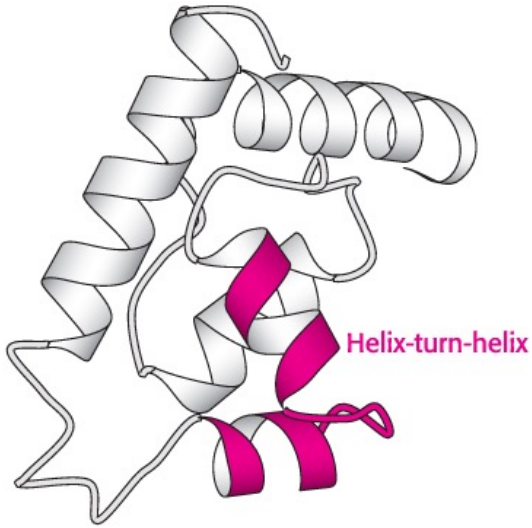
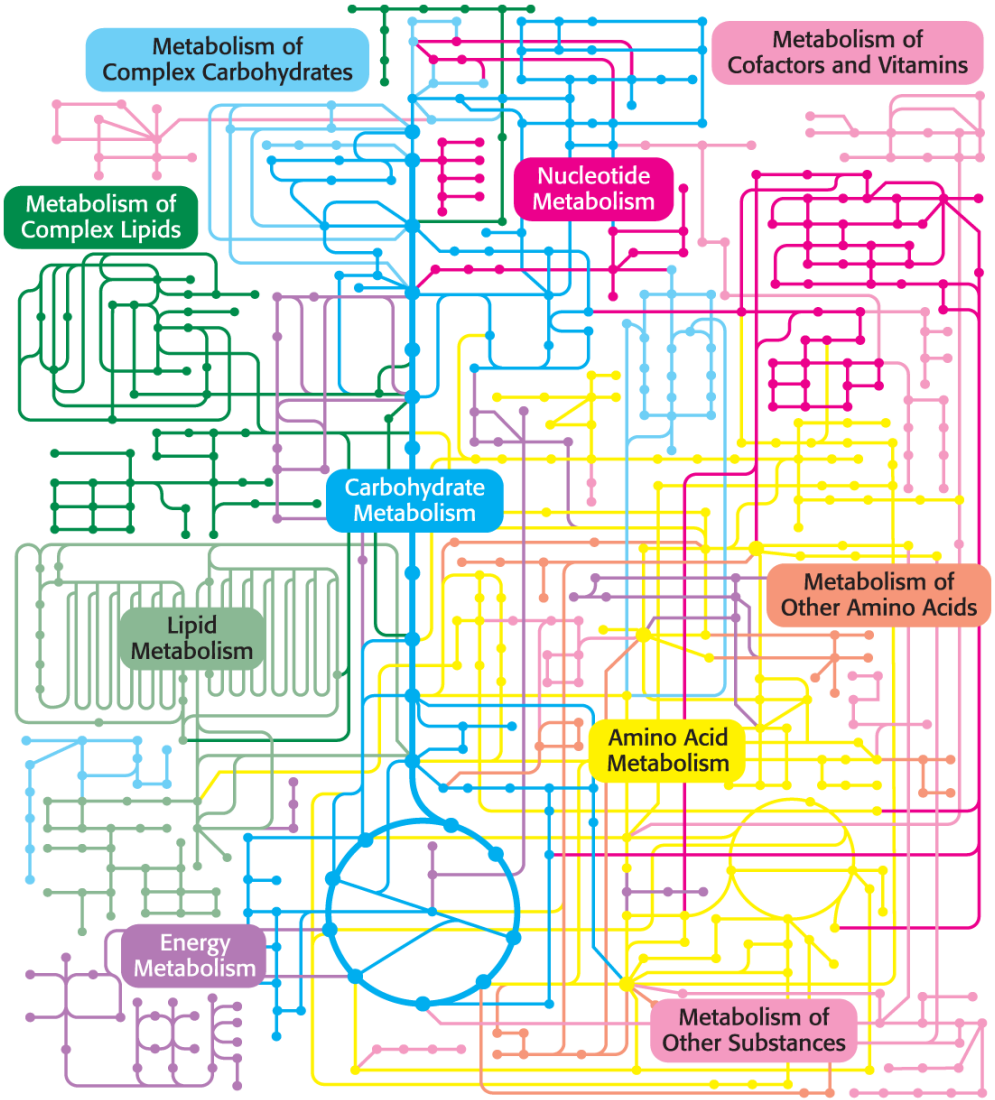
Lecture 3
Basic Concepts and Kinetics of Enzymes

From last lecture…



- **Amino Acids: Building Blocks of Proteins**
  - peptide bonds
  - polypeptide chains
  - determining the sequence/charge of the peptide
- **Hierarchy of protein structure**
  - sequence of amino acids (1°)
  - local folding patterns(2°)
    - **α**-helices, β-sheets, loops and turns (stabilized by H-bonds)
  - overall 3D shape of a single polypeptide chain (3°)
  - assembly of multiple polypeptide chains (4°)
  - enable proteins to perform diverse biological functions (structural support, signaling, and enzymatic activity)



Tymoczko et al., *Biochemistry: A Short Course*, 4e, © 2019 W. H. Freeman and Company

Metabolic Pathways

How do cells control and balance the processes of building and breaking down their components

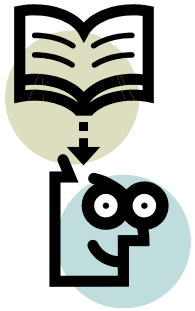
in a coordinated fashion at any given time?

via various **enzyme**-powered pathways!

Basic Concepts and Kinetics of Enzymes

In Lecture 3:

- Enzymes and Their Catalytic Activity
- Cofactors
- Free Energy and Enzymatic Activity
- Enzymes and the Transition State
- Kinetics is the Study of Reaction Rates
- The Michaelis-Menten Model
- Allosteric Enzymes
- Enzyme Studies

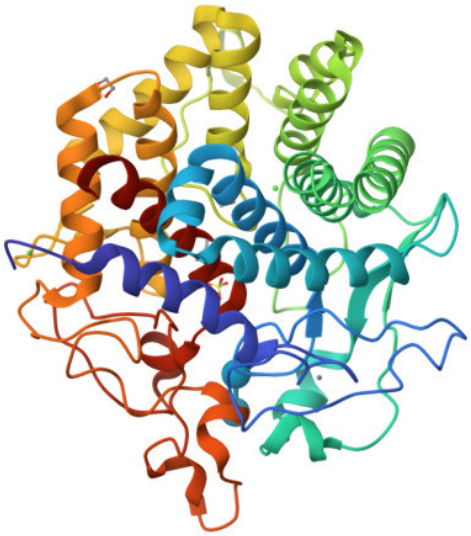


Readings:

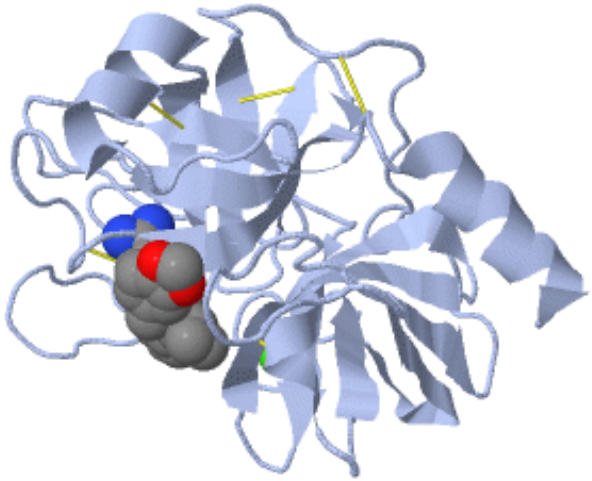
Biochemistry (Chap 6-7):
2nd Edition, pp. 93 - 124
3rd Edition, pp. 97 - 123
4th Edition, pp. 105 - 132

