BIO303 - Biochemistry II

PPT Lec-55 To Lec-70

QUIZ NO # 2 **(Solution)**

Aug 22, 2022 12:00 AM

Aug 24, 2022 11:59 PM

By Muhammad Faryad

Red and green line take you to mcqs while searching.

Nucleotides and Nucleic Acids

Transfer RNA (tRNA) (Countinued)

Arms or loops of tRNA

- All tRNA molecules contain 4 main arms or loops.
- **1-Acceptor arm:** This is made up of unpaired sequences of cytosine-cytosine-adenine (CCA) at the 3´end.

Nucleotides and Nucleic Acids

- The 3´OH group of adenine binds with the carboxylic group of a specific amino acid and carries it to ribosomes for protein synthesis.

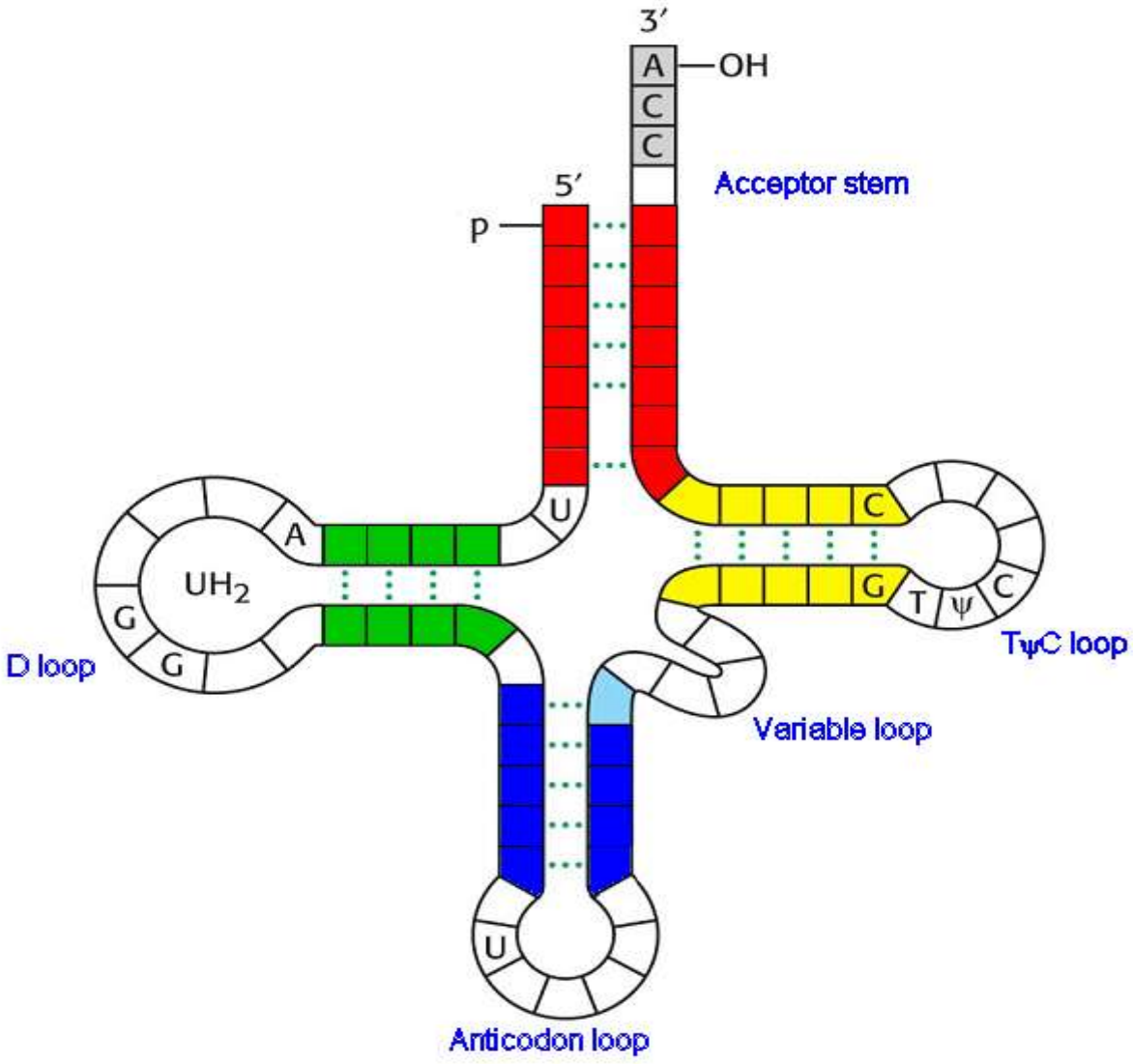
Nucleotides and Nucleic Acids

- **2-Anticodon arm:** It is in the form of a loop and carries specific sequences of three bases which constitute the anticodon.
- The bases of anticodon are bonded with three complementary bases of codon on mRNA.

Nucleotides and Nucleic Acids

- **3-D arm:** It contains the base dihydrouridine.
- **4-TΨC arm:** It contains thymine, pseudouridine and cytosine.
- The extra arm and the TΨC arms help to define a specific tRNA.

Nucleotides and Nucleic Acids



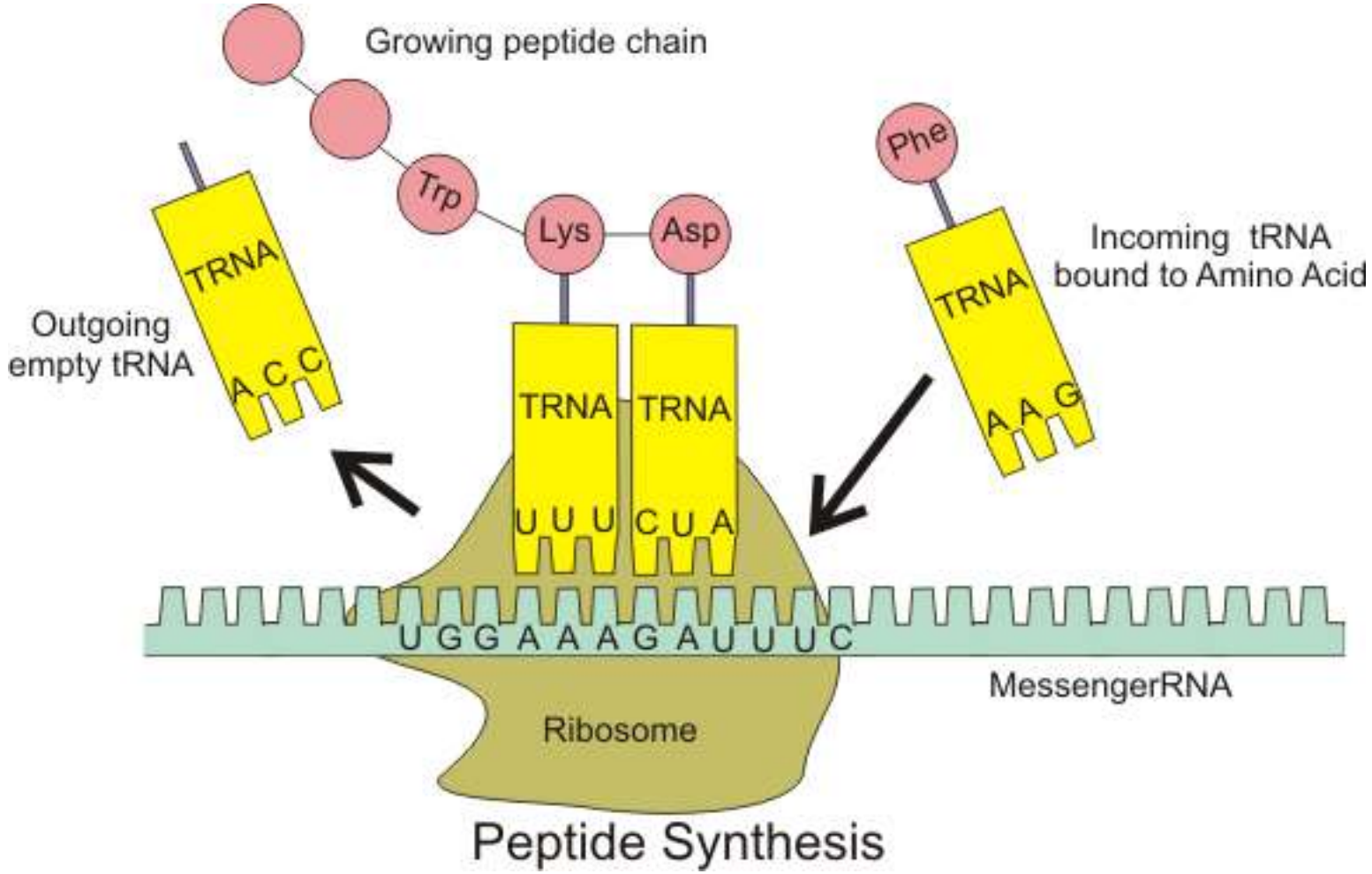
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Nucleotides and Nucleic Acids

Function of tRNA

- The t RNA molecules serve as ADAPTERS for the translation of information in the sequence of nucleotides of the mRNA into specific amino acids.

Nucleotides and Nucleic Acids



Nucleotides and Nucleic Acids

- There is at least one (and often several) specific type of tRNA molecule for each of the amino acids commonly found in proteins.
- Each t RNA carries its specific amino acid to the site of protein synthesis.

Nucleotides and Nucleic Acids

- There it recognizes the genetic code word on mRNA (codon) and this specifies the addition of its amino acids to the growing peptide chain.

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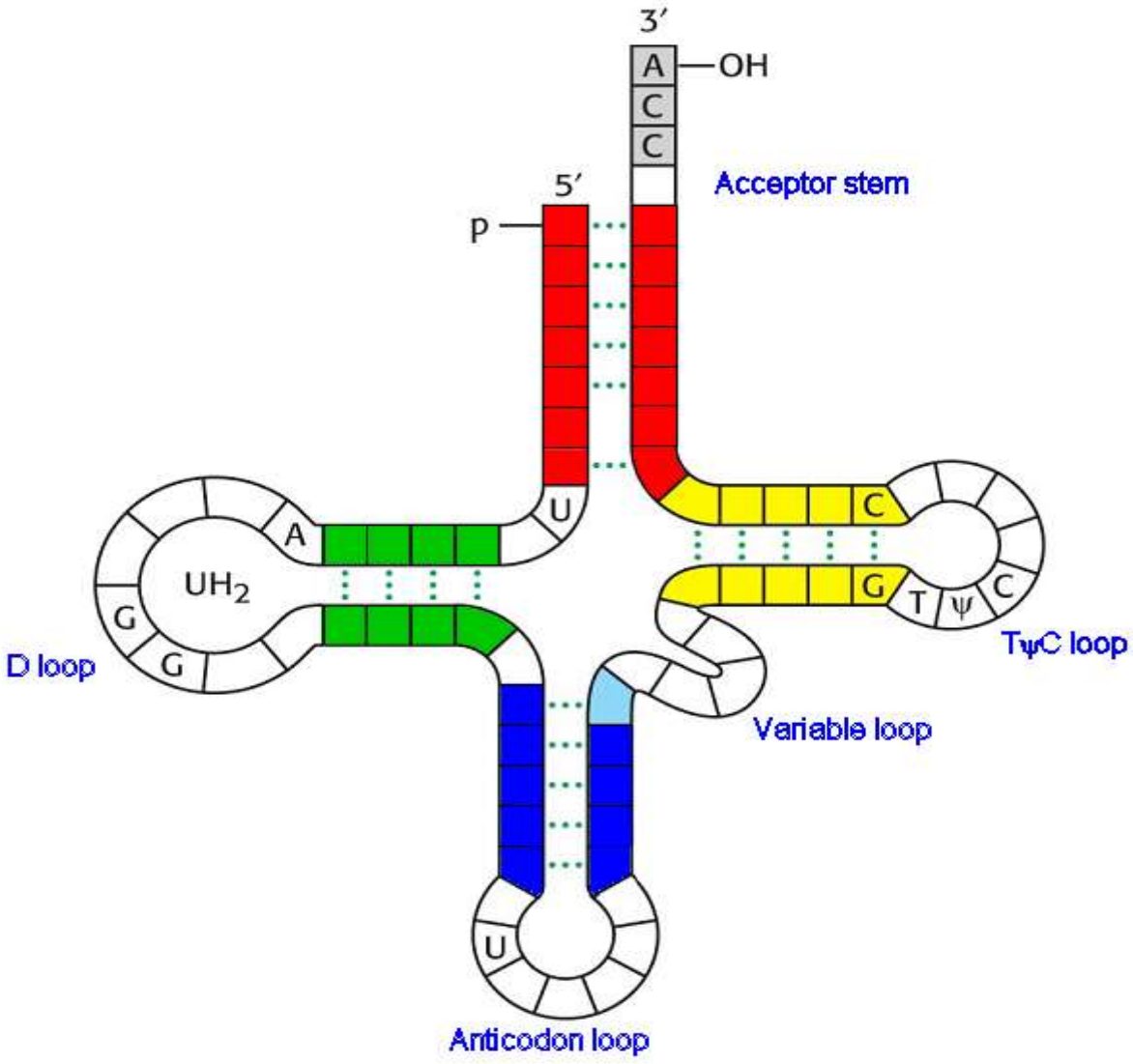
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Nucleotides and Nucleic Acids



