Enzymology- An overview-1

Enzymes- An introduction

- Biologic (organic catalysts) polymers that catalyze the chemical reactions.

- Enzymes are neither consumed nor permanently altered as a consequence of their participation in a reaction.

- With the exception of catalytic RNA molecules, or ribozymes, enzymes are proteins.

- In addition to being highly efficient, enzymes are also extremely selective catalysts

-Thermolabile, site specific, with a high turn over number compared to the inorganic catalysts.

#RNA not functioning → RNA functioning

processing

enzyme = low time, low energy rxn low requiring E.

shorted time

enzymes

ribozymes

* Metal ions = catalysts

hydrolation H^+ → (Ni) catalysts

inorganic

the difference ① term over number

- organic

*enzyme

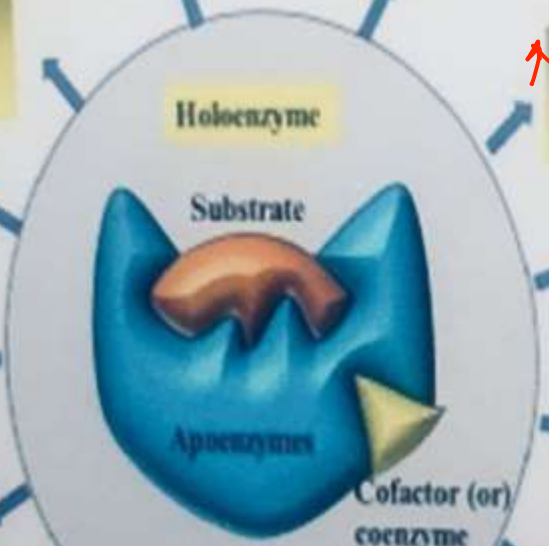
limit → $10^6 - 10^{12}$ molecules

- inorganic metal ion

limit → 10^3

the same reaction

Characteristics of the enzymes



- Enzymes are both intracellular and extracellular catalysts
- Some are globular proteins and few are RNA-based molecules
- Some enzymes need coenzymes or cofactors
- Enhance the speed of biochemical reactions
- Forms enzyme-substrate complex
- Lowers the activation energy
- Active site contains less hydrophobic amino acids
- Produces product using specific substrate
- Sensitive to temperature, pH, and substrate concentration
- Required in very less amount compared to chemical catalyst
- Active site contains 3 to 12 amino acids
- Enzymes can be recycled or reused
- Enzymes are larger than substrate
- Function can be inhibited by inhibitors

Nomenclature of enzymes

-In most cases, enzyme names end in **–ase**

-The common name for a hydrolase is derived from the substrate

Urea: remove -a, replace with **-ase** = urease

Lactose: remove - **ose**, replace with - **ase** = lactase

- Other enzymes are named for the substrate and the reaction catalyzed

Lactate dehydrogenase

Pyruvate decarboxylase

removal ≠ Oxidation.

remove H means oxidation

- Some names are historical - no direct relationship to substrate or reaction type

- Catalase
- Pepsin → Stomach
- Chymotrypsin
- Trypsin → Intestine

(protein molecules)

breaking down the pipted bond "pipteclaises"

because the are breaking the bond protein

Classification of Enzymes

- Enzyme Commission (EC) – according to **International Union of Biochemistry and Molecular Biology (IUBMB)**

- Each enzyme was given 4 digit numbers [1.2.3.4]

1st one of the 6 major classes of enzyme activity

2nd the subclass (type of substrate or bond cleaved)

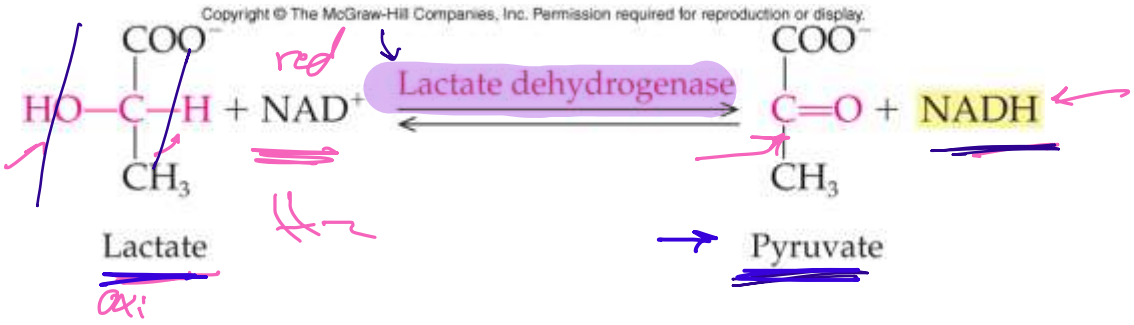
3rd the sub-subclass (group acted upon, cofactor required, etc...)