Enzymes are biological catalysts…

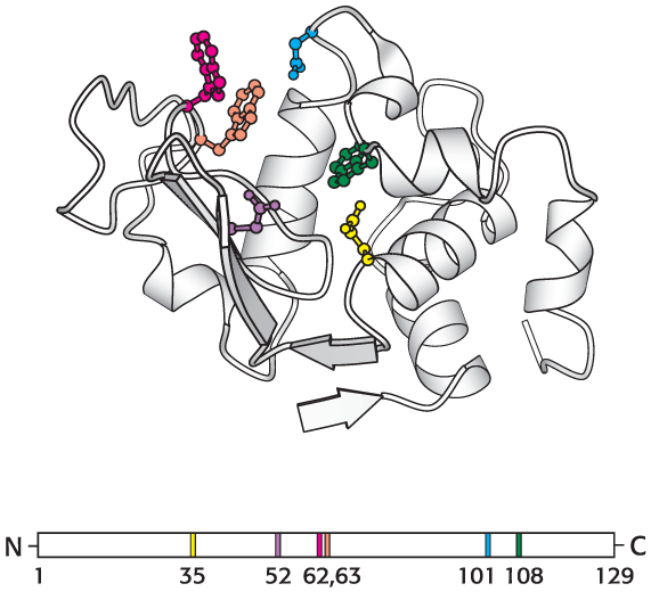
cellulase



trypsin



lysozyme

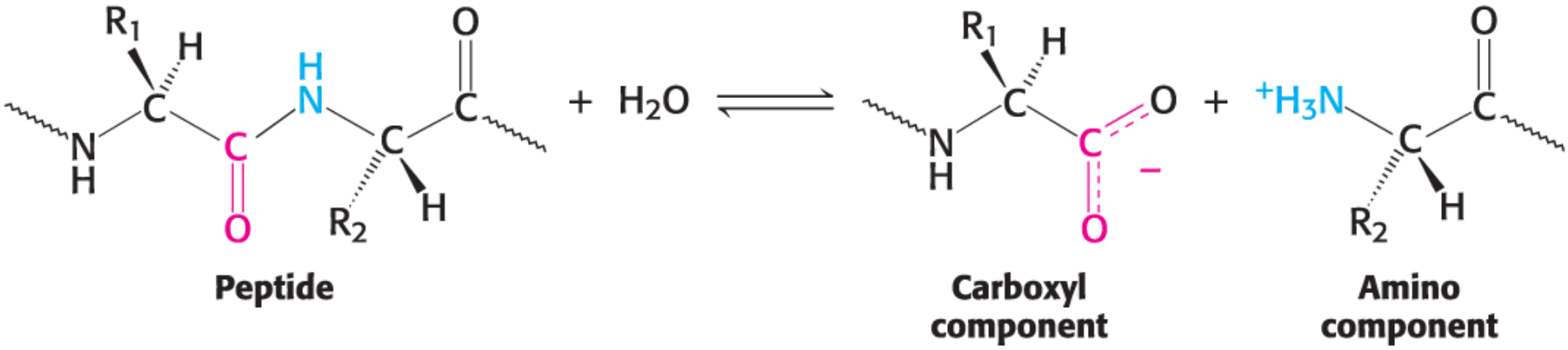


https://proteopedia.org/

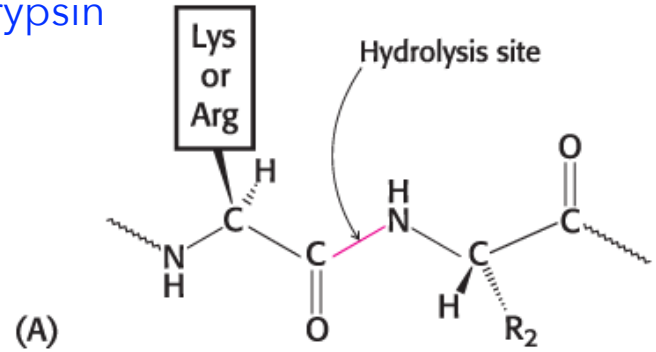
https://www.rcsb.org/structure/1ia7

that are highly specific…

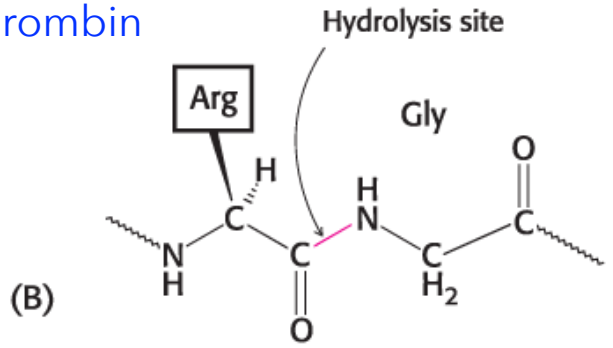
Proteolytic enzymes



Trypsin



Thrombin

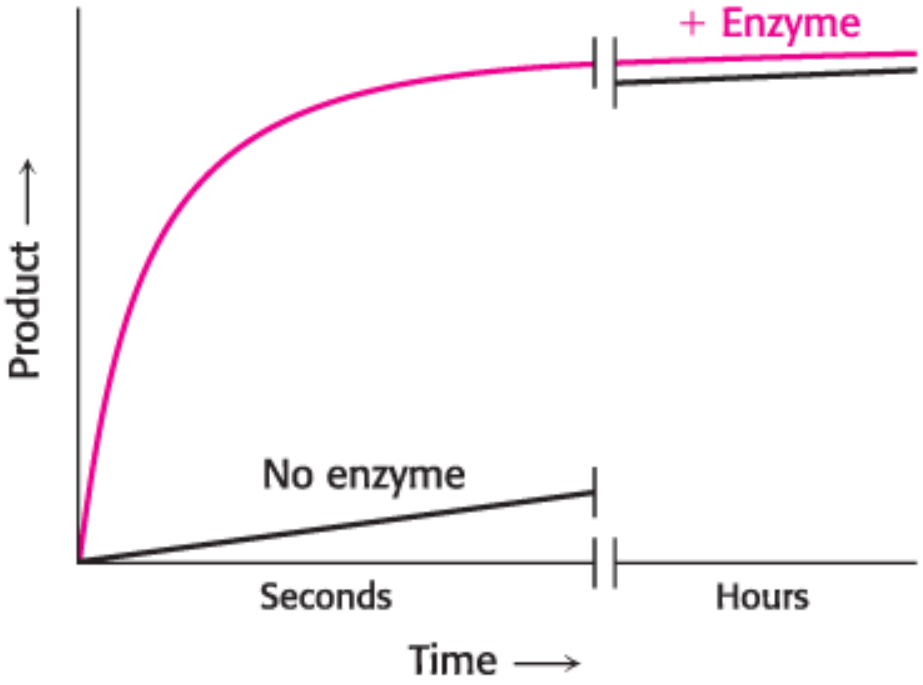


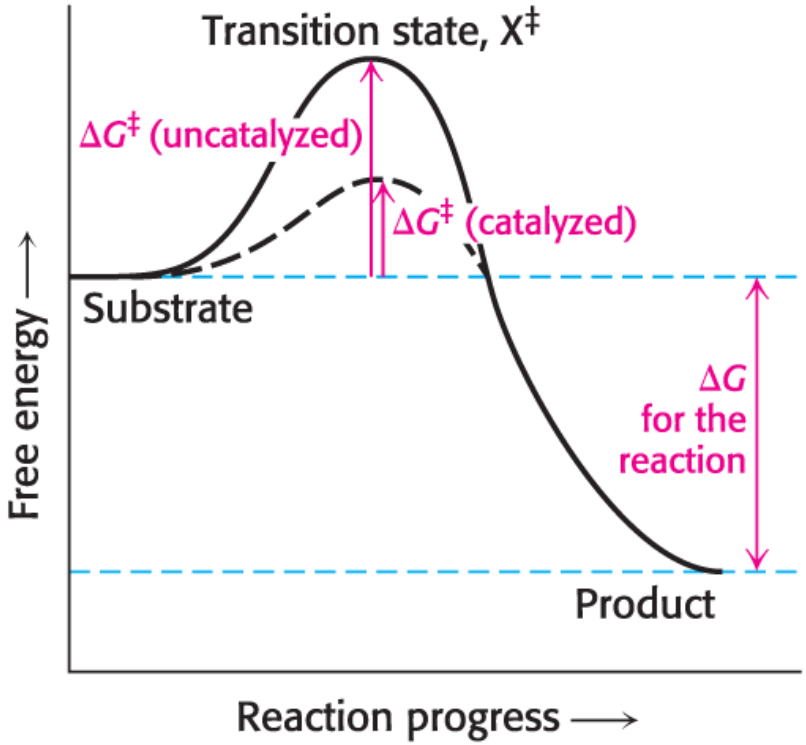
and can increase reaction rate by 10^6-10^{15} fold!

Enzyme	Nonenzymatic half-life
OMP decarboxylase	78,000,000 years
Staphylococcal nuclease	130,000 years
AMP nucleosidase	69,000 years
Carboxypeptidase A	7.3 years
Ketosteroid isomerase	7 weeks
Triose phosphate isomerase	1.9 days
Chorismate mutase	7.4 hours
Carbonic anhydrase	5 seconds

How do enzymes increase the rate of reaction?

How do enzymes accelerate the reaction rate?





By decreasing the activation energy!

Free Energy Is a Useful Thermodynamic Function for Understanding Enzymes

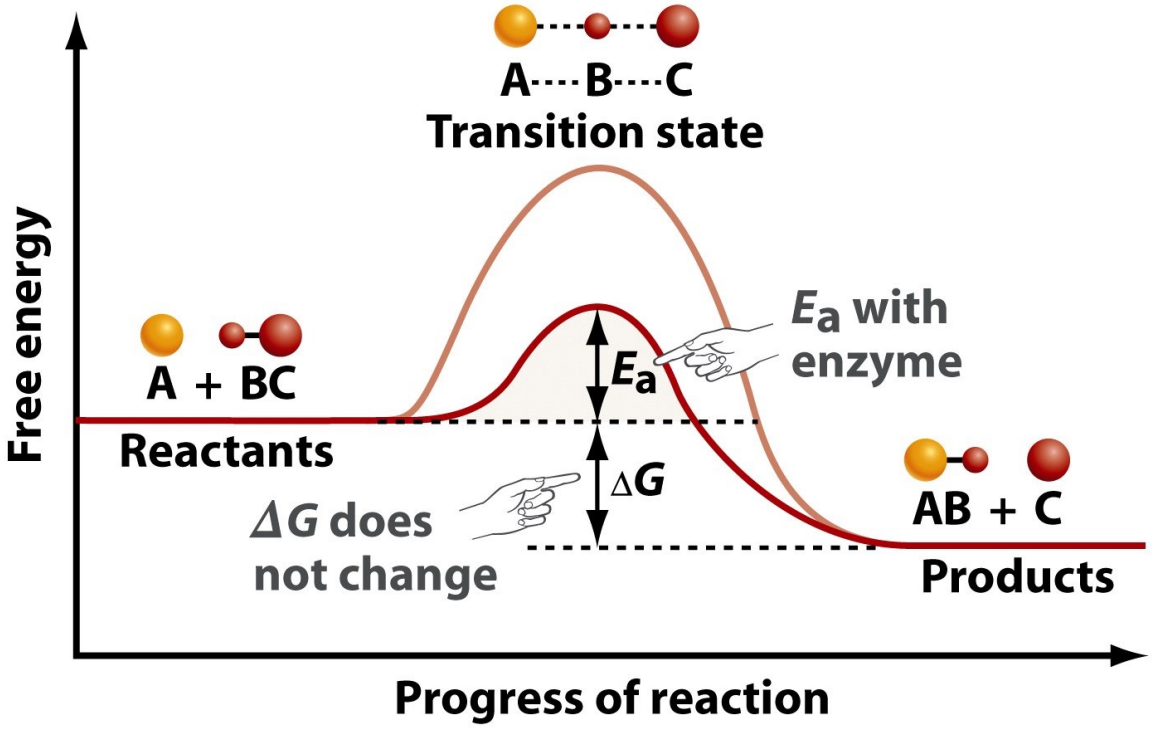
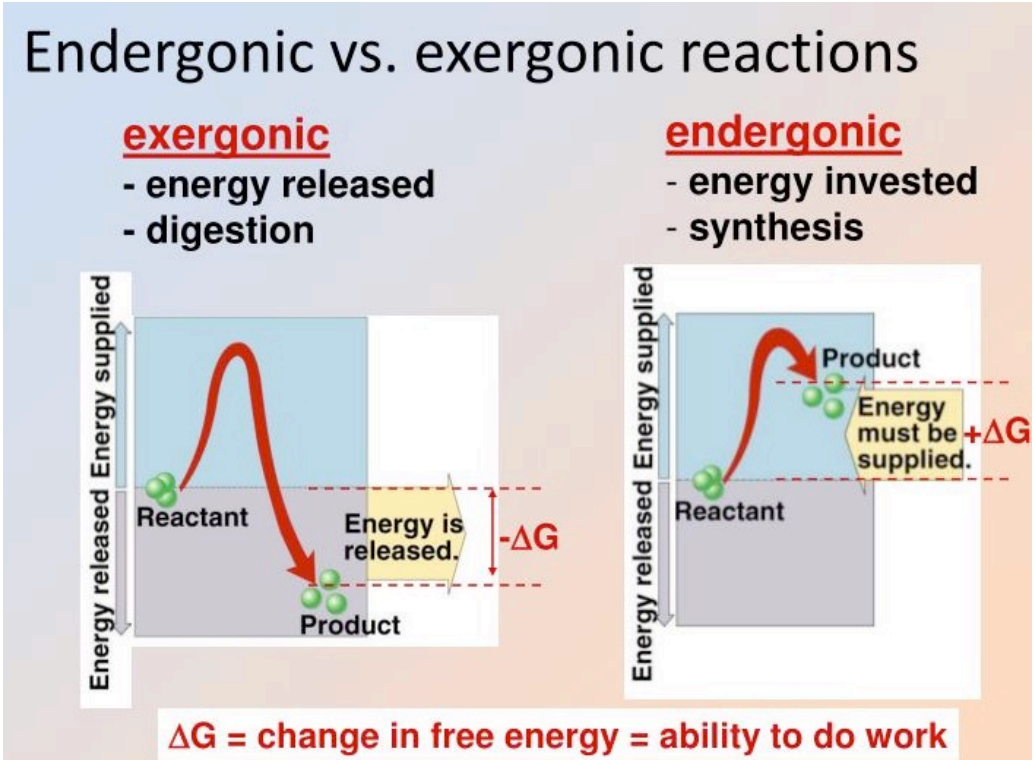


Figure 3-21 Biological Science, 2/e

- Free energy (*G*) is a measure of energy capable of doing work.
- The change in free energy when a reaction occurs is ΔG.
- Enzymes do not alter the ΔG of a reaction.

The Free Energy and the Spontaneity of the Reaction

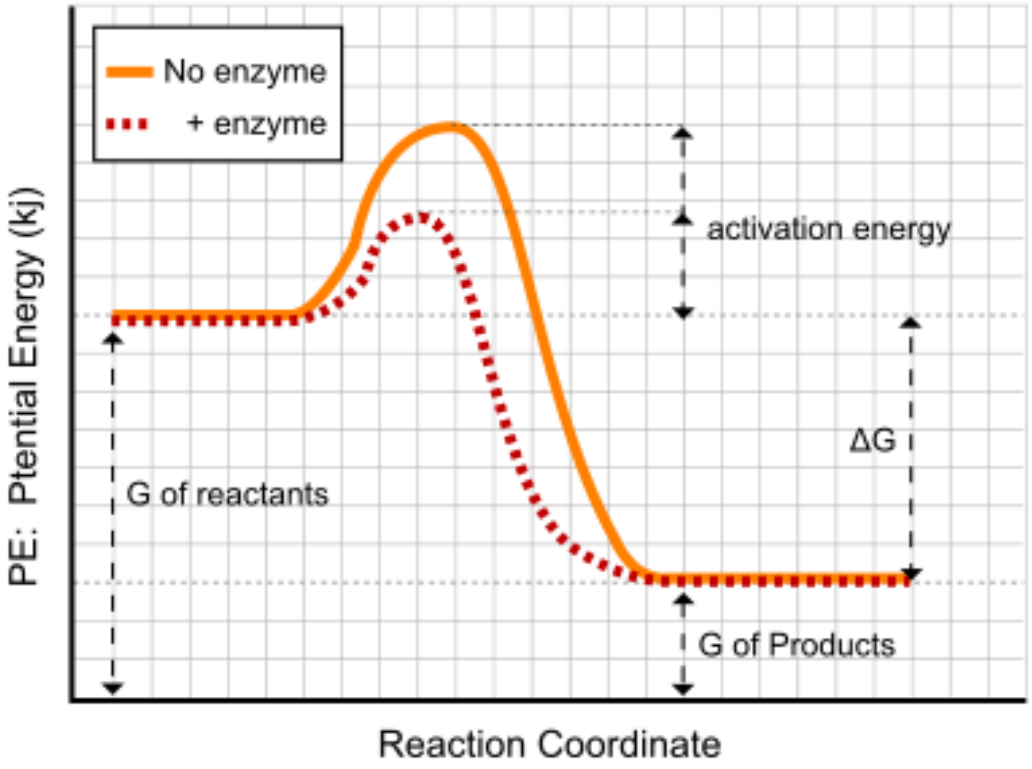


http://ib.bioninja.com.au/higher-level/topic-8-metabolism-cell/untitled-6/activation-energy.html

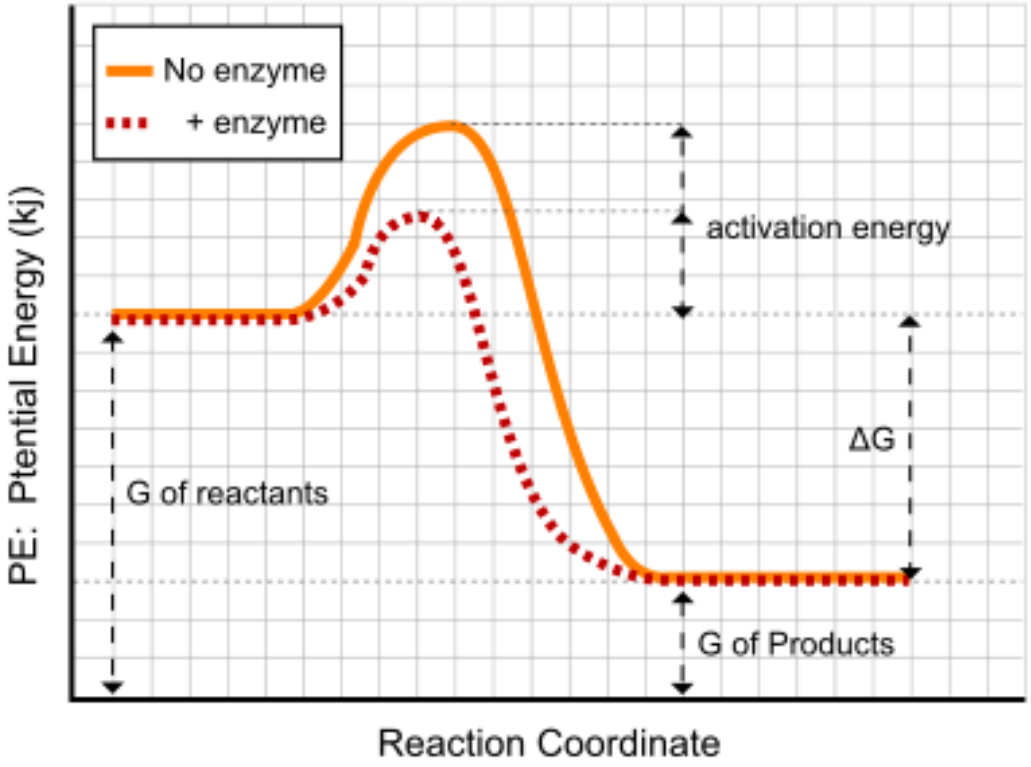
- A reaction will occur without the input of energy, or spontaneously, only if ΔG is negative. Such reactions are called ***exergonic reactions***.
- A reaction will not occur if the ΔG is positive. These reactions are called ***endergonic reactions***.