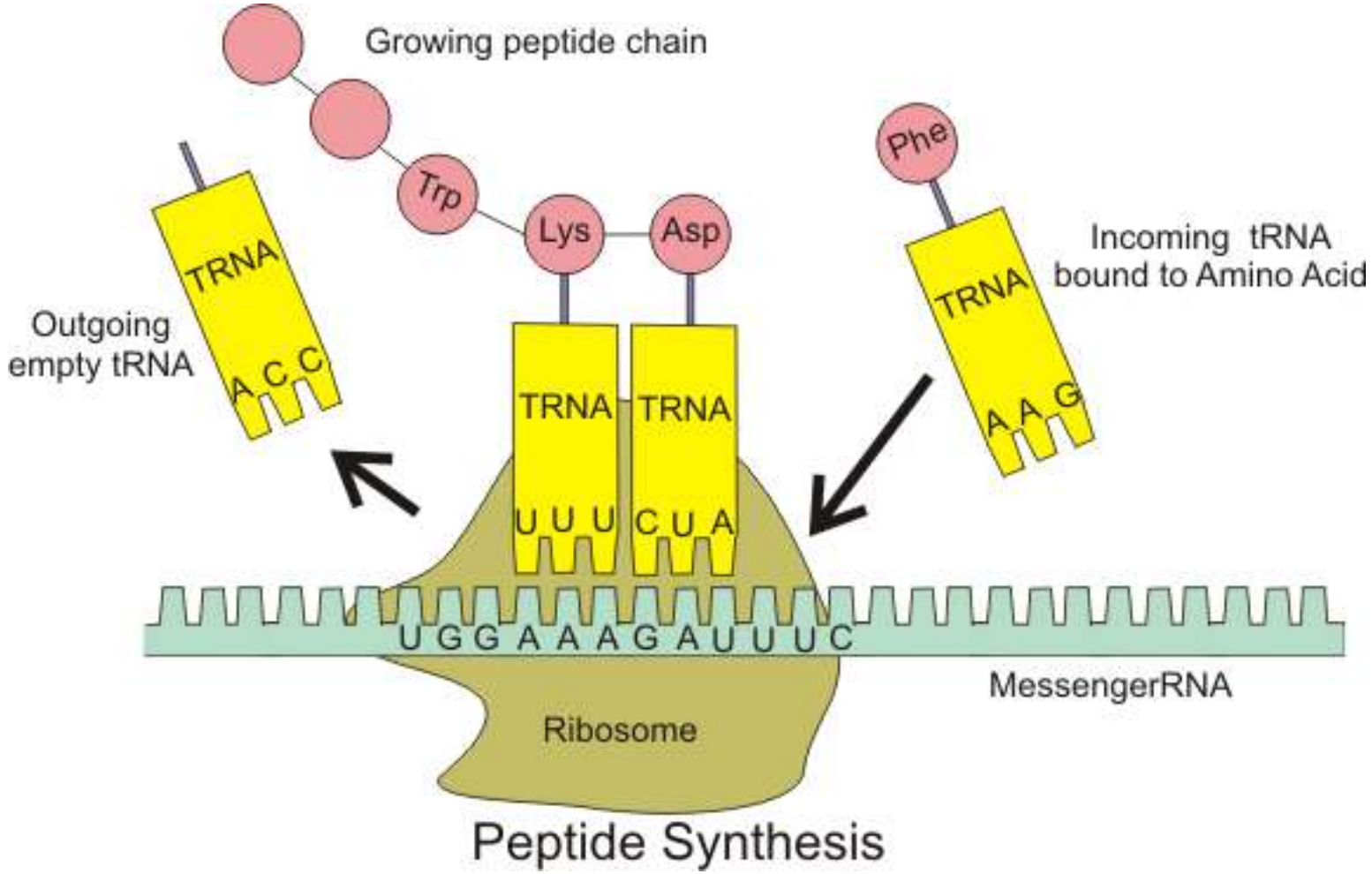
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Nucleotides and Nucleic Acids

Ribosomal RNA (rRNA)

- found in association with several proteins as a component of ribosomes--- a cytoplasmic nucleoprotein structure that acts as the machinery for the synthesis of proteins from the mRNA template.

Nucleotides and Nucleic Acids

- RNAs make up 80% of the total RNA in the cell.
- The ribosomal subunits are defined according to their sedimentation velocity in **Svedberg units**.

Nucleotides and Nucleic Acids

- Svedberg unit is related to the molecular weight and shape of the compound.
- The bases in r RNA are mainly adenine, guanine, cytosine and uracil and a few pseudouridine

Nucleotides and Nucleic Acids

Eukaryotic Ribosome

- The mammalian ribosome contains two major nucleoprotein subunits:
- a larger one with 60S
- a smaller one with 40S.

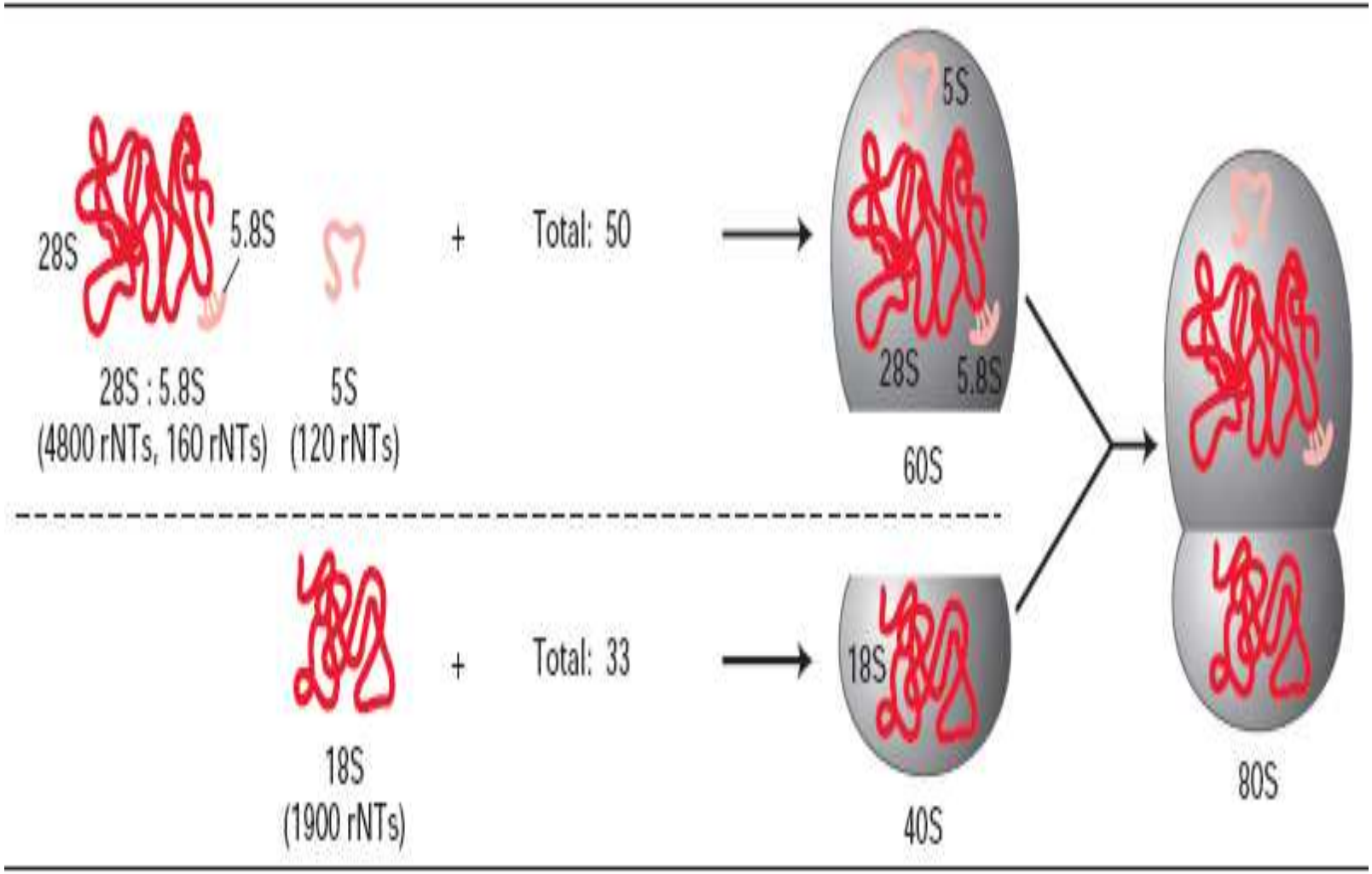
Nucleotides and Nucleic Acids

- The **60S** subunit contains
- a 5S rRNA
- a 5.8S rRNA
- a 28S rRNA
- more than 50 specific polypeptides.

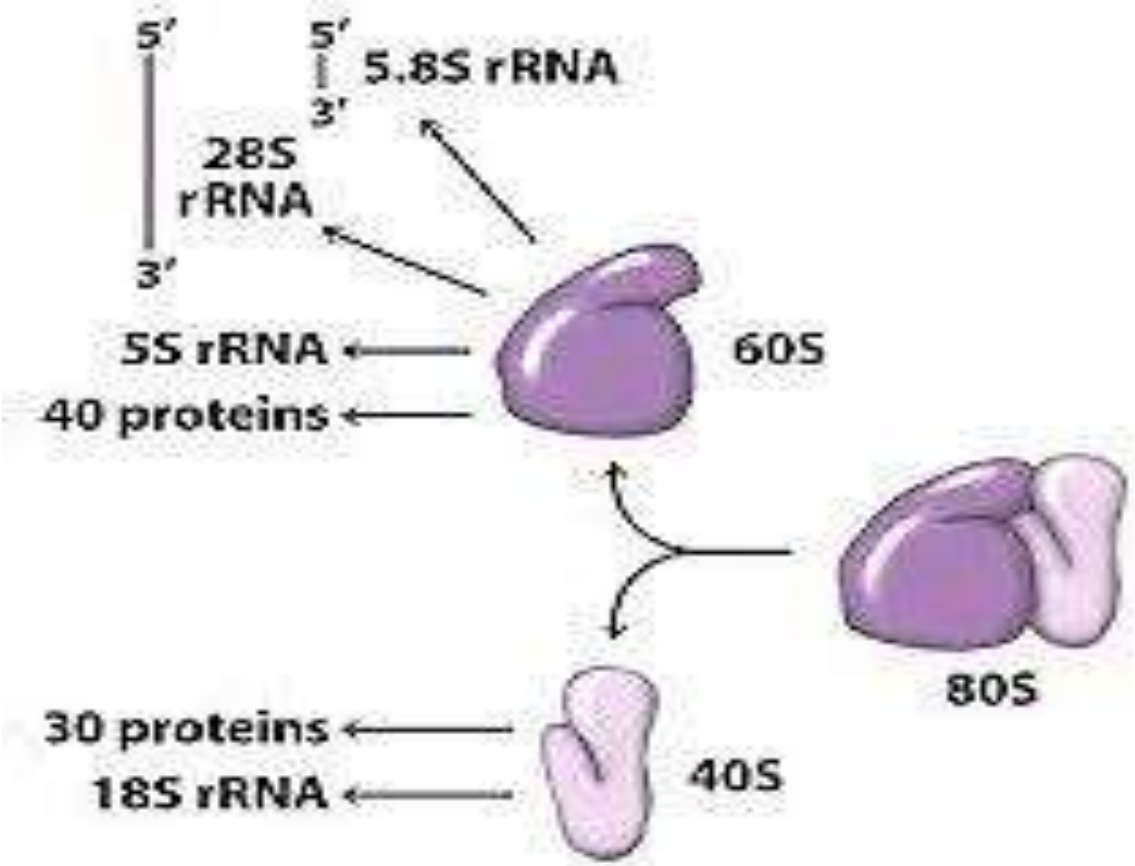
Nucleotides and Nucleic Acids

- The **40S** subunit is smaller and contains
- a single 18S rRNA
- Approx. 30 distinct polypeptide chains.

Nucleotides and Nucleic Acids



Nucleotides and Nucleic Acids



Alternate diagram

Nucleotides and Nucleic Acids

- In eukaryotes, all of the ribosomal RNA molecules except the 5S rRNA, which is independently transcribed, are processed from a single 45S precursor RNA molecule in the nucleolus- packed with the specific ribosomal proteins.

Nucleotides and Nucleic Acids

- The rRNA are necessary for ribosomal assembly and play a key role in the binding of mRNA to ribosomes and its translation
- In the cytoplasm, the ribosomes remain quite stable and capable of many translation cycles

Nucleotides and Nucleic Acids

Other types of RNA

Small nuclear RNA (snRNA)

- Small nuclear RNA (snRNA) are large number of small stable RNA species found in eukaryotic cells.
- Most of them are complexed with proteins to form ribonucleoproteins.

Nucleotides and Nucleic Acids

- They are distributed in the nucleus, in the cytoplasm or in both.
- They are significantly involved in rRNA and mRNA processing and gene regulation.

Nucleotides and Nucleic Acids

- **Large & Small Noncoding Regulatory RNAs**
- One of the most exciting discoveries in the last decade of eukaryotic regulatory biology has been the identification and characterization of regulatory nonprotein coding RNAs (ncRNAs).

Nucleotides and Nucleic Acids

- NcRNAs exist in two general size classes,
- small consisting of microRNA (miRNAs) and silencing (siRNAs) and

- Large consisting of long noncoding RNAs (lncRNAs)

Nucleotides and Nucleic Acids

- The small ncRNAs termed microRNA (miRNAs) and silencing (siRNAs) typically inhibit gene expression at the level of specific protein production by
- targeting mRNAs through one of several distinct mechanisms.

Nucleotides and Nucleic Acids

- Both siRNAs and miRNAs typically hybridize, via the formation of RNA–RNA hybridization to their targeted mRNAs

Nucleotides and Nucleic Acids

- **long noncoding RNAs (lncRNAs).**
- LncRNAs, which as their name implies, do not code for protein (ie, the mRNA encoding genes).
- ncRNAs make up a significant portion of eukaryotic transcription

Nucleotides and Nucleic Acids

- ncRNAs play many roles ranging from contributing to structural aspects of chromatin to regulation of mRNA gene transcription by RNA polymerase II.