4th a serial number… (order in which enzyme was added to list)

1- Oxidoreductases (**EC.1**) catalyze redox reactions, such as (Alcohol dehydrogenase [EC 1.1.1.1])

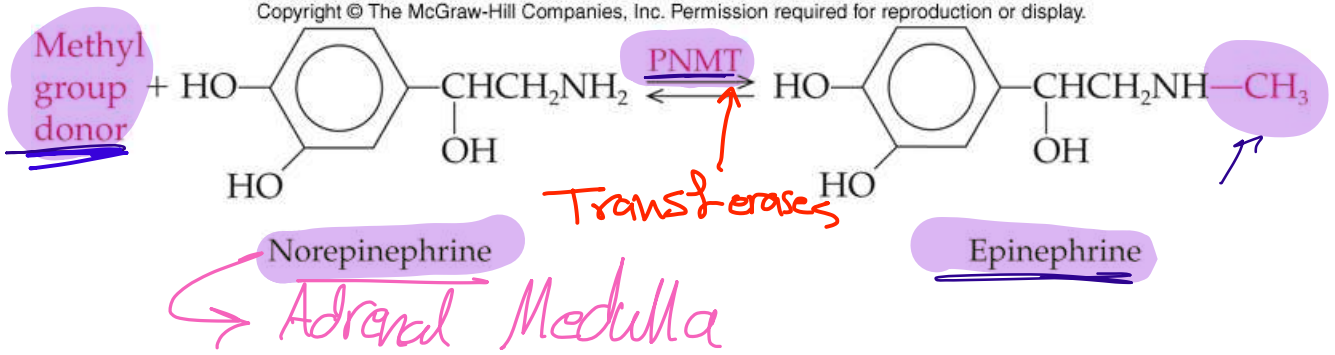
1. Reductases
2. Oxidases

* Lactate dehydrogenase.



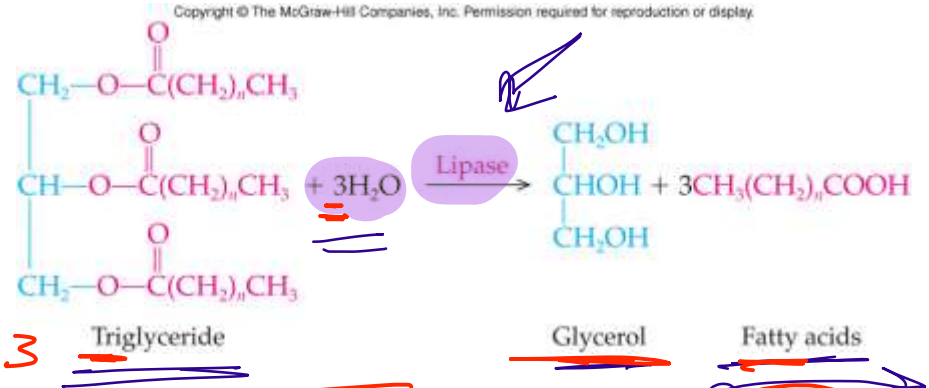
2- Transferases (**EC.2**) transfer a group from one molecule to another, such as (Hexokinase [EC 2.7.1.2])

- Transaminases catalyze transfer of an amino group
- Kinases transfer a phosphate group



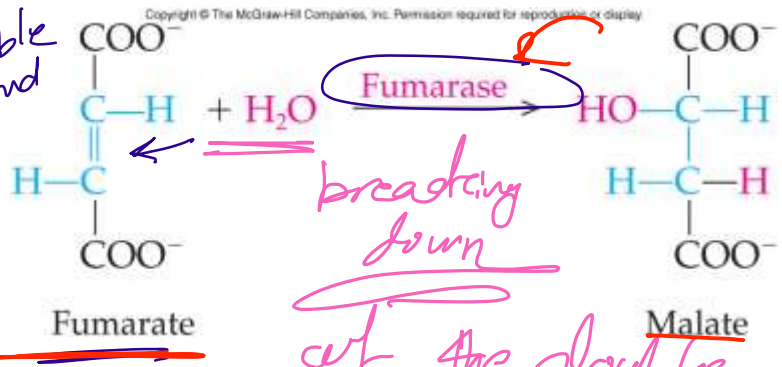
3- Hydrolases (**EC.3**) cleave bonds by adding water, such as (Alkaline phosphatase [EC 3.1.3.1])

- Phosphatases
- Peptidases
- Lipases



4- Lyases (**EC.4**) catalyze removal of groups to form double bonds or the reverse break double bonds, such as (Pyruvate decarboxylase [EC 4.1.1.1])

