1. **What are enzymes?** Be able to describe the chemical nature of enzymes and their function in biochemical reactions.

2. **How do enzymes work, and why are they so specific?** Be able to provide an overview of what happens as one or more substrates and an enzyme come together so that the catalyzed reaction can occur, and be able to list the properties of enzymes that make their specificity possible.

3. **What effects do temperature, pH, enzyme concentration, and substrate concentration have on enzyme activity?** Be able to describe the changes in enzyme activity that result when temperature, pH, enzyme concentration, or substrate concentration change.

4. **How is enzyme activity regulated?** Be able to define and identify feedback control, allosteric control, reversible and irreversible inhibition, inhibition by covalent modification, and genetic control of enzymes.

5. **What are vitamins?** Be able to describe the two major classes of vitamins, the reasons vitamins are necessary in our diets, and the general results of excesses or deficiencies.
1. What are enzymes?

**Enzyme:** A protein or other molecule that acts as a catalyst for a biological reaction.

**Active site:** A pocket in an enzyme with the specific shape and chemical makeup necessary to bind a substrate.

**Substrate:** A reactant in an enzyme-catalyzed reaction.

**Specificity (enzyme):** The limitation of the activity of an enzyme to a specific substrate, specific reaction, or specific type of reaction.

**Thrombin:** is specific for catalyzing hydrolysis of a peptide bond adjacent to arginine and does so primarily in a protein essential to blood clotting.
Catalase: is almost completely specific for one reaction—the decomposition of hydrogen peroxide.

Specificity of Enzymes: for one of two enantiomers is a matter of fit. A chiral reactant fits a chiral reaction site. The enantiomer at the top fits the reaction site like a hand in a glove, but the enantiomer at the bottom does not.

Lactate Dehydrogenase: The enzyme lactate dehydrogenase catalyzes the removal of hydrogen from L-lactate but not from D-lactate.
**Turnover Number:** Catalytic activity is measured by turnover number, the maximum number of substrate molecules acted upon per enzyme per unit time. Most enzymes turn over 10-1000 molecules per second.

<table>
<thead>
<tr>
<th>ENZYME</th>
<th>REACTION CATALYZED</th>
<th>TURNOVER NUMBER (MAXIMUM NUMBER OF CATALYTIC EVENTS PER SECOND)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papain</td>
<td>Hydrolysis of peptide bonds</td>
<td>10</td>
</tr>
<tr>
<td>Ribonuclease</td>
<td>Hydrolysis of phosphate ester link in RNA</td>
<td>10^2</td>
</tr>
<tr>
<td>Kinases</td>
<td>Transfer of phosphoryl group between substrates</td>
<td>10^3</td>
</tr>
<tr>
<td>Acetylcholinesterase</td>
<td>Deactivation of the neurotransmitter acetylcholine</td>
<td>10^4</td>
</tr>
<tr>
<td>Carbonic anhydrase</td>
<td>Converts CO_2 to HCO_3^-</td>
<td>10^6</td>
</tr>
<tr>
<td>Catalase</td>
<td>Decomposition of H_2O_2 to H_2O + O_2</td>
<td>10^7</td>
</tr>
</tbody>
</table>

**Cofactor:** A nonprotein part of an enzyme that is essential to the enzyme’s catalytic activity; a metal ion or a coenzyme.

**Coenzyme:** An organic molecule that acts as an enzyme cofactor.

**Why are cofactors necessary?** The functional groups in proteins are limited to those of the amino acid side chains. By combining with cofactors, enzymes acquire chemically reactive groups not available as side chains.
**Classification of Enzymes:** Enzymes are divided into six main classes according to the general kind of reaction they catalyze.

**Oxidoreductases:** catalyze redox reactions of substrates, most commonly addition or removal of oxygen or hydrogen. These enzymes require coenzymes that are reduced or oxidized as the substrate is oxidized or reduced.

![Oxidoreductase reaction diagram]

**Transferases:** catalyze transfer of a group from one molecule to another. Kinases transfer a phosphate group from ATP to give ADP and a phosphorylated product.
Hydrolases: catalyze the breaking of bonds with addition of water. The digestion of carbohydrates and proteins by hydrolysis requires these enzymes.

\[
\text{A-B} + \text{H}_2\text{O} \rightarrow \text{A-OH} + \text{B-H}
\]

Ligases: catalyze the bonding together of two substrates. Such reactions are generally not favorable and require energy from ATP hydrolysis.

\[
\text{A} + \text{B} + \text{Adenosine triphosphate (ATP)} \rightarrow \text{A-B} + \text{Adenosine diphosphate (ADP)} + \text{HOPO}_3^{2-} + \text{H}^+
\]

\[
\text{CO}_2 + \text{CH}_3\text{-C}-\text{CO}^-= \text{ATP} \rightleftharpoons \text{OC}-\text{CH}_2\text{-C}-\text{CO}^- + \text{ADP} + \text{HOPO}_3^{2-} + \text{H}^+
\]

Isomerases: catalyze the isomerization (rearrangement of atoms) of a substrate in reactions that have but one substrate and one product.
Lyases: catalyze the addition of a molecules to a double bond or the reverse reaction in which a molecule is eliminated from a double bond.

