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Chemical Basis of Life

CLEP Biology Rapid Learning Series

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Learning Objectives

By viewing this tutorial, you will learn about:

- Atoms and chemical bonds
- Organic chemicals
- Acids, bases and buffers
- Biochemical reactions

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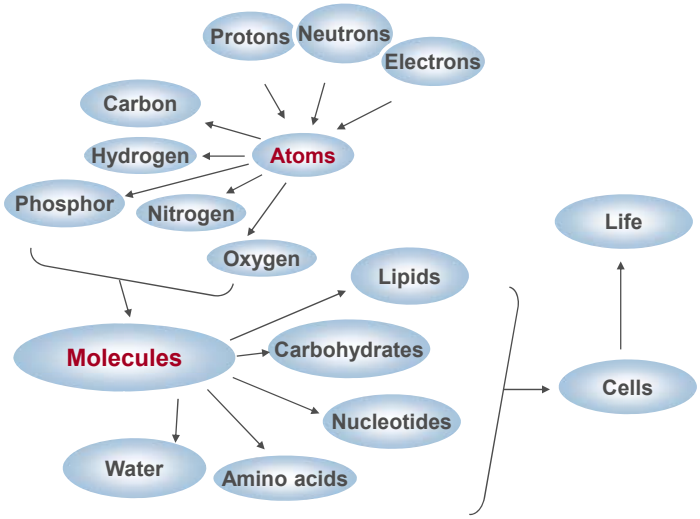
Concept Map



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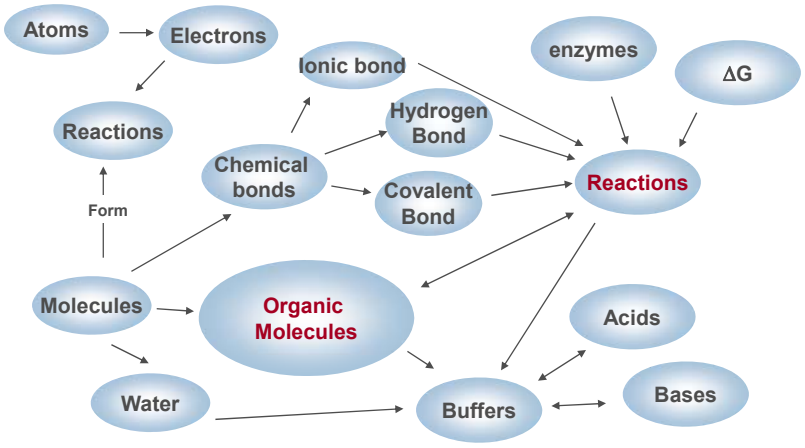
Chemistry & Life



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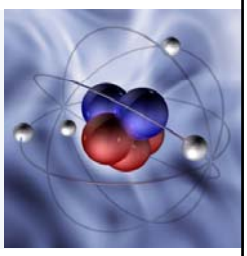
Atoms and Molecules



Atomic compositon

Electron shells

Types of bonds

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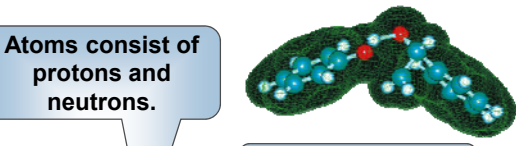
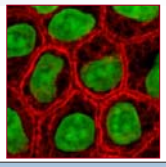
Lives and Atoms





Atoms consist of protons and neutrons.

Atoms make up molecules.

Cells are made up of organic and inorganic molecules.

Living organisms are made up of cells.

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Atomic Structure

Protons = atomic number

Neutrons = mass number - atomic number

Electrons = equal to protons, if neutral

Phosphorus has an atomic number of 15 and an mass number of 31.

Protons = 15

Neutrons = 31 – 15 = 16

Electrons = 15 (same as protons)

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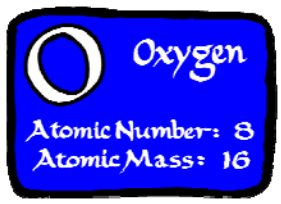
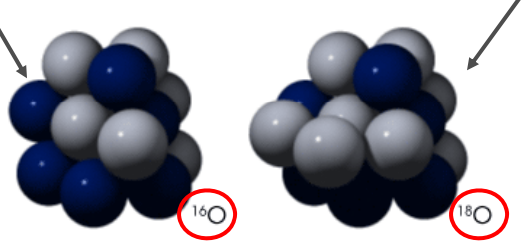
Isotopes



8 protons + 8 neutrons

8 protons + 10 neutrons



Isotopes

Same number of protons, different number of neutrons.