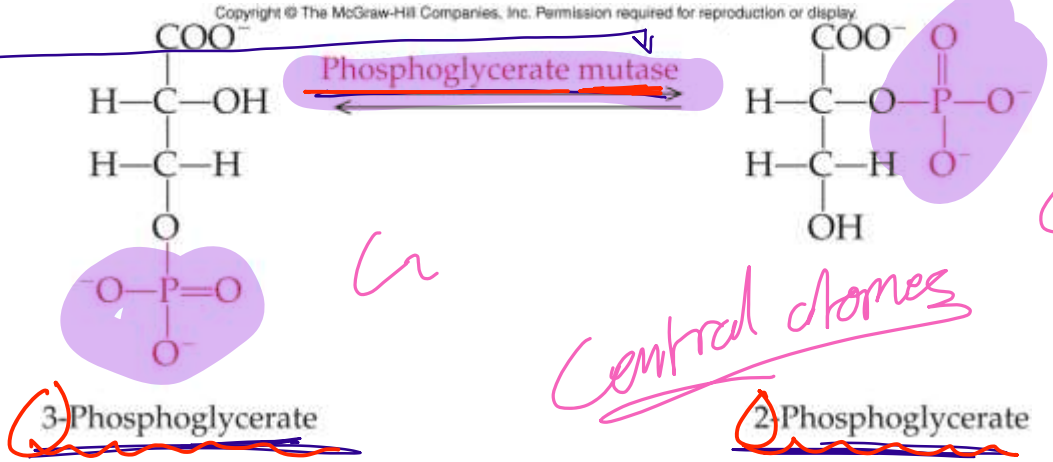
- Decarboxylases
- Synthases



5- Isomerases (**EC.5**) catalyze intramolecular rearrangements, such as (Alanine racemase [EC 5.1.1.1])

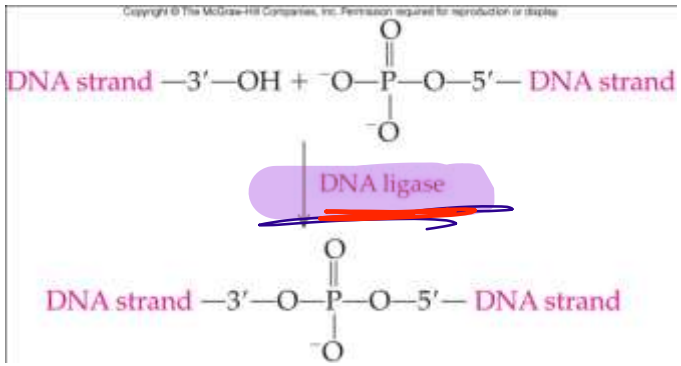
- Epimerases
- Mutases

⇒ phosphoglycerate mutase (intra)



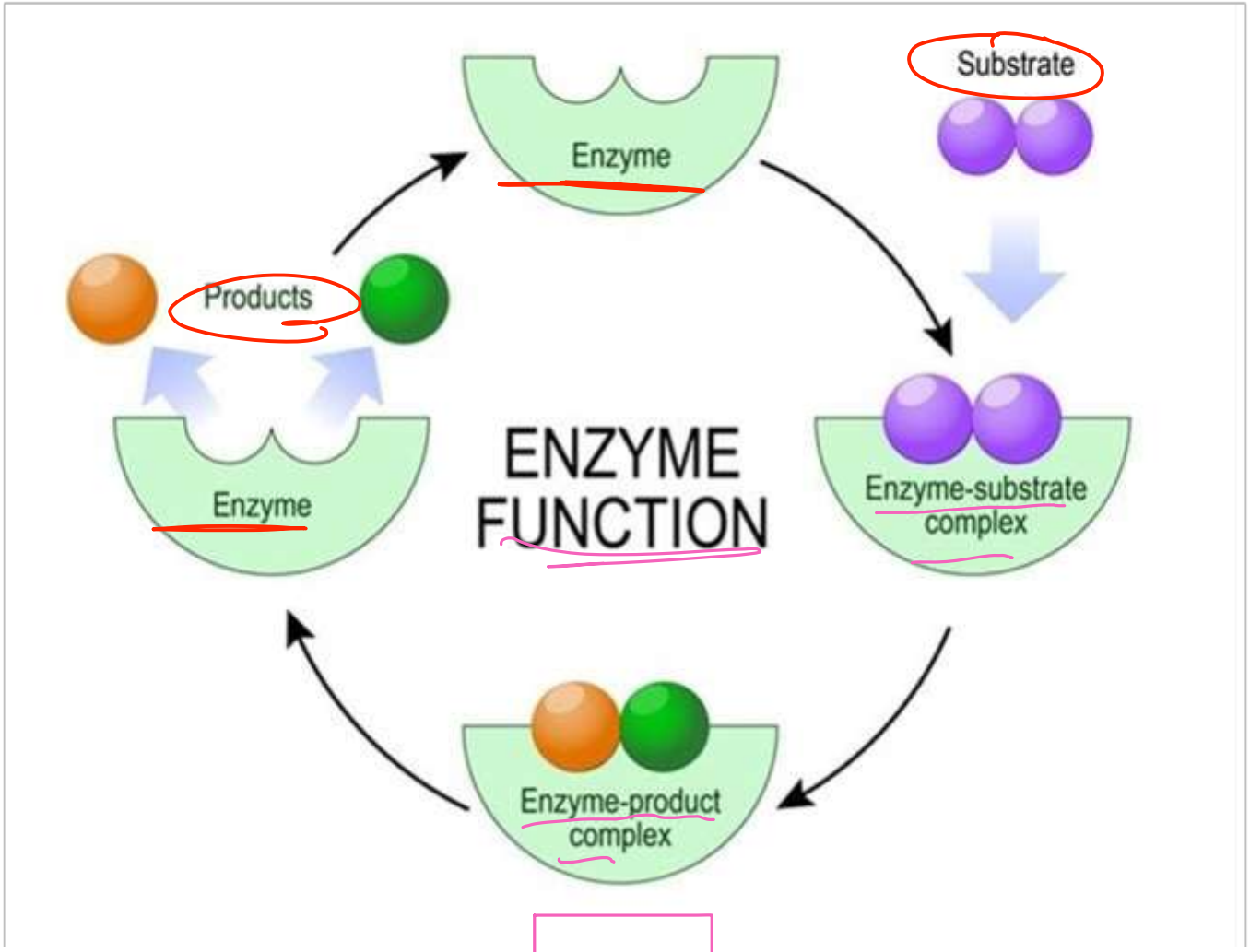
C2 C3 Central atoms

6- Ligases (**EC.6**) catalyze a reaction in which a C-C, C-S, C-O, or C-N bond is made or broken, such as (Isoleucine-tRNA ligase [EC 6.1.1.5])



* DNA ligase.