END

Enzymes

IUB Classification of Enzymes

- International Union of Biochemists (IUB) developed an unambiguous system of enzyme nomenclature in which each enzyme has a
- unique name and
- code number

Unique name and code no identify the type of reaction catalyzed and the substrates involved

Enzymes

- As an example, the formal systematic name of the enzyme (hexokinase) catalyzing the reaction
- ATP + D-glucose→ ADP + D-glucose-6 phosphate is
- ATP:glucose phosphotransferase,

ATP:glucose phosphotransferase

Enzymes

- Its Enzyme Commission (E.C.) number is 2.7.1.1.
- (2) denotes the class name (transferase)
- (7) the subclass phosphotransferase
- (1) denotes a hydroxyl group as acceptor
- (1) D-glucose as the phosphoryl group acceptor.

Enzymes

- In the systematic naming system, enzymes are divided into six major classes each with numerous subgroups

Enzymes

CLASSIFICATION OF ENZYMES

Group of Enzyme	Reaction Catalysed	Examples
1. Oxidoreductases	Transfer of hydrogen and oxygen atoms or electrons from one substrate to another.	Dehydrogenases Oxidases
2. Transferases	Transfer of a specific group (a phosphate or methyl etc.) from one substrate to another.	Transaminase Kinases
3. Hydrolases	Hydrolysis of a substrate.	Estrases Digestive enzymes
4. Isomerases	Change of the molecular form of the substrate.	Phospho hexo Isomerase, Fumarase
5. Lyases	Nonhydrolytic removal of a group or addition of a group to a substrate.	Decarboxylases Aldolases
6. Ligases (Synthetases)	Joining of two molecules by the formation of new bonds.	Citric acid synthetase

Enzymes

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3. Hydrolases	**Hydrolysis of a substrate.**	**Estrases Digestive enzymes**

Enzymes

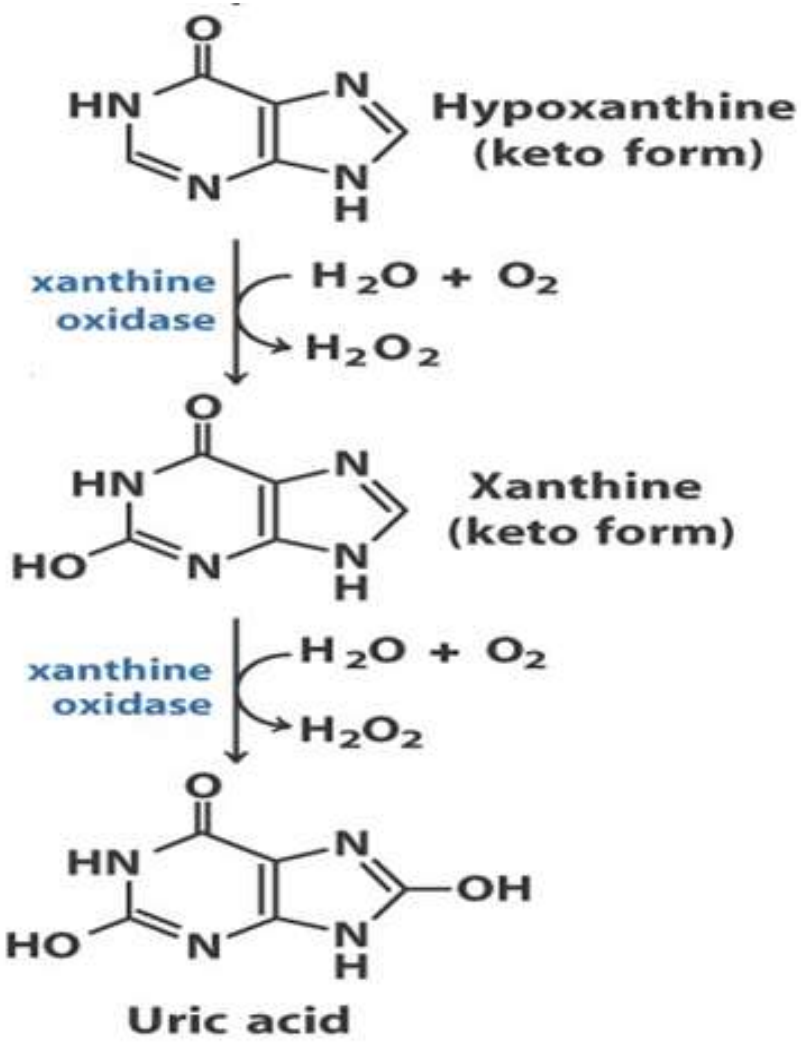
CLASSIFICATION OF ENZYMES		
Group of Enzyme	**Reaction Catalysed**	**Examples**
4. Isomerases	**Change of the molecular form of the substrate.**	**Phospho hexo Isomerase, Fumarase**
5. Lyases	**Nonhydrolytic removal of a group or addition of a group to a substrate.**	**Decarboxylases Aldolases**
6. Ligases (Synthetases)	**Joining of two molecules by the formation of new bonds.**	**Citric acid Synthetase**

Enzymes

1) Oxidoreductases

- catalyze oxidation reduction reactions
- further divided into four subgroups;
- Oxidase,
- Dehydrogenases,
- Hydroperoxidases
- Oxygenases.

Enzymes



- Two reactions both catalyzed by Xanthine oxidase are given
- Hypoxanthine → xanthine
- Xanthine → Uric acid

Enzymes

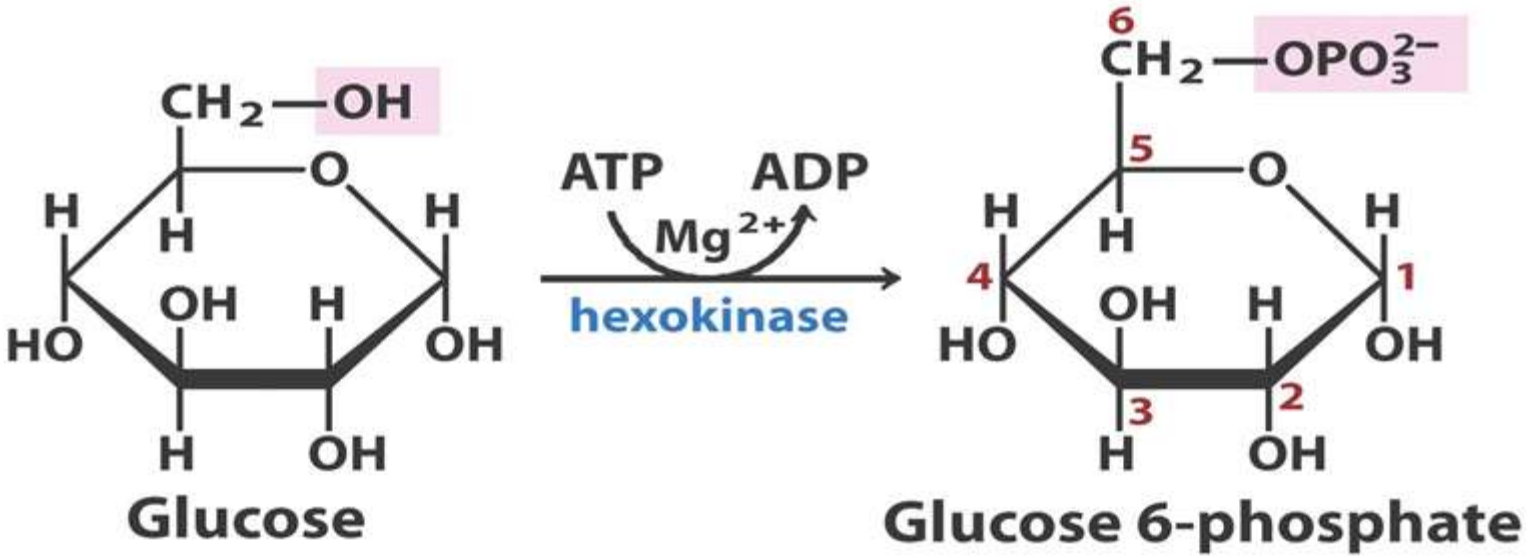
2) Transferases

- These bring about a transfer of functional groups such as
- phosphate and
- amino group
- from one molecule to another molecule called donor and acceptor molecules respectively.

Enzymes

- The common examples of this group are
- Transminases
- Phosphotransfrases (Kinases)

Enzymes



- Hexokinase is a phosphotransfease which catalyze the transfer of phosphate groups.

- Glucose + ATP → Glucose 6-phosphate + ADP.

Enzymes

IUB Classification of Enzymes (Contd.)

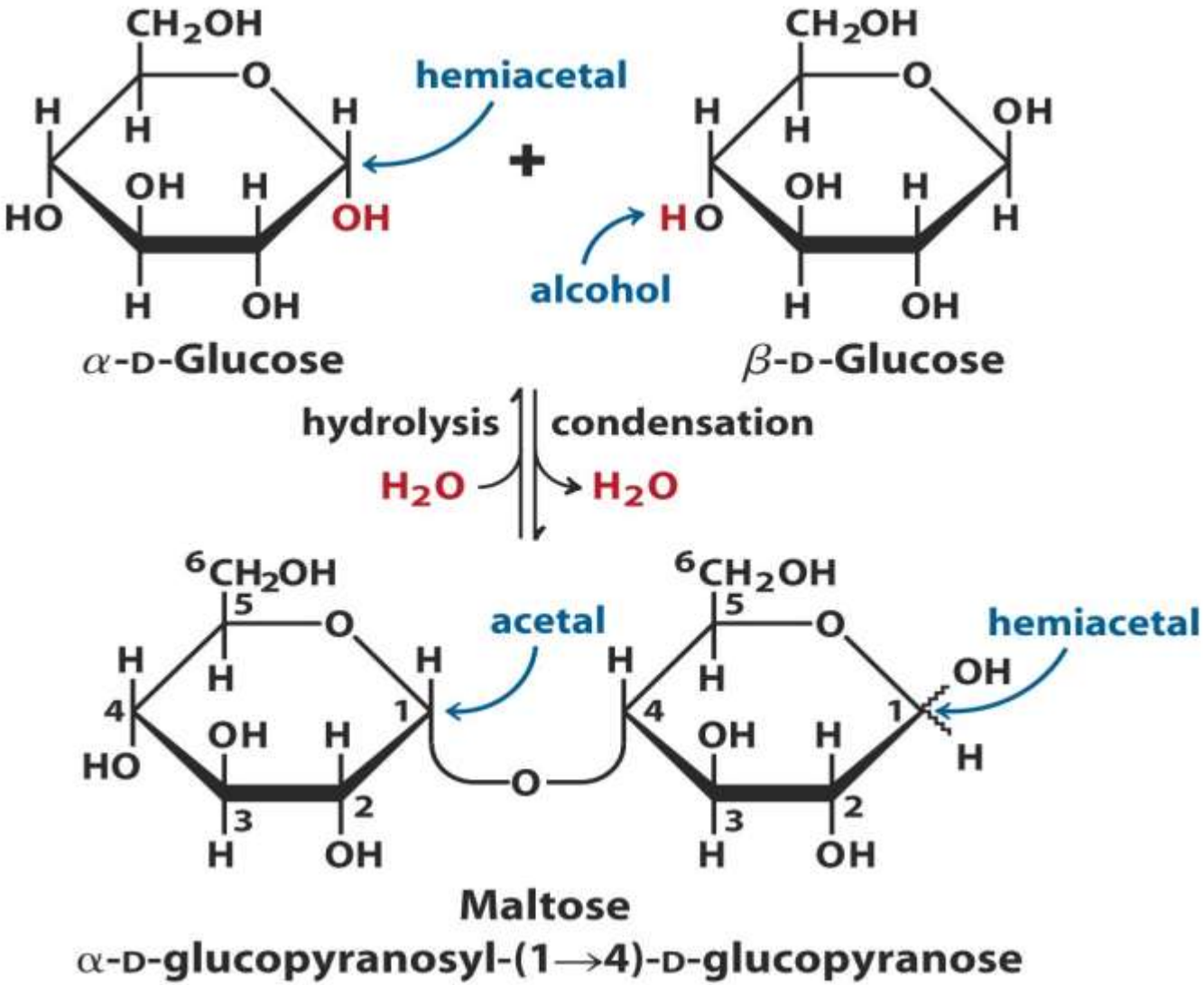
3) Hydrolases

- These enzymes catalyze hydrolysis, i.e.
- add water molecule to the substrate which is simultaneously decomposed; the functional group of substrate is transferred to water.

Enzymes

- Common example of hydrolases are:
- Protein hydrolyzing Enzymes (peptidases).
- Carbohydrases
- **Hydrolases** Lipid hydrolyzing enzymes e.g. Lipases and
- Phospholipases.