![Chemical reaction diagram]

Naming Enzymes:

Enzymes have the family-name ending - ase .

Exceptions occur for enzymes such as papain and trypsin , which are still referred to by older common names.

Modern systematic names always have two parts:
the first identifies the substrate on which the enzyme operates
the second part is an enzyme subclass name like those shown on the next slide.
Only responsible for the six classes discussed above

Know the six classes we discussed in bold

2. How do enzymes work, and why are they so specific?

**Lock and Key Model:** Historically, the lock-and-key model came first. The substrate is described as fitting into the active site as a key fits into a lock.

**Induced Fit Model:** accounts for changes in the shape of the enzyme active site that accommodate the substrate and facilitate the reaction. As an enzyme and substrate come together, their interaction induces exactly the right fit for catalysis of the reaction.
The induced-fit model of enzyme action has a flexible active site that changes shape to best fit the substrate and catalyze the reaction.

Properties of enzymes that make their specificity possible.

1. Bring substrate(s) and catalytic sites together (proximity effect).

2. Hold substrate(s) at the exact distance and in the exact orientation necessary for reaction (orientation effect).

3. Provide acidic, basic, or other types of groups required for catalysis (catalytic effect).

4. Lower the energy barrier by inducing strain in bonds in the substrate molecule (energy effect).
3. What effects do temperature, pH, enzyme concentration, and substrate concentration have on enzyme activity?

**Concentration:** Under most conditions the rate of an enzyme catalyzed reaction is controlled by the amount of substrate and the overall efficiency of the enzyme.

If the enzyme–substrate complex is rapidly converted to product, the rate at which enzyme and substrate combine to form the complex becomes the limiting factor.

At low substrate concentration, the reaction rate is directly proportional to the substrate concentration.

With increasing substrate concentration, the rate drops off as more of the active sites are occupied.

With all active sites occupied, the rate reaches a maximum.

In the presence of excess substrate, the concentration of an enzyme can vary according to our metabolic needs.

If the concentration of substrate does not become a limitation, the reaction rate varies directly with the enzyme concentration.

**Be able to explain either of these graphs if given on exam***
Effect on temperature and pH on Enzyme Activity:
Enzyme catalytic activity is highly dependent on pH and temperature.

Optimum conditions vary slightly for each enzyme but are generally near normal body temperature and the pH of the body fluid in which the enzyme functions.

Pepsin, which initiates protein digestion in the highly acidic environment of the stomach, has its optimum activity at pH 2.

Trypsin, which acts in the alkaline environment of the small intestine, has optimum activity at pH 8.

(a) The rate increases with increasing temperature until the protein begins to denature; then the rate decreases rapidly.

(b) The optimum activity for an enzyme occurs at the pH where it acts.

Be able to identify the temp and pH of active enzyme by looking at graph
4. How is enzyme activity regulated?

**Activation:** Any process that starts or increases the action of an enzyme

**Inhibition:** Any process that slows or stops the action of an enzyme

*Feedback and Allosteric Control are two strategies for enzyme regulation.*

**Feedback control:** Regulation of an enzyme’s activity by the product of a reaction later in a pathway.

If a product near the end of a metabolic pathway inhibits an enzyme that functions near the beginning of that pathway, then no energy is wasted making the ingredients for a plentiful substance.

**Allosteric control:** An interaction in which the binding of a regulator at one site on a protein affects the protein’s ability to bind another molecule at a different site.

Allosteric control can be either positive or negative.

Binding a positive regulator changes the active sites so that the enzyme becomes a better catalyst and the rate accelerates.

Binding a negative regulator changes the active sites so that the enzyme is a less effective catalyst and the rate slows down.
Enzyme inhibition can be reversible or irreversible.

**Reversible inhibition:** the inhibitor can leave, restoring the enzyme to its uninhibited level of activity.

**Irreversible inhibition:** the inhibitor remains permanently bound and the enzyme is permanently inhibited.

The inhibition can also be competitive or noncompetitive, depending on whether the inhibitor binds to the active site or elsewhere.

A competitive inhibitor can eventually be overcome by higher substrate concentrations. With a noncompetitive inhibitor the maximum rate is lowered for all substrate concentrations.

**Be able to describe or draw this chart**
covalent modification: There are two general modes of enzyme regulation: removal of a covalently bonded portion of an enzyme, or addition of a group.

zymogens or proenzymes: Some enzymes are synthesized in inactive forms. Activation requires a chemical reaction that splits off part of the molecule.

Genetic (enzyme) control: Regulation of enzyme activity by hormonal control of the synthesis of enzymes is especially useful for enzymes needed only at certain times.

5. What are vitamins?

Vitamin: An organic molecule, essential in trace amounts that must be obtained in the diet because it is not synthesized in the body.

Vitamins are grouped by solubility into two classes: water-soluble and fat-soluble.

The hazards of overdosing on fat-soluble vitamins are greater than those of the water-soluble vitamins because of their ability to accumulate in body fats. Excesses of the water-soluble vitamins are more likely to be excreted in the urine.