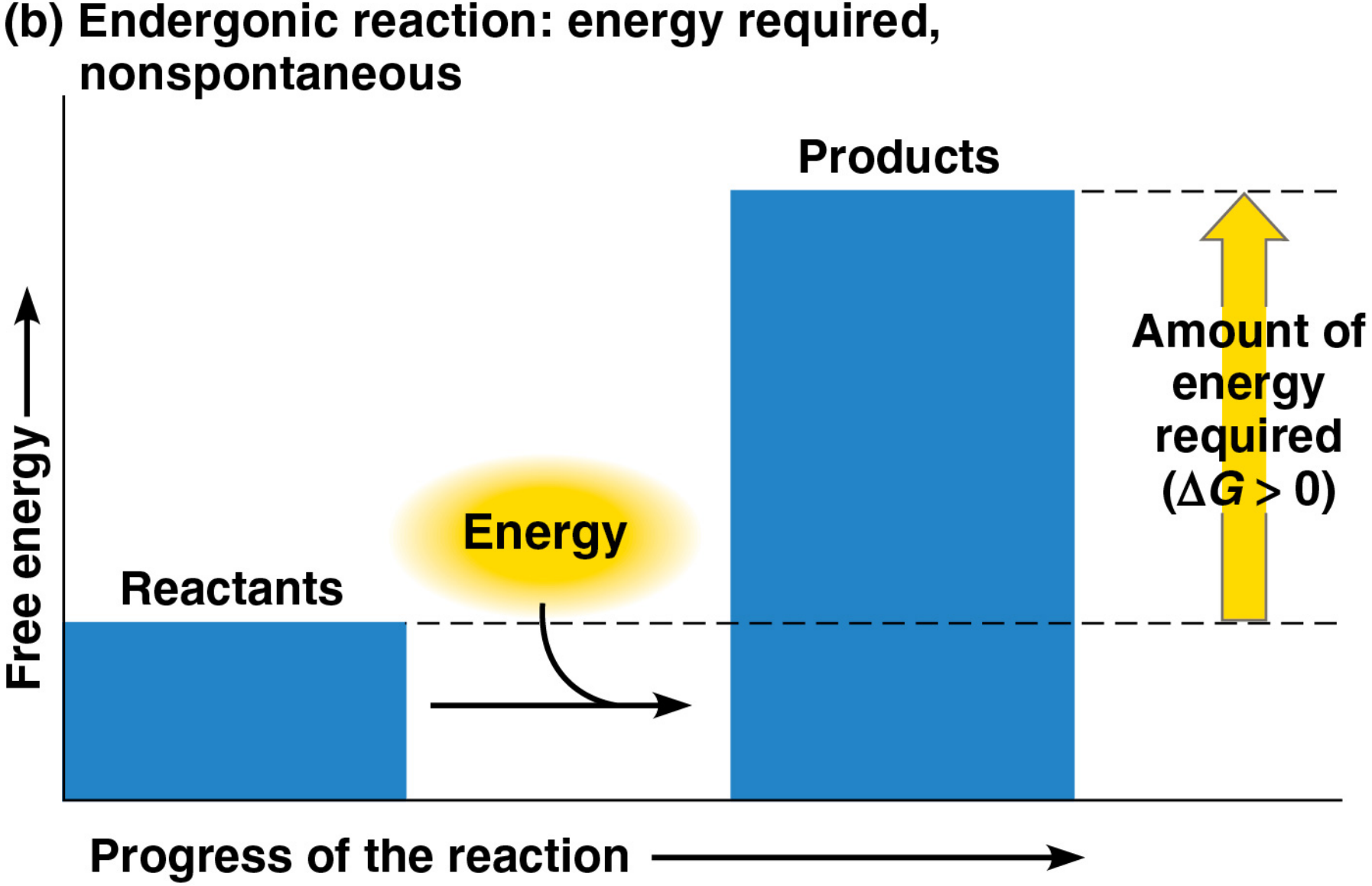


(a) Gravitational motion

(b) Diffusion

(c) Chemical reaction



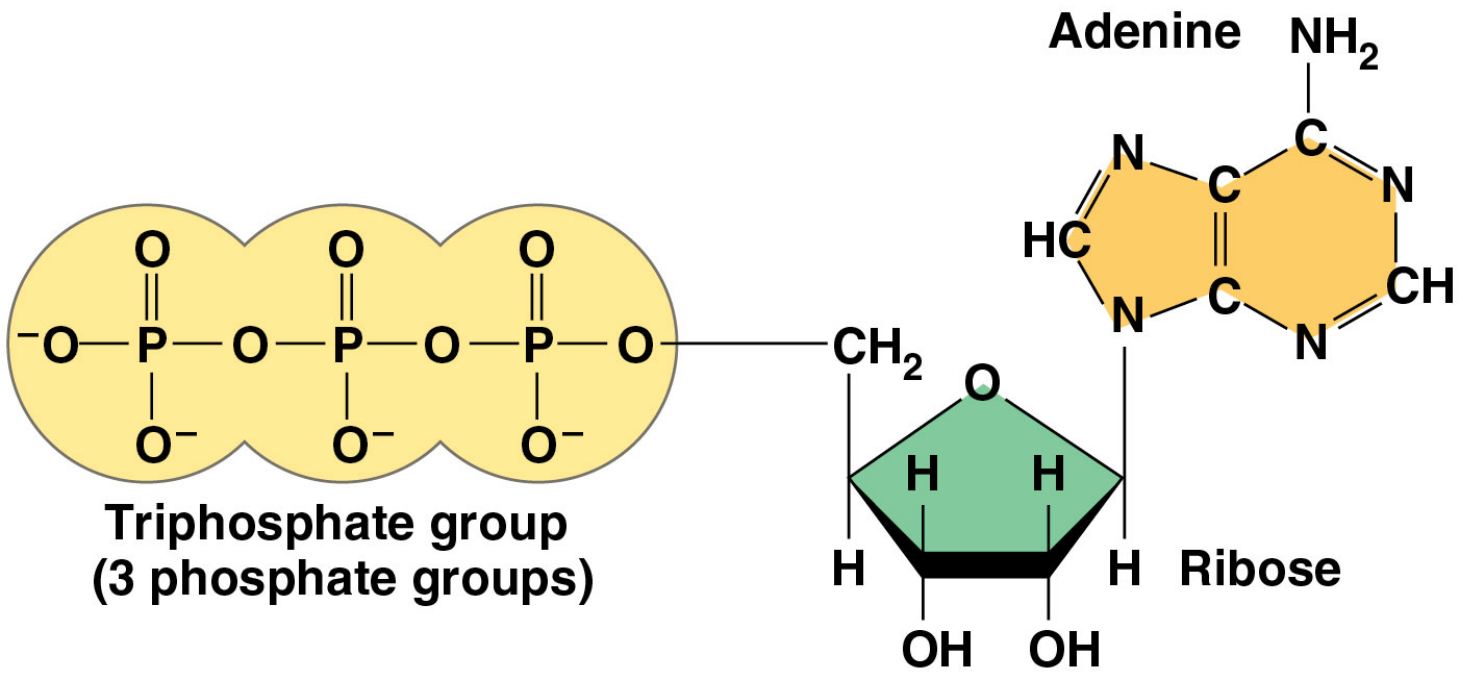


- A living cell is NOT at equilibrium
  - Constant flow of materials in/out of cell

- A cell does three main kinds of work:
  1. Mechanical
  2. Transport
  3. Chemical

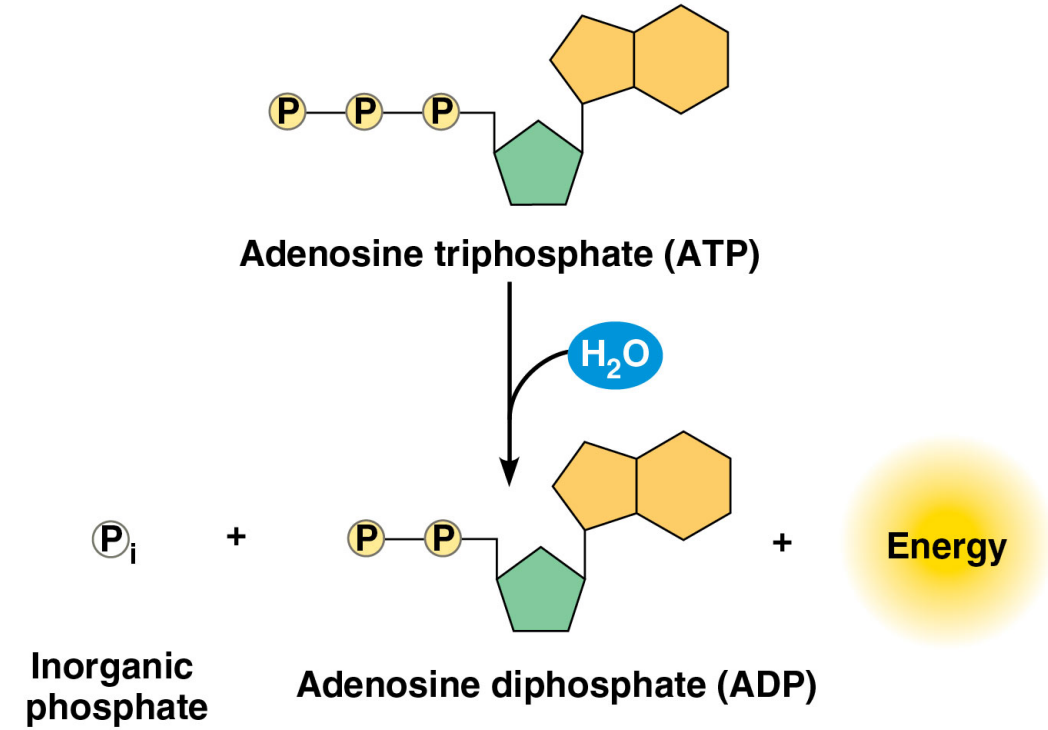
- Cells manage energy resources to do work by energy coupling: using an ***exergonic*** process to drive an ***endergonic*** one

- **ATP** (**adenosine triphosphate**) is the cell's main energy source in energy coupling
- ATP = adenine + ribose + 3 phosphates



