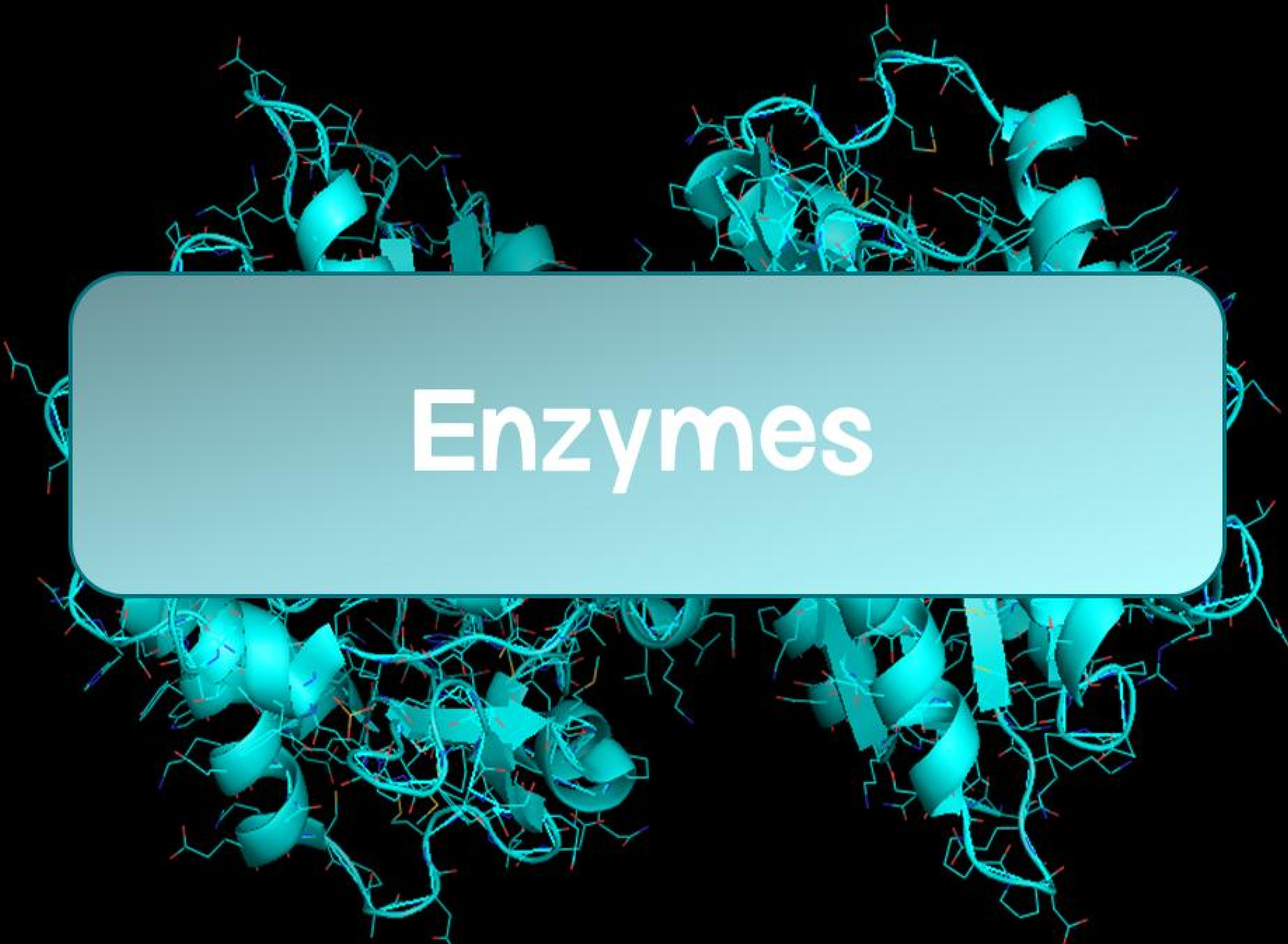
Enzymes



Metabolism

Metabolism: all of the chemical reactions in an organism

Metabolic pathways: series of chemical reactions that either build complex molecules or break down complex molecules

Substrate → Intermediate → Intermediate → Product

Enzyme 1 Enzyme 2 Enzyme 3

Metabolic Pathways

There are two types of metabolic pathways

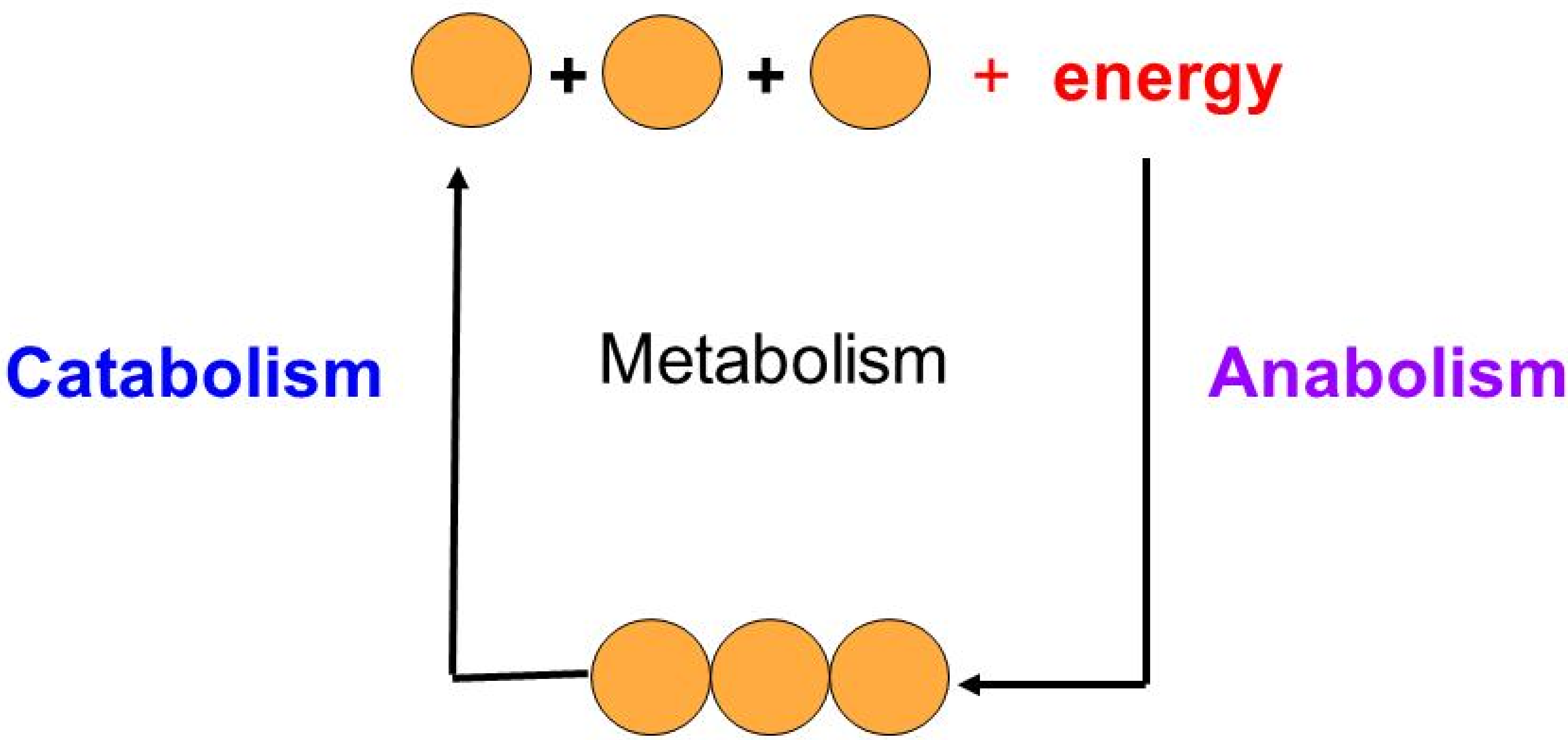
Catabolic Pathways

Pathways that release energy by breaking down complex molecules into simpler compounds

Anabolic Pathways

Pathways that consume energy to build complicated molecules from simpler compounds

Metabolic Pathways



Energy

- Energy: the ability to do work
- Organisms need energy to survive and function
  - A loss in energy flow results in death

Energy

- Kinetic energy: energy associated with motion
  - Thermal energy: energy associated with the movement of atoms or molecules
- Potential energy: stored energy
  - Chemical energy: potential energy available for release in a chemical reaction

Laws of Thermodynamics

The study of energy transformations in matter is called thermodynamics

- The laws apply to the universe as a whole

Laws of Thermodynamics

1st Law:

- Energy cannot be created or destroyed
- Energy can be transferred or transformed

The chemical (potential) energy stored in the nut will be transformed into kinetic energy for the squirrel to climb the tree

Laws of Thermodynamics

2nd law:

- Energy transformation increases the **entropy** (disorder) of the universe
- During energy transfers or transformations, some energy is unusable and often lost as heat