Enzymes

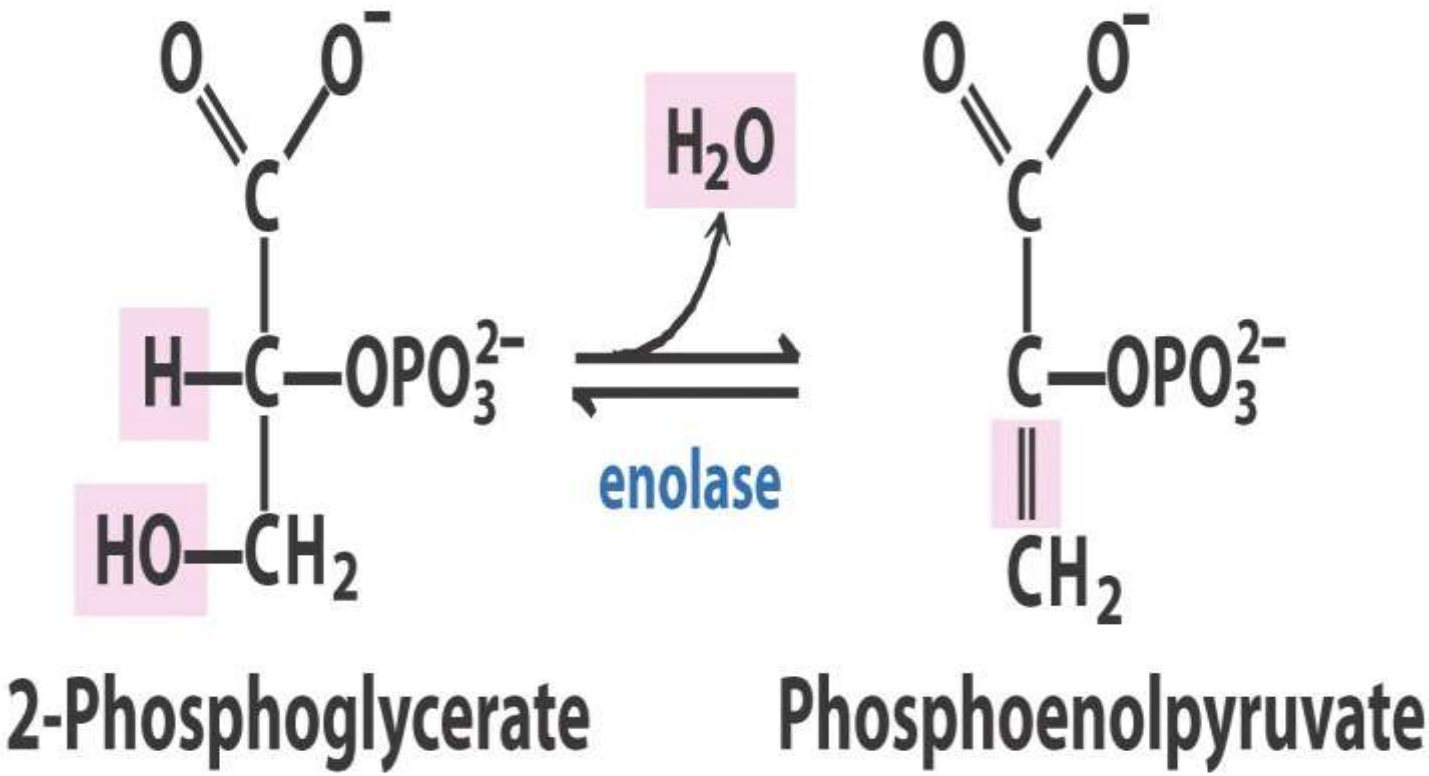

hemiacetal
alcohol
α-D-Glucose
β-D-Glucose
hydrolysis
condensation
H2O
H2O
acetal
hemiacetal
Maltose
α-D-glucopyranosyl-(1→4)-D-glucopyranose

Enzymes

4) Lyases

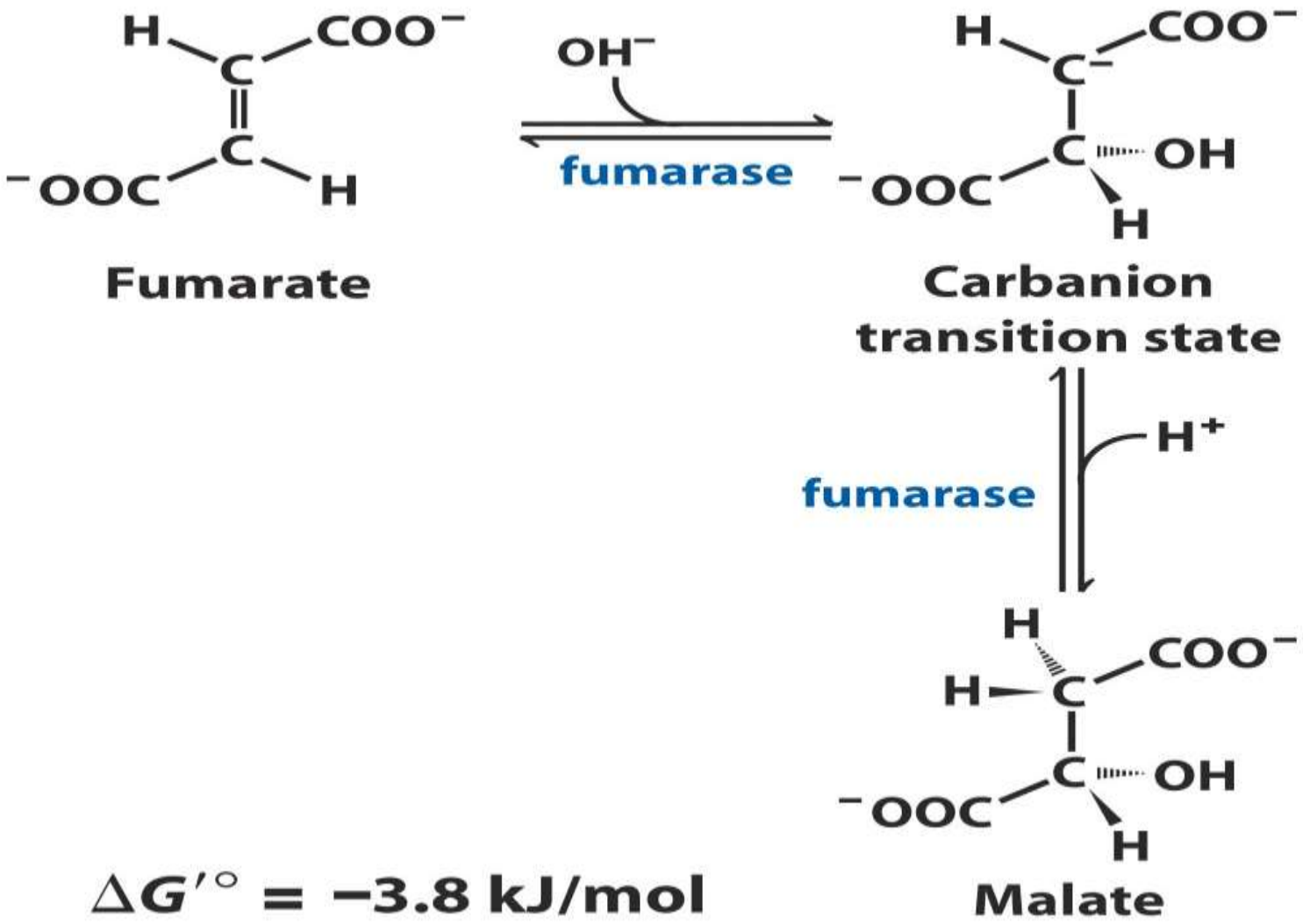
- Theses enzymes catalyze the addition of
- NH_3,
- H_2O or
- CO_2 to double bonds or
- the removal of these groups leaving behind double bonds.

Enzymes



$\Delta G'^{\circ} = 7.5$ kJ/mol

Enzymes



$\Delta G'^{\circ} = -3.8$ kJ/mol

Enzymes

- Lyases are included in a separate class because they catalyze these reactions by means other than hydrolysis or oxidation.

END

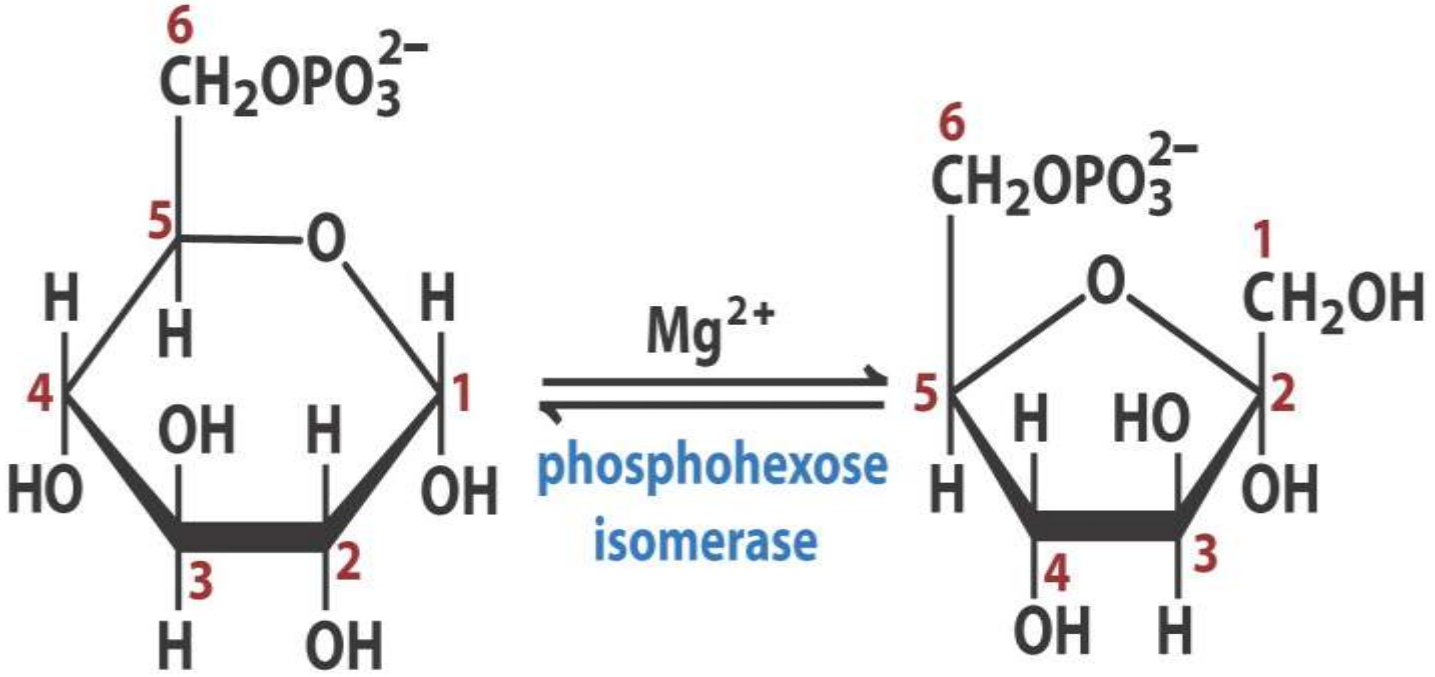
Enzymes

IUB Classification of Enzymes (Contd.)

5) Isomerases

- These enzymes catalyze the structural change within a single molecule by the transfer of groups within it, resulting in the formation of an isomeric form of substrate.