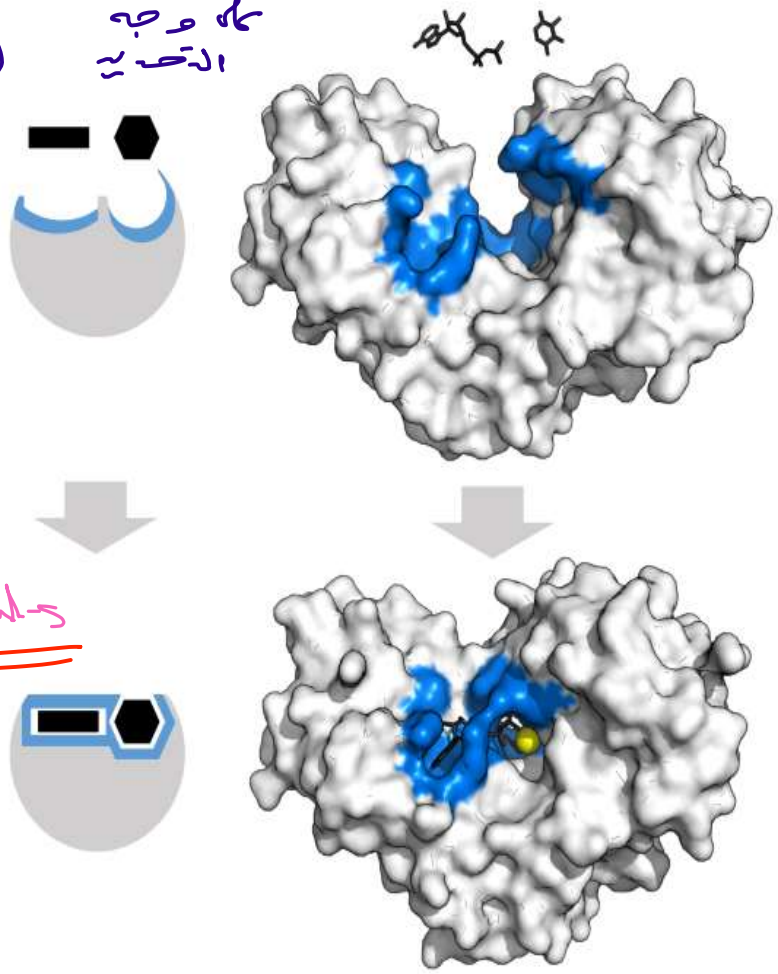
* all of them Using energy


Substrate
Enzyme
Products
Enzyme
ENZYME FUNCTION
Enzyme-substrate complex
Enzyme-product complex

Active site

the binding site of the enzyme molecule

- Takes the form of a cleft or pocket
- Takes up a relatively small part of the total volume of an enzyme
- 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
- The active sites of multimeric enzymes are located at the interface between subunits and recruit residues from more than one monomer



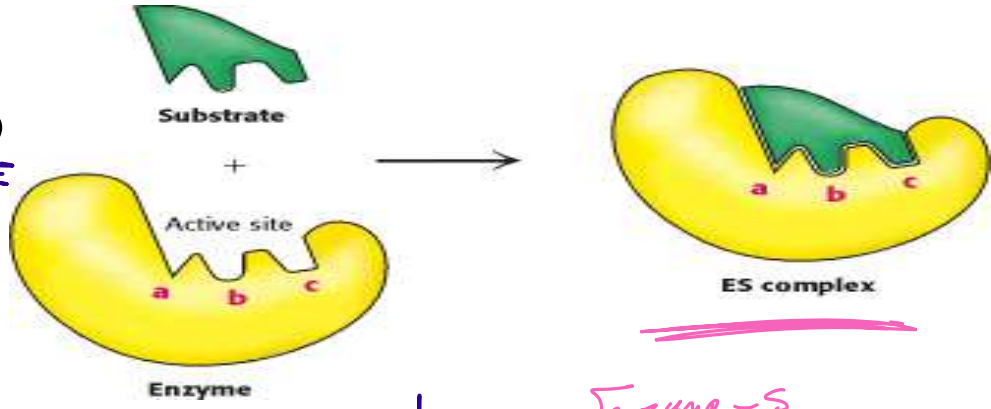
more the one polypeptid chain in the interface between the subunits

Enzyme substrate binding

-Two models have been proposed to explain how an enzyme binds its substrate: the lock-and –key model and the induced-fit model.