As the squirrel climbs the tree some energy is released as heat

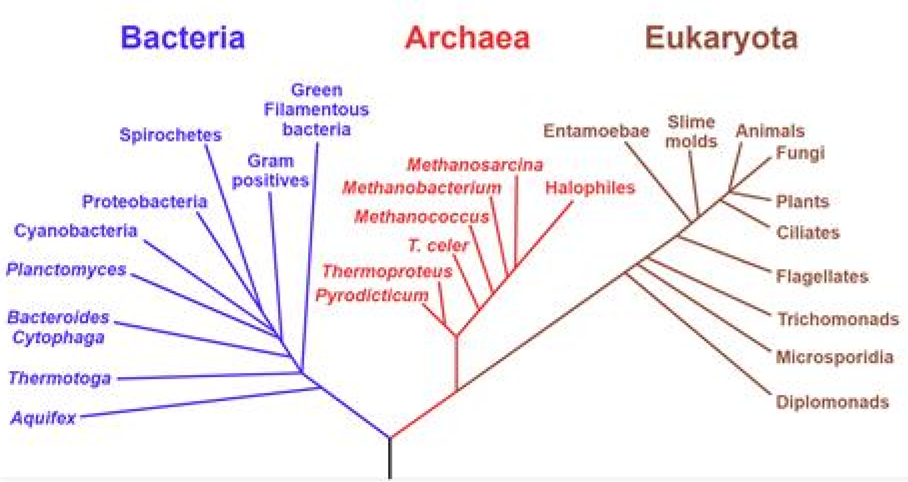
Misconception Check

Cells create organized structures by taking in less organized starting materials (ie make proteins from amino acids). If this is true, how do cells not violate the 2nd law of thermodynamics?

Answer: after the squirrel ate the nut, catabolic reactions turned complex molecules into simpler ones. As the squirrel climbs it is also releasing CO_2 and H_2O which increases entropy

Misconception Check

In comparison to early life on Earth, organisms today are highly organized and complex. How does this increase in organization over time not violate the 2nd law of thermodynamics?



Answer: the entropy of organisms may decrease, as long as the total entropy of the **universe** increases

Free Energy

Since the laws of thermodynamics apply to the universe as a whole, scientists use a concept called **free energy** to determine the likelihood of reactions in organisms, or if the reactions are energetically favorable

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

ΔG: change in free energy

ΔH: change in total energy

T: absolute temp (K)

ΔS: change in entropy

Free Energy

The free energy change of reactions determine whether or not the reaction occurs spontaneously

Based on free energy changes, chemical reactions can be classified as exergonic or endergonic

No outside input of energy is required

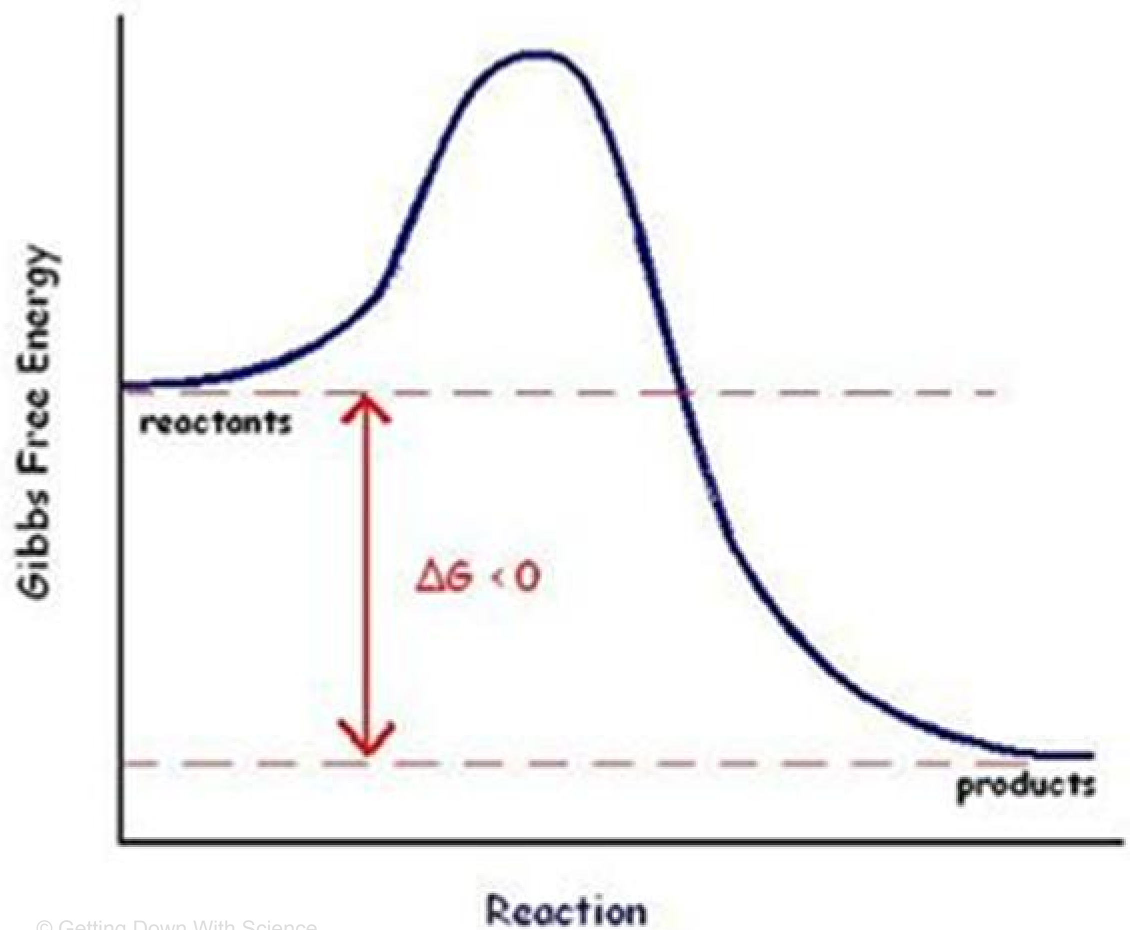
Free Energy

Exergonic reactions: reactions that release energy

- I.e. Cellular respiration

ΔG < 0

Reaction is spontaneous



Free Energy

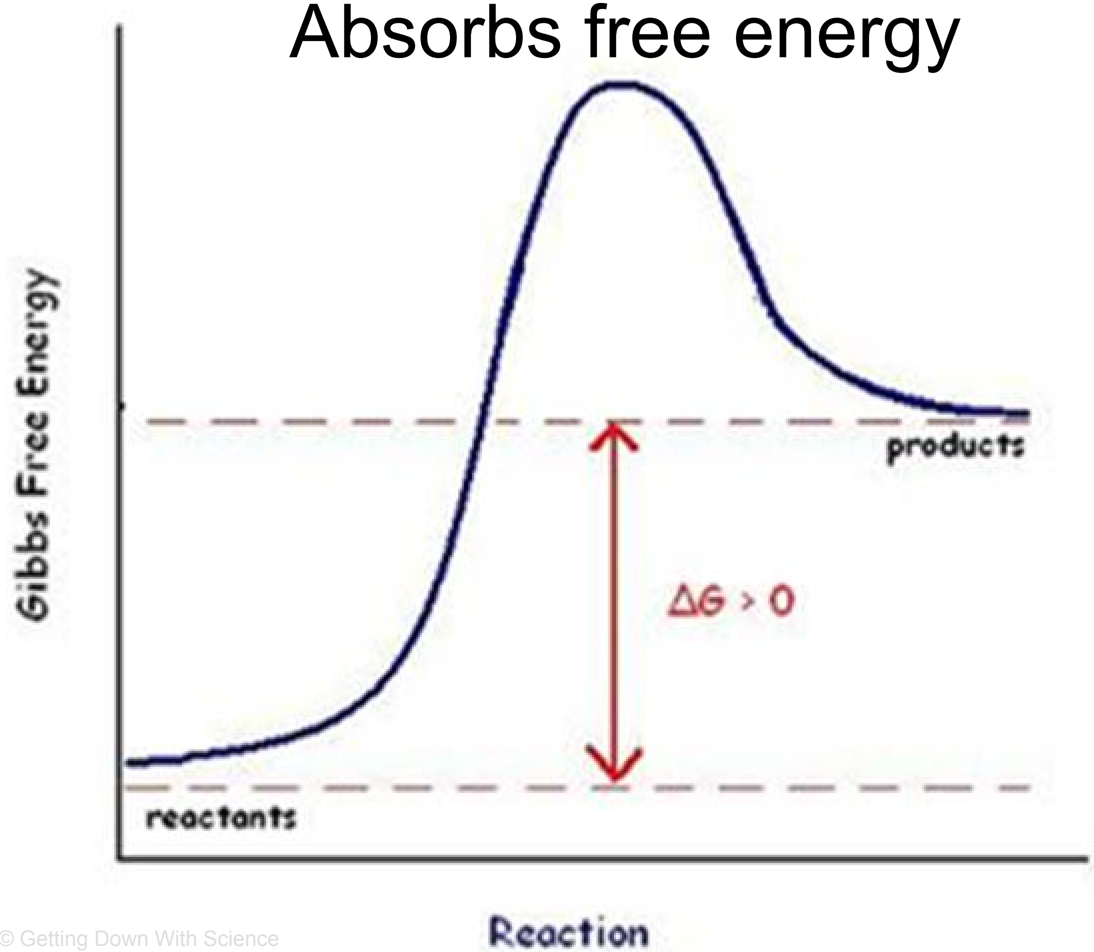
<u>Endergonic reactions</u>: reactions that absorb energy