Enzymes

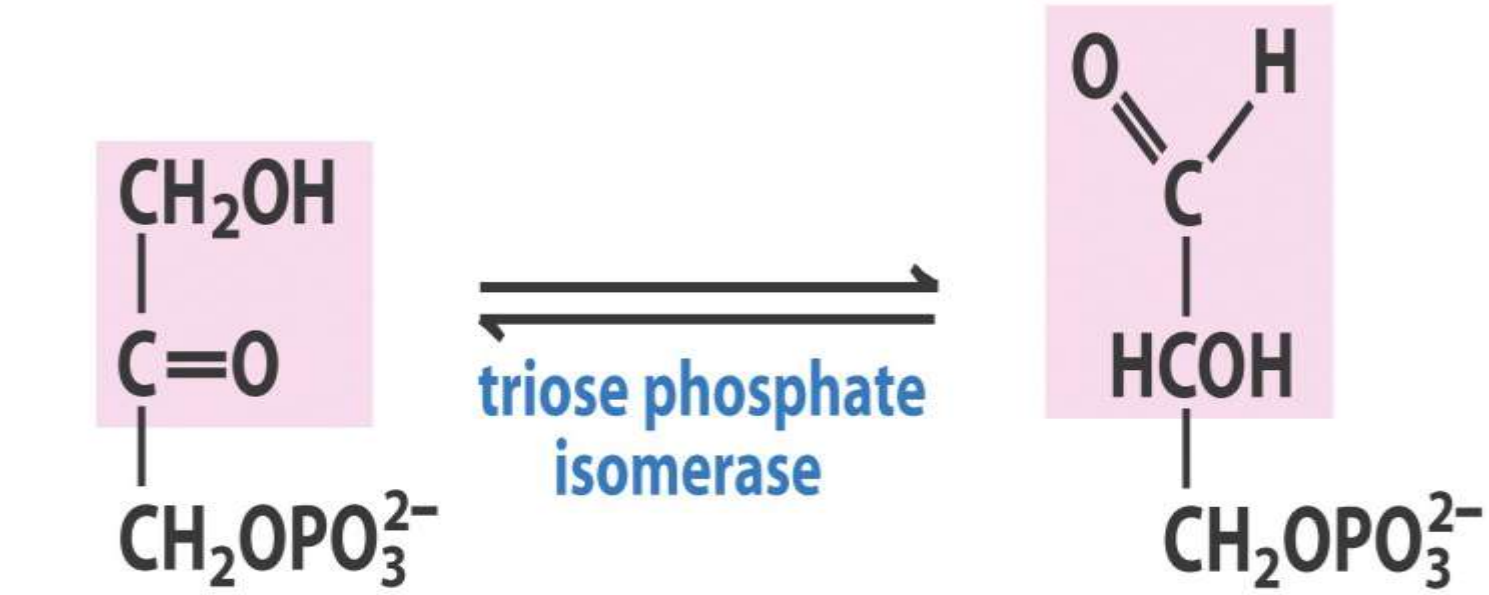


Glucose 6-phosphate

Fructose 6-phosphate

$\Delta G'^{\circ} = 1.7$ kJ/mol

Enzymes



Dihydroxyacetone phosphate

Glyceraldehyde 3-phosphate

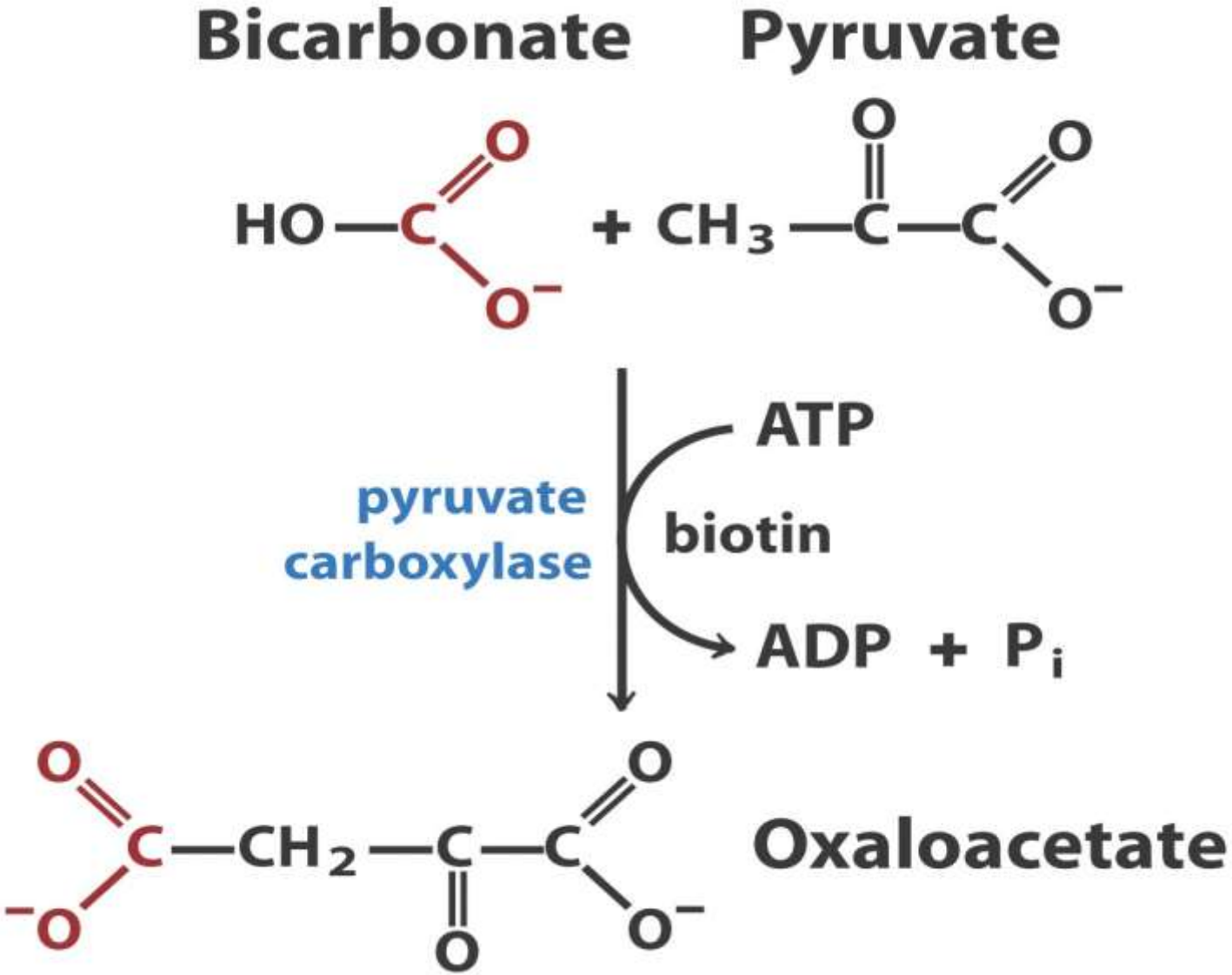
$\Delta G'^{\circ} = 7.5$ kJ/mol

Enzymes

6) Ligases

- These enzymes catalyze condensation reactions joining two molecules by forming
- C-O,
- C-S,
- C-N and
- C-C bonds.

Enzymes


Bicarbonate
Pyruvate
HO
C
O
O⁻
+ CH₃
C
C
O
O
O⁻
pyruvate carboxylase
ATP
biotin
ADP + Pi
O
C
CH₂
C
C
O
O
O
⁻O
O⁻
Oxaloacetate

Enzymes

- The energy for condensation is provided by cleavage of high energy phosphates, e.g. ATP, GTP etc.

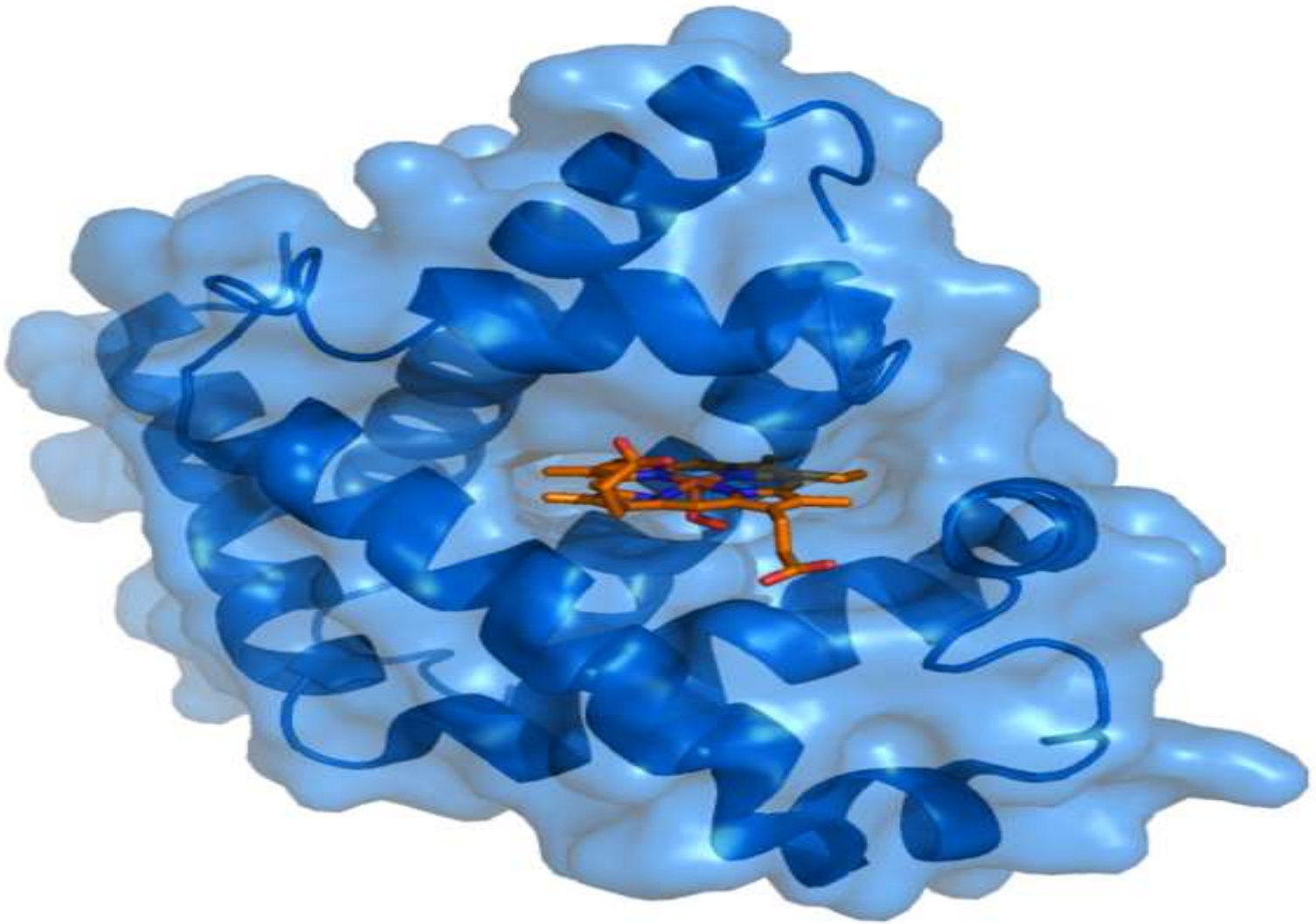
END

Enzymes

Ligand

- In biochemistry and pharmacology, a **ligand** (from the Latin *ligandum, binding*) is a substance (usually a small molecule),
- that forms a complex with a biomolecule to serve a biological purpose.

Enzymes



Enzymes

- In a narrower sense, it is a signal triggering molecule, binding to a site on a target protein
- A molecule bound reversibly by a protein is called a **ligand.**
- Ligands include substrates, inhibitors, activators, and neurotransmitters

Enzymes

- A ligand may be any kind of molecule, including another protein.

- A ligand binds at a site on the protein called the **binding site,**

Enzymes

- **binding site** is complementary to the ligand in
- size,
- shape,
- charge, and
- hydrophobic or
- hydrophilic character.

Enzymes

- Furthermore, the interaction is **specific**: the protein can discriminate among the thousands of different molecules in its environment and selectively bind only one or a few.

Enzymes

- The binding of a protein and ligand is often coupled to a **conformational change** in the protein that makes the binding site more complementary to the ligand, permitting tighter binding called **induced fit.**

Enzymes

- A given protein may have **separate binding sites** for several different ligands.
- In a multi-subunit protein, a conformational change in one subunit often affects the conformation of other subunits.

Enzymes

- Interactions between **ligands** and proteins may be regulated, through interactions with additional ligands.
- These other ligands may cause conformational changes in the protein that affect the binding of the **first ligand**.

END

Enzymes

Mechanism of Enzyme Action

Enzymes bind and chemically transform other molecules— they catalyze reactions.

- The molecules acted upon by enzymes are called reaction **substrates** rather than ligands.

Enzymes

- Enzymes are highly effective catalysts, commonly enhancing reaction rates by a factor of 10^5 to 10^{17}.
- The distinguishing feature of an enzyme-catalyzed reaction is that it takes place within the confines of a pocket on the enzyme called the **active site.**

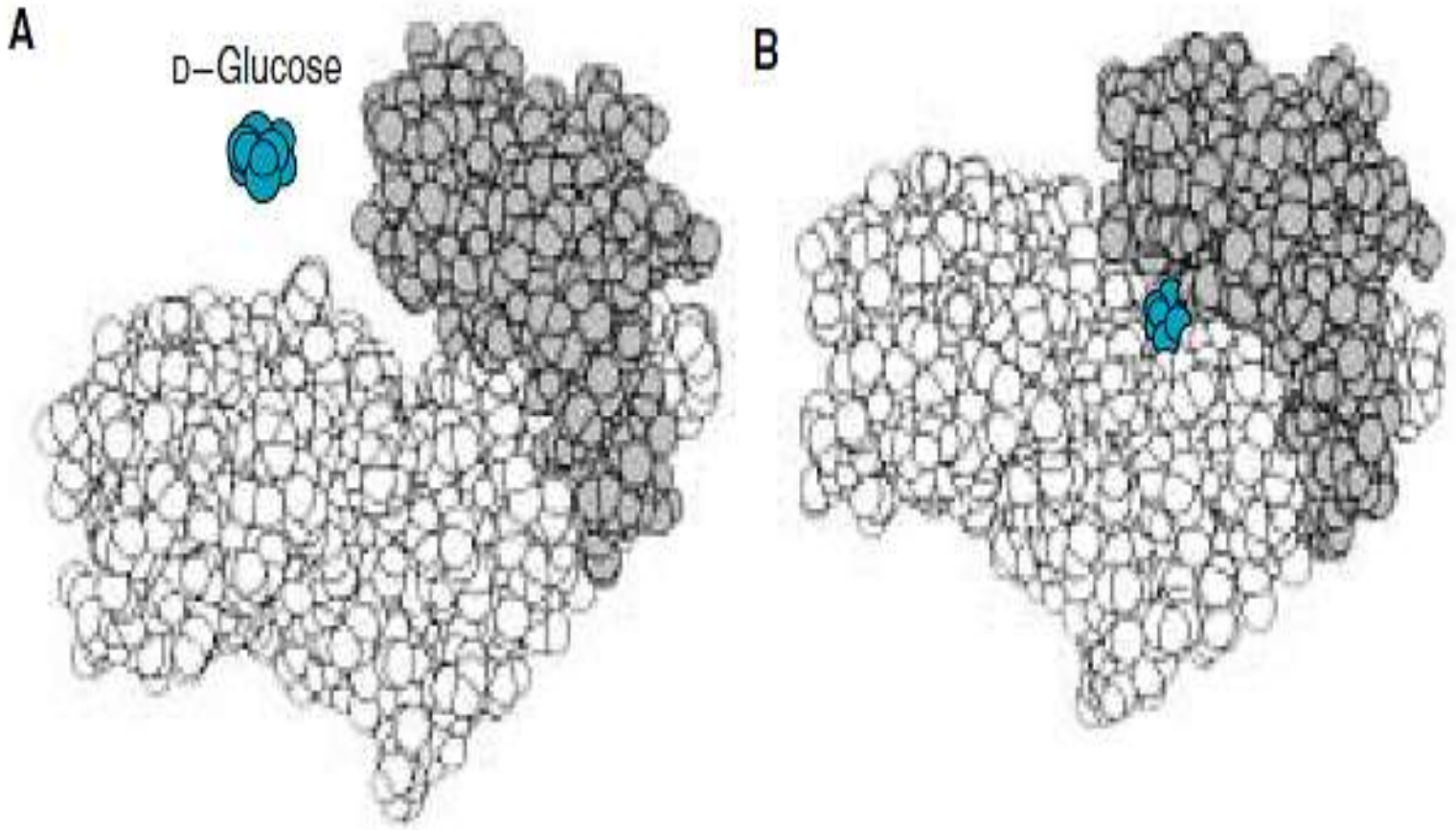
Enzymes

- The surface of the active site is lined with **amino acid** residues with side chains that complement and bind the substrate and catalyze its chemical transformation.

Enzymes

- Often, the active site encloses a substrate, sequestering it completely from solution.
- The enzyme substrate complex, whose existence is central to the action of enzymes.