- Lock-and-Key Model of Enzyme-Substrate Binding, in this model, the active site of the unbound enzyme is complementary in shape to the substrate.

-"lock and key model" **accounted for the exquisite specificity of enzyme-substrate interactions**, the implied rigidity of the enzyme's active site failed to account for the dynamic changes that accompany catalysis.



Induced-Fit Model of Enzyme-Substrate Binding

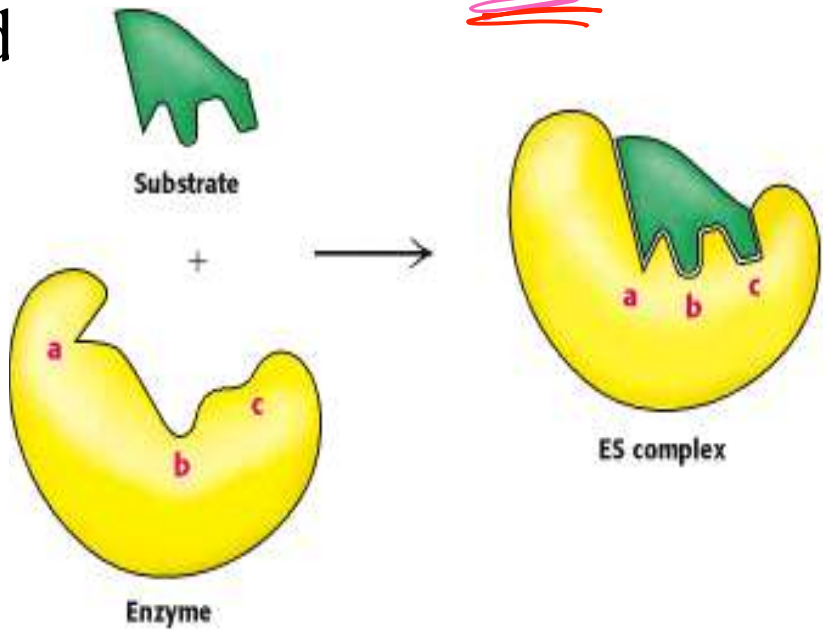
- In this model, the enzyme changes shape on substrate binding.

* flixdable

-The active site forms a shape complementary to the substrate only after the substrate has been bound.

* In the beginning not fit

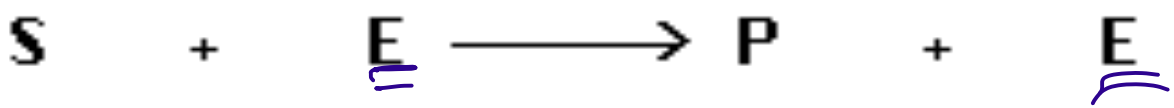
- When a substrate approaches and binds to an enzyme they induce a conformational change, a change analogous to placing a hand (substrate) into a glove (enzyme).



approaches = تقترب

Mechanism of Action of Enzymes

- Enzymes are catalysts and increase the speed of a chemical reaction without themselves undergoing any permanent chemical change. They are neither used up in the reaction nor do they appear as reaction products.
- The basic enzymatic reaction can be represented as follows:

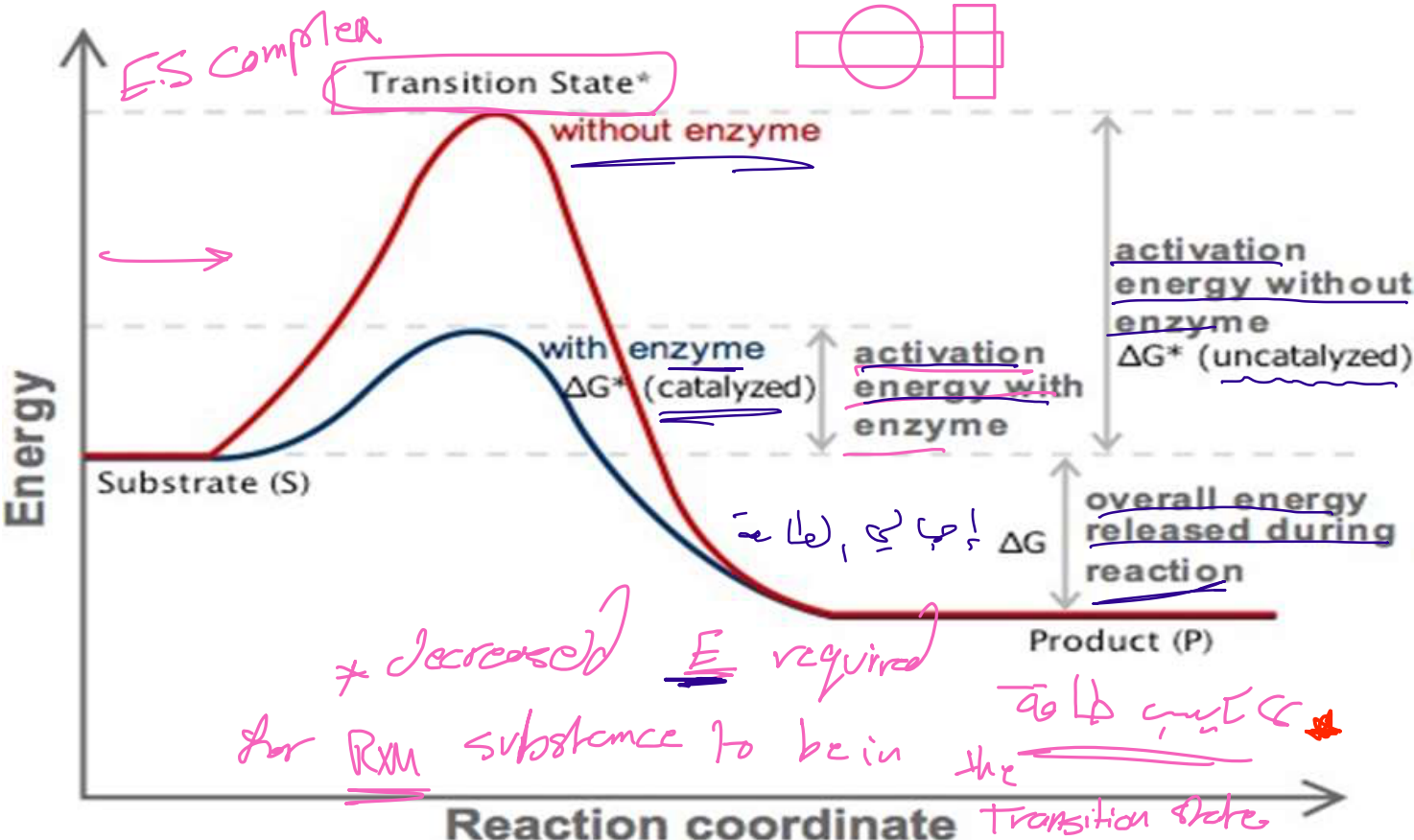


- Where E represents the enzyme catalyzing the reaction, S the substrate, the substance being changed, and P the product of the reaction.
- The mechanism of action of enzymes can be explained by two perspectives:

1- Thermodynamic changes
2- Processes at the active site

Thermodynamic changes

- All enzymes accelerate reaction rates by providing transition states with a lowered $\Delta G^{\ddagger}$ for formation of the transition states.
- The lower activation energy means that more molecules have the required energy to reach the transition state.



Processes at the active site

1- **Catalysis by proximity**: for the molecules to react they must come within bond-forming distance of one another. When an enzyme binds substrate molecules at its active site, it creates a region of high local substrate concentration. Enzyme-substrate interactions orient reactive groups and bring them into proximity with one another.

2- **Acid base catalysis**: the **ionizable functional groups** of aminoacyl side chains of prosthetic groups contribute to catalysis by acting as acids or bases.

- General acid catalysis involves **partial proton transfer** from **a donor** to lower the free energy of the transition state.
- General base catalysis involves **partial proton abstraction** from **an acceptor** to lower the free energy of the transition state.

3- **Catalysis by strain**: enzymes that catalyze the **lytic reactions** involve breaking a covalent bond typically bind their substrates in **a configuration slightly unfavorable** for the bond that will undergo cleavage.

4- **Covalent catalysis**: accelerates reaction rates through **transient** formation of enzyme-substrate covalent bond.

Three stages in covalent catalysis:

1- Nucleophilic reaction between enzyme and substrate

2- Electrophilic withdrawal of electrons from substrate

3- Elimination reaction (reverse of stage 1)

5- Metal Ion catalysis (M.I)

- Two classes of metal ion dependent enzymes:

1- Metalloenzymes contain tightly bound transition metal ions (Fe^{2+}, Fe^{3+}, Cu^{2+}, Zn^{2+}, Mn^{2+})

2- Metal-activated enzymes loosely bind metal ions (alkali or alkaline metal including Na^{+}, K^{+}, Mg^{2+} and Ca^{2+})

- Metal ions enhance catalysis in three major ways:

1- Binding to and orienting substrates for reaction as Mg^{2+} binding to ATP

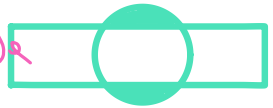
2- Mediating redox reaction through changes in oxidation state such as reduction of O_2 to H_2O through electron transfer

3- Electrostatic stabilization or shielding of negative charges as Mg^{2+} binding to ATP

6- Electrostatic catalysis

- Enzymes seem to arrange **active site charge distributions** to stabilize the **transition states** of catalyzed reactions
- Substrate binding generally **excludes water from an enzyme active site** generating **a low dielectric constant** within the active site
- Electrostatic interactions are stronger
- pka's can vary by several pH units due to proximity of charged groups
- Alternative form of electrostatic catalysis: several enzymes as **superoxide dismutase** apparently **use charge distributions** to guide **polar substrates** to their active sites

Enzyme Specificity



- In general, there are four distinct types of specificity:

1- Absolute specificity: the enzyme will catalyze only one reaction.