(a) The structure of ATP

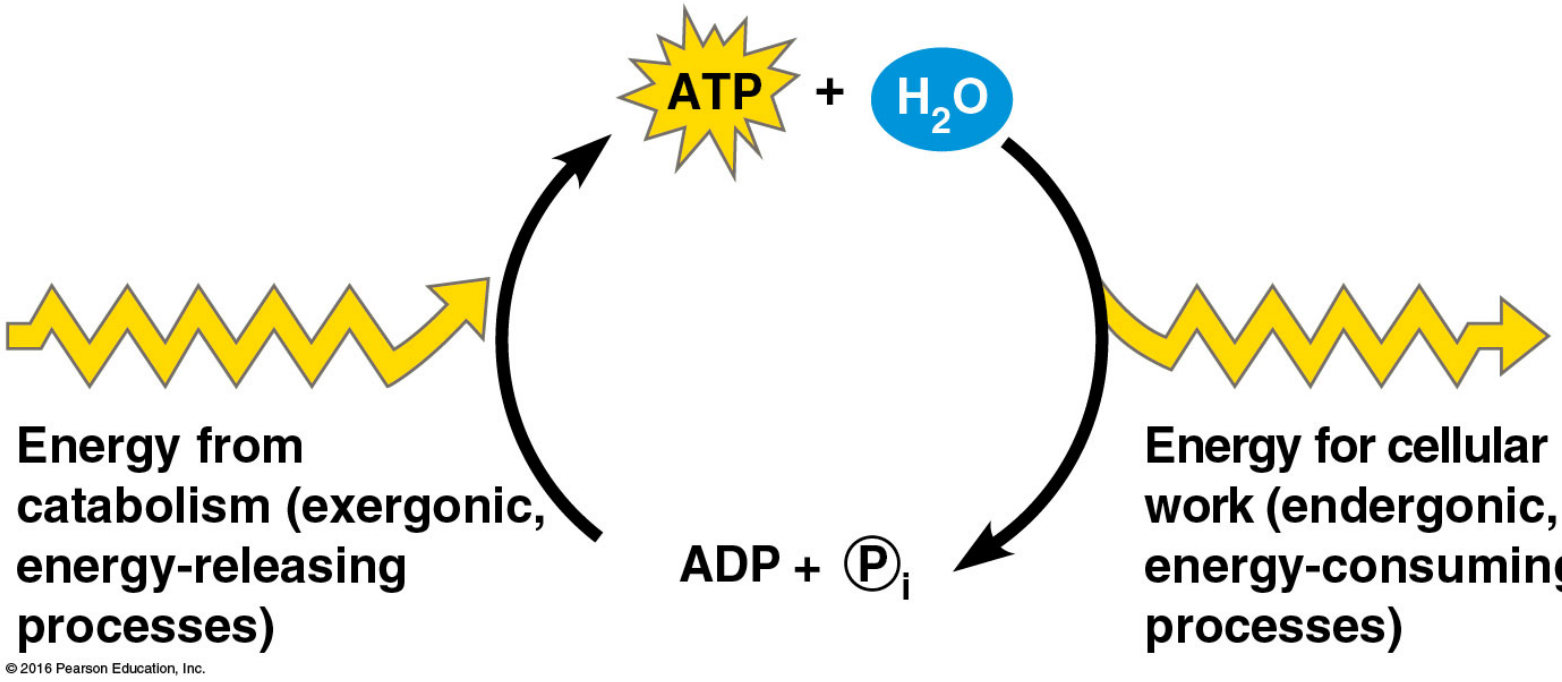
- When the bonds between the phosphate groups are broken by hydrolysis → ***Energy is released***
- This release of energy comes from the chemical change to a state of lower free energy, not in the phosphate bonds themselves

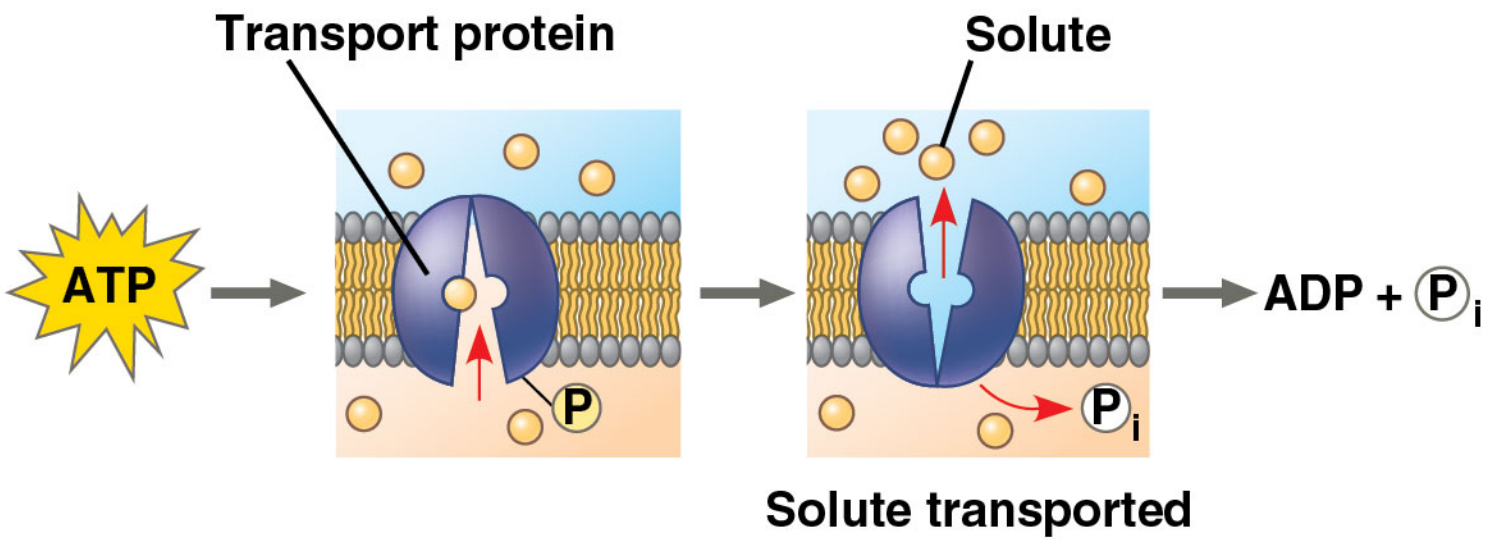


(b) The hydrolysis of ATP

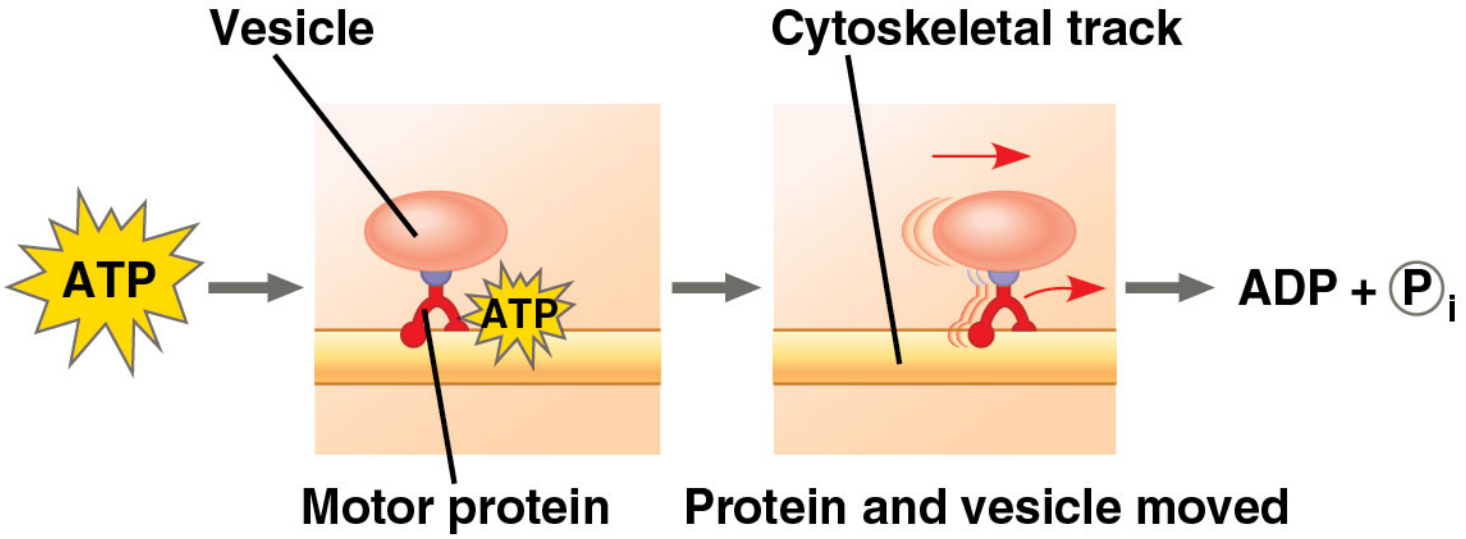
HOW ATP PERFORMS WORK

- ***Exergonic*** release of P_i is used to do the ***endergonic*** work of cell
- When ATP is hydrolyzed, it becomes ADP (adenosine diphosphate)



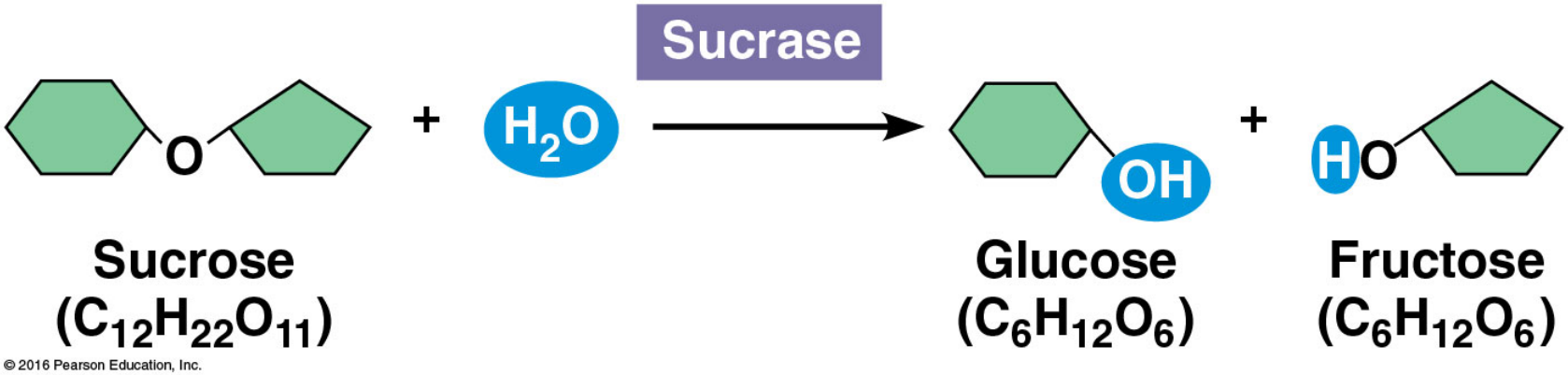


(a) Transport work: ATP phosphorylates transport proteins.

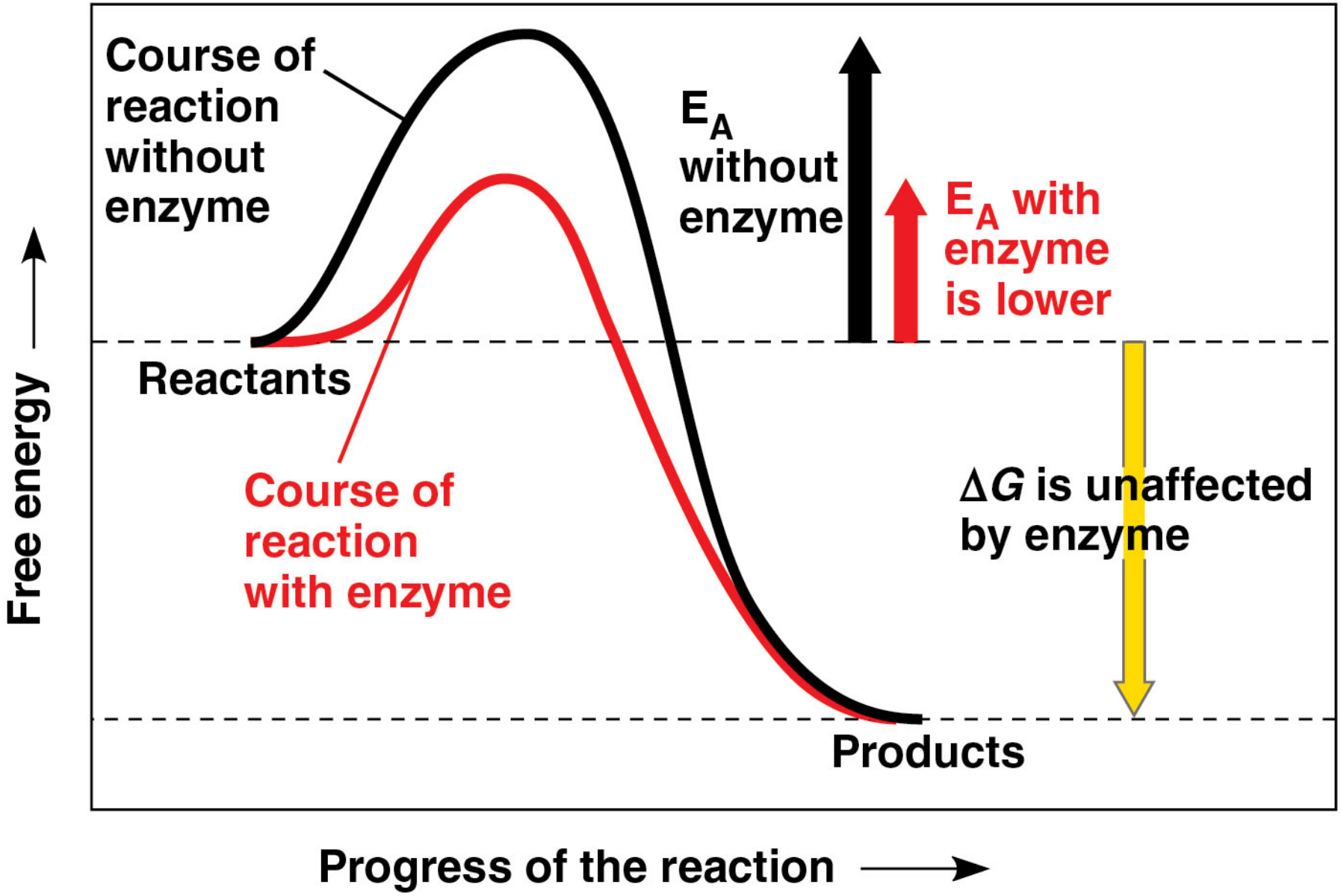


(b) Mechanical work: ATP binds noncovalently to motor proteins and then is hydrolyzed.

- Catalyst: substance that can change the rate of a reaction without being altered in the process
- Enzyme = biological catalyst

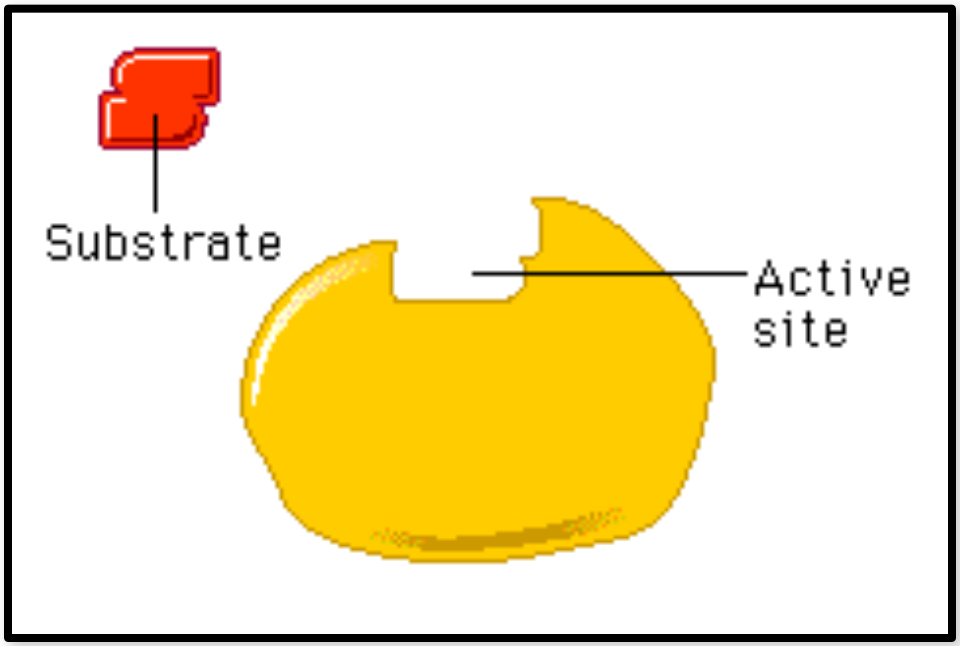


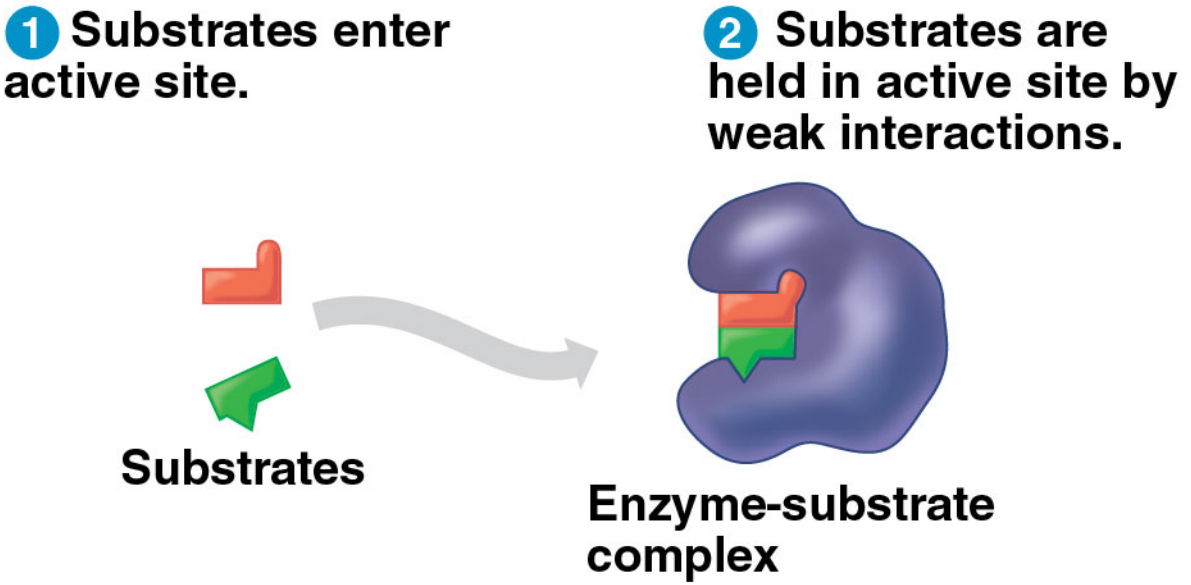
- breaking bonds)

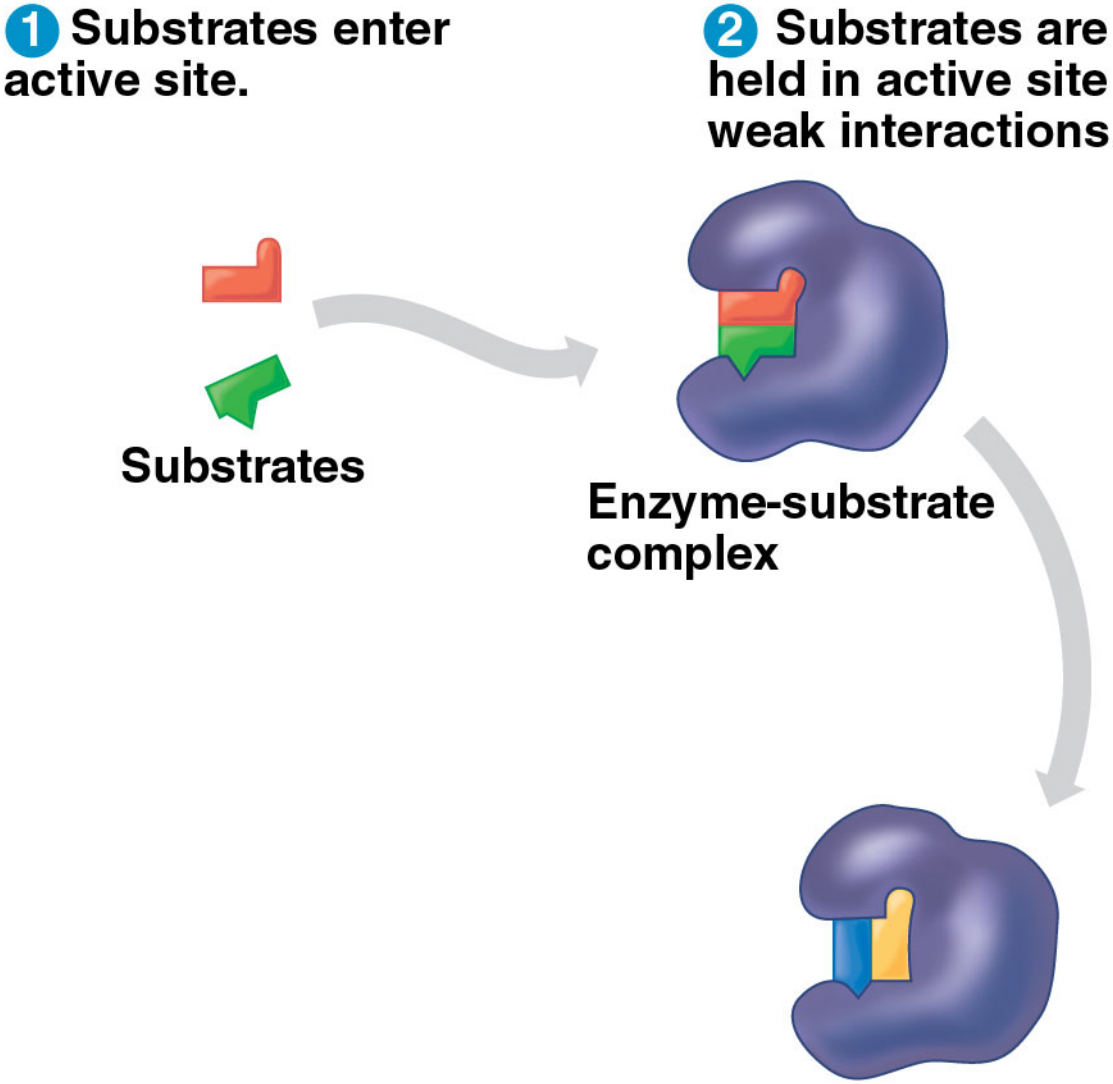


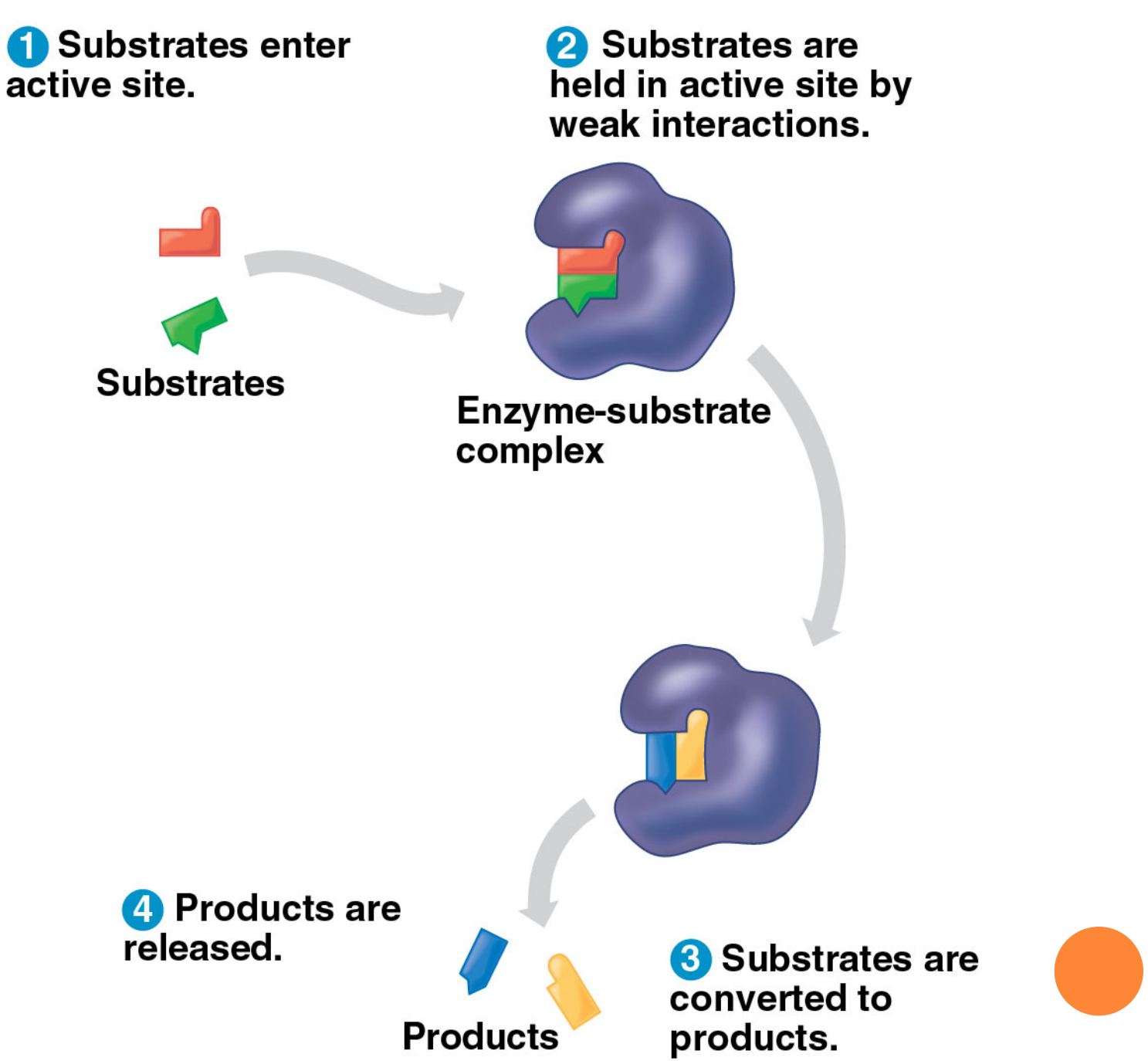
SUBSTRATE SPECIFICITY OF ENZYMES

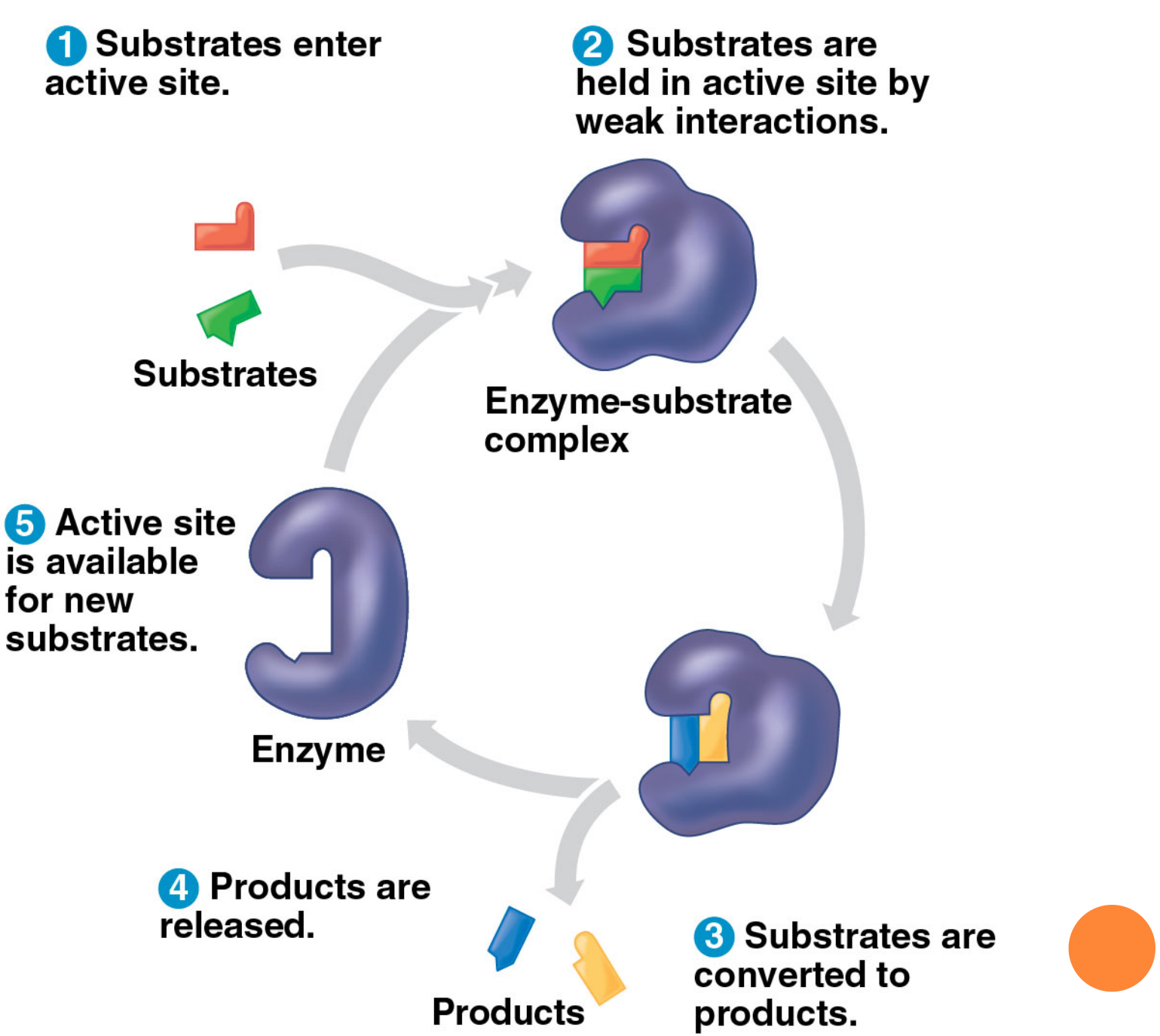
- The reactant that an enzyme acts on is called the enzyme's substrate
- The enzyme binds to its substrate, forming an enzyme-substrate complex
- The active site is the region on the enzyme where the substrate binds



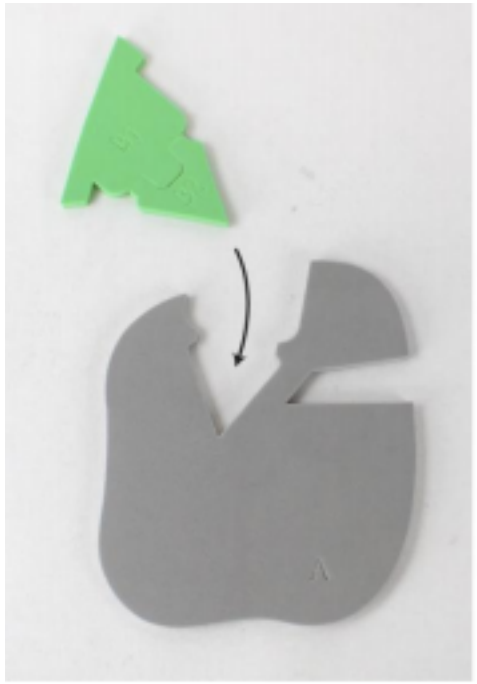






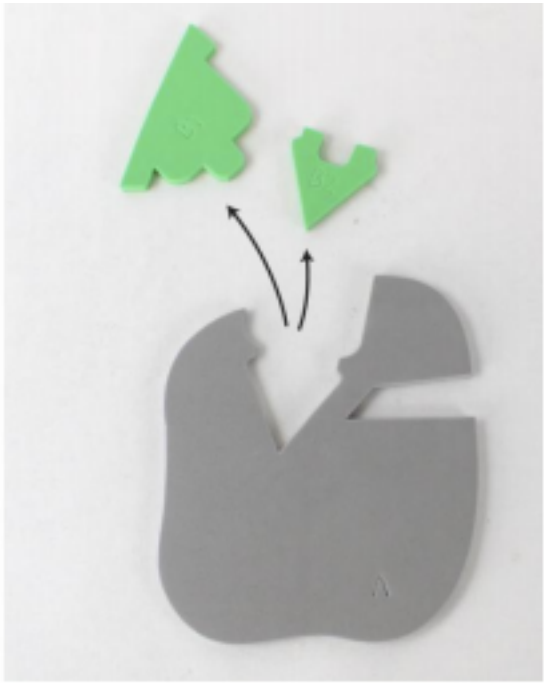


ENZYME ACTION: CATABOLISM



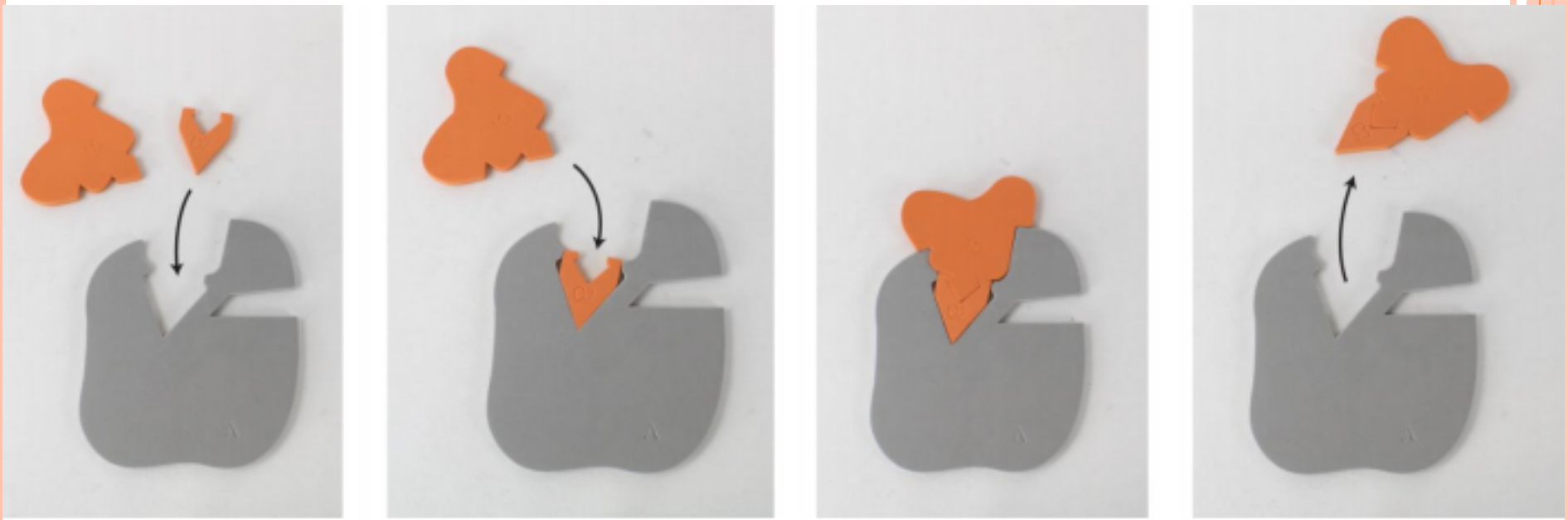
Step 1

Step 2

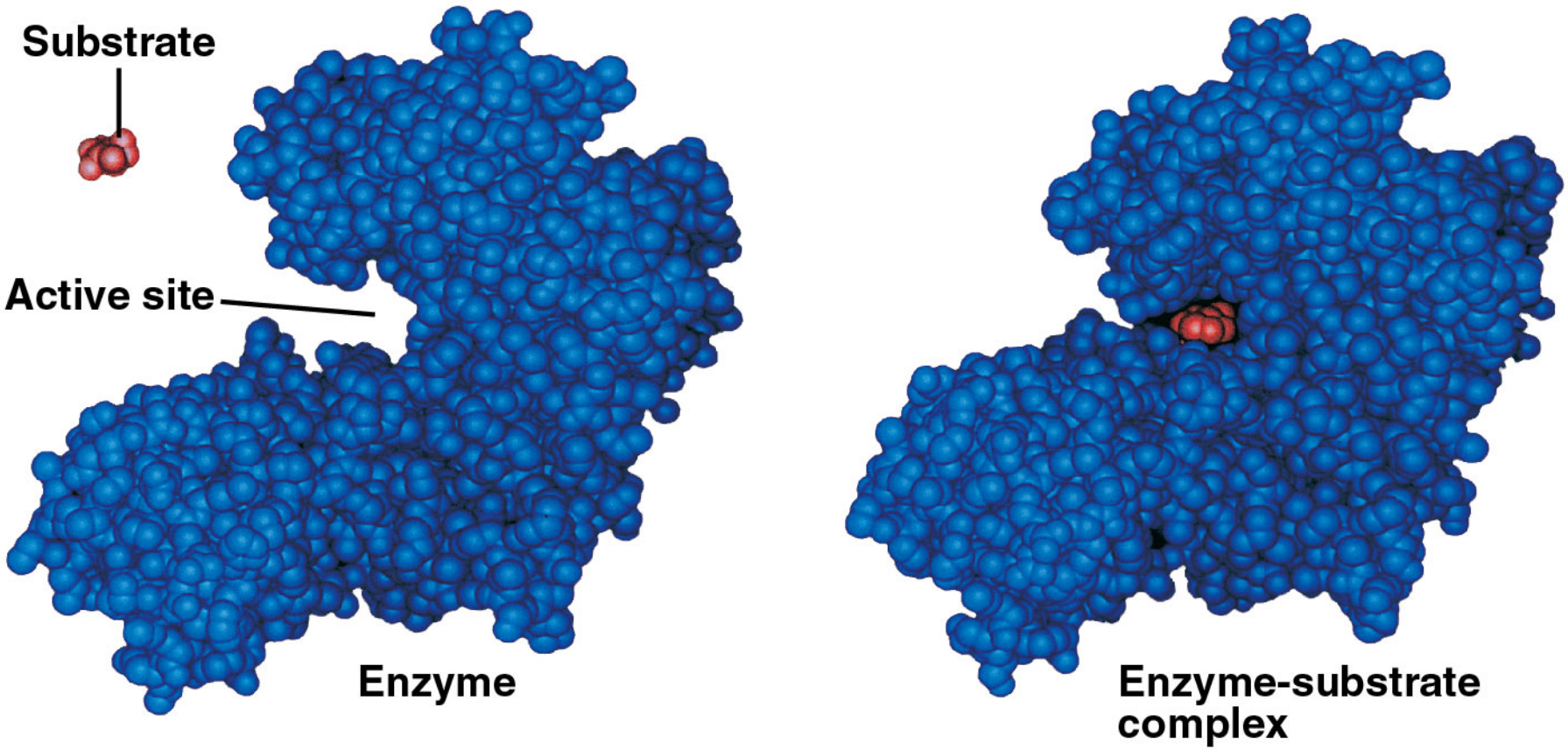


Step 3

ENZYME ACTION: ANABOLISM

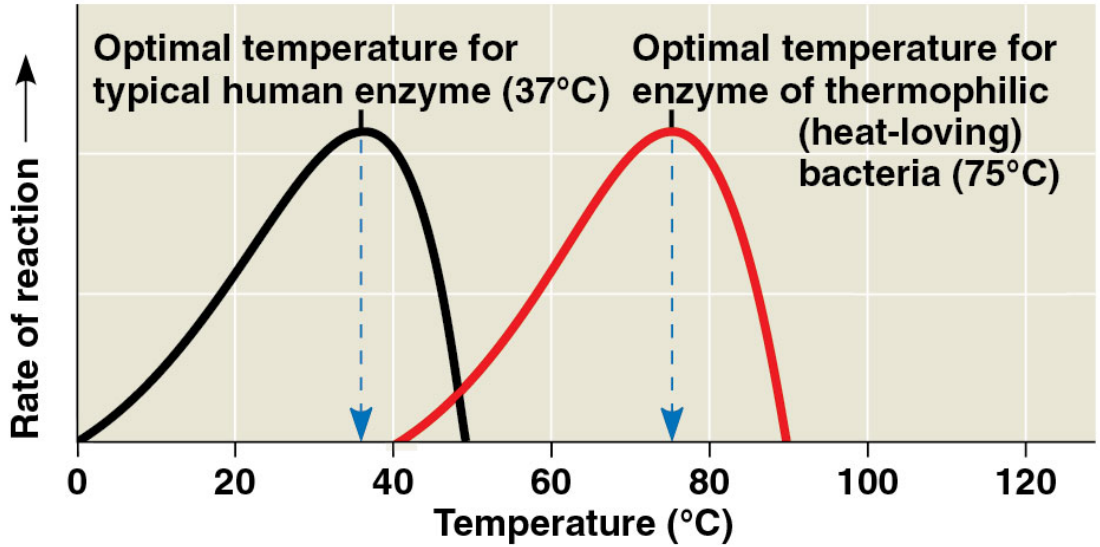


INDUCED FIT: ENZYME FITS SNUGLY AROUND SUBSTRATE -- "CLASPING HANDSHAKE"

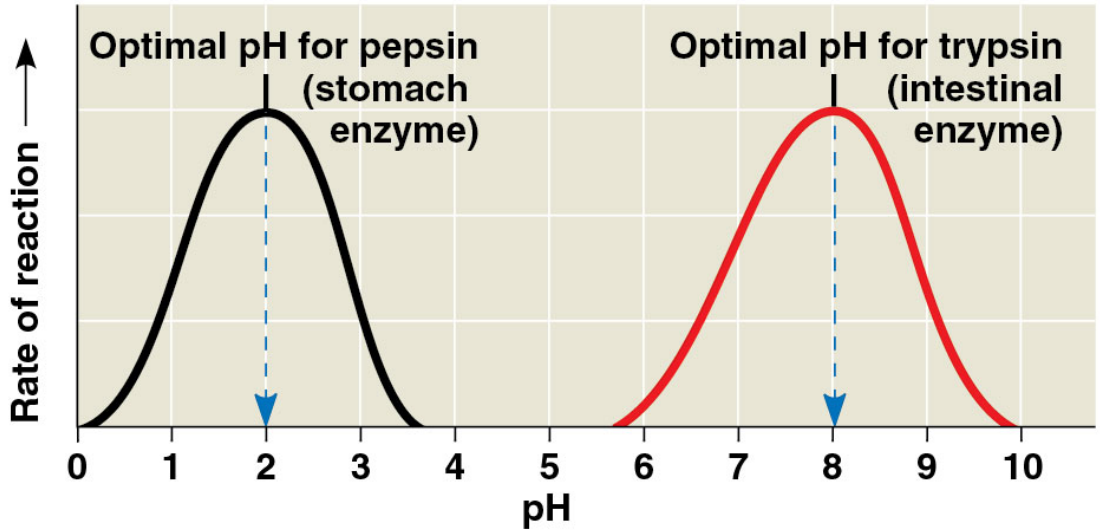


An enzyme's activity can be affected by:

- Temperature
- pH
- Chemicals



(a) Optimal temperature for two enzymes



(b) Optimal pH for two enzymes

ENZYME STRUCTURE & FUNCTION

- Change to the **molecular structure** of a component in an enzymatic system may result in a change of **function** or **efficiency** of the system
- **Denaturation**: disrupt protein structure → reduce enzymatic activity
- **Environmental pH**: alter efficiency of enzyme activity; disruption of H-bonds
- In some cases, enzyme denaturation is *reversible* → enzyme regains activity

COFACTORS

- Cofactors: nonprotein enzyme helpers such as minerals (eg. Zn, Fe, Cu)
- Coenzymes: organic cofactors (eg. vitamins)

Enzyme Inhibitors

- Competitive inhibitor: binds to the *active site* of an enzyme, competes with substrate
- Noncompetitive inhibitor: binds to *another part* of an enzyme → enzyme changes shape → active site is nonfunctional

ENZYME SPECIFICITY

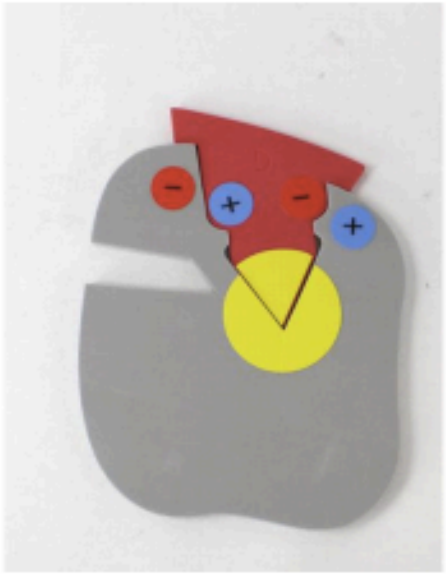


Figure 1: Enzyme-substrate complex

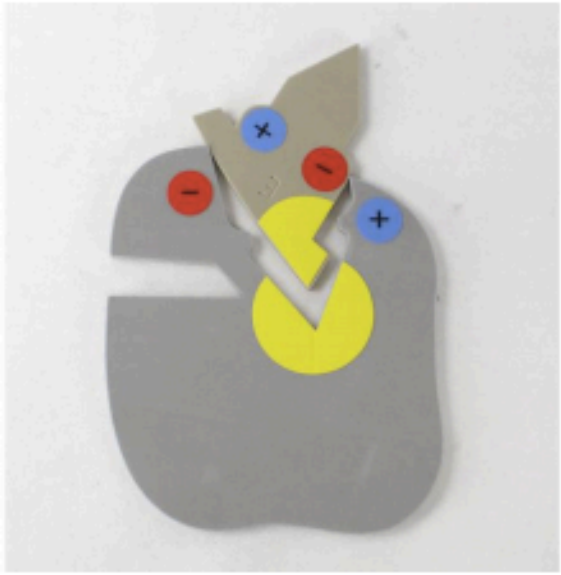


Figure 2: The charges align between the enzyme and the substrate; however, the enzyme's shape will not "fit".

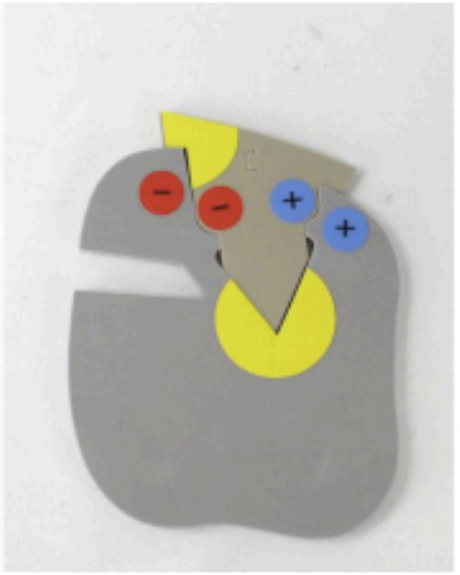
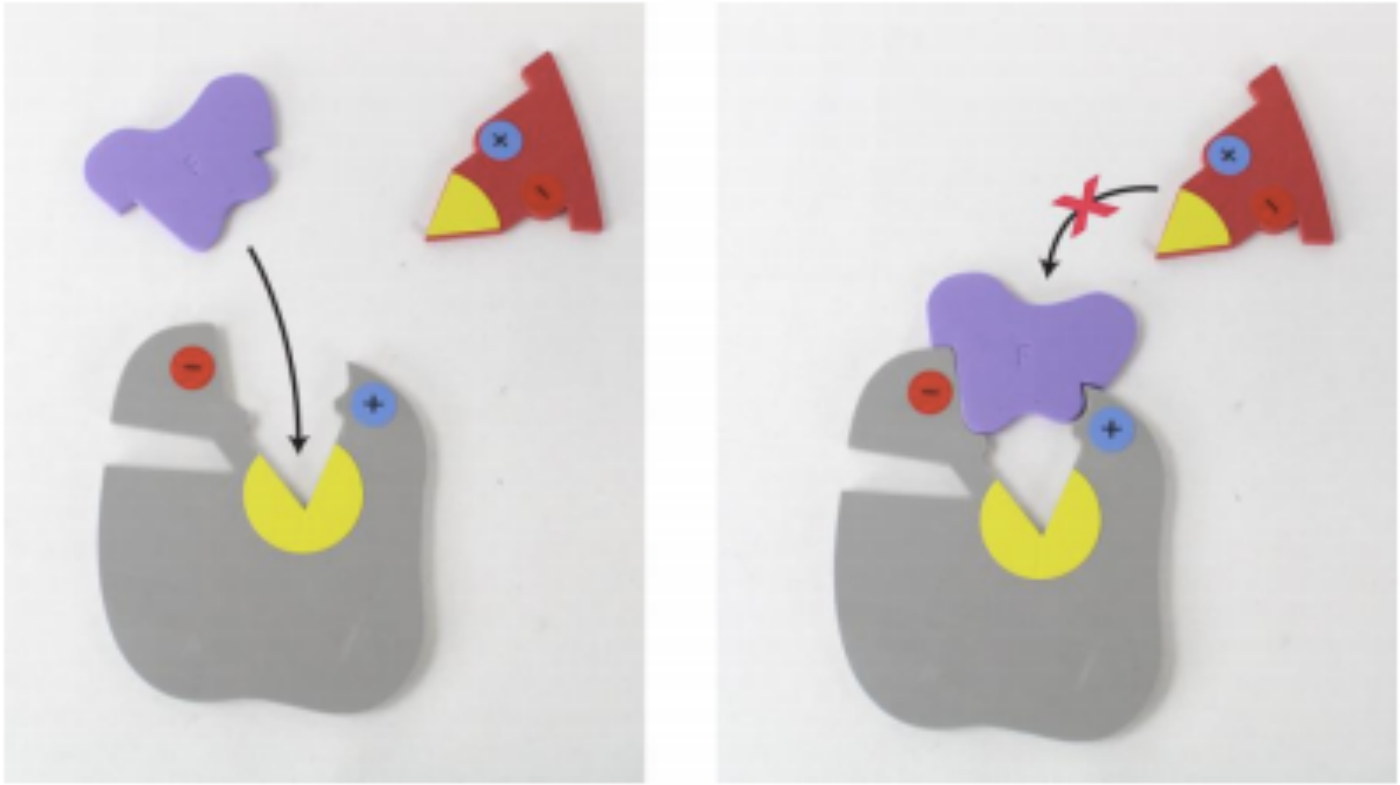
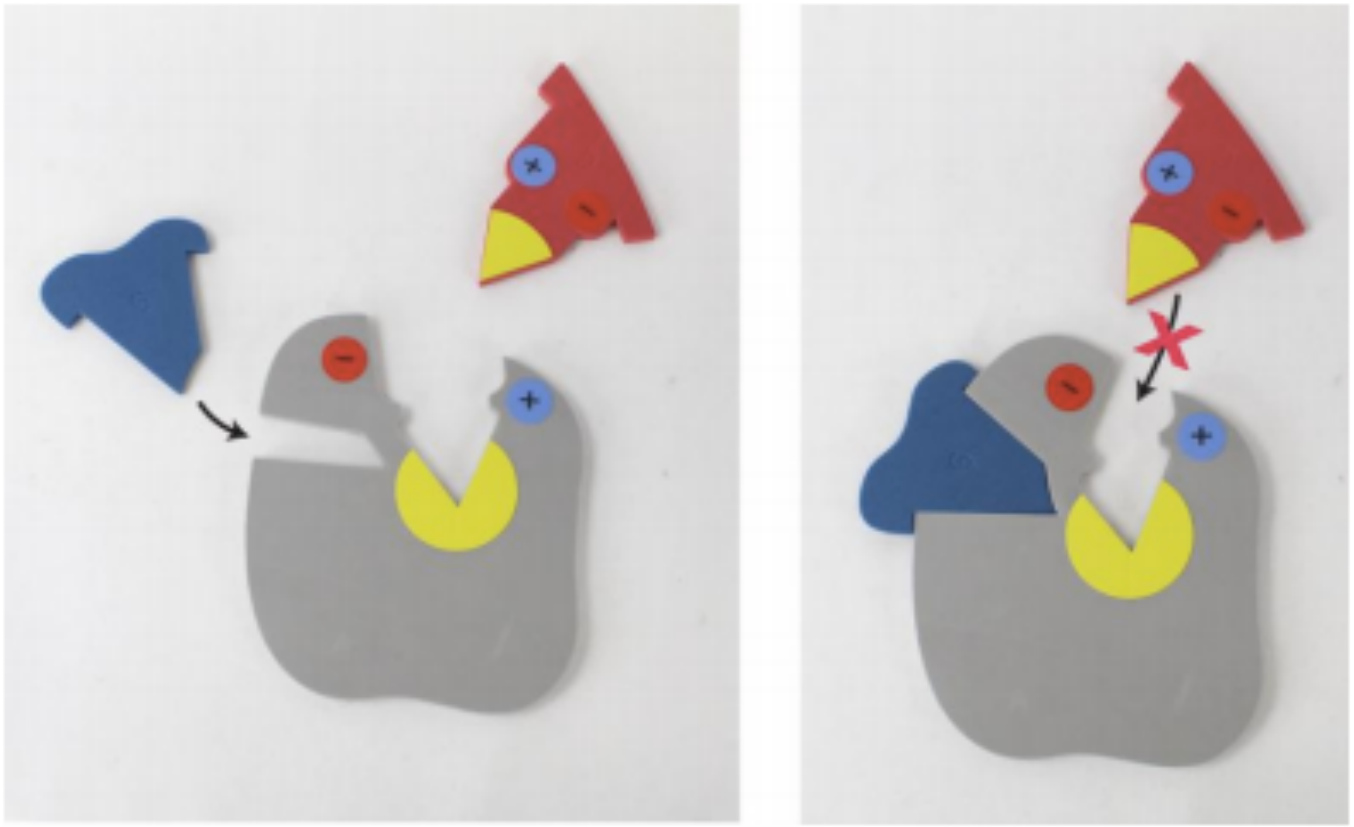


Figure 3: The shape of the substrate appears to fit but the charges do not align in the active site of the enzyme.

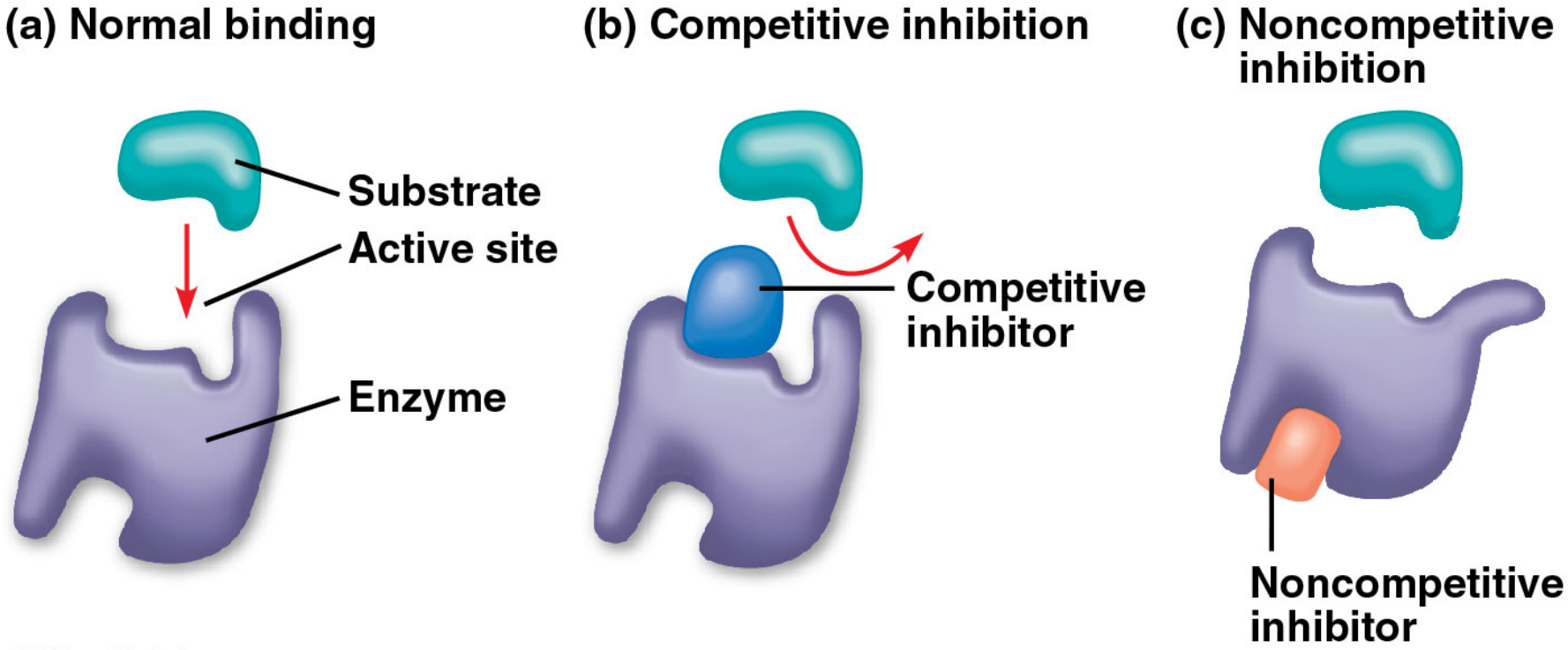
COMPETITIVE INHIBITION



NONCOMPETITIVE INHIBITION

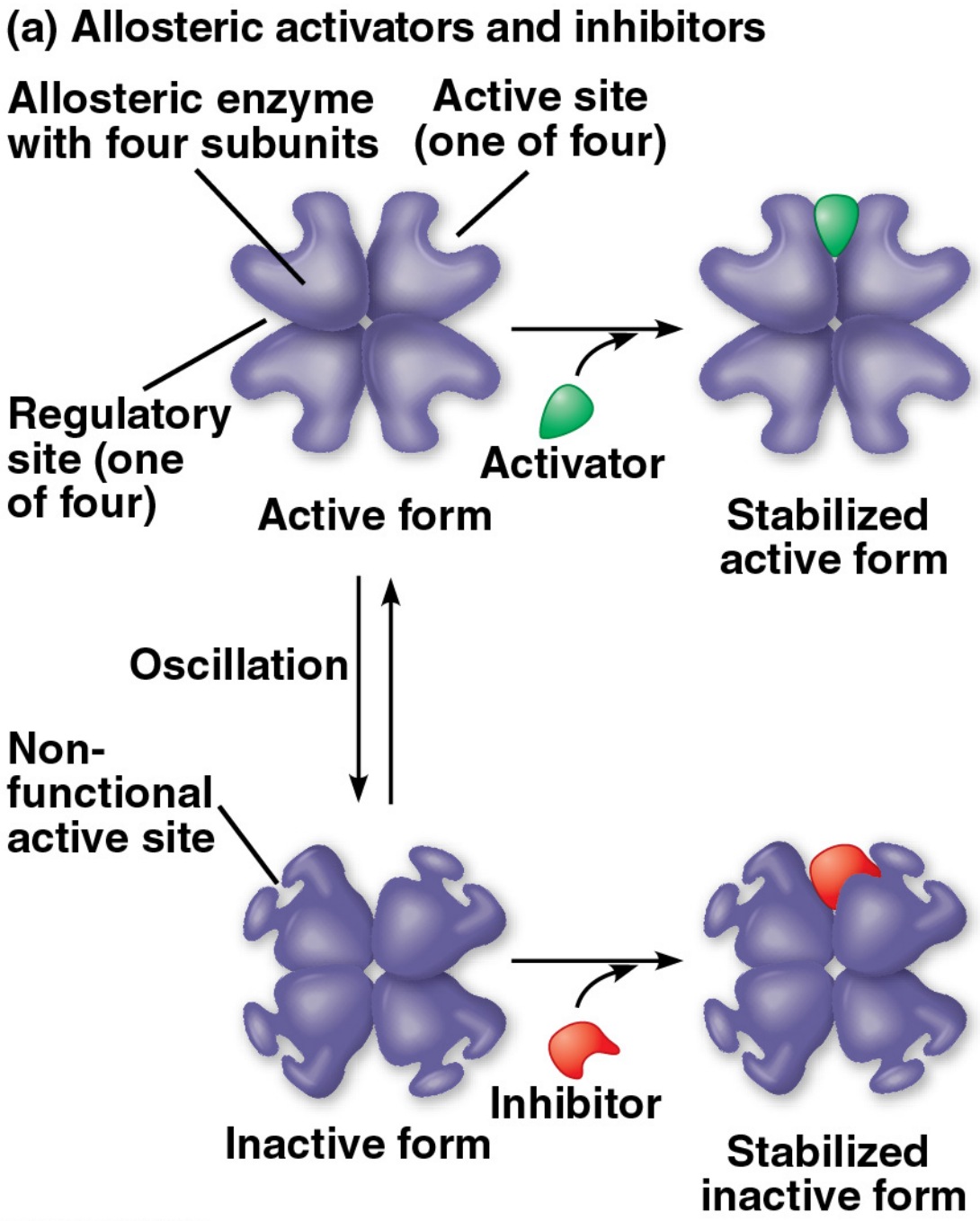


INHIBITION OF ENZYME ACTIVITY

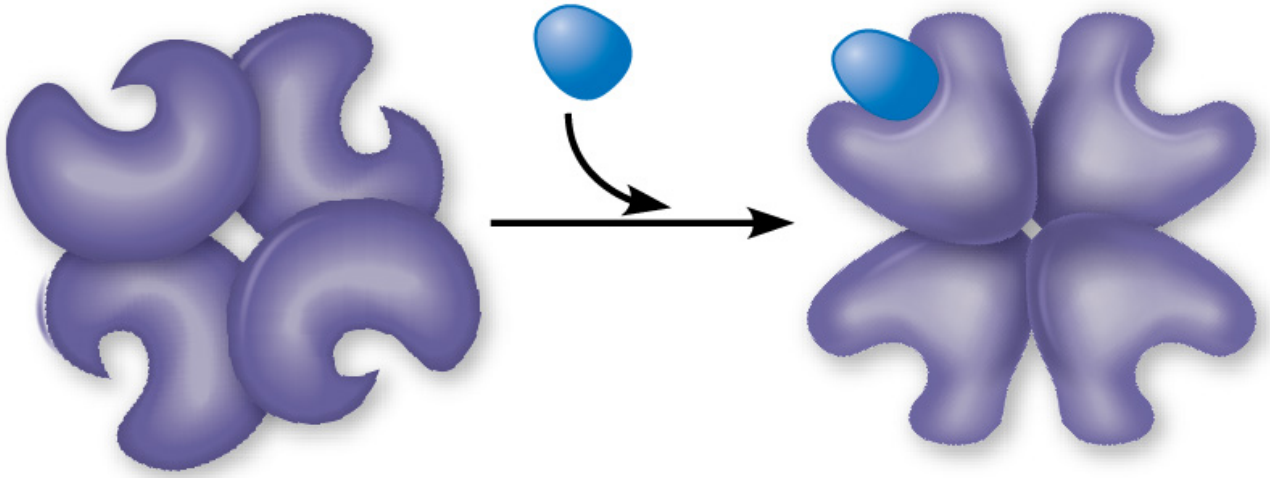


REGULATION OF ENZYME ACTIVITY

- To regulate metabolic pathways, the cell switches on/off the genes that encode specific enzymes
- **Allosteric regulation**: protein's function at one site is affected by binding of a **regulatory molecule** to a separate site (allosteric site)
  - Activator – stabilizes active site
  - Inhibitor – stabilizes inactive form
  - Cooperativity – one substrate triggers shape change in other active sites → increase catalytic activity



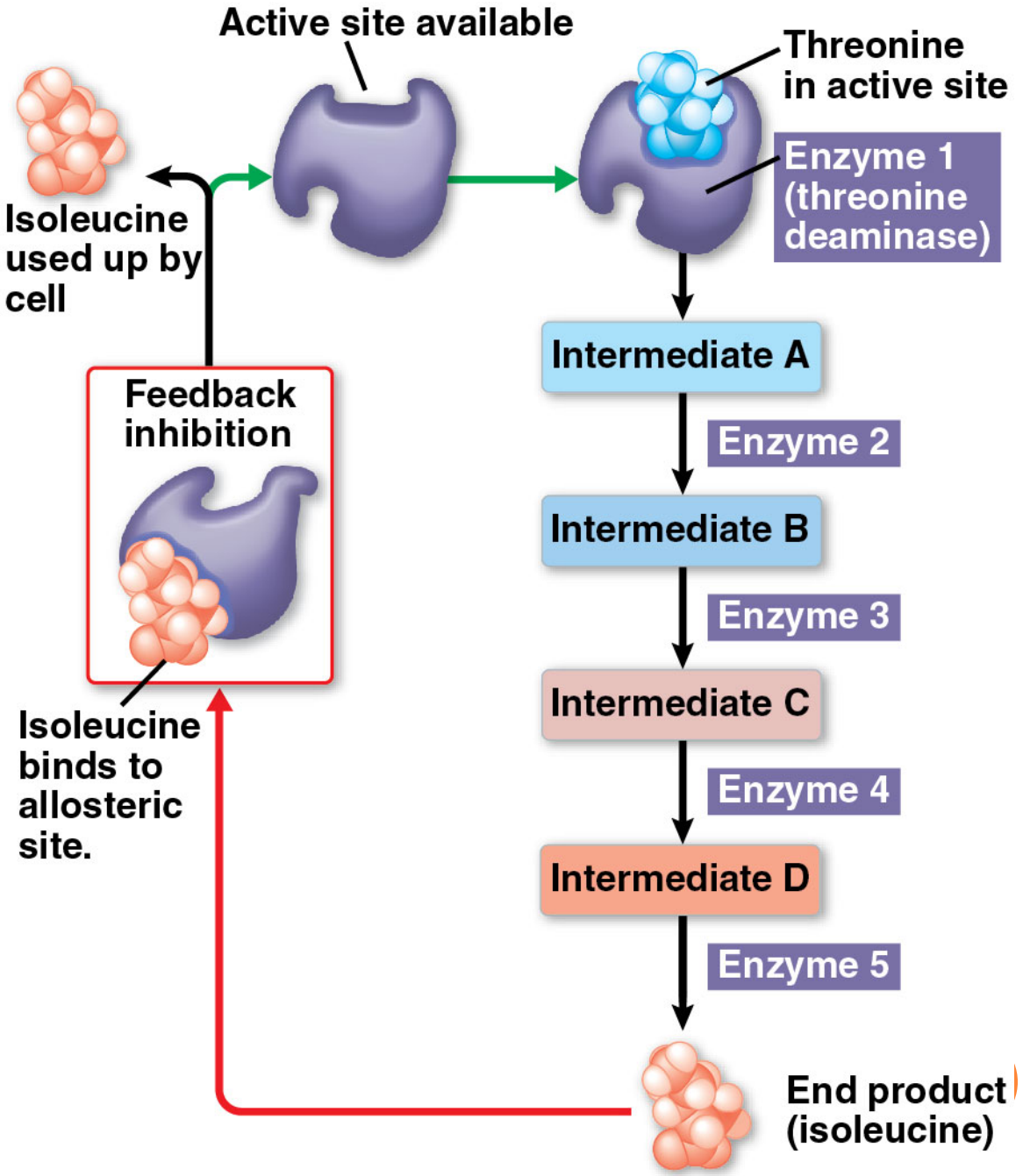
(b) Cooperativity: another type of allosteric activation



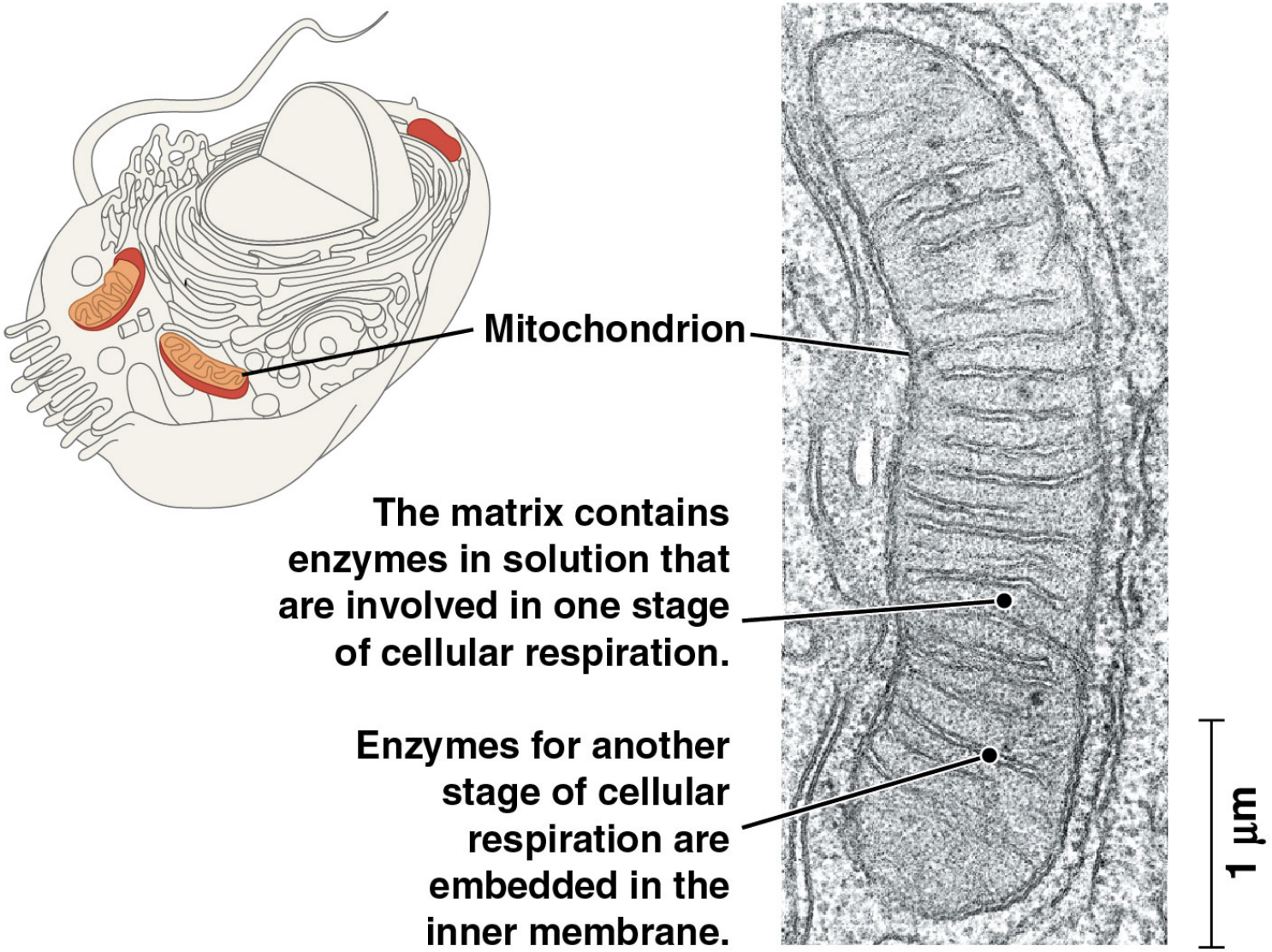
FEEDBACK INHIBITION

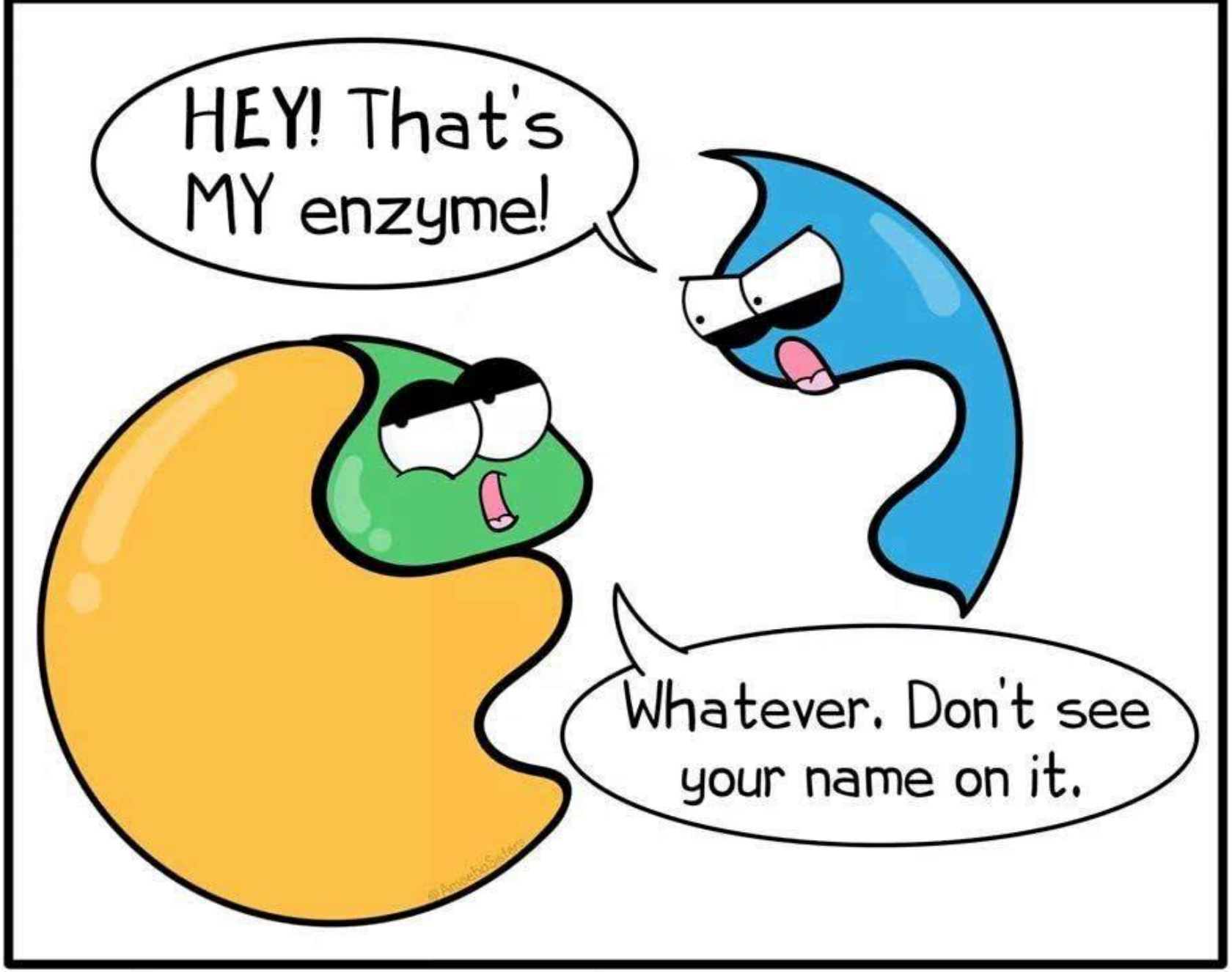
- End product of a metabolic pathway shuts down pathway by binding to the allosteric site of an enzyme
- Prevent wasting chemical resources, increase efficiency of cell

FEEDBACK INHIBITION



ORGANIZATION OF ENZYMES WITHIN A CELL





Competitive Inhibitors: If it fits, it sits.