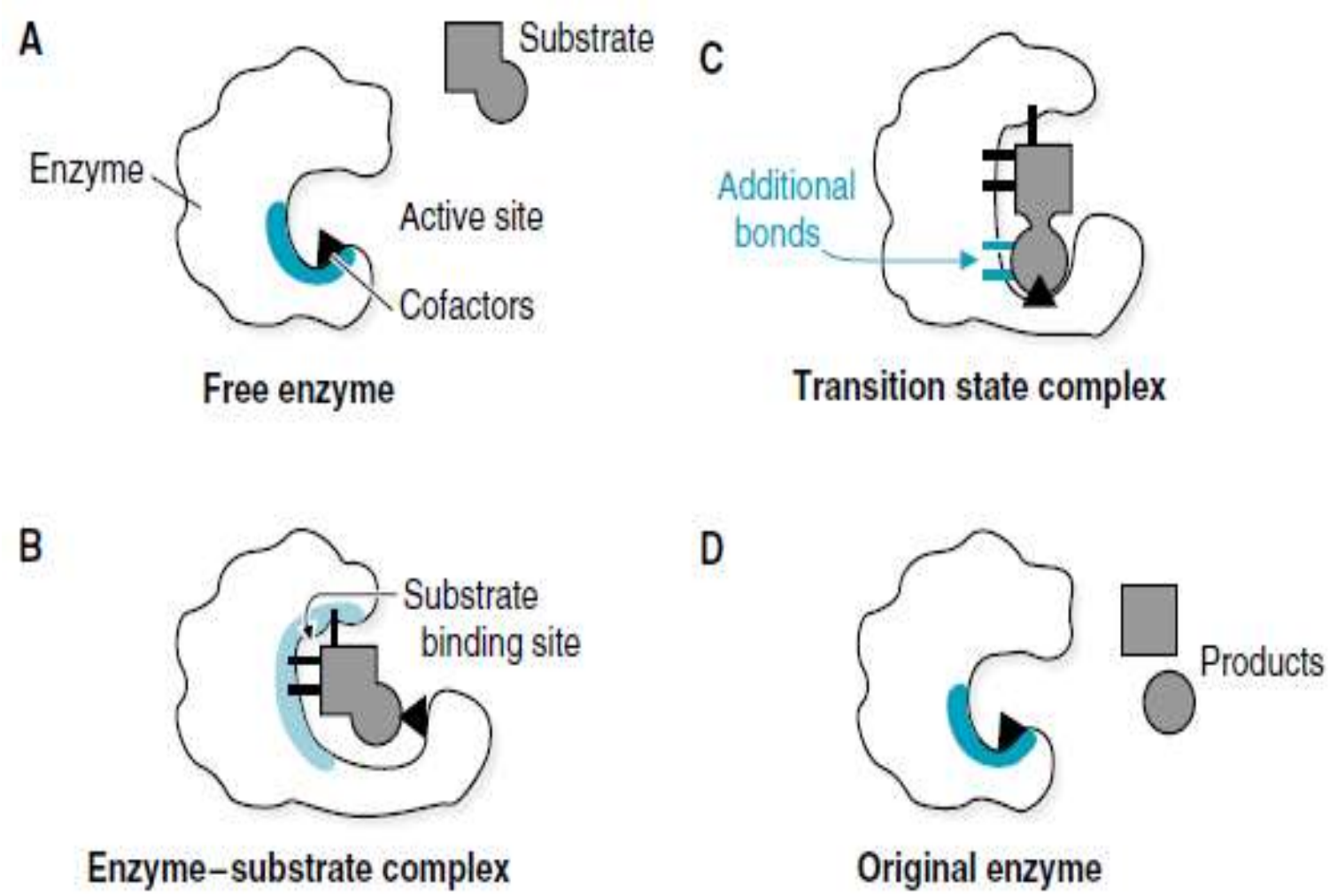
Enzymes



Enzymes

- Enzyme-catalyzed reactions have three basic steps:
- binding of substrate: **E+S↔ES**
- conversion of bound substrate to bound product: **ES ↔ EP**
- release of product : **EP ↔ E+P**

Enzymes


A
Substrate
Enzyme
Active site
Cofactors
Free enzyme
C
Additional bonds
Transition state complex
B
Substrate binding site
Enzyme–substrate complex
D
Products
Original enzyme

Enzymes

- To understand catalysis, we must first appreciate the important distinction between
- reaction equilibria and
- reaction rates.

END

Enzymes

Mechanism of Enzyme Action (Contd.)

Reaction Equilibria

- The function of a catalyst is to increase the rate of a reaction.
- Catalysts *do not affect reaction equilibria*
- Any reaction, such as $S \leftrightarrow P$, can be described by a reaction coordinate diagram

Enzymes

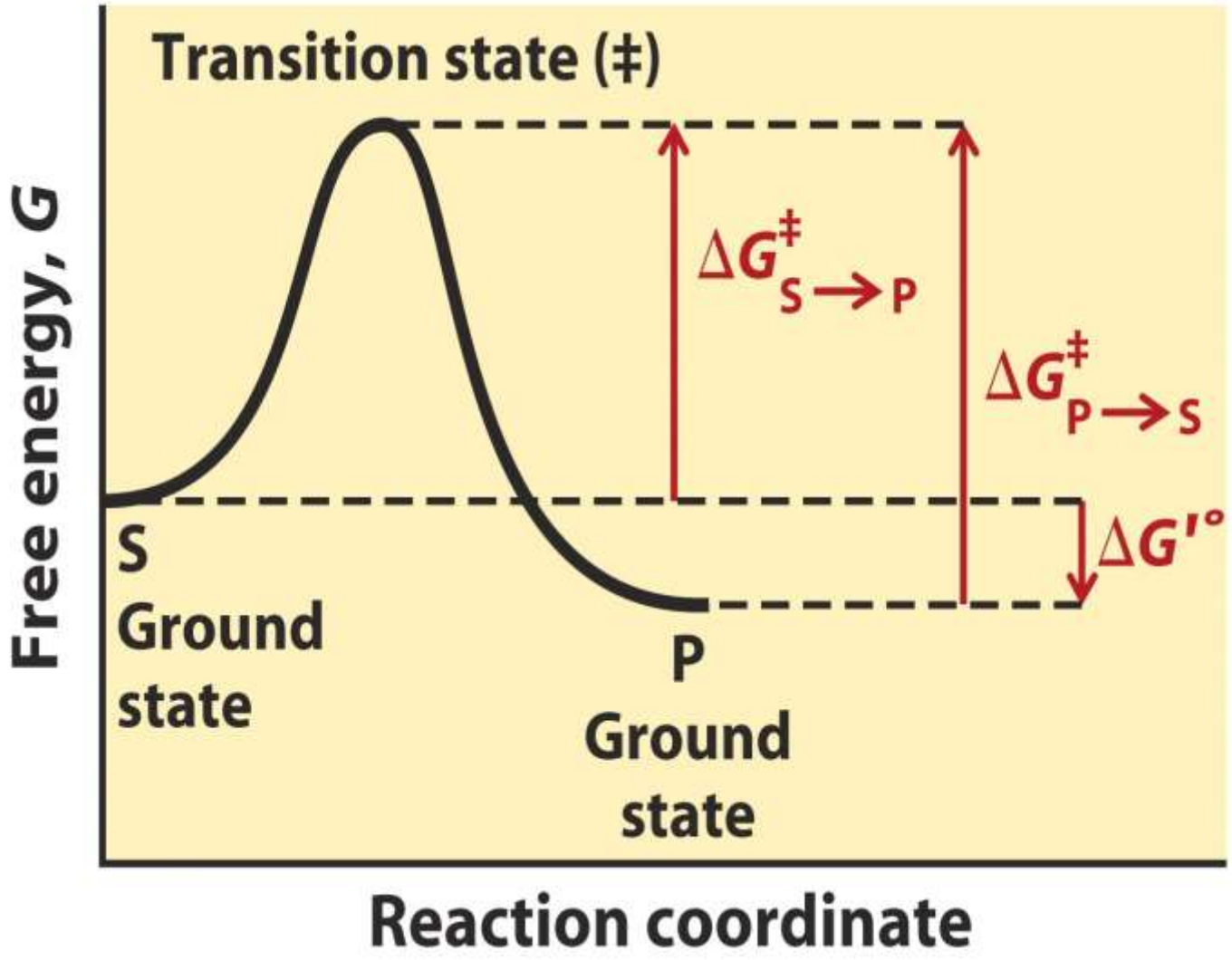
- The free energy of the system is plotted against the progress of the reaction **S** → **P**.

- A diagram of this kind is a description of the energy changes during the reaction.

Enzymes

- The horizontal axis (reaction coordinate) reflects the progressive chemical changes (e.g., bond breakage or formation) as S is converted to P.

Enzymes


Transition state (‡)
$\Delta G^{\ddagger}_{S \rightarrow P}$
$\Delta G^{\ddagger}_{P \rightarrow S}$
$\Delta G'^{\circ}$
S
Ground state
P
Ground state
Free energy, G
Reaction coordinate

Enzymes

Activation energies, *G‡,*

- The activation energies, *G‡, for* the
- **S → P and P → S** reactions are indicated.
- *G′º is the overall standard* free-energy change in the direction **S → P**

Enzymes

Free-energy change ΔG

- When a reacting system is not at equilibrium, the tendency to move toward equilibrium represents a driving force
- the magnitude of which can be expressed as the free-energy change for the reaction, ΔG.

Enzymes

Standard free-energy change, ΔG^{o}

- Under standard conditions (298 K = 25 C)
- when reactants and products are initially present at 1 M concentrations or
- for gases, at partial pressures of 101.3 (kPa), or 1 atm

Enzymes

- the force driving the system toward equilibrium is defined as the standard free-energy change, ΔG^{o}
- However, because the conditions in the body systems are different from standard conditions
- energy in biological systems is described in terms of free energy, G'^{o}.

END

Enzymes

Mechanism of Enzyme Action (Contd.)

Ground State

&

Transition State

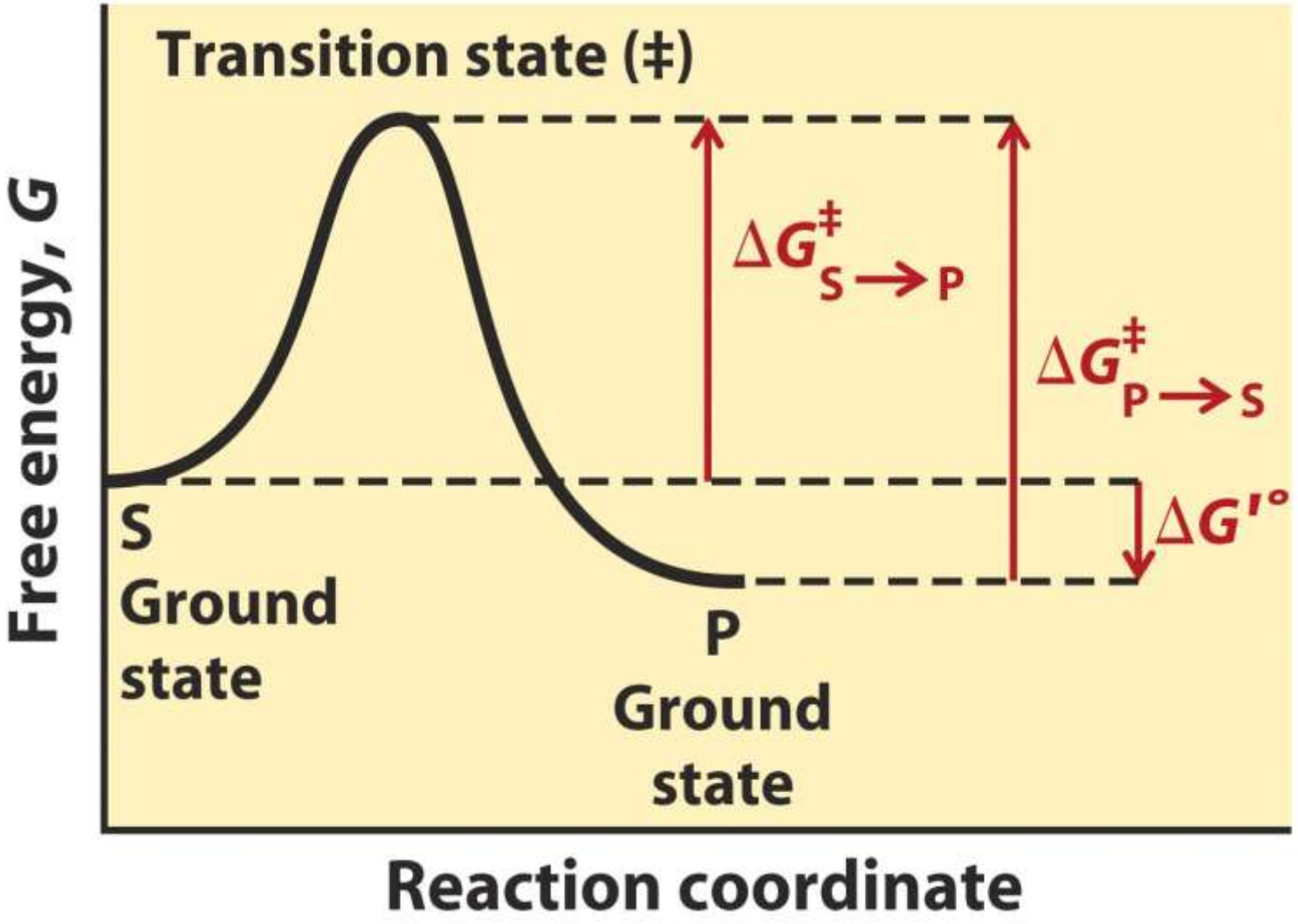
Enzymes

- The starting point for either the forward or the reverse reaction is called the **ground state**
- The equilibrium between S and P reflects the difference in the free energies of their ground states.

Enzymes

- The free energy of the ground state of P is **lower** than that of S
- So G'^{o} *for the* reaction is negative and the equilibrium favors P.
- The position and *direction* of equilibrium are *not affected by* any catalyst.