The Free Energy and the Spontaneity of the Reaction

- If a reaction is at equilibrium, there is no net change in the amount of reactant or product. At equilibrium, $\Delta G = 0$.
- The ΔG of a reaction depends only on the free energy difference between reactants and products and is independent of how the reaction occurs.
- The ΔG of a reaction provided no information about the rate of the reaction.

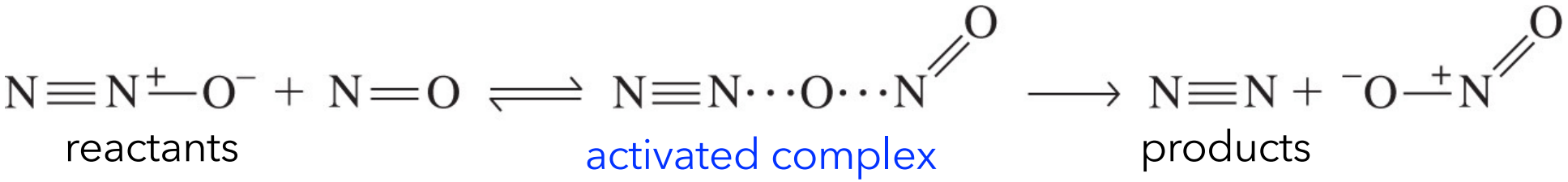


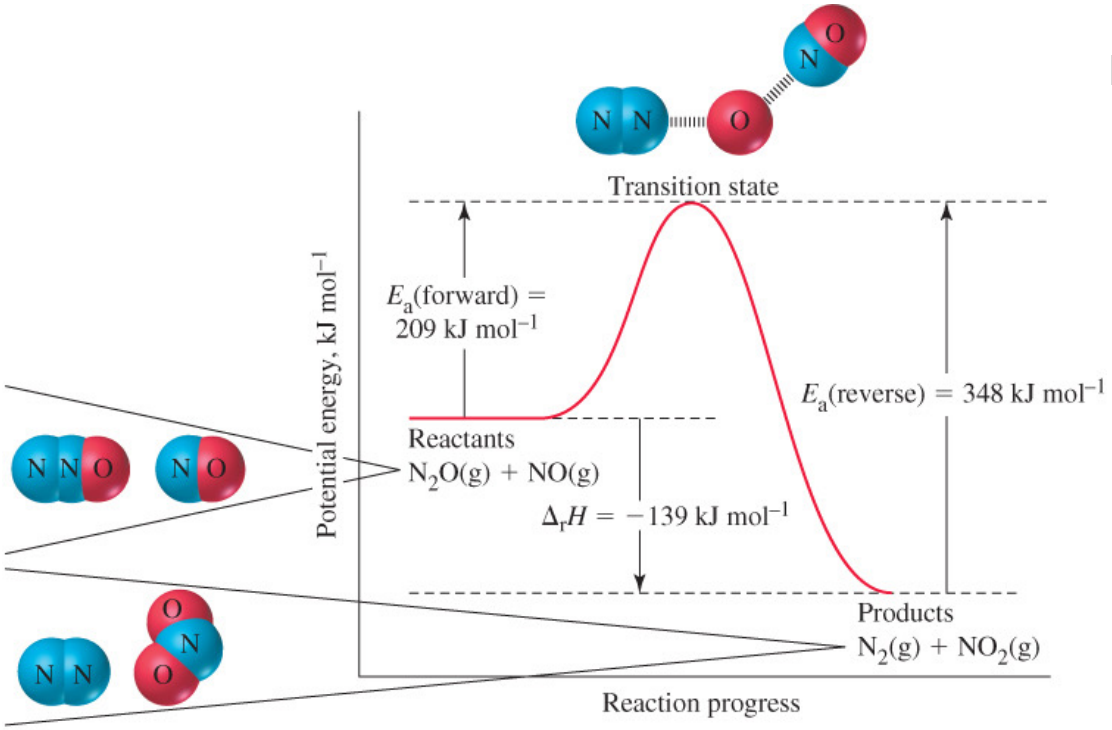
Enzymes alter the reaction rate but not the reaction equilibrium



- The reaction equilibrium is determined only by the free energy difference between the products and reactants. Enzymes cannot alter this difference.

Recall Transition State





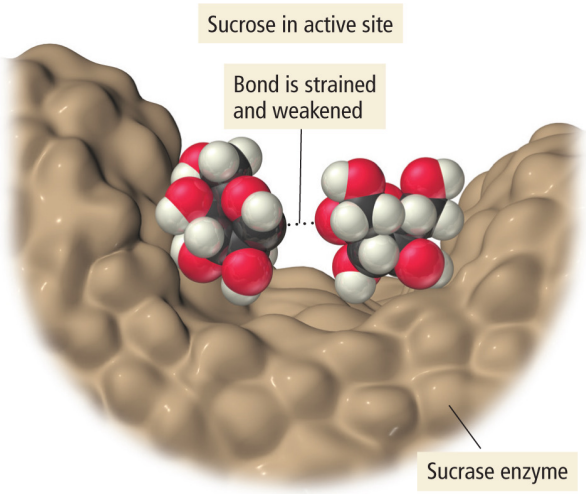
$N_2O(g) + NO(g) \rightarrow N_2(g) + NO_2(g)$

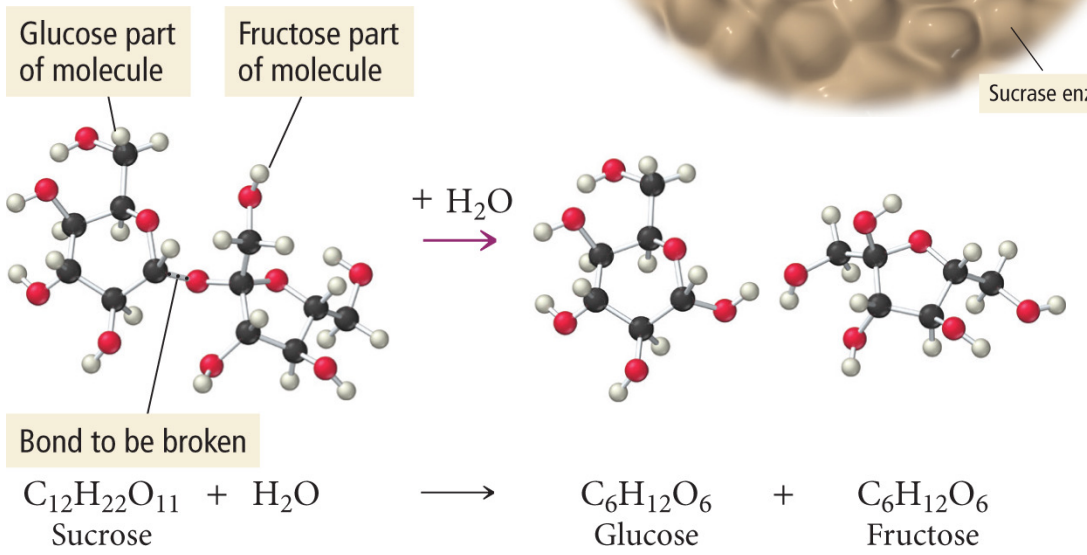
activated complex:
hypothetical transitory species that exists in high-energy transition state between reactants and products

Enzymes as Catalysts

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES$$

$$ES \xrightarrow{k_2} E + P$$





Sucrose breaks up into glucose and fructose during digestion

Learn how to draw and label an energy diagram or a reaction coordinate…

Free Energy and the Equilibrium Constant

$$\Delta G = \Delta G^\circ + RT \ln K$$

$$0 = \Delta G^\circ + RT \ln K$$

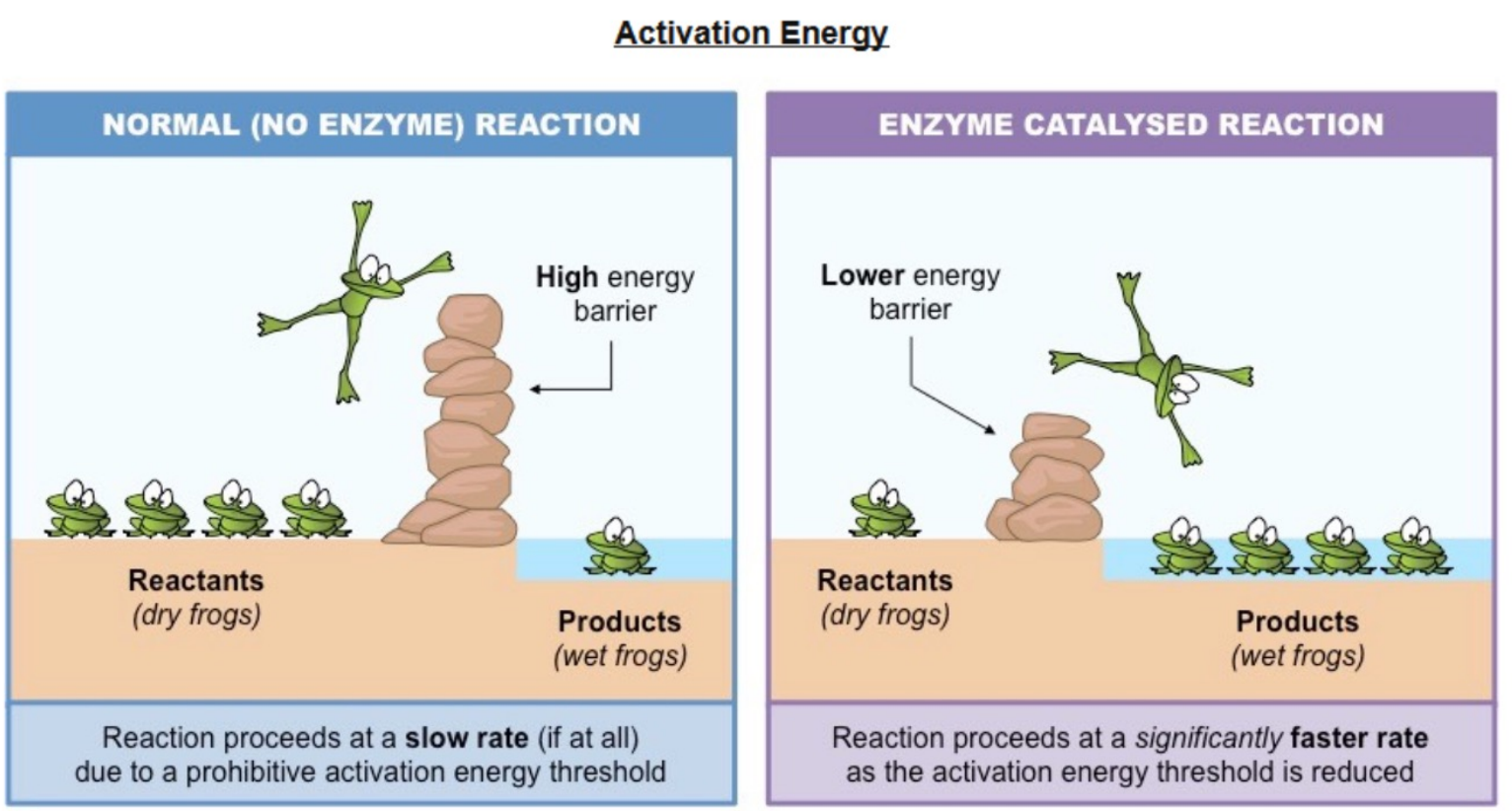
$$\Delta G^\circ = -RT \ln K$$

$$K'_{eq} = e^{-\Delta G^{\circ\prime}/RT}$$

$$K'_{eq} = e^{-\Delta G^{\circ\prime}/2.47}$$

K'_{eq}	$\Delta G^{\circ\prime}$: kJ mol^{-1}
10^{-5}	28.53
10^{-4}	22.84
10^{-3}	17.11
10^{-2}	11.42
10^{-1}	5.69
1	0
10	−5.69
10^{2}	−11.42
10^{3}	−17.11
10^{4}	−22.84
10^{5}	−28.53

Enzymes lower the activation energy barrier



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Free Energy and the Equilibrium Constant

$$\Delta G = \Delta G^{\circ\prime} + RT \ln K \qquad \Delta G^{\circ\prime} = -RT \ln K'_{eq}$$

- ΔG of a reaction ➜ depends on the nature of the reactants (ΔG°) and their concentrations (K)
- Criterion for spontaneity is ΔG, not $\Delta G^{\circ\prime}$ (standard Gibbs Free Energy at pH= 7 for biochemical reactions)
- Reactions that are not spontaneous can be made spontaneous by adjusting the concentrations of their reactants and products ➜ coupling reactions!

How do enzymes increase the rate of reaction?