- I.e. Photosynthesis

$\Delta G > 0$

Reaction is not spontaneous

Absorbs free energy



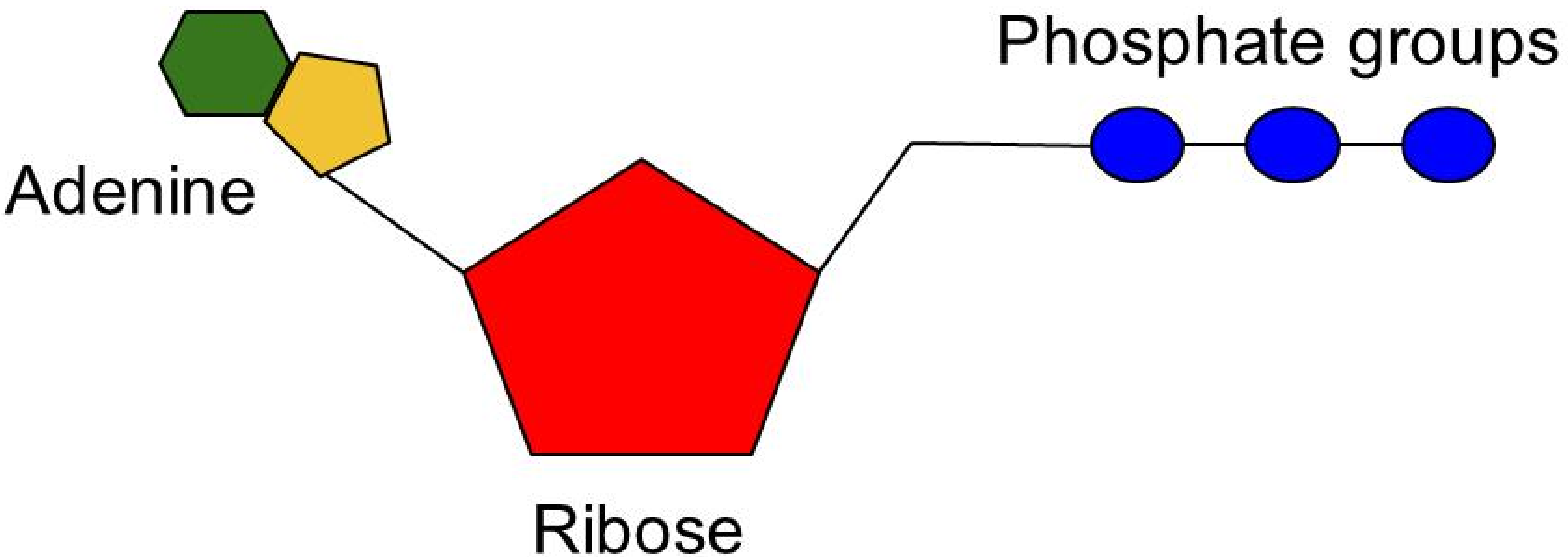
Cells and Energy

- Living cells have a constant flow of materials in and out of the membrane
  - Cells are not at equilibrium
- Cell's perform three kinds of work
  - Mechanical: movement (i.e. beating cilia, movement of chromosomes, contraction of muscle cells)
  - Transport: pumping substances across membranes against spontaneous movement
  - Chemical: synthesis of molecules (ie building polymers from monomers)

ATP

Adenosine triphosphate: molecule that organisms use as a source of energy to perform work

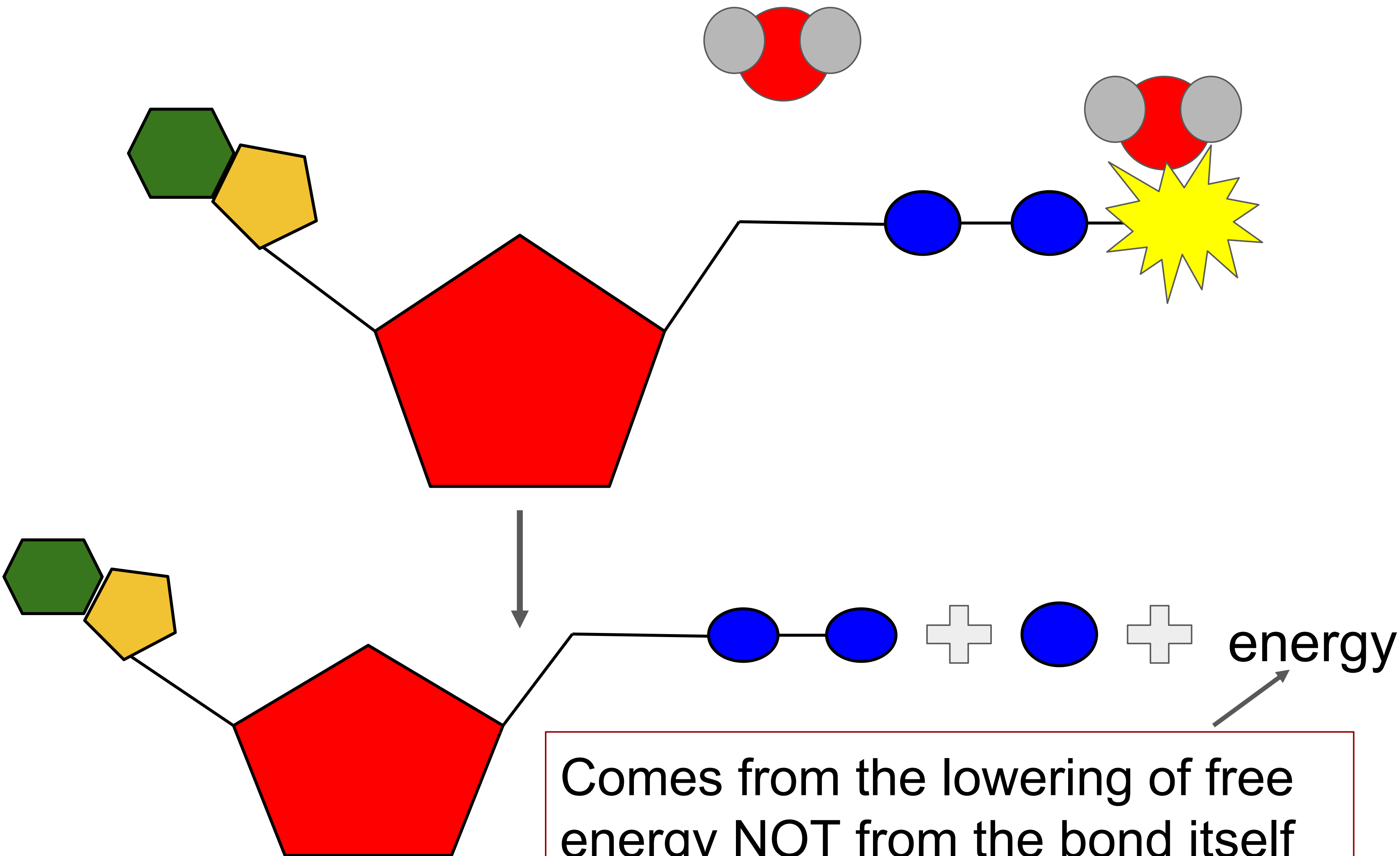
Structure:



ATP

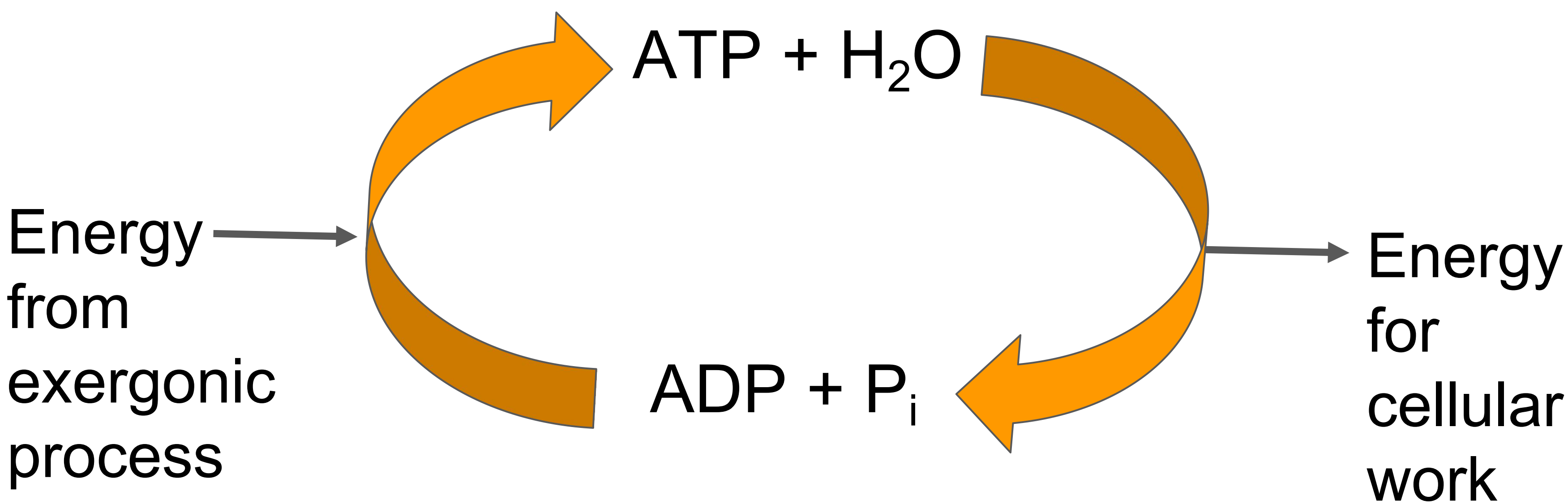
- ATP couples exergonic reactions to endergonic reactions to power cellular work
  - Exergonic process drives the endergonic process
- Organisms obtain energy by breaking the bond between the 2nd and 3rd phosphate in a hydrolysis reaction
  - ATP → ADP
- Phosphorylation: the released phosphate moves to another molecule to give energy

Hydrolysis of ATP



Regeneration of ATP

- ADP can be regenerated to ATP via the ATP cycle



Rate of Metabolic Reactions

The laws of thermodynamics tell us if a reaction is spontaneous, but it does not describe the rate of the reaction

- Some spontaneous reactions move so slowly that it would be impossible for cells to utilize them efficiently
  - The hydrolysis of sucrose to glucose would take nearly 1000 years to happen spontaneously!