Enzymes


Transition state (‡)
$\Delta G^{\ddagger}_{S \rightarrow P}$
$\Delta G^{\ddagger}_{P \rightarrow S}$
$\Delta G'^{\circ}$
S
Ground state
P
Ground state
Free energy, G
Reaction coordinate

Enzymes

- But there is an **energy barrier** between S and P**:** The energy required for
- alignment of reacting groups
- formation of transient unstable charges
- bond rearrangements
- and other transformations

Enzymes

- This is illustrated by the energy “hill”
- To undergo reaction, the molecules must overcome this barrier and therefore must be raised to a higher energy level
- This is called the **transition state.**

Enzymes

- It is simply a fleeting molecular moment in which events such as
- bond breakage,
- bond formation, and
- charge development
- have proceeded to the precise point at which decay to either substrate or product is equally likely.

Enzymes

- The difference between the energy levels of the ground state and the transition state is the **activation energy, *G*‡.**

Enzymes

- At the top of the energy hill is a point at which decay to the S or P state is equally probable (it is downhill either way)

Enzymes

- A substance that modifies the transition state to lower the activation energy is termed a catalyst; a biological catalyst is termed an enzyme.

END

Enzymes

Mechanism of Enzyme Action (Contd.)

Activation energy $\Delta G^{\ddagger}$.

- The difference between the energy levels of the ground state and the transition state is the **activation energy $\Delta G^{\ddagger}$.**

Enzymes

- The rate of a reaction reflects this activation energy: a higher activation energy corresponds to a slower reaction.

Enzymes

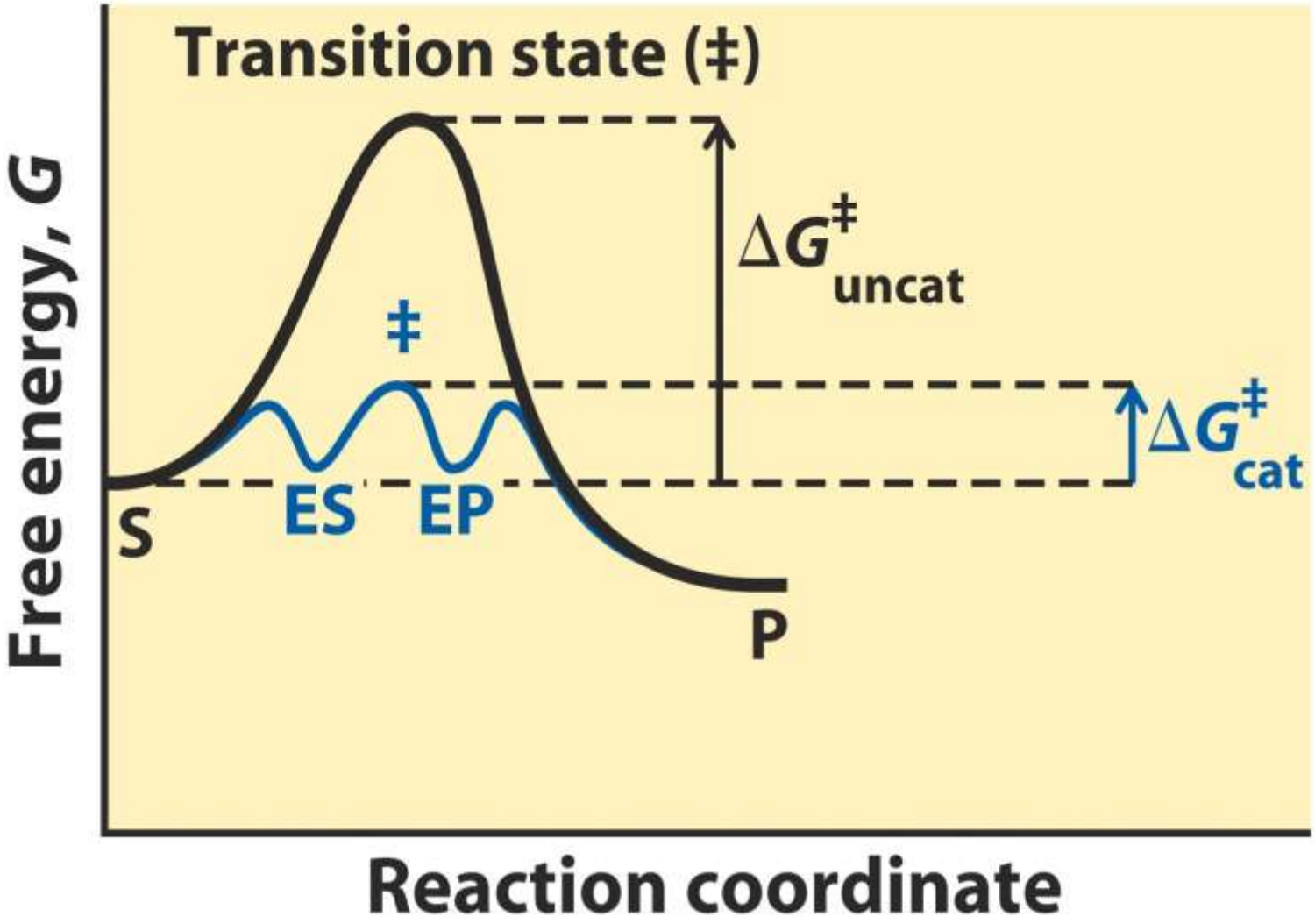
- Reaction rates can be increased by raising the temperature, thereby increasing the number of molecules with sufficient energy to overcome the energy barrier.

Enzymes

- Alternatively, the activation energy can be lowered by adding a catalyst.

- Catalysts enhance reaction rates by lowering activation energies.

Enzymes


Transition state (‡)
Free energy, G
$\Delta G^{‡}_{uncat}$
‡
$\Delta G^{‡}_{cat}$
S
ES
EP
P
Reaction coordinate

Reaction coordinate diagram comparing enzyme catalyzed
and uncatalyzed reactions. In the reaction S→P, the ES and EP intermediates occupy minima in the energy progress curve of
the enzyme-catalyzed reaction. The terms $G‡_{uncat}$ and $G‡_{cat}$ correspond to the activation energy for the uncatalyzed
reaction and the overall activation energy for the catalyzed reaction, respectively.
The activation energy is lower when the enzyme catalyzes the reaction.

Enzymes

- The role of enzymes is to accelerate the inter-conversion of S and P.
- i.e ***enzymes lower the energy of activation, $\Delta G^{\ddagger}$, of a reaction*****.**
- The enzyme is not used up in the process, and the equilibrium point is unaffected.

Enzymes

- However, the reaction reaches equilibrium much faster when the appropriate enzyme is present,
- because the rate of the reaction is increased.

END

Enzymes

The Induced Fit Hypothesis

- Some proteins can change their shape (conformation)

- When a substrate combines with an enzyme, it induces a change in the enzyme's conformation

Enzymes

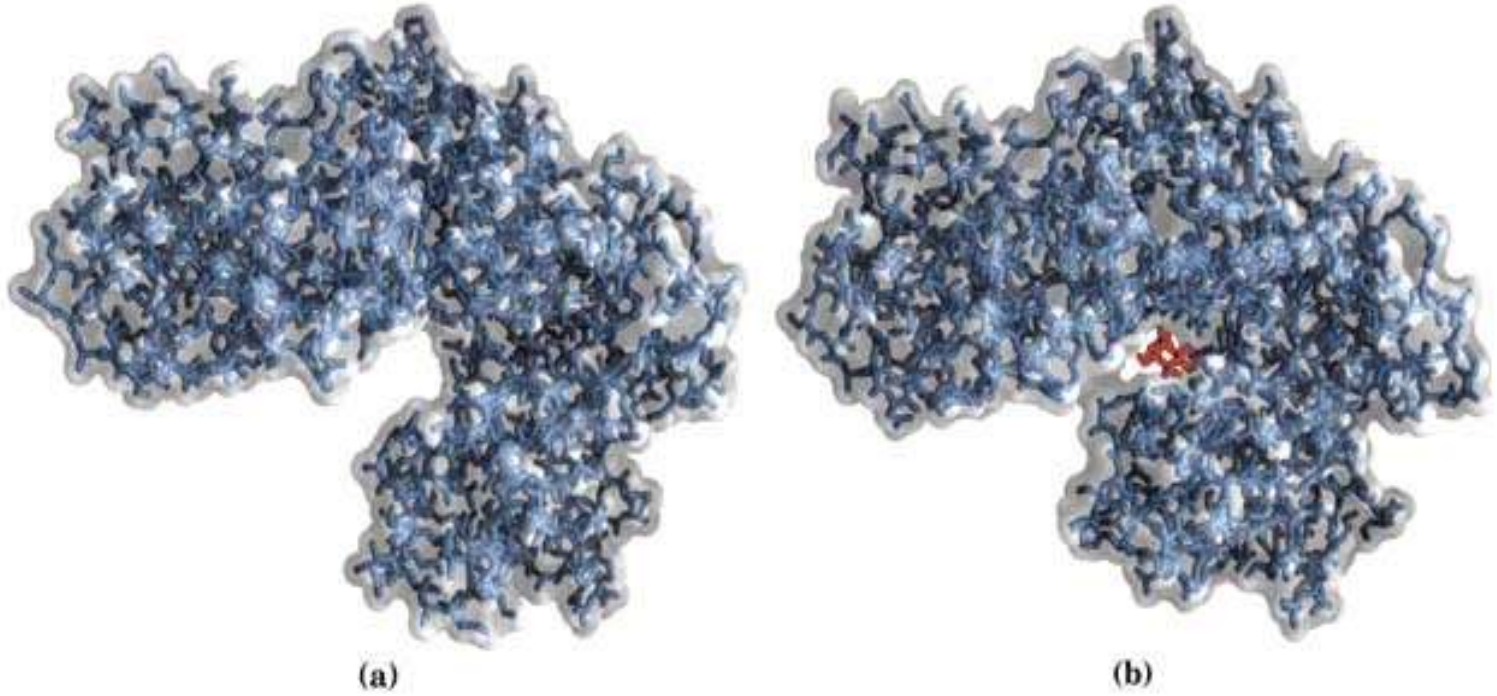
- This change in conformation when the substrate binds is induced by multiple weak interactions with the substrate.
- There may also be rearrangements of covalent bonds during an enzyme-catalyzed reaction.

Enzymes

- This conformational change is referred to as **induced fit.**

Enzymes

The Induced Fit Hypothesis



Hexokinase (a) without (b) with glucose substrate

Enzymes

- Chemical reactions of many types take place between substrates and enzyme's functional groups (specific amino acid side chains, metal ions, and coenzymes

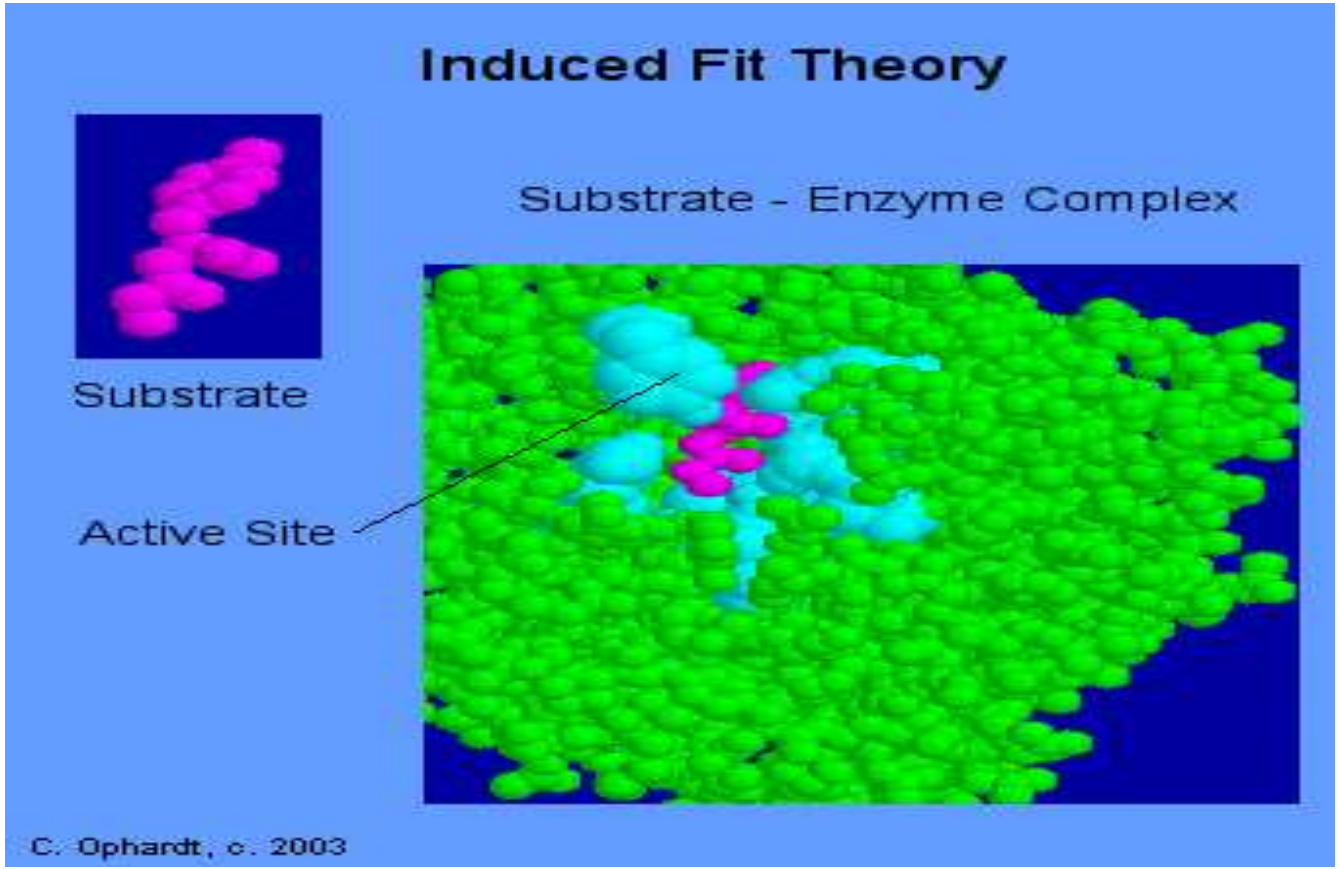
Enzymes

- Induced fit serves to bring specific functional groups on the enzyme into the proper position to catalyze the reaction.