Enzymes Stabilize the Transition State

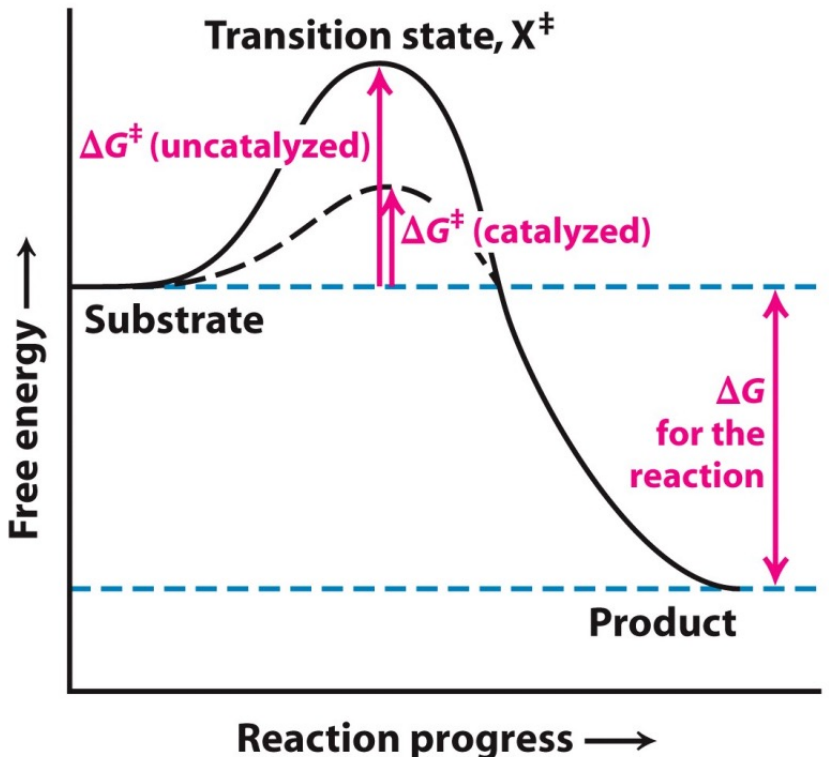
- A chemical reaction proceeds through a transition state – a fleeting molecular form that is no longer substrate but not yet product.

$$S \rightleftharpoons X^{\ddagger} \rightarrow P$$

- The transition state ($X^{\ddagger}$) is designated by the double dagger.
- The energy required to form the transition state from the substrate is called the activation energy, symbolized by $\Delta G^{\ddagger}$,

$$\Delta G^{\ddagger} = G_X^{\ddagger} - G_S$$

- Enzymes facilitate the formation of the transition state (lowers $\Delta G^{\ddagger}$).



How do enzymes stabilize the transition state?

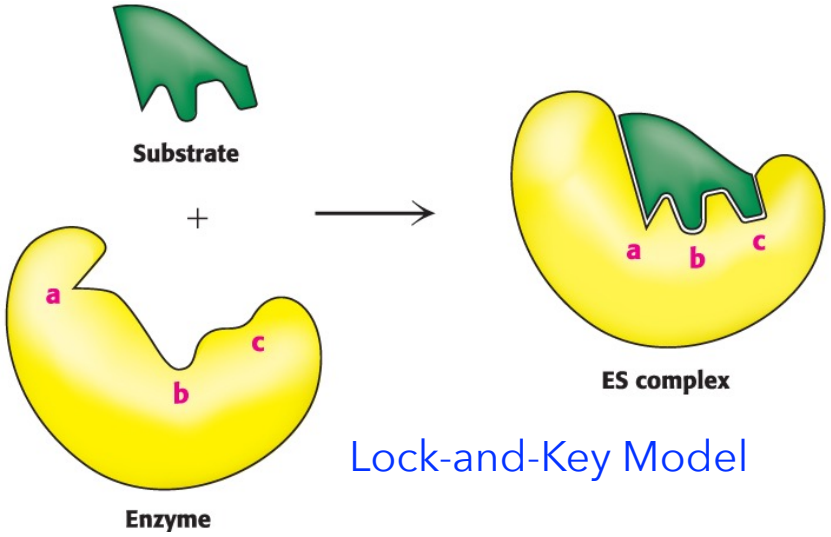
Enzyme Action

a note on optimal temperature and on weak, reversible forces

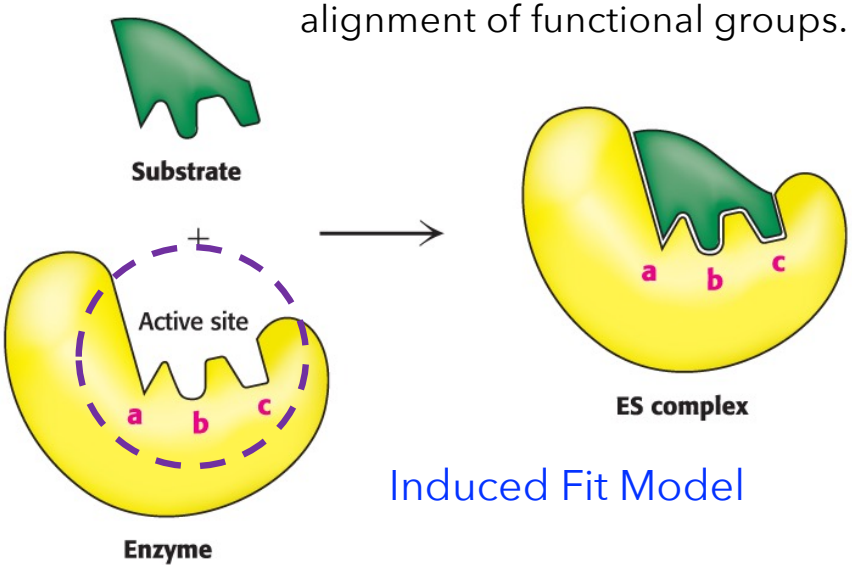
substrate
enzyme $E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \xrightarrow{k_2} E + P$ product

enzyme-substrate complex

- Enzyme-substrate interactions are fleeting, relying on molecular movements for optimal alignment of functional groups.

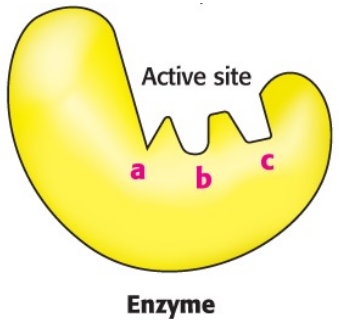


Lock-and-Key Model

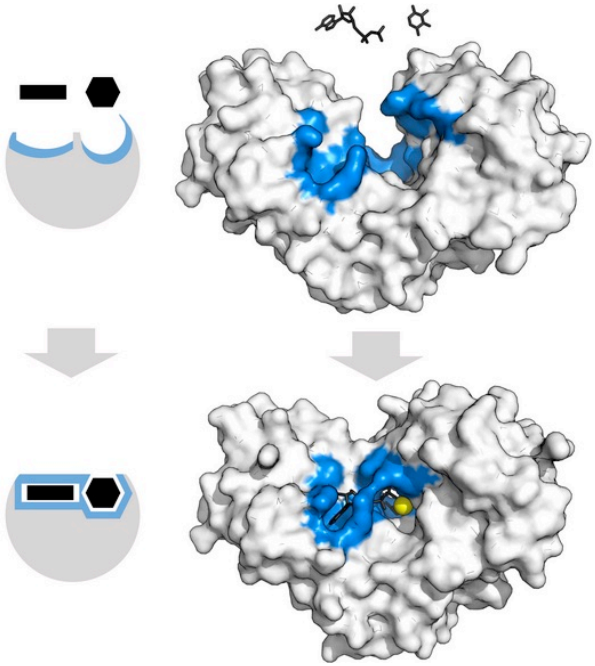


Induced Fit Model

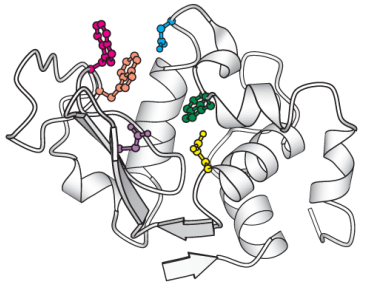
The enzyme's "Active Site"



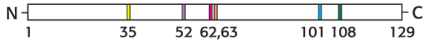
- active site → region of an enzyme that binds substrates (and cofactors, if any) and contains the catalytic groups (amino acid residues involved in bond formation/breakage).
- Facilitates the formation of the transition state → lowers the activation energy ($\Delta G^{\ddagger}$) → increasing the reaction rate.
- Proteins are flexible and exist in multiple conformations.
- Interaction between the enzyme and substrate adapts to promotes the formation of the transition state.
- The active site is critical to enzyme specificity, catalysis, and the dynamic nature of enzyme-substrate interactions.



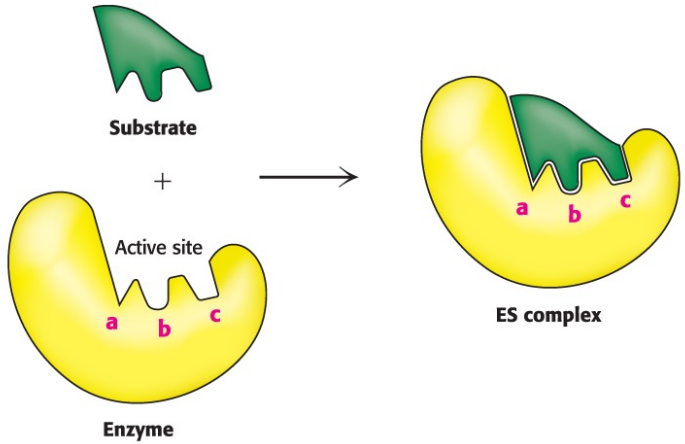
Common features of the active sites



lysozyme



- The active site is a three-dimensional cleft or crevice.
- The active site takes up a small part of the total volume of an enzyme → cooperative motions of the enzyme correctly position the catalytic residues at the active site.
- Active sites are unique microenvironments (water can be excluded, polar, nonpolar) → to optimize binding and catalysis.
- Substrates are bound to enzymes by multiple weak attractions.
- The specificity of binding depends on the precisely defined arrangement of atoms in an active site.

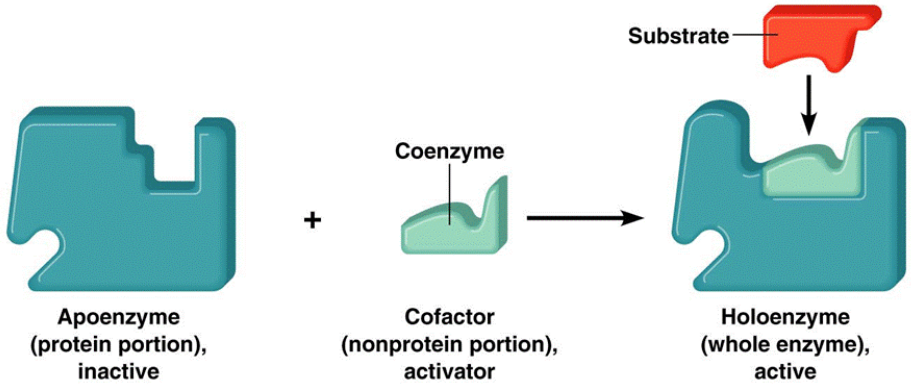


Binding Energy in Enzyme Catalysis

- binding energy ➜ free energy released when a substrate forms weak, non-covalent interactions (e.g., hydrogen bonds, ionic bonds, van der Waals forces) with the enzyme's active site
- only the correct substrate can form the maximum number of interactions with the enzyme ➜ ensuring specificity
- energy released from these interactions ➜ stabilizes the transition state ➜ lowers the energy barrier ($\Delta G^{\ddagger}$) for the reaction
- maximal binding energy occurs when the substrate is in the transition state ➜ enzyme’s active site is specifically shaped to stabilize this high-energy, unstable state
- enzyme flexibility ensures optimal alignment of the substrate in the active site ➜ maximizing binding energy and catalysis efficiency.

Many Enzymes Require Cofactors for Activity

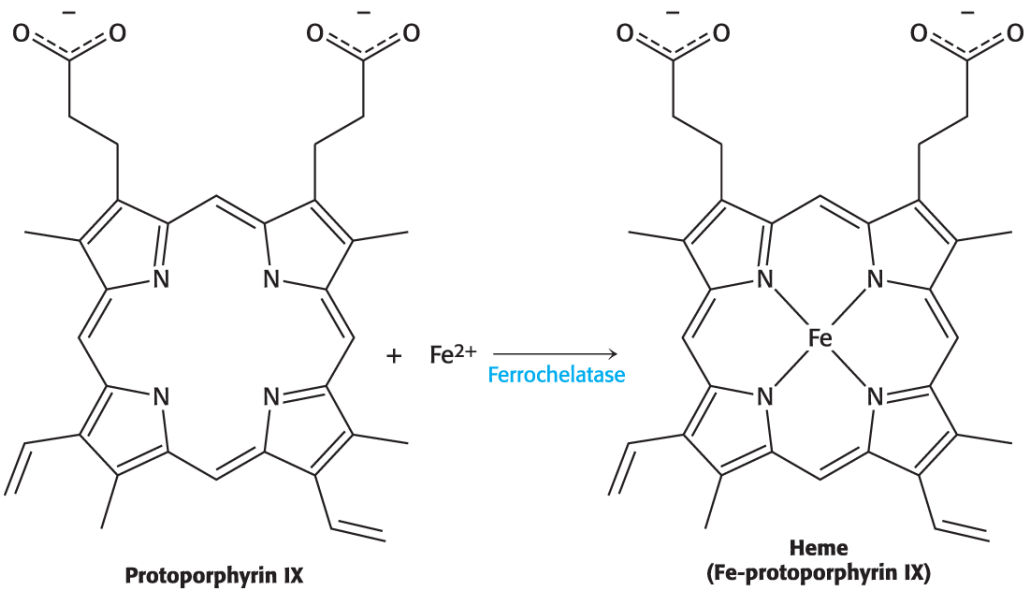
- **Cofactors** are small molecules that some enzymes require for activity: (i) coenzymes (organic molecules derived from vitamins) and (ii) metals.
- Tightly bound coenzymes are called **prosthetic groups.**
- An enzyme with its cofactor is a **holoenzyme.** Without the cofactor, the enzyme is called an **apoenzyme**.