Think Pair Share

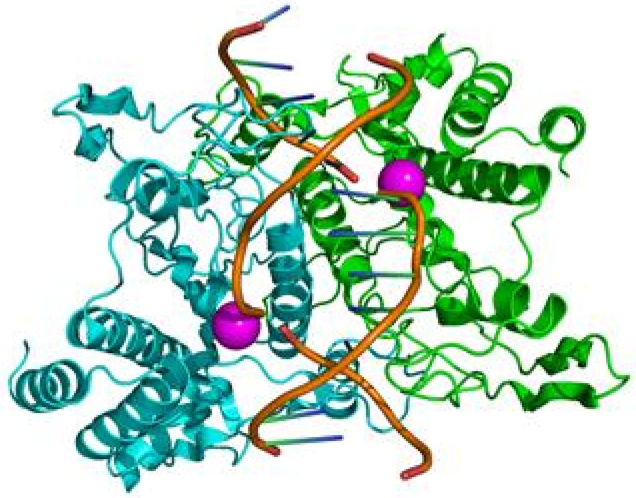
If it takes nearly 1000 years for the hydrolysis of sucrose, then how is it possible that cells do this each day without waiting 1000 years?

→ Enzymes

Enzymes

Enzymes: macromolecules that catalyze (speed up) reactions by lowering the activation energy

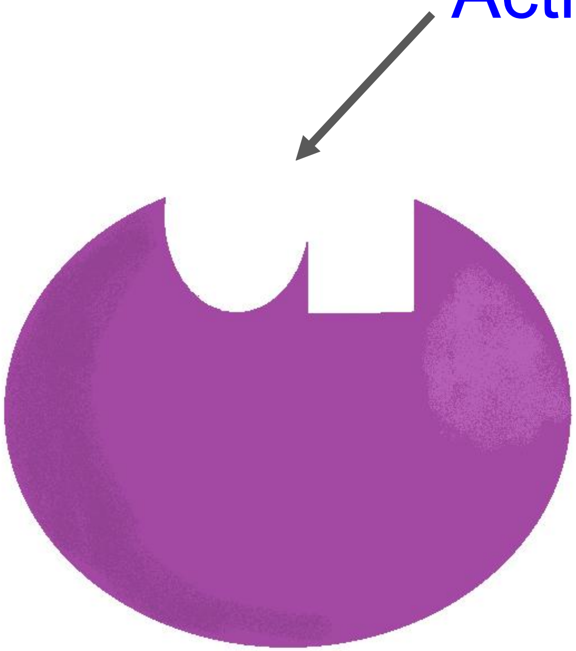
- Are not consumed by the reaction
- Type of protein
- Enzyme names end in -ase