Enzymes

Induced Fit Theory

- Enzyme is not rigid, changes shape with substrate.



Enzymes

- The active site is also moulded into a precise conformation
- Making the chemical environment suitable for the reaction

END

Enzymes

Cofactors, Coenzymes and Prosthetic groups

- Some enzymes require no chemical groups for activity other than their amino acid residues.
- Whereas some enzymes require molecules other than proteins for enzymic activity.

Enzymes

- If the non-protein moiety is a metal ion such as Zn^{2+} or Fe^{2+}, it is called a cofactor.

- If it is a complex organic molecule or metallo-organic compound it is termed a coenzyme.

Enzymes

Some Coenzymes That Serve as Transient Carriers

Coenzyme	*Examples of chemical groups transferred*
Biocytin	CO_2
Coenzyme A	Acyl groups
5′-Deoxyadenosylcobalamin (coenzyme B_{12})	H atoms and alkyl groups
Flavin adenine dinucleotide	Electrons
Lipoate	Electrons and acyl groups
Nicotinamide adenine dinucleotide	Hydride ion ($:H^-$)

Enzymes

Some Inorganic Elements That Serve as Cofactors for Enzymes

Cu^{2+}	Cytochrome oxidase
Fe^{2+} or Fe^{3+}	Cytochrome oxidase, catalase, peroxidase
K^{+}	Pyruvate kinase
Mg^{2+}	Hexokinase, glucose 6-phosphatase, pyruvate kinase
Mn^{2+}	Arginase, ribonucleotide reductase

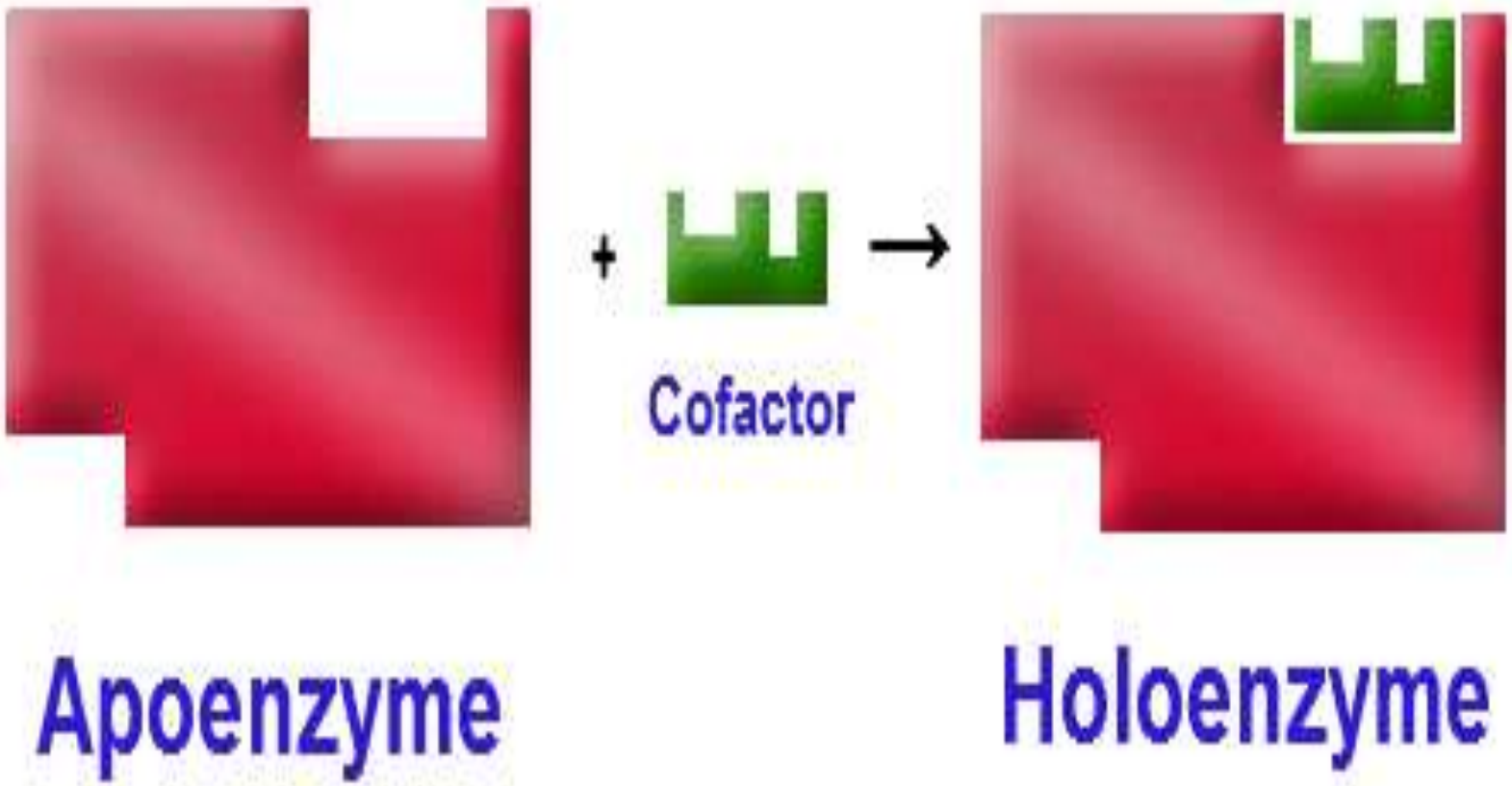
Enzymes

- A coenzyme or metal ion that is very tightly or even covalently bound to the enzyme protein is called a prosthetic group.

Enzymes

- The term holoenzyme refers to the active enzyme with its non-protein component,
- whereas the enzyme without its non-protein moiety is termed an apoenzyme (apoprotein) and is inactive.

Enzymes



Enzymes

- Coenzymes serve as recyclable shuttles that transport many substrates from one point within the cell to another.
- The function of these shuttles is twofold.

Enzymes

- First, they stabilize species
- such as hydrogen atoms (FADH) or hydride ions (NADH)
- that are too reactive to persist for any significant time in the presence of the water or organic molecules that permeate cells.

Enzymes

- Second, they serve as an adaptor or handle that facilitates the
- recognition and binding of small chemical groups, such as acetate (coenzyme A) or glucose (UDP), by their target enzymes

END

Enzymes

Reaction Rates and Order of Reactions

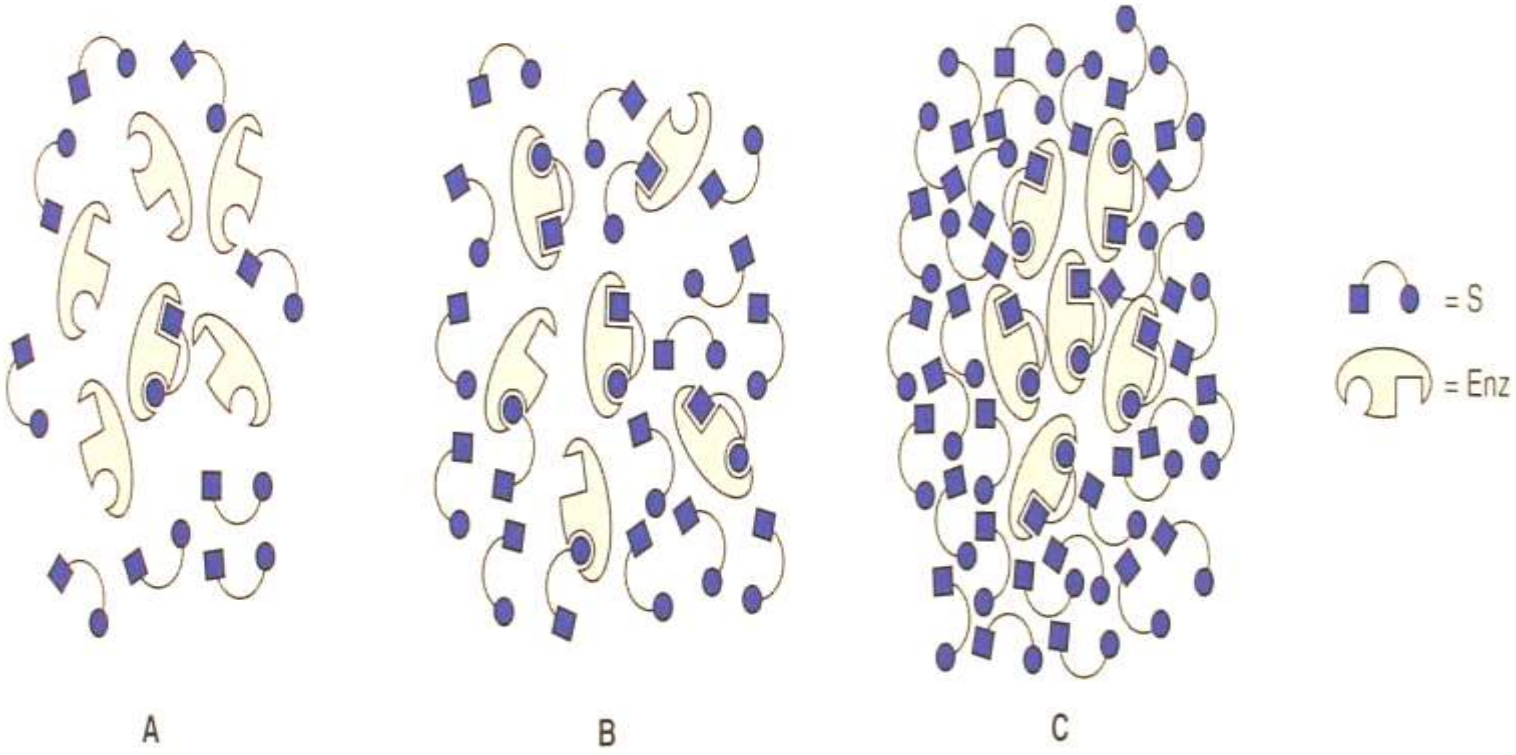
Reaction Velocity (v)

- The rate or velocity of a reaction (v) is the number of substrate molecules converted to product per unit time;
- Velocity is usually expressed as **µmol of product** formed **per minute**.

Enzymes

- The rate of an enzyme-catalyzed reaction increases with substrate concentration until a maximal velocity (Vmax) is reached- reflecting the **saturation** with substrate of **all available binding sites are occupied** on the enzyme molecules present.

Enzymes



Enzymes

- An equilibrium such as S $\leftrightarrow$ P is described by an **equilibrium constant, Keq**, or simply **K.**
- Under the standard conditions used to compare biochemical processes, an equilibrium constant is denoted ***K´eq*** (or ***K´*)*.***

Enzymes

- The rate of any reaction is determined by the concentration of the reactant (or reactants) and by a **rate constant,** usually denoted by **k.**

Enzymes

- For the uni molecular reaction S → P, the rate (or velocity) of the reaction, V—representing the amount of S that reacts per unit time—is expressed by a **rate equation:** V = k[S].

Enzymes

- In this reaction, the rate depends only on the concentration of S.
- This is called a first-order reaction.
- The factor k is a proportionality constant that reflects the probability of reaction under a given set of conditions (pH, temperature, and so forth).

Enzymes

- If a reaction rate depends on the concentration of two different compounds.
- or if the reaction is between two molecules of the same compound, the reaction is second order.

Enzymes

- The rate equation then becomes

- $V = k[S_1][S_2]$

END

- 3. (4 pts) The rate law of the following overall reaction A + B --> C is measured to be rate = *k*[A]2. Which one of the following will **NOT** increase the rate of the reaction?
- a) increasing the concentration of reactant A
- b) increasing the concentration of reactant B
- c) increasing the temperature of the reaction
- d) adding a catalyst for the reaction
- e) All of these will increase the rate.

- the molecule which acts directly on an enzyme to lower its catalytic rate is
- Inhibitor
- **The slowest step** in a reaction mechanism is known as the rate-determining step.
- **Peptidyl transferase** is an enzyme that catalyzes the addition of an amino acid residue in order to grow the polypeptide chain in protein synthesis. It is located in the large ribosomal subunit, where it catalyzes the peptide bond formation.

- what is the substrate for amylase? **starch**
- Removal of phosphoryl groups is catalyzed by **Protein phosphatases**.
- Transposons are repetitive DNA sequences that **have the capability to move (transpose) from one location to another in genome**.

- Transposons mobile genetic elements can be transferred from one dna protein to another. the enzyme carrying out the….
- A zymogen (/ˈzaɪmədʒən, -moʊ-/), also called a proenzyme (/ˌproʊˈɛnzaɪm/), is **an inactive precursor of an enzyme**.

- The minimum amount of energy needed for a reaction to take place is called the **activation energy** .
- **Alkaline phosphatase** catalyzes a simple hydrolysis reaction:
- The **enzyme fumarase cat alyzes the conversion of fumarate to malate**

- What is the general mechanism of an enzyme?
- it acts by reducing the activation energy
- **Enolase** catalyzes the conversion of 2-phosphoglycerate to phosphoenolpyruvate during both glycolysis and gluconeogenesis, and is required by all three domains of life.

- A catalyst speeds up a chemical reaction, without being consumed by the reaction. It increases the reaction rate by **lowering the activation energy for a reaction**.