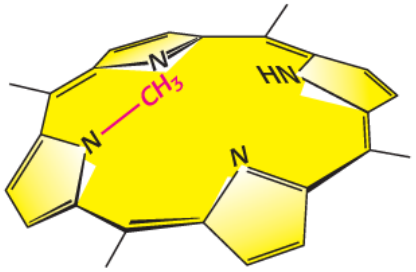


Cofactor	**Enzyme***
Coenzyme†	
Thiamine pyrophosphate (TPP)	Pyruvate dehydrogenase
Flavin adenine dinucleotide (FAD)	Monoamine oxidase
Nicotinamide adenine dinucleotide (NAD^+)	Lactate dehydrogenase
Pyridoxal phosphate (PLP)	Glycogen phosphorylase
Coenzyme A (CoA)	Acetyl CoA carboxylase
Biotin	Pyruvate carboxylase
5'-Deoxyadenosylcobalamin	Methylmalonyl mutase
Tetrahydrofolate	Thymidylate synthase
Metal	
Zn^{2+}	Carbonic anhydrase
Mg^{2+}	*Eco*RV
Ni^{2+}	Urease
Mo	Nitrogenase
Se	Glutathione peroxidase
$Mn^{2+\leftrightarrow 3+}$	Superoxide dismutase
K^+	Acetoacetyl CoA thiolase

Transition State Analogs Are Potent Inhibitors of Enzymes

- Ferrochelatase → final enzyme in the biosynthetic pathway for the production of heme → catalyzes the insertion of Fe^{2+} into protoporphyrin IX.





N-methylmesorporphyrin

N-alkylation forces bends the porphyrin → resembles the presumed transition state → potent inhibitor of ferrochelatase

Quick Quiz 1

Enzymes are specific for the reactions that they catalyze because:

A. the geometry of active sites contains protrusions that interact covalently with only their specific substrates.

B. the geometry of active sites perfectly matches their specific product.

C. they decrease the ΔG of the specific reaction.

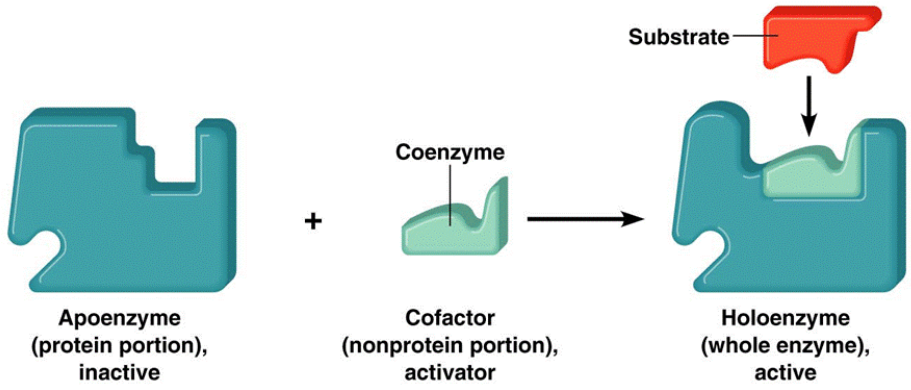
D. B & C

E. None of the above.

Quick Quiz 2

Which of the following is true of a holoenzyme but not an apoenzyme?

A. contains a cofactor
B. is catalytically inactive
C. contains a denatured active site
D. contains more than one active site
E. Both B & C



Quick Quiz 3

A reaction can take place spontaneously only if:

A. ΔG is positive.

B. ΔG is negative.

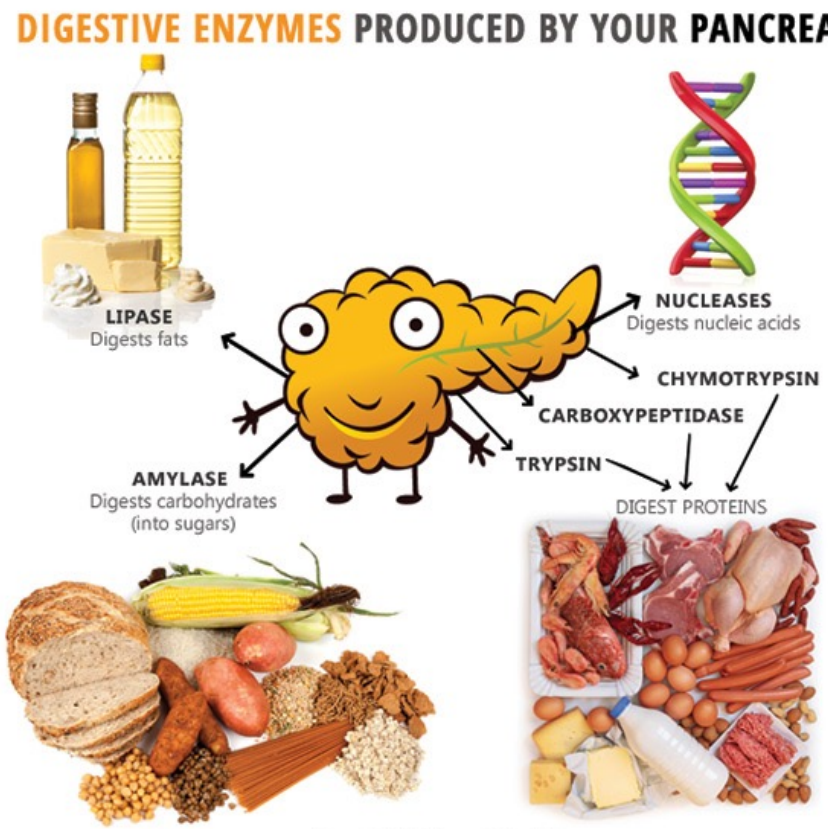
C. $\Delta G‡$ is greater than ΔG.

D. A & C

E. B & C

Major Classes of Enzymes

- **Oxidoreductases:** catalyze oxidation-reduction reactions
  - Lactate dehydrogenase – helps convert lactic acid (produced during exercise) back to pyruvate for energy recovery ('recharging a battery' by restoring energy molecules).
- **Transferases:** move functional groups between molecules
  - Aminotransferase – moves amino groups during protein metabolism
- **Hydrolases:** cleave bonds with the addition of water
  - Trypsin – breaks down proteins in your digestive system, like scissors cutting long protein chains into smaller, absorbable pieces.
- **Ligases:** joins two molecules, powered by ATP
  - DNA ligase – works like glue during DNA replication to seal DNA fragments
- **Isomerases:** rearranges atoms within a molecule.
  - Triose phosphate isomerase – during glycolysis, this enzyme switches the structure of sugars like a puzzle rearrangement to fit the next step.
- **Lyases:** adds or removes functional groups to form or break double bonds
  - Fumarase – helps the aerobic metabolism of fuels (think: making energy in mitochondria) by converting fumarate to malate, like changing gears in a car to keep it moving efficiently.


DIGESTIVE ENZYMES PRODUCED BY YOUR PANCREAS
LIPASE
Digests fats
NUCLEASES
Digests nucleic acids
CHYMOTRYPSIN
CARBOXYPEPTIDASE
TRYPSIN
AMYLASE
Digests carbohydrates
(into sugars)
DIGEST PROTEINS
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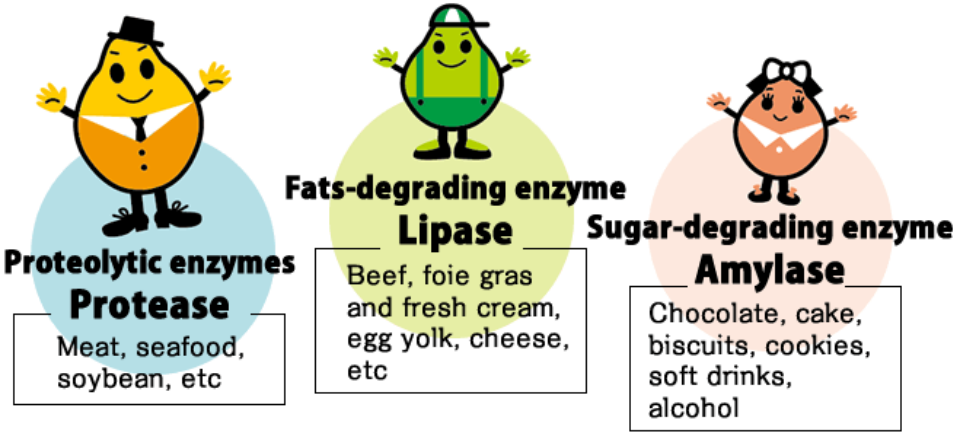
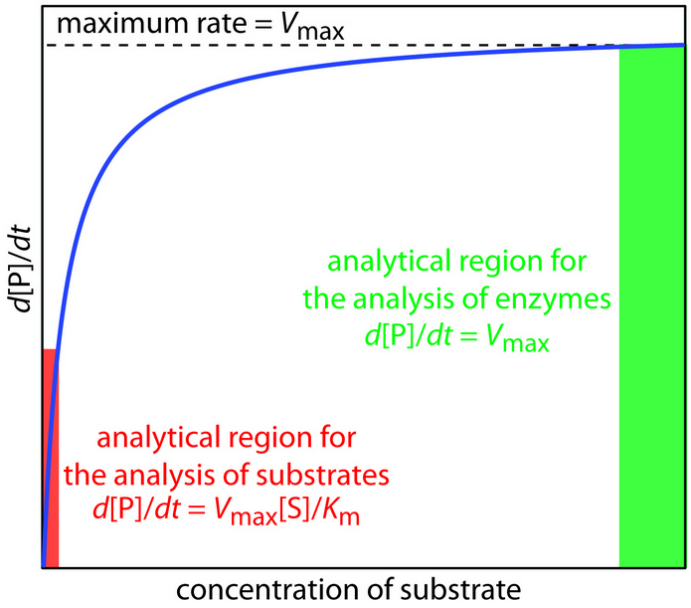

Proteolytic enzymes
Protease
Meat, seafood, soybean, etc
Fats-degrading enzyme
Lipase
Beef, foie gras and fresh cream, egg yolk, cheese, etc
Sugar-degrading enzyme
Amylase
Chocolate, cake, biscuits, cookies, soft drinks, alcohol

Kinetics and Regulation

Kinetics is the Study of Reaction Rates

- **An enzyme's activity, measured as the rate of product formation, varies with the substrate concentration.**



- The progress of the reaction can be expressed as a velocity (***V***), either the rate of disappearance of the substrate (A) or the rate of the appearance of the product (P):

A ➜ P $\qquad V = -d[A]/dt = d[P]/dt$

- Suppose that we can readily measure the disappearance of A. The velocity of the reaction is given by the formula below, where k is a proportionality constant.

$$V = k[A]$$

- Many important biochemical reactions are bimolecular or second-order reactions.

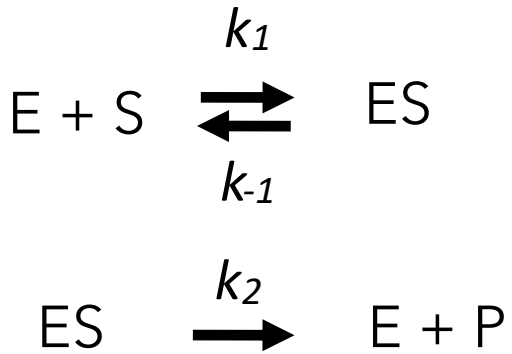
2A ➜ P $\qquad$ A + B ➜ P

The rate equations for these reactions are:

$V = k[A]^2 \qquad V = k[A][B]$

Rate of Reaction

$rate = V_0 = k_2[ES]$ catalytic velocity



Steady state approximation [Intermediate] stays constant

rate of production of ES = rate of consumption of ES

$$k_1[E][S] = k_{-1}[ES] + k_2[ES]$$

$$[E]_T = [ES] + [E] \quad \text{or} \quad [E] = [E]_T - [ES]$$

$[E]_T$ = total concentration of the enzyme
[E] = concentration of free enzyme in solution
[ES] = concentration of enzyme-substrate complex
[S] = concentration of substrate

Steady state approximation (continued)

$$k_1[E][S] = k_{-1}[ES] + k_2[ES] \quad \text{and} \quad [E] = [E]_T - [ES]$$

$$[ES] = \frac{k_1[E]_T[S]}{k_1[S] + k_{-1} + k_2}$$

Express [E] in terms of $[E]_T$ and [ES] and isolate [ES]

$$[ES] = \frac{k_1[E]_T[S]}{k_1[S] + k_{-1} + k_2} \quad \frac{\left(\frac{1}{k_1}\right)}{\left(\frac{1}{k_1}\right)}$$