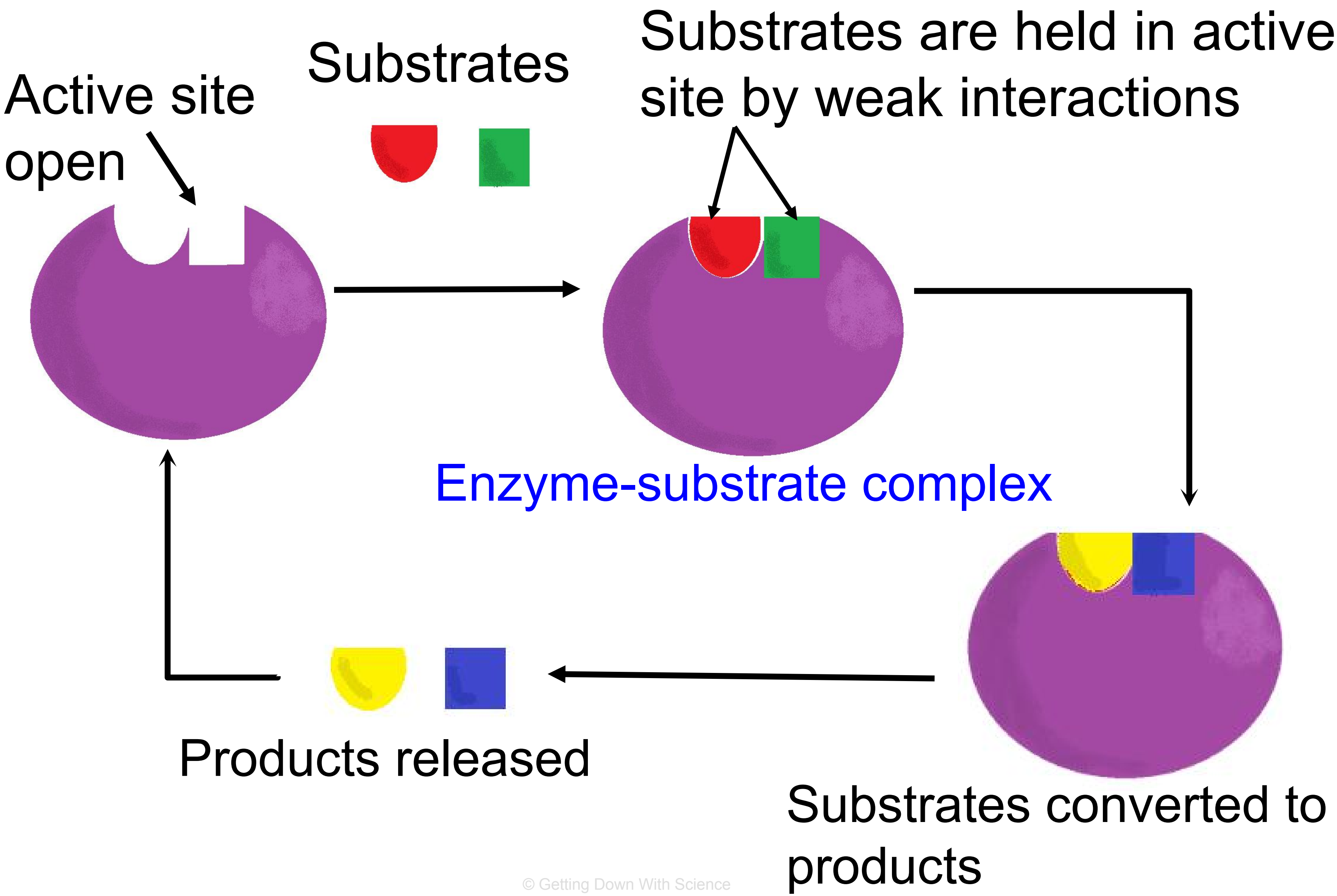
Enzyme Structure

The enzyme acts on a reactant called a substrate

Active site: area for substrate to bind

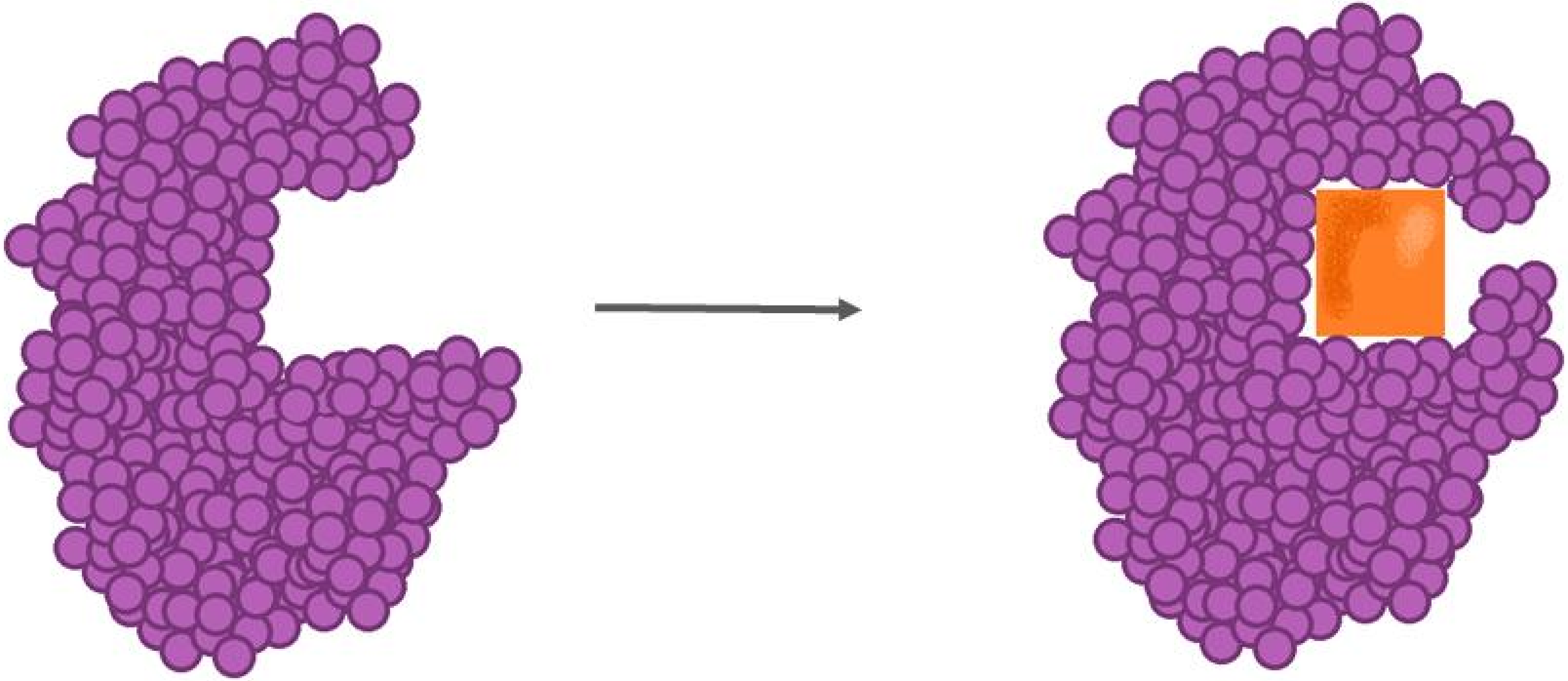


Enzyme Function



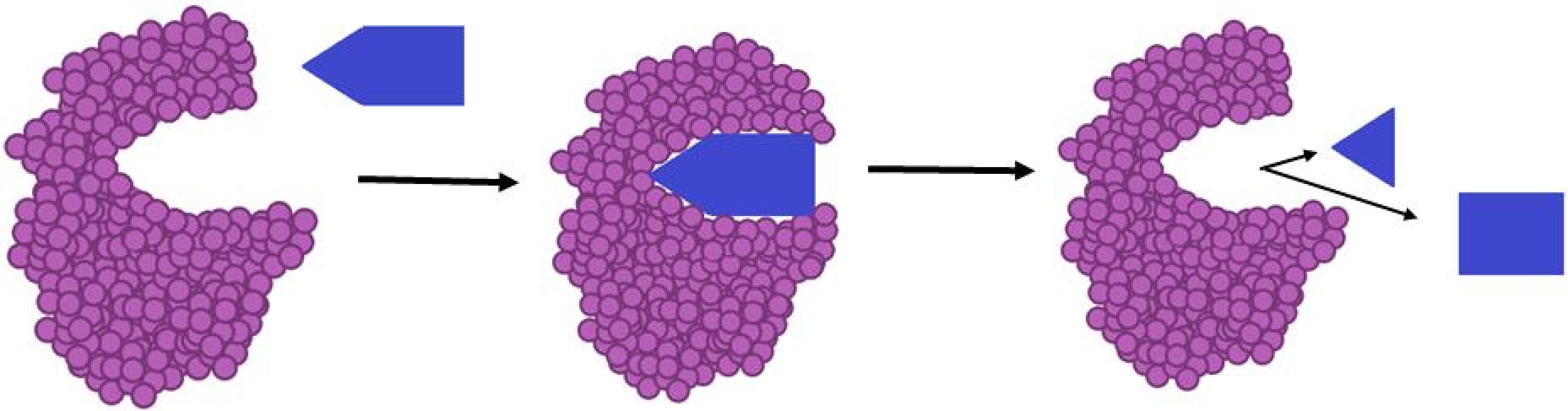
Induced Fit

Induced fit: enzymes will change the shape of their active site to allow the substrate to bind better



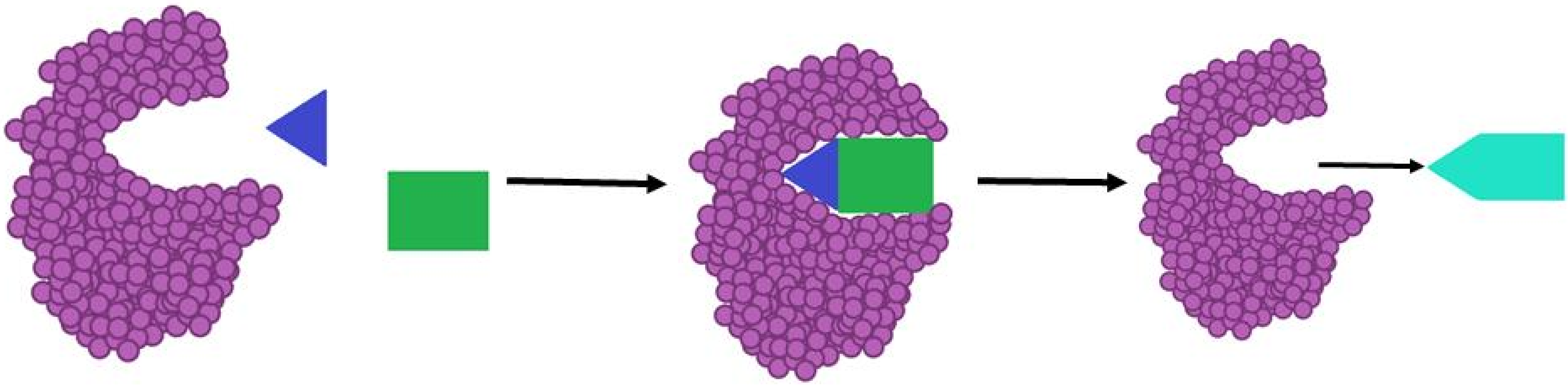
Enzyme-substrate complex

Enzyme Catabolism



Enzyme helps break down complex molecules

Enzyme Anabolism



Enzyme helps build complex molecules

Effects on Enzymes

Enzymes are proteins, which means their 3D shape can be affected by different factors.

- The efficiency of enzymes can be affected by:
  - Temperature
  - pH
  - Chemicals

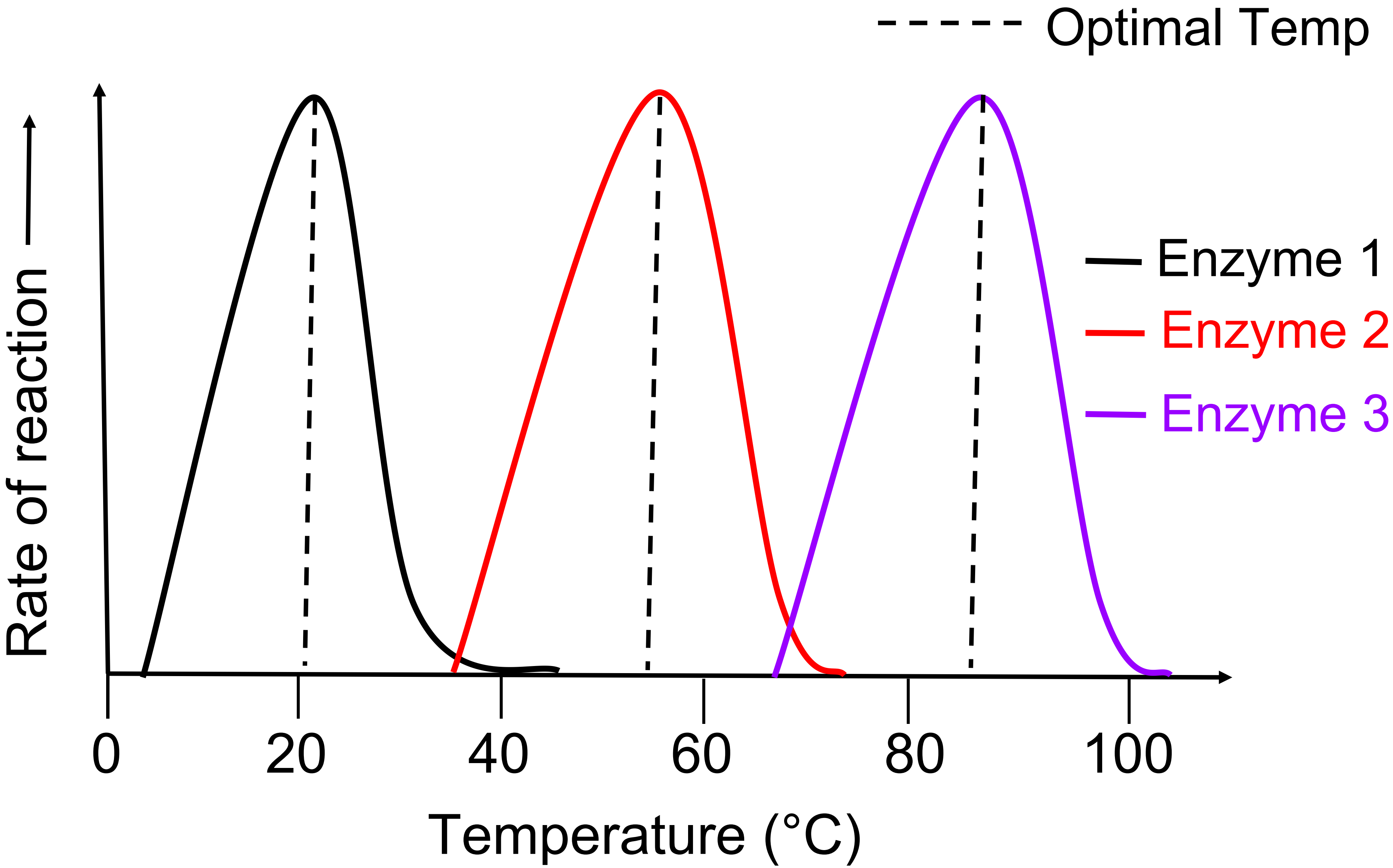
Remember:
A change in **shape** means a change in **function**