2- Group specificity: the enzyme will act only on molecules that have specific functional groups, such as amino, phosphate and methyl groups

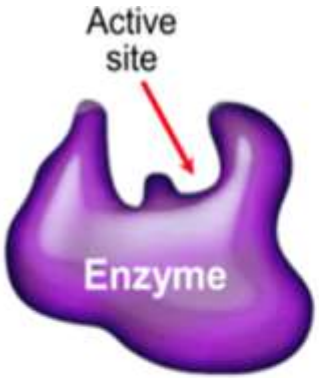
3- Linkage specificity: the enzyme will act on a particular type of chemical bond regardless of the rest of the molecular structure

4- Stereo chemical specificity: the enzyme will act on a particular steric or optical isomer.

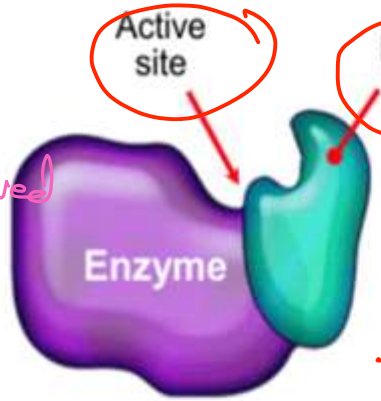
- Some enzyme require cofactors to be active.
- Cofactors are a non-protein components of the enzyme.
- Organic Molecules (Coenzymes)
- Inorganic ions e.g., Ca2+ , Zn2+ (Prosthetic group)
- Cofactors may be:

1- The Permanently attached cofactors, are called Prosthetic group (such as a vitamin, sugar, or lipid or inorganic such as a metal ion)

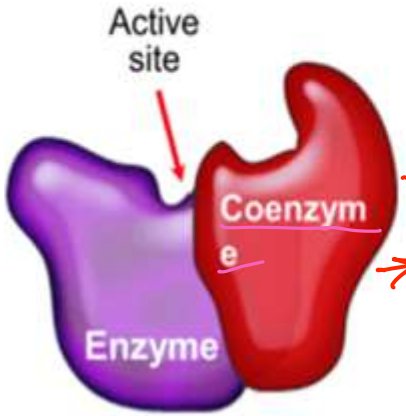
2- Temporarily attached cofactors are called coenzyme, its detach after a reaction and may participate in the reaction with other enzyme.



Enzyme is protein only
Example: lysozyme



Enzyme + prosthetic group
Example:
flavoprotein + FAD



Enzyme + coenzyme
Example:
dehydrogenases + NAD

Cofactors

- Cofactors can be subdivided into two groups: metals and small organic molecules

- Cofactors that are small organic molecules are called coenzymes.

- Most common cofactor are also metal ions.

- If tightly bound, the cofactors are called prosthetic groups.

- Loosely bound Cofactors serve functions similar to those of prosthetic groups but bind in a transient, dissociable manner either to the enzyme or to a substrate

Prosthetic groups

metal ions / Vitamin / sugar / lipid

- Tightly integrated into the enzyme structure by covalent or non-covalent forces. e.g.;

1. Pyridoxal phosphate → V-B6
2. Flavin mononucleotide (FMN) V-B2
3. Flavin adenine dinucleotide (FAD) V-B2
4. Thiamin pyrophosphate (TPP) V-B1
5. Biotin V-B7 V-H
6. Metal ions – Co, Cu, Mg, Mn, Zn

* Coenzyme also working as Prosthetic groups

- Metals are the most common prosthetic groups

mostly

Coenzymes

- Very often vitamins
- They serve as recyclable shuttles—or group transfer agents—that transport many substrates from their point of generation to their point of utilization.
- The water-soluble B vitamins supply important components of numerous coenzymes.
- Chemical moieties transported by coenzymes include hydrogen atoms or hydride ions, methyl groups (folates), acyl groups (coenzyme A), and oligosaccharides (dolichol).

Important Prosthetic Groups and Coenzymes

Prosthetic Group	Enzymes/ Proteins
Zn^{++}	Carbonic anhydrase , Alcohol dehydrogenase
Fe^{+++} or Fe^{++}	Hemoglobin, Cytochromes, ferrodoxin
Cu^{++} or Cu^{+++}	Cytochrome oxidase
K^{+} and Mg^{++}	Pyruvate Phosphokinase

Coenzymes	Vitamins
Nicotinamide adenine dinucleotide (NAD^{+}) or nicotinamide adenine dinucleotide phosphate ($NADP^{+}$)	vitamin B_3 (niacin)
Flavin mononucleotide (FMN^{+}) or flavin adenine dinucleotide(FAD^{+})	vitamin B_2 (riboflavin)
Pyridoxal phosphate	vitamin B_6 (pyridoxine)
Coenzyme A	Pantothenic Acid

Diagnostic significance of enzymes

1- Enzymes can act as diagnostic markers of underlying diseases .