Simplify by multiplying by $1/k_1$

$$[ES] = \frac{[E]_T[S]}{[S] + \frac{k_{-1} + k_2}{k_1}}$$

Michaelis constant, K_M

$$[ES] = \frac{[E]_T[S]}{[S] + K_M} \qquad K_M = \frac{k_{-1} + k_2}{k_1}$$

Michaelis constant, K_M

- has units of concentration
- Independent of enzyme and substrate concentration

$$V_0 = k_2[ES]$$

Now we make kinetic assumptions…

If [S] >> K_M

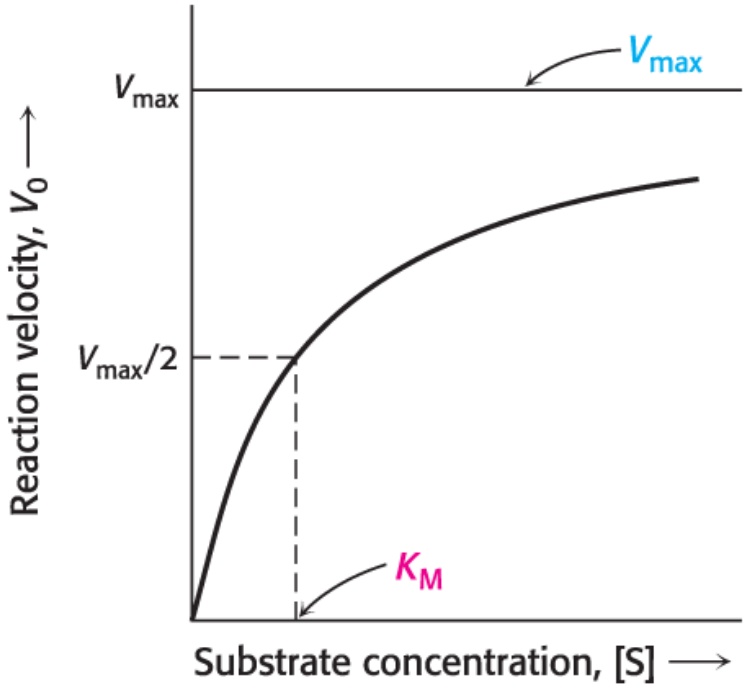
(catalytic sites on the enzymes are saturated w/ substrate)

$$rate \approx \frac{k_2[E]_T[S]}{[S]} \approx k_2[E]_T$$

maximal velocity or V_{max}

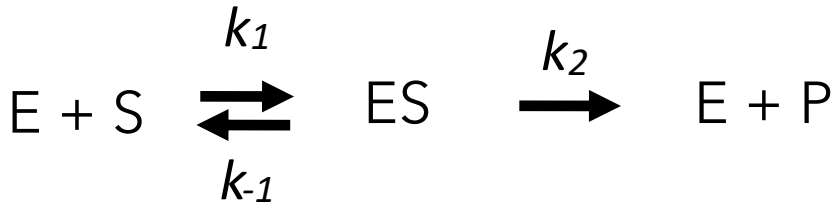
$$Vo = \frac{V_{max}[S]}{[S] + K_M}$$

Michaelis-Menten Equation



V_{max} and K_M are used to characterize enzyme-catalyzed reactions

The Michaelis-Menten Model



$$V_0 = V_{max} \frac{[S]}{[S] + K_M}$$

Michaelis-Menten Equation → described the variation of enzyme activity as a function of substrate concentration

- A specific ES complex is a necessary intermediate in catalysis.
- The initial velocity is determined by measuring product formation as a function of time and then determining the velocity soon after the reaction has started.
- Leonor Michaelis and Maud Menten derived an equation to describe the initial reaction velocity as a function of substrate concentration.

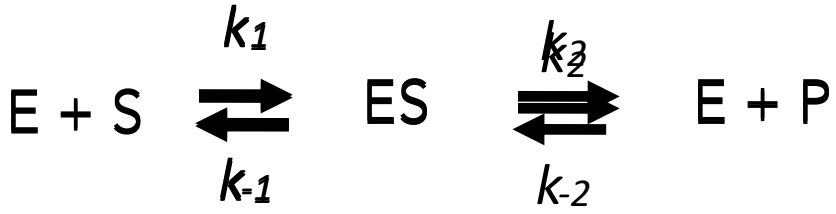
$$K_M = \frac{k_{-1} + k_2}{k_1}$$

Michaelis constant → unique to each enzyme; describes enzyme-substrate interaction

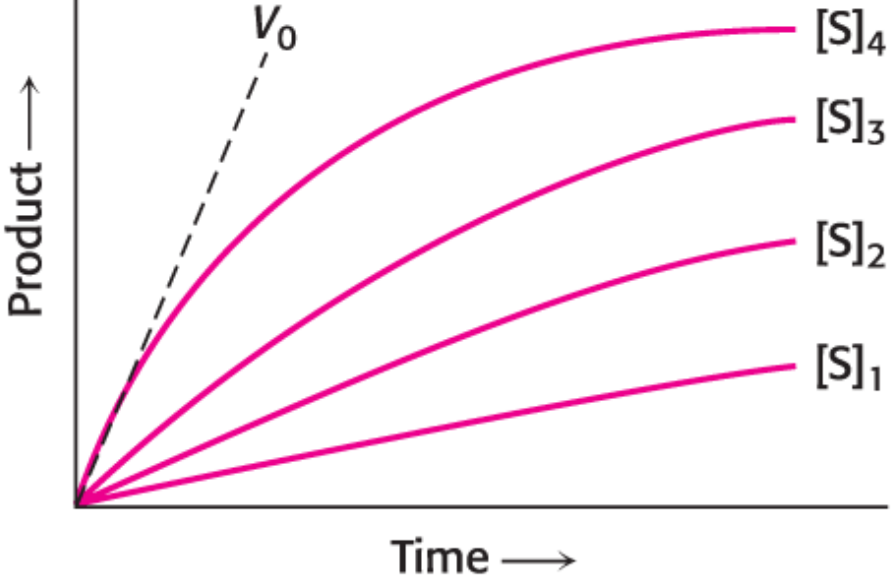
$$V_{max} = k_2[E]_T$$

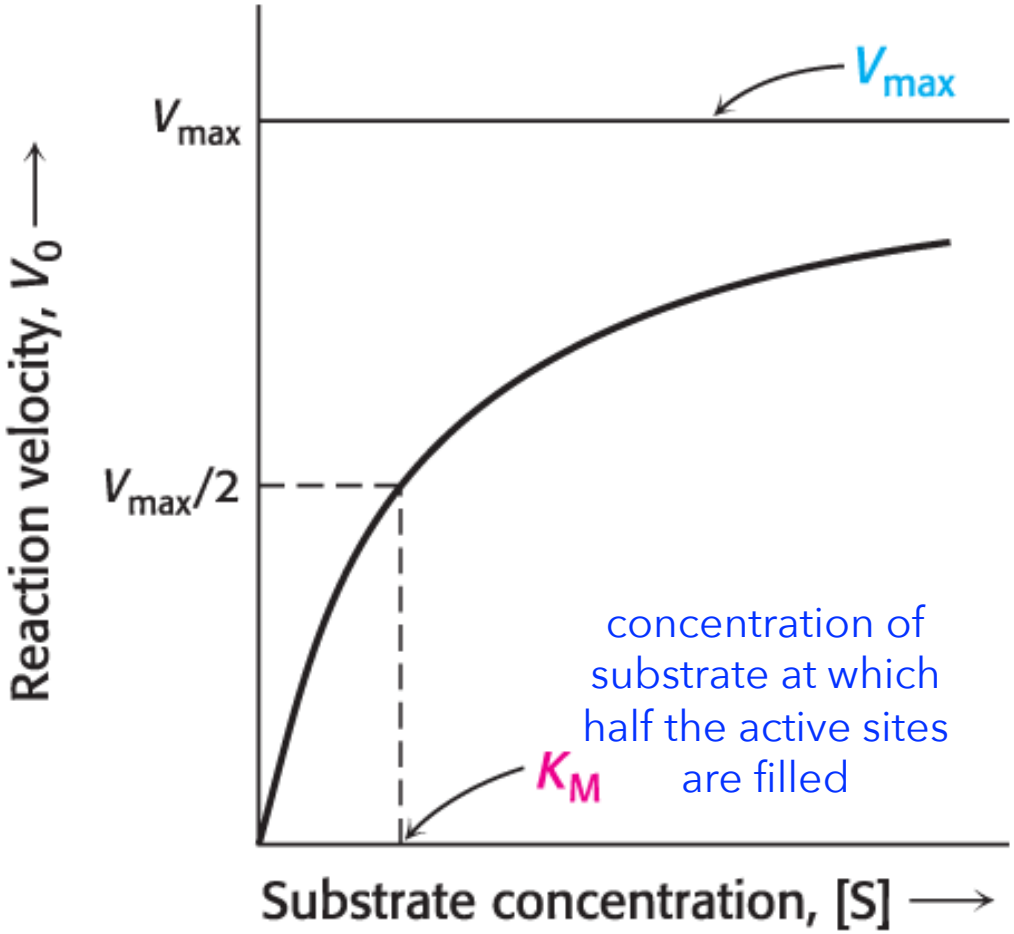
Maximal velocity → all enzymes are bound to the substrate

Experimental Determination of K_m and V_{max}



initial velocity (V_0) ➜ rate of catalysis ➜ rate of product formation at t = 0 and [P] ~ 0



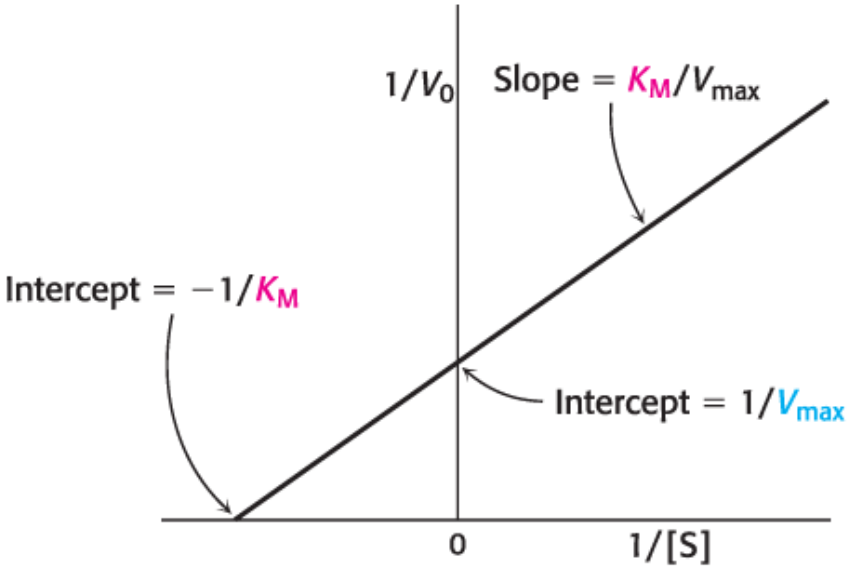


K_m and V_{max} can be determined by several means

- The Michaelis-Menten equation can be manipulated into one that yields a straight-line plot.

$$\frac{1}{V_0} = \frac{K_M}{V_{max}} \cdot \frac{1}{S} + \frac{1}{V_{max}}$$

- This double-reciprocal equation is called the Lineweaver-Burke equation.
- A double-reciprocal plot of enzyme kinetics is generated by plotting $1/V_0$ as a function 1/[S].
- The slope is K_M/V_{max}, the intercept on the vertical axis is $1/V_{max}$, and the intercept on the horizontal axis is $-1/K_M$.



Describing enzyme-catalyzed reaction

- K_M values for enzymes vary widely and evidence suggests that the K_M value is approximately the substrate concentration of the enzyme in vivo.

- If the enzyme concentration, $[E]_T$, is known, then $V_{max} = k_2[E]_T$

  and $k_2 = V_{max}/[E]_T$

- k_2, also called k_{cat}, is the turnover number of the enzyme, which is the number of substrate molecules converted into product per second when enzyme is fully saturated with substrate

Enzyme	**Substrate**	**K_M (μM)**
Chymotrypsin	Acetyl-L-tryptophanamide	5000
Lysozyme	Hexa-*N*-acetylglucosamine	6
β-Galactosidase	Lactose	4000
Carbonic anhydrase	CO_2	8000
Penicillinase	Benzylpenicillin	50

Enzyme	**Turnover number (per second)**
Carbonic anhydrase	600,000
3-Ketosteroid isomerase	280,000
Acetylcholinesterase	25,000
Penicillinase	2000
Lactate dehydrogenase	1000
Chymotrypsin	100
DNA polymerase I	15
Tryptophan synthetase	2
Lysozyme	0.5

k_{cat}/K_M is a measure of catalytic efficiency

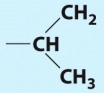
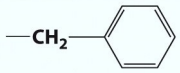
- If [S]<<K_M, we can assume that free enzyme [E] ≈ $[E]_T$. The Michaelis-Menten equation can be manipulated to yield:

$$V_0 = \frac{k_{cat}}{K_M}[S][E]_T$$

- Under these conditions, k_{cat}/K_M (specificity constant) is a measure of catalytic efficiency because it takes into account both the rate of catalysis (k_{cat}) with a particular substrate and nature of the enzyme substrate interaction (K_M).