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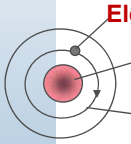
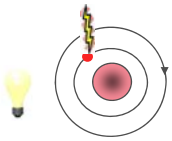
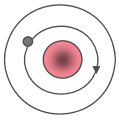
Electrons and Energy

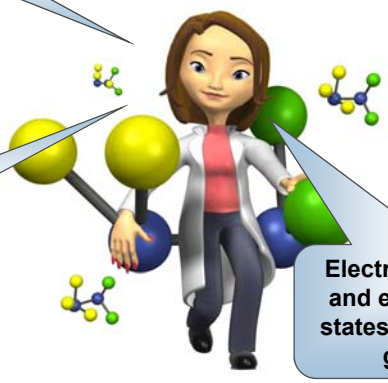
Electrons have both energy wave and particle or mass characteristics.

Electrons orbit the nucleus at near the speed of light.









Protons and neutrons make up an atoms nucleus.

Electrons can be excited and enter higher energy states different from their ground states.

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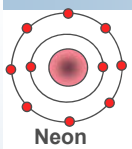
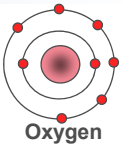
Energy Shells

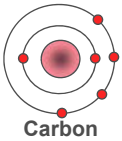


When the outer shell is filled the element is inert e.g. helium and neon.



When the outer shell is not filled, the element is chemically reactive e.g. hydrogen, carbon and oxygen.

The inner shell is the K shell having 2 electrons.



Electrons occupy shells around the atomic nucleus.

Shell	Electrons
K	2
L	8
M	18
N	32
O	32
P	18
Q	8

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Chemical Bonds - Ionic Bonds

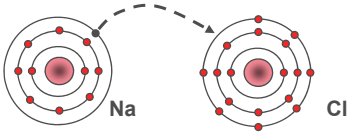
Atoms form bonds by gaining, losing, or sharing electrons.

Ionic Bond

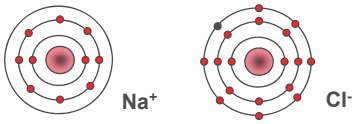
Atoms become ions when gaining or losing electrons, ionic bonds are weak and tend to dissociate in water.

Example: NaCl

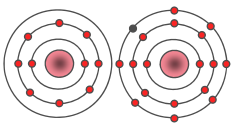
Atoms



Ions



Molecule



NaCl

Opposite charges bring the two ions together to form a molecule

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Chemical Bonds - Covalent Bonds

Covalent Bond

Covalent bonds form when atoms share electrons. They are very strong bonds - the major one in organic chemicals.

Example: CH_4 (methane)

4 hydrogen and 1 carbon atoms

Methane Molecule
Each hydrogen and carbon have filled number of electron in their outer shell.

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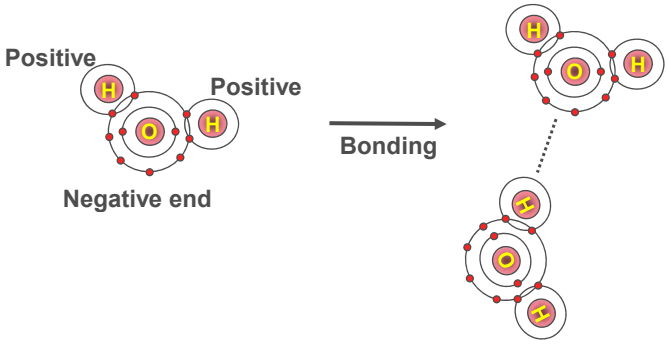
Chemical Bonds - Hydrogen Bonds

Hydrogen Bond

Weak electrical attraction between the positive end of one molecule and the negative end of another.

Example: H_2O



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Water

A polar molecule forming intermolecular hydrogen bonding.

Water is very polar.

Water carries waste materials and can absorb and transport heat.

Water is the most abundant compound in living things.

Most metabolic reactions occur in water.

Water is important in transporting materials in the body since it is a major component of blood.