Effects on Enzymes

Optimal conditions: the conditions (temperature and pH) that allow enzymes to function optimally (at their best)

- The rate of enzyme activity increases with temperature (due to collision) up to a certain point
  - After a certain point, the enzyme will denature
- Enzymes function best at a specific pH
  - Being outside the normal pH range can cause hydrogen bonds in the enzyme to break, changing the shape of the enzyme

Optimal Temperature



Enzyme cofactors

- Cofactors: **non protein** molecules that assist enzyme function
  - Inorganic cofactors consist of metals
  - Can be bound loosely or tightly
  - Holoenzyme: an enzyme with the cofactor attached
- Coenzymes: **Organic** cofactors
  - I.e., vitamins

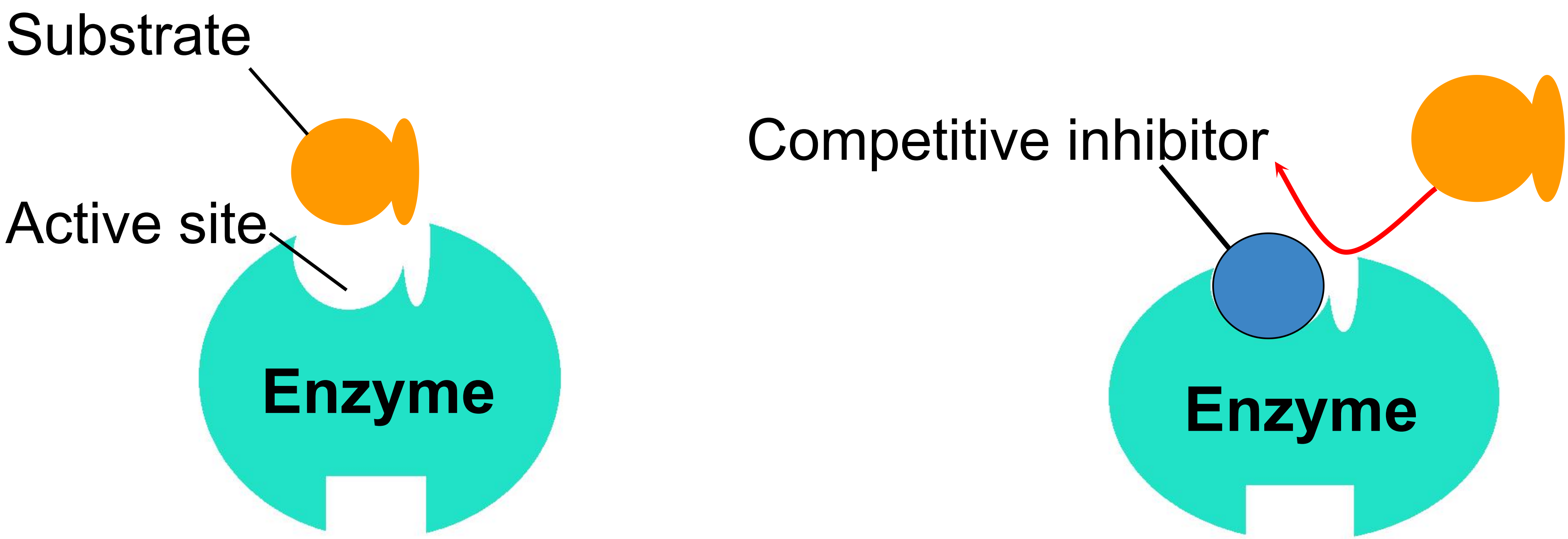
Enzyme Inhibitors

- Enzyme inhibitors: reduce the activity of specific enzymes
  - Inhibition can be permanent or reversible
    - Permanent: inhibitor binds with covalent bonds
      - Example: toxins and poisons
    - Reversible: inhibitor binds with weak interactions

Enzyme Inhibitors

Competitive inhibitors: reduce enzyme activity by **blocking** substrates from binding to the **active site**

- Inhibition can be reversed with increased substrate concentrations



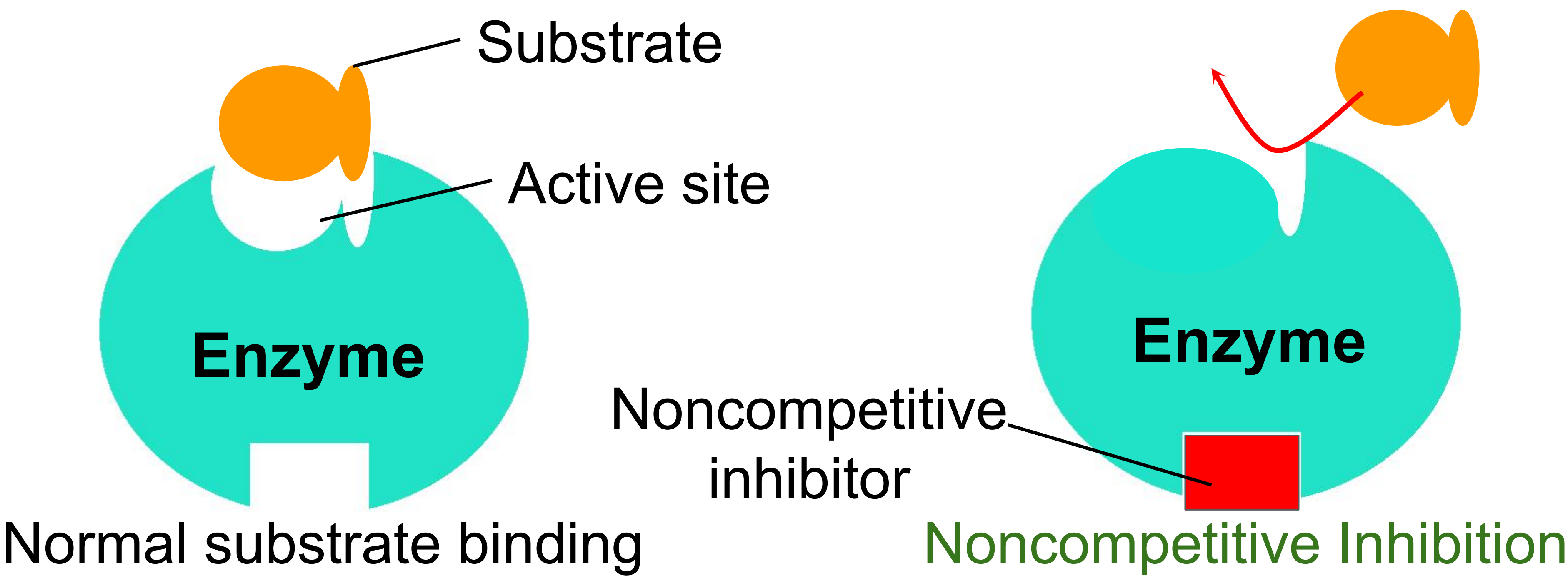
Normal substrate binding

Competitive Inhibition

Enzyme Inhibitors

Noncompetitive inhibitors: bind to an area other than the active site (allosteric site), which changes the shape of the active site preventing substrates from binding