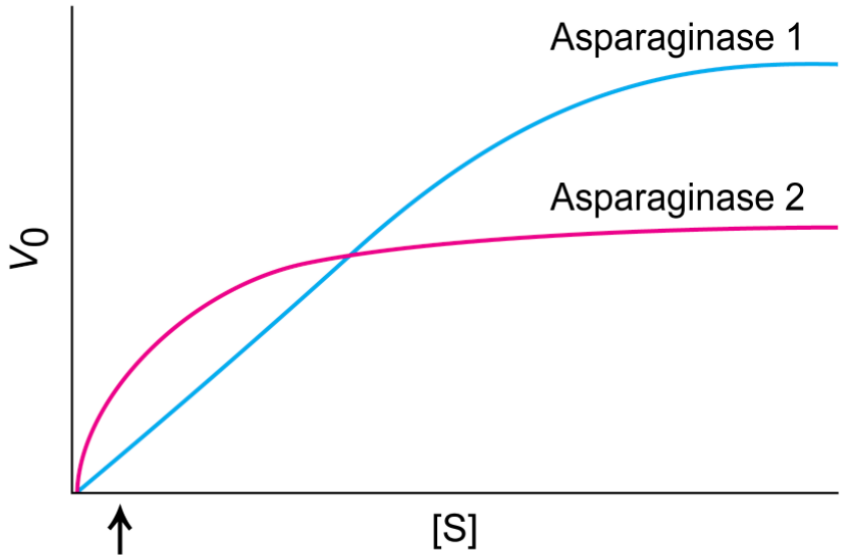
Enzyme	k_{cat}/K_M (s^{-1} M^{-1})
Acetylcholinesterase	1.6×10^8
Carbonic anhydrase	8.3×10^7
Catalase	4×10^7
Crotonase	2.8×10^8
Fumarase	1.6×10^8
Triose phosphate isomerase	2.4×10^8
β-Lactamase	1×10^8
Superoxide dismutase	7×10^9

Table 7.3 Substrate preferences of chymotrypsin

Amino acid in ester	Amino acid side chain	k_{cat}/K_M (s^{-1} M^{-1})
Glycine	H	1.3×10^{-1}
Valine		2.0
Norvaline	—$CH_2CH_2CH_3$	3.6×10^2
Norleucine	—$CH_2CH_2CH_2CH_3$	3.0×10^3
Phenylalanine		1.0×10^5

The amino acid asparagine can promote cancer cell proliferation. Treating patients with the enzyme asparaginase is sometimes used as a chemotherapy treatment. Asparaginase hydrolyzes asparagine to aspartate and ammonia.

Considering the provided Michaelis–Menten curves for two different asparaginase enzymes, complete the passage. The arrow indicates the concentration of asparagine in the human body.



The V_{max} of asparaginase 1 is [ ] the V_{max} of asparaginase 2. At the substrate concentration indicated by the arrow, asparaginase 1 reaction velocity is [ ] asparaginase 2 reaction velocity. The K_M of asparaginase 1 is [ ] the K_M of asparaginase 2. Considering the performance of the enzymes, [ ] would make a more effective chemotherapeutic agent.

A researcher purifies a mutant version of the glucokinase enzyme. She combines the purified glucokinase with glucose and ATP to produce glucose 6−phosphate. She records the initial velocity (V_0) of glucose 6−phosphate production at various substrate concentrations ([S]). She determines a Michaelis–Menten constant (K_M) of 8.5 mM for the mutant enzyme.

[S] (mM)	$V_0\left(\frac{\mu mol}{min}\right)$
5	0.67
10	0.97
50	1.5
100	1.7

Calculate the maximum velocity (Vmax) of the mutant glucokinase to one decimal place using the Michaelis–Menten equation.

Most Biochemical Reactions Include Multiple Substrates

- Multiple substrate reactions can be divided into two groups.
- ***Sequential reactions*** are characterized by formation of a ternary complex consisting of the two substrates and the enzyme.
- ***Double-displacement reactions*** are characterized by the formation of a substituted enzyme intermediate. Double-displacement reactions are also called ping-pong reactions.

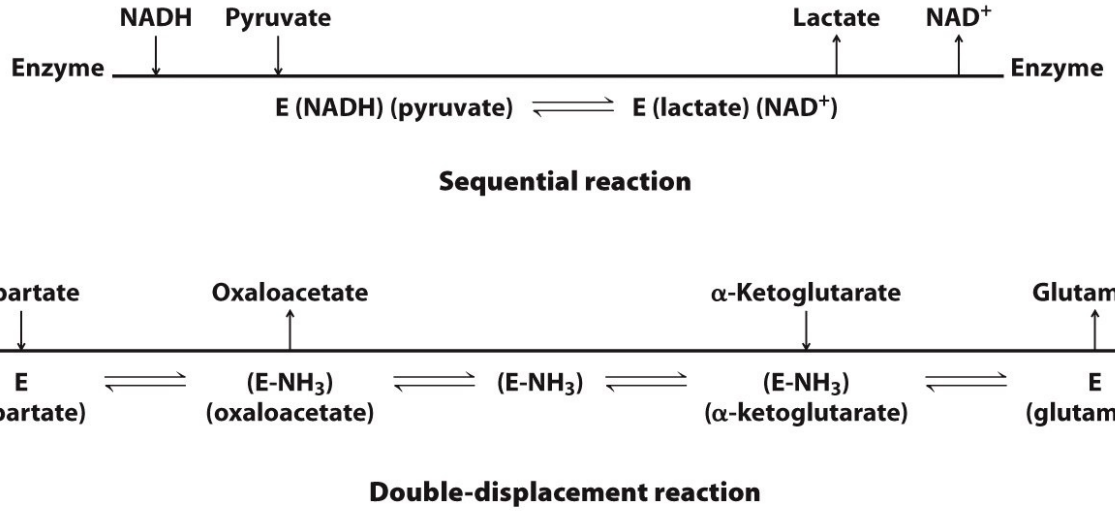
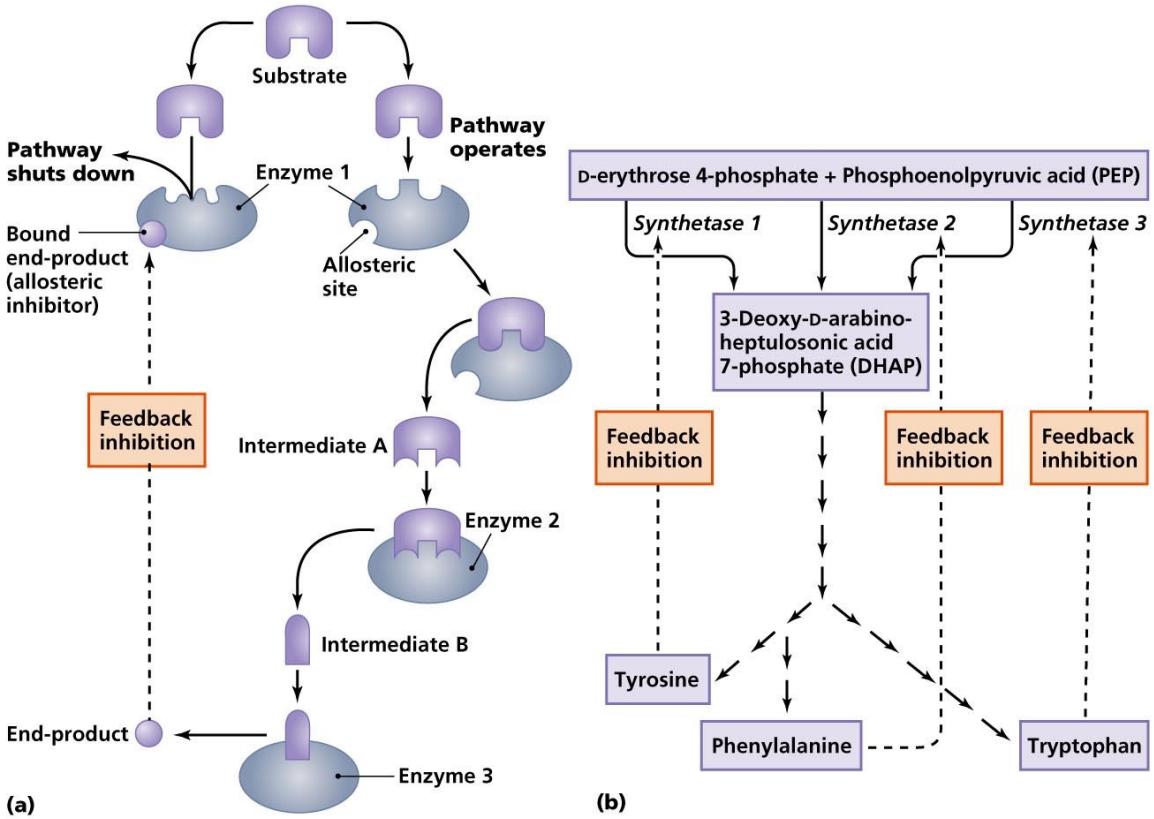


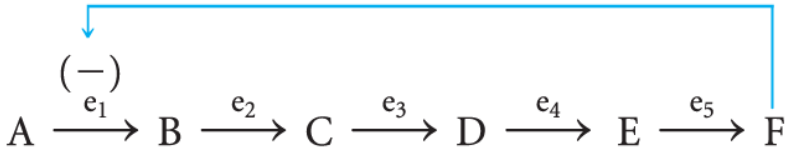
Figure 7.6
Biochemistry: A Short Course, Second Edition

Allosteric enzymes

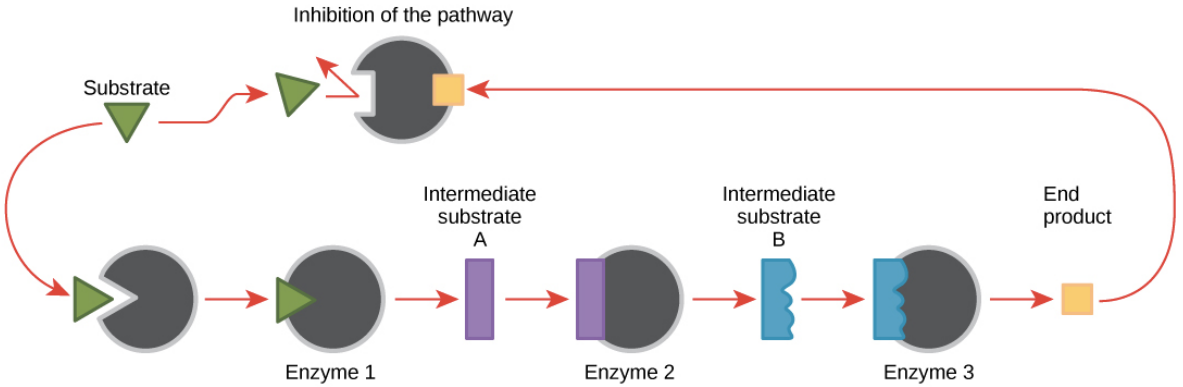
- Allosteric enzymes control the flux of biochemical reactions in metabolic pathways.



Allosteric enzymes

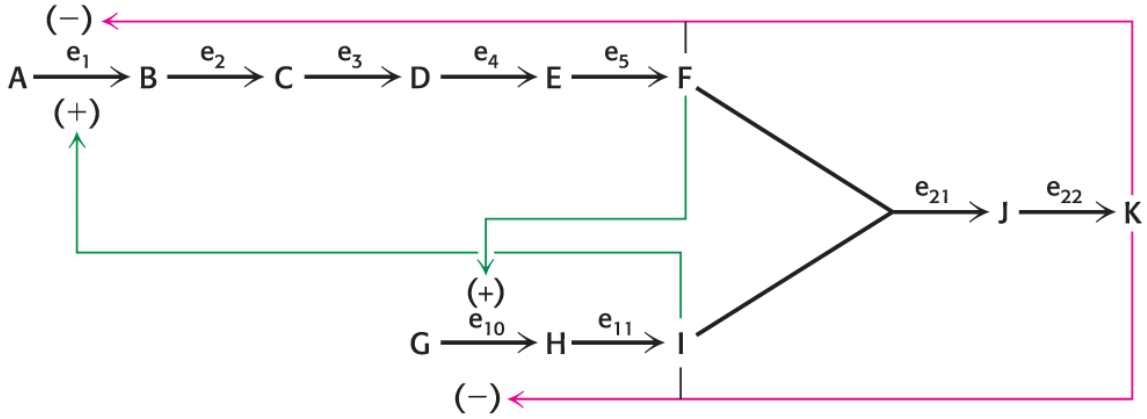


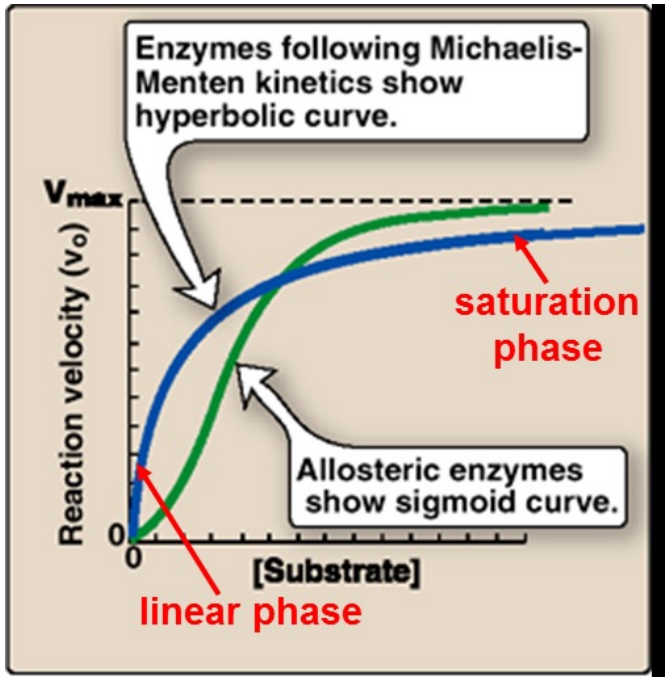
- The conversion of A to B is the committed step, because once this occurs B is committed to being converted into F.
- Allosteric enzymes catalyze the committed step of metabolic pathways.
- Michaelis-Menten enzymes facilitate the remaining steps.
- The amount of F synthesized can be regulated by feedback inhibition.
- The pathway product F inhibits enzyme e_1 by binding to a regulatory site on the enzyme that is distinct from the active site.



Allosteric enzymes

- The regulation of metabolic pathways can be quite complex.
- Allosteric enzymes may be inhibited or stimulated by several regulatory molecules.