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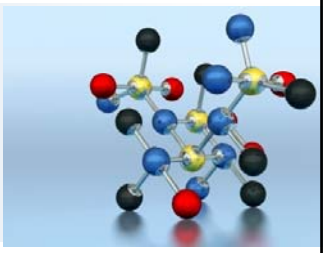
Organic Molecules



Organic Molecules

Chemical Bonds

Macromolecules

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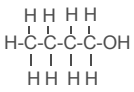
Organic Molecules

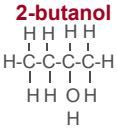
Molecular formulas are an expression in the simplest whole-number terms of the composition of a substance, e.g. glucose is made of 6 carbons,12 hydrogens and 6 oxygens: $C_6H_{12}O_6$

Isomers: molecules having same molecular formula but different structure formula, e.g. 1-butanol and 2-butanol.

1-butanol



2-butanol



Organic compounds are molecules that contain carbon.

Structure formula is a form to write out how atoms are arranged in a molecule.

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Chemical Bonds

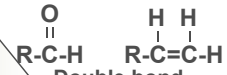
Triple bond: Atoms in a molecule share three pairs of electrons.

R-C≡N
Triple Bond

Chemical bonds store energy: the energy in a double bond is greater than that in a single bond but less than that in a triple bond.

Single bond

Single bond: Atoms share one pair of electrons in the molecule, e.g., CH3-CH3



Double bond

Double bond: Atoms in a molecule share two pairs of electrons, e.g., R-CHO, R-CH=CH2

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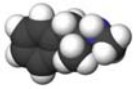
Class of Organic Chemicals

Alcohols, R-OH

Camphor

Ketones R-C-R (O)

Methamphetamine



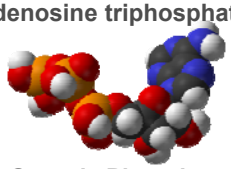
Amine
R-NH2

Vanillin

Aldehydes

R-CHO

Adenosine triphosphate

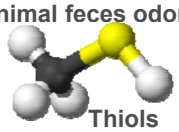


Organic Phosphates
$R\text{-}OPO_3^{2-}$

Acetic Acid

Carboxylic Acids,
R-COOH

Methanethiol
Animal feces odor



Thiols
R-SH

Organic chemicals are classified by their functional groups which determine the properties of a molecule.

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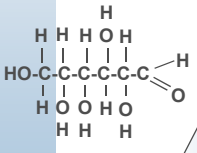
Important Organic Molecules

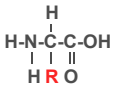
What are four examples of biologically important organic molecules?

Saccharides, amino acids, fatty acids and nucleotides.

Saccharides have C, H and O and glucose is an example of a monosaccharide.

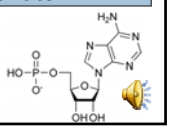


Amino acids have C, H, N and O. They also have an amino group and a carboxyl group.



Fatty acids have mostly C and H with a CH_3 and carboxyl group.

Nucleotides have C, H, O, N and P. They also have a base, ribose and phosphate.



$CH_3\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}COOH$

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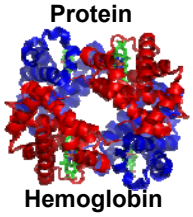
Macromolecules

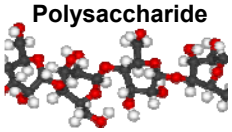
Macromolecules are large molecules that may be biopolymers like DNA or non-polymeric molecules e.g. lipids, proteins and polysaccharides.

Protein



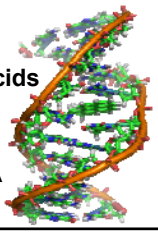
Hemoglobin

Polysaccharide



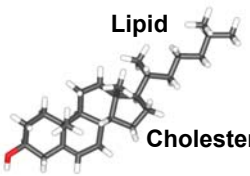
Cellulose

Nucleic Acids



DNA

Lipid



Cholesterol

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Acids, Bases and Buffers

Define acid, base and pH.

Properties of weak acids and weak bases.

Describe electrolyte and buffer solutins.

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Acid

An acid is a compound that when dissolved in water has pH of less than 7.

Common examples of acids are vinegar and sulfuric acid (in car batteries). They are frequently sour to the taste (e.g. lemon juice), and sting when in contact with mucus membranes.

Also, an acid (commonly referred to as HA in formulas) is a compound that will donate a hydrogen ion (H^+) to a base.

In water a weak acid HA comes apart (dissociates) and is described by this equation: $HA + H_2O \leftrightarrow H_3O^+ + A^-$

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Base

A base is a substance that can accept protons. It can also be thought of as a compound that donates electron pairs and is a source for hydroxide anions (OH^-)

While acids increase the hydronium ion concentration in water (H_3O^+), bases decrease H_3O^+.

Properties of bases include: bitter tasting, slippery or