2- Enzymes can also act as reagents for various biochemical estimations and detections

Enzymes as diagnostic markers

1- **Functional plasma enzymes** (Plasma derived enzymes):

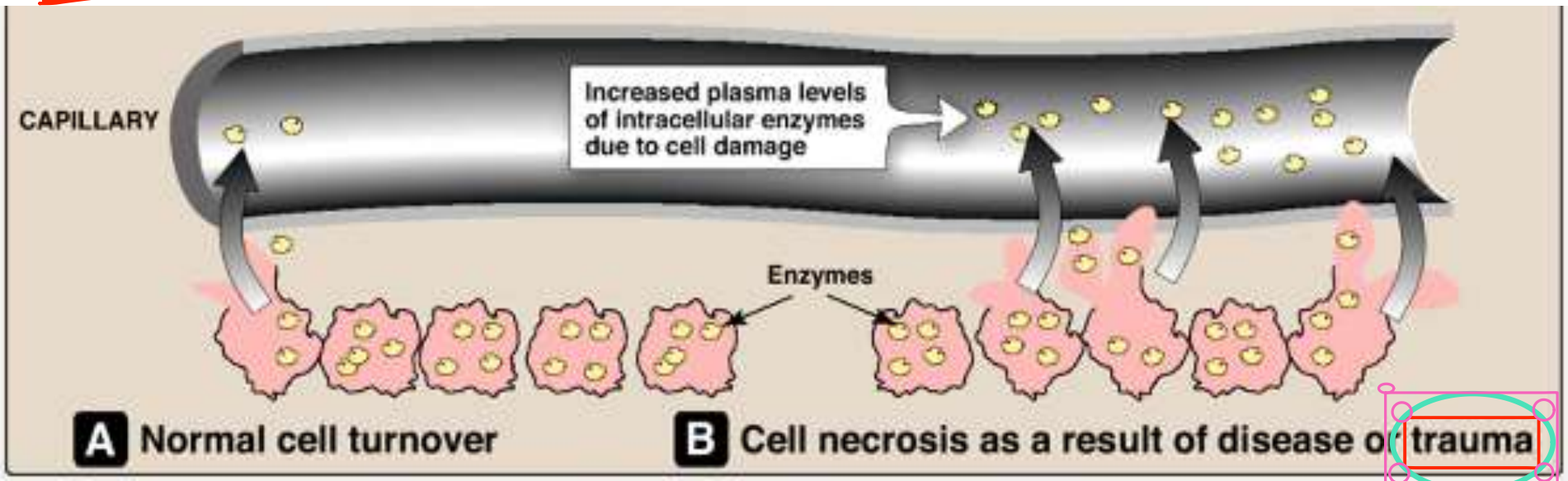
- Certain enzymes, proenzymes, and their substrates are present at all times in the circulation of normal individuals and perform a physiologic function in the blood.

Examples of these functional plasma enzymes include **lipoprotein lipase**, **pseudo cholinesterase**, and the **proenzymes of blood coagulation and blood clot dissolution** .

The majority of them are synthesized in and secreted by liver.

2- **Nonfunctional plasma enzymes** (Cell derived enzymes):

- Plasma also contains numerous other enzymes that perform no known physiologic function in blood.
- These apparently nonfunctional plasma enzymes arise from the routine normal destruction of erythrocytes, leukocytes, and other cells.
- Tissue damage or necrosis resulting from injury or disease is generally accompanied by increases in the levels of several nonfunctional plasma enzymes.



Isoenzymes (Isoenzymes)

- Are homologous enzymes that catalyze the same reaction but have differences in enzymatic properties.
- Often different isoenzymes are found in different locations in a cell or in different organs/tissues of an organism.
- They are from different polypeptide chains that coded by different genes and so, they are affected by different activators and different inhibitors in different tissues.

e.g.:

Lactate dehydrogenase isoenzymes,

- The enzyme interconverts lactate and pyruvate (LDH)
- Humans have two isoenzymic chains for lactate dehydrogenase: LDH (M) found in muscle and LDH (H) found in heart.
- M is optimized to work under anaerobic conditions and H optimized to work under aerobic conditions.

-There are 5 different isoenzymes.
-The relative ratio of the isoenzymes depends on the location in the organism as well as the developmental stage.

Isoenzyme	Tissue origin
LDH1 (H4)	Cardiac and kidney
LDH2 (H3M)	Cardiac, kidney, brain and RBCs
LDH3 (H2M2)	Brain, lung and WBCs
LDH4 (HM3)	Lung, skeletal muscle
LDH5 (M4)	Skeletal muscle and liver

CK/CPK Isoenzymes

- There are three Isoenzymes.
- Measuring them is of value in the presence of elevated levels of CK or CPK to determine the source of the elevation.
- Each isoenzyme is a dimer composed of two protomers 'M' (for muscles) and 'B'(for Brain).
-These isoenzymes can be separated by, electrophoresis or by ion exchange chromatography.

Isoenzyme	Electrophoretic mobility	Tissue of origin	Mean % in blood
MM(CK3)	Least	Skeletal muscle Heart muscle	97-100%
MB(CK2)	Intermediate	Heart muscle	0-3%
BB(CK1)	Maximum	Brain	0%

Enzyme Kinetics

- It is the field of biochemistry concerned with the quantitative measurement of the rates of enzyme-catalyzed reactions and the study of the factors affecting these rates.
- The rate of a chemical reaction is described by the number of molecules of reactant(s) to be converted into product(s) in a specified time period which is dependent on the concentration of the chemicals involved in the process and on rate constants that are characteristic of the reaction.

CK_3 CK_2 CK_1

MM MB BB

muscle Heart muscle Brain

Skeletal Heart

97–100% 3% 0%

BLM

Weight ↑ — ↓

least — Maximum.

fatigue Excitation