- The reaction velocity of allosteric enzymes displays a sigmoidal relationship to substrate concentration.

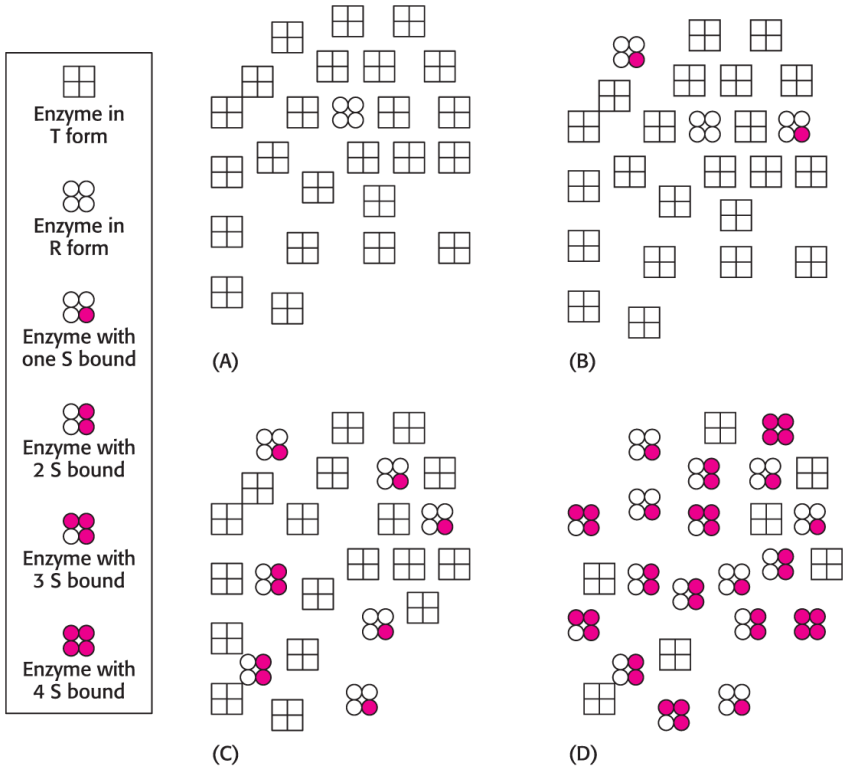
Allosteric Enzymes and Quaternary Structure

- All allosteric enzymes display quaternary structure with multiple active sites and regulatory sites.
- One model that explains the behavior of allosteric enzymes is the ***concerted model***.

Features of the concerted model:

- The enzyme exists into two different quaternary structures, designated ***T(tense)*** and ***R (relaxed).***
- T and R are in equilibrium, with T being the more stable state.
- The R state is enzymatically more active than the T state.
- All active sites must be in the same state.

- The ***sequential model*** for allosteric enzymes proposes that subunits undergo sequential changes in structure



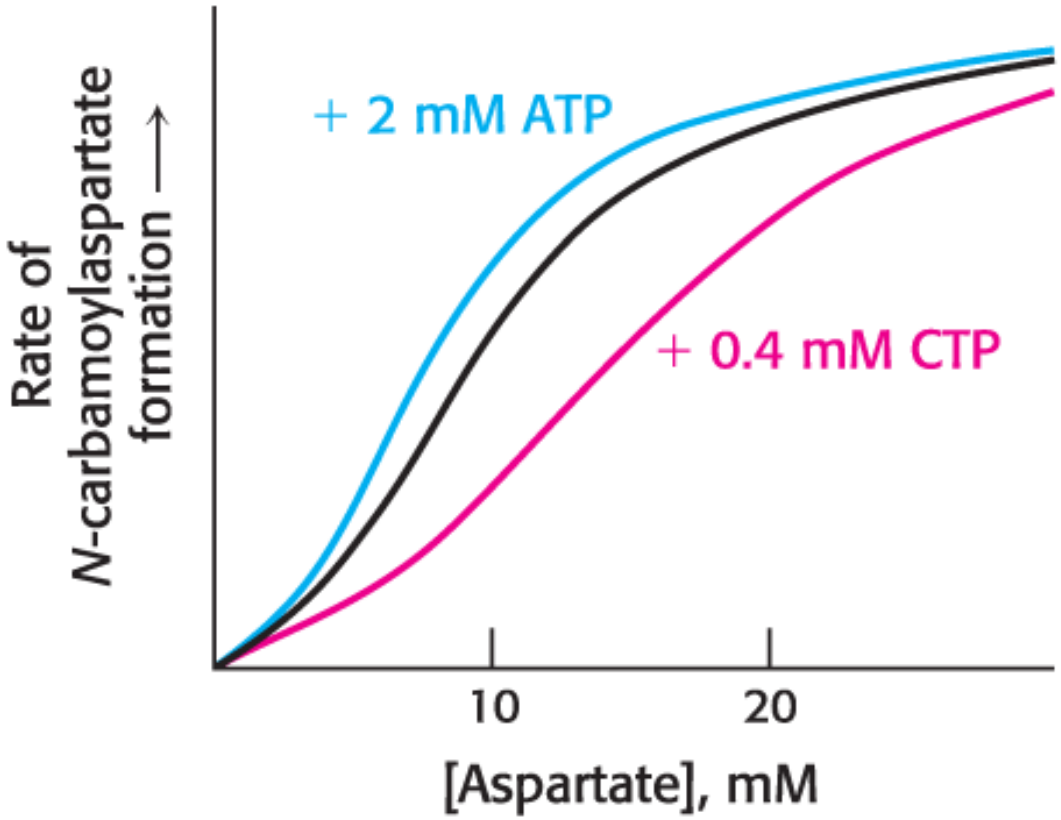
Quick Quiz 5

An allosteric enzyme can exist in two states, _____ and _____.

A. tight; responsive
B. tense; responsive
C. tense; relaxed
D. tight; relaxed
E. turgid; relaxed

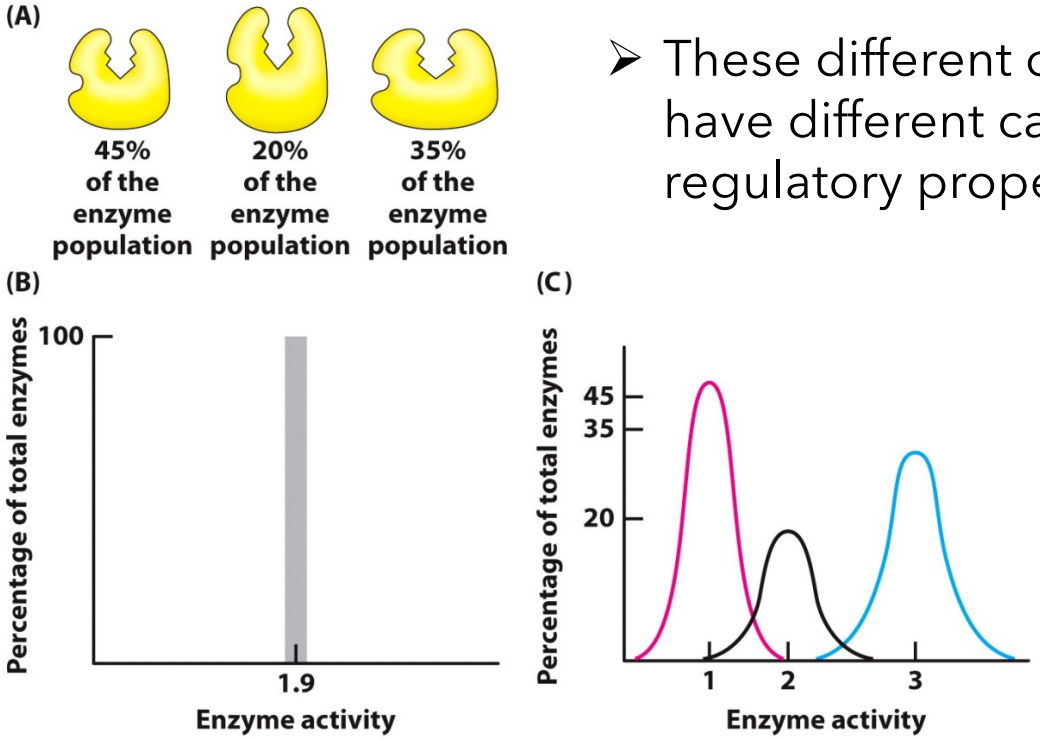
Regulator Molecules Modulate the R ⇌ T Equilibrium

- Allosteric regulators disrupt the R ⇌T equilibrium when they bind the enzyme.
- Inhibitors stabilize the T state while activators stabilize the R state.
- The disruption of the T ⇌ R equilibrium by substrates is called the ***homotropic*** effect.
- The disruption of the T ⇌ R equilibrium by regulators is called the ***heterotrophic*** effect.

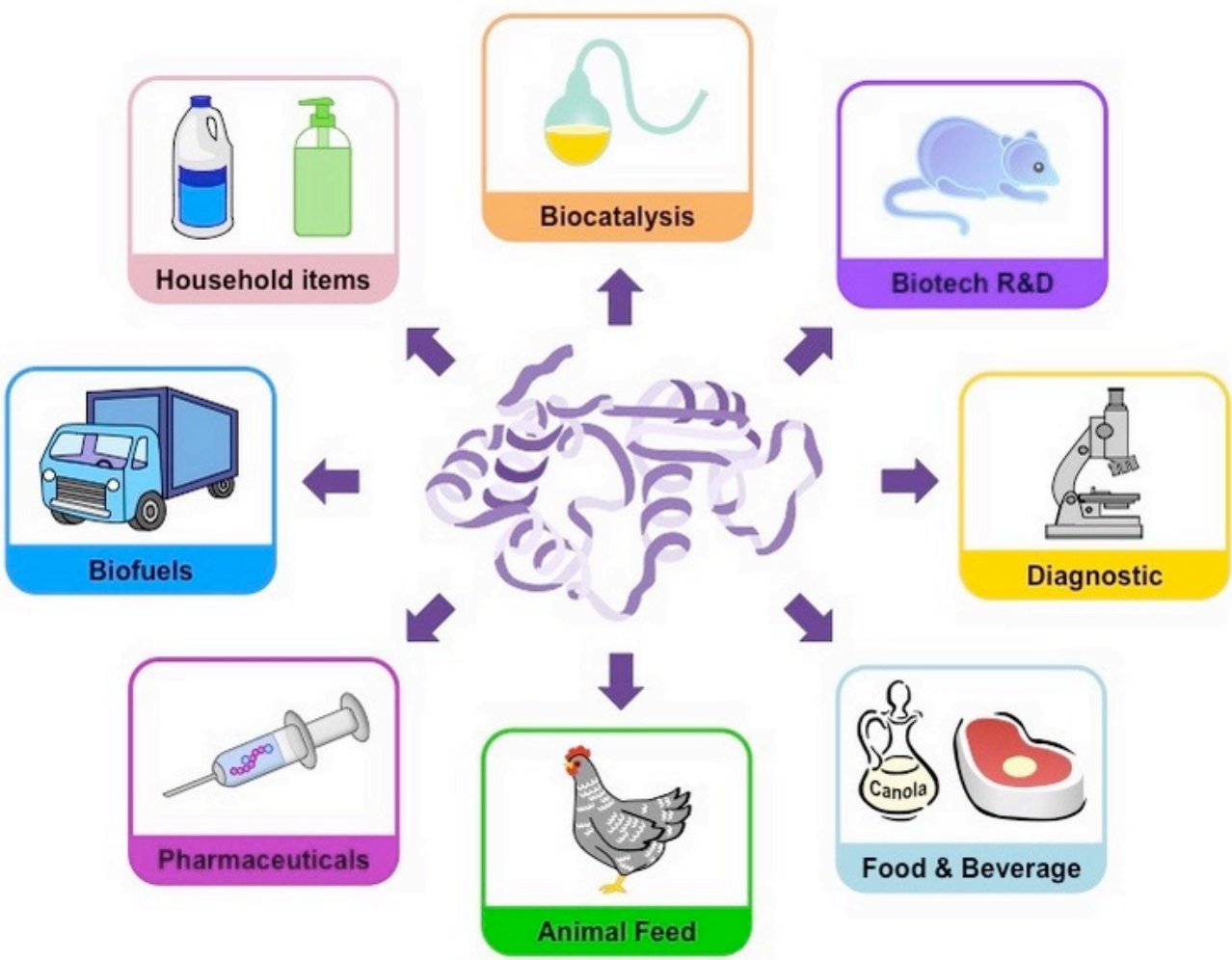


Enzymes Can Be Studied One Molecule at a Time

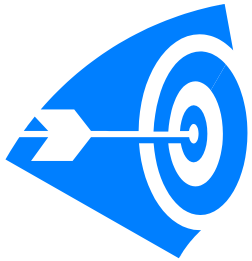
- Studies of individual enzyme molecules suggest that some enzymes may exist in multiple conformations that are in equilibrium.



- These different conformations may have different catalytic or regulatory properties.


Household items
Biocatalysis
Biotech R&D
Biofuels
Diagnostic
Pharmaceuticals
Animal Feed
Canola
Food & Beverage

Assigned Problems



Chapter	Tymochko, Berg, Stryer, Biochemistry, 2nd Edition,	**Chapter**	Tymochko, Berg, Stryer, Biochemistry, 2nd Edition,
6	11, 12 - 21	7	3, 6, 7, 9, 10, 13, 15, 19, 20, 22, 25, 28, 29
Chapter	Tymochko, Berg, Stryer, Biochemistry, 3nd Edition,	**Chapter**	Tymochko, Berg, Stryer, Biochemistry, 3nd Edition,
6	11, 12 - 21	7	3, 6, 7, 9, 10, 12, 16, 20, 21, 23, 26, 29, 30