- Type of allosteric inhibition

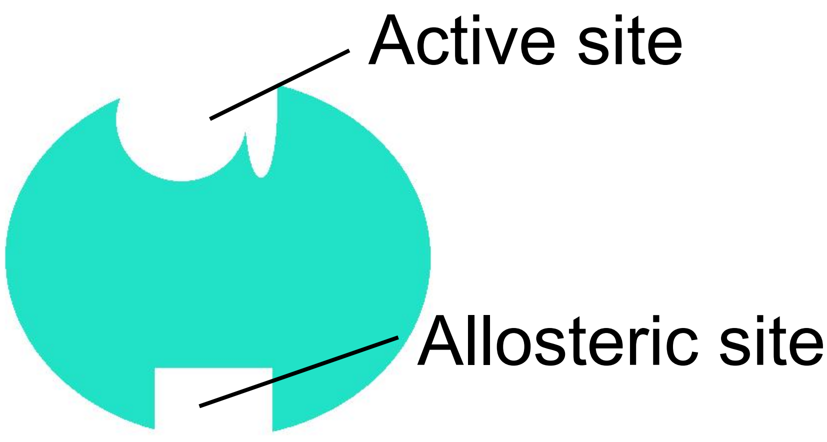


Regulation of Chemical Reactions

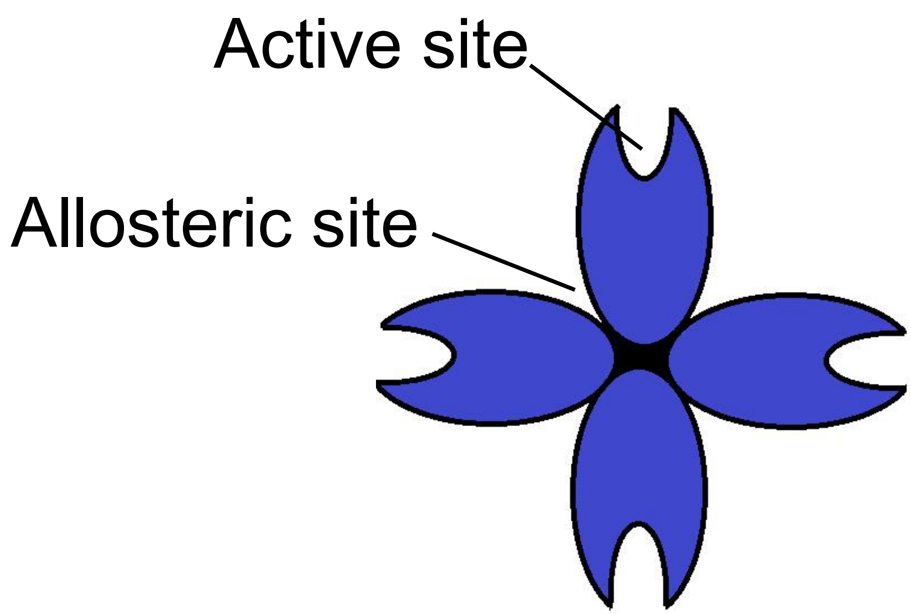
- A cell must be able to regulate its metabolic pathways
- How?
  - Control where and when enzymes are active
  - Switch genes that code for enzymes on or off

Allosteric Regulation

- Allosteric enzymes have <u>two</u> binding sites
  - 1 active site
  - 1 allosteric site (regulatory site, site other than the active site)



Enzyme



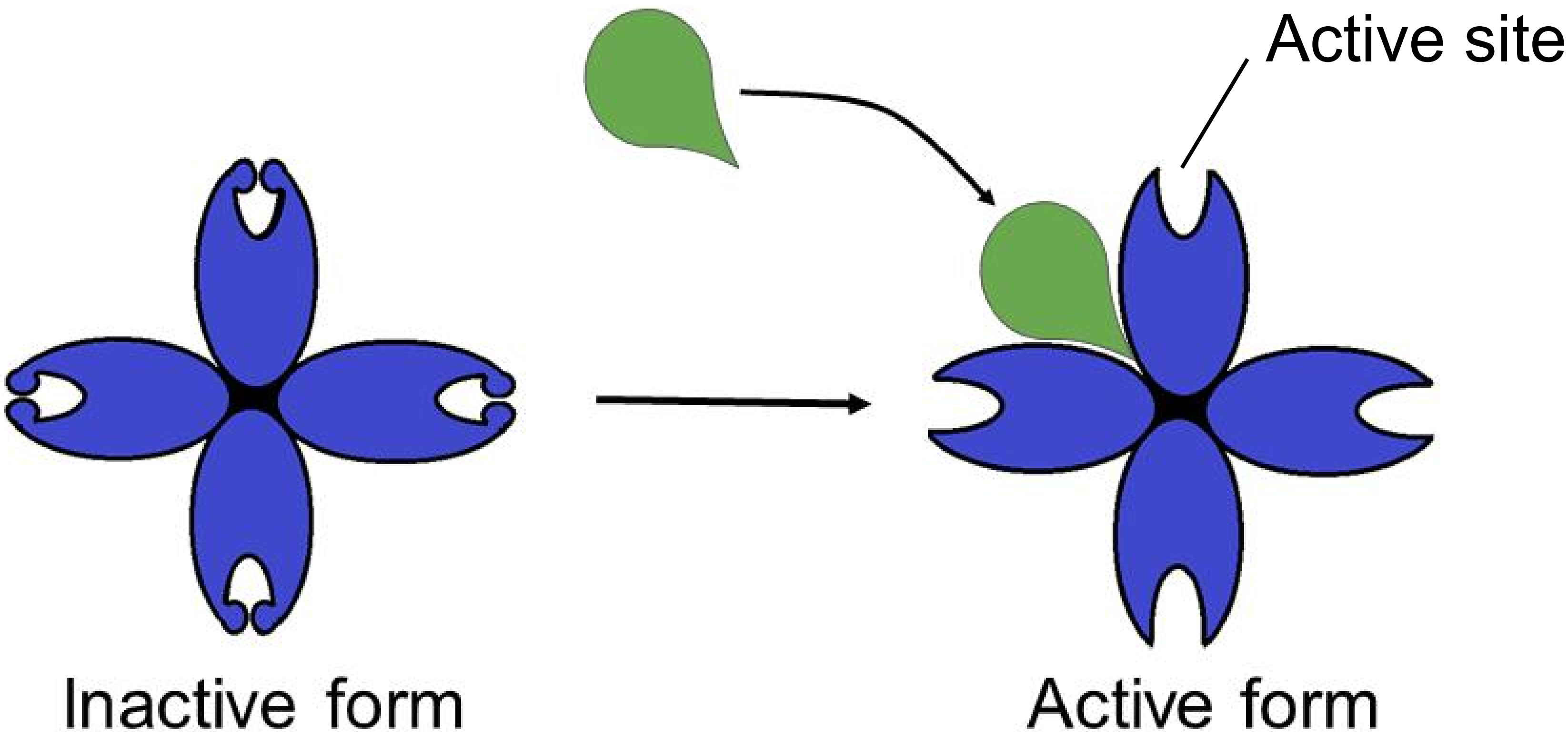
Multi-subunit enzyme

Allosteric Regulation

- Allosteric regulation: molecules bind (noncovalent interactions) to an allosteric site which changes the shape and function of the active site
  - May result in inhibition (by an inhibitor) or stimulation (by an activator) of the enzymes activity

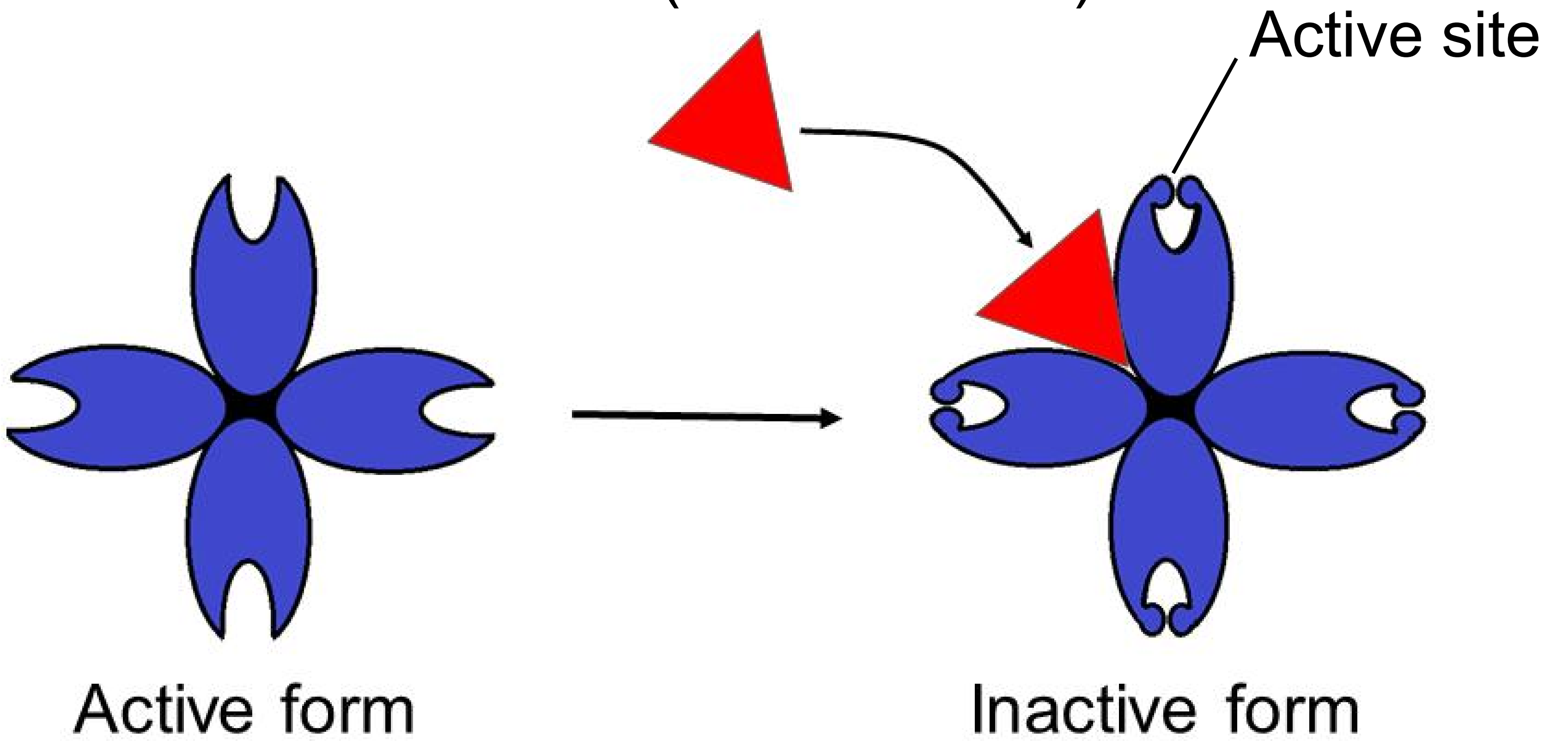
Allosteric Regulation: Activator

- Allosteric activator: substrate binds to allosteric site and stabilizes the shape of the enzyme so that the active sites remain open



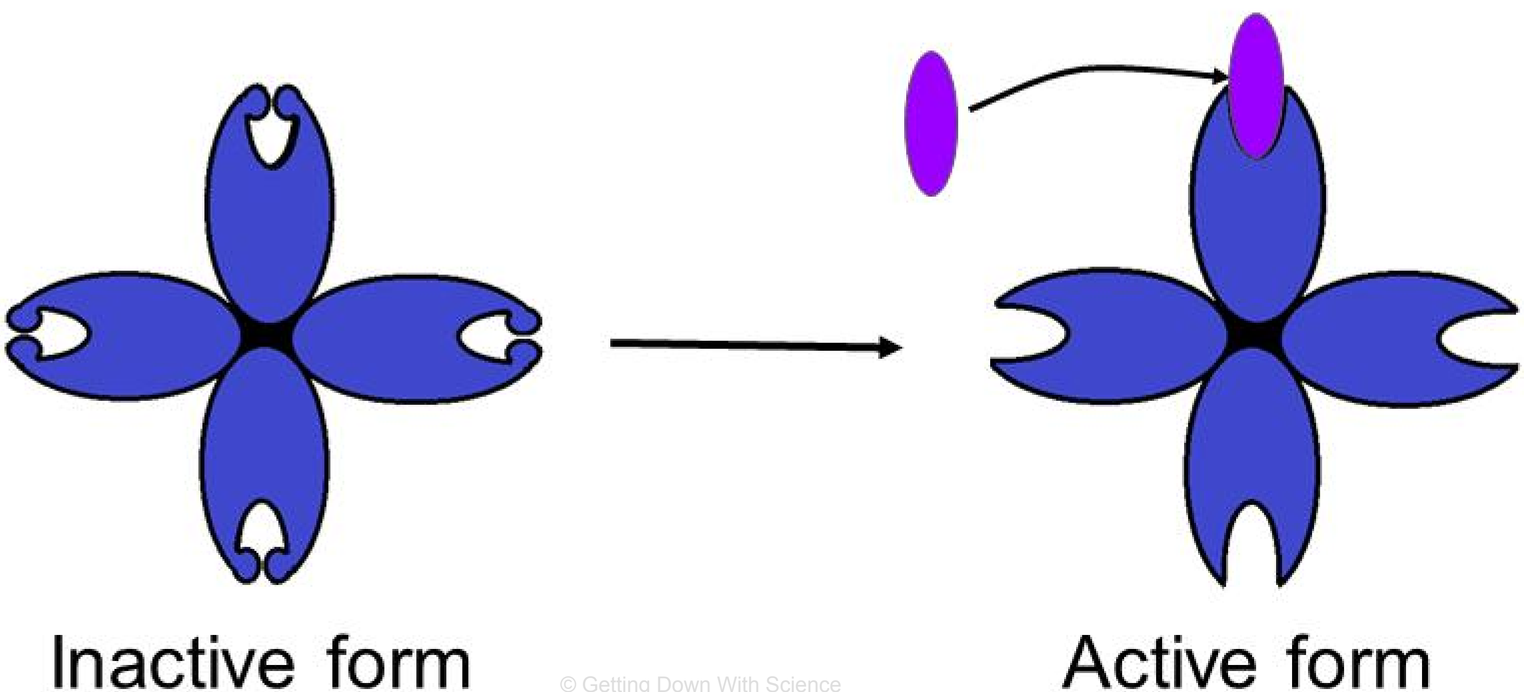
Allosteric Regulation: Inhibitor

- Allosteric inhibitor: substrate binds to allosteric site and stabilizes the enzyme shape so that the active sites are closed (inactive form)



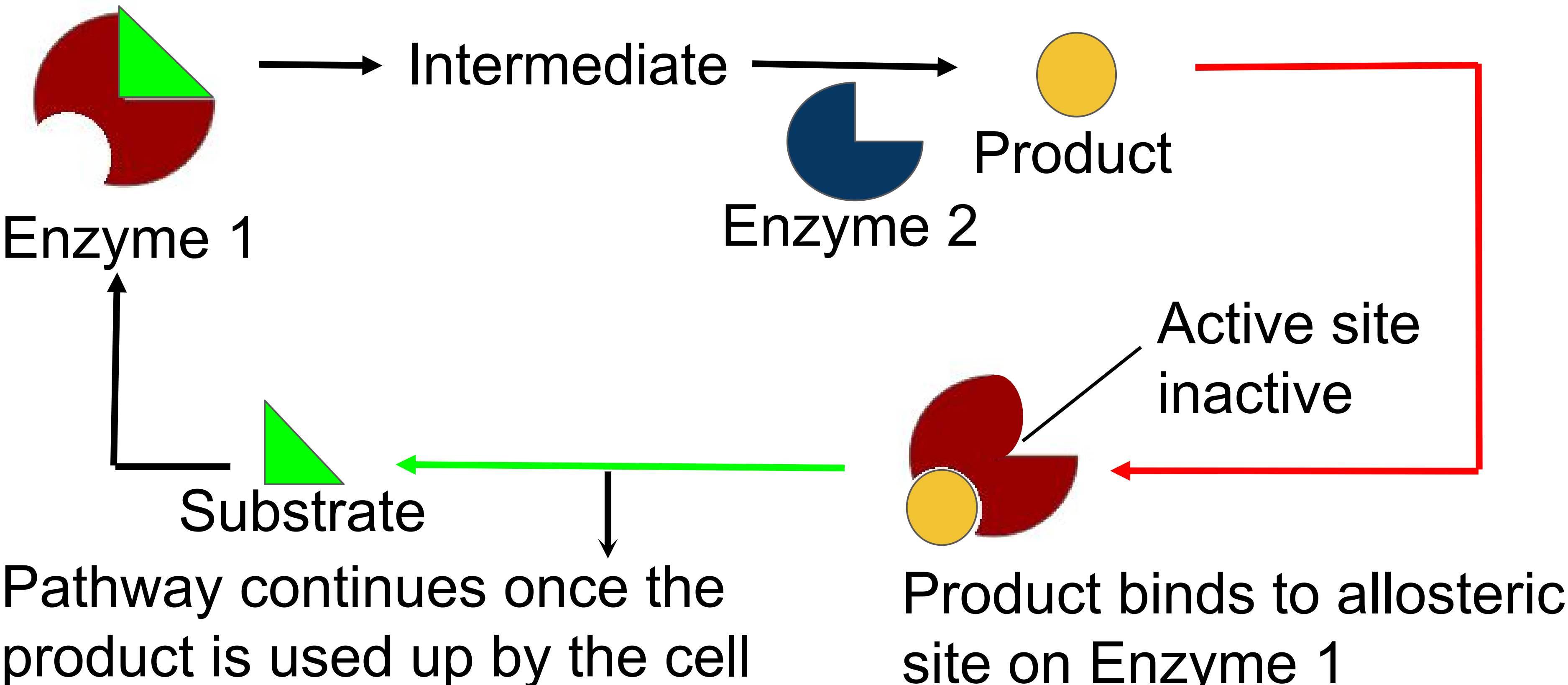
Allosteric Regulation: Cooperativity

- Cooperativity: substrate binds to one active site (on an enzyme with more than one active site) which stabilizes the active form
  - Considered allosteric regulation since binding at one site changes the shape of other sites



Feedback Inhibition

Sometimes, the end product of a metabolic pathway can act as an inhibitor to an early enzyme in the same pathway



Practice Mini FRQ

The common cold is a viral infection that affects the upper respiratory tract. Symptoms include a cough, runny nose, and fever. (a) **Identify** what physiological changes occur in the body when a fever is present. (b) **Explain** how a fever can be beneficial in combating viral infections, particularly in terms of its effect on viral enzymes. (c) **Explain** why a prolonged fever (lasting more than 3 days) can be detrimental to the human body, including the potential impact on the body's own enzymes and proteins.

Practice Mini FRQ

The human body needs vitamins to function properly. For example, a deficiency in vitamin B 12 leads to muscle weakness and fatigue because the body is unable to produce red blood cells. (a) **Explain** how vitamins function as coenzymes in the body and why they are necessary for enzyme activity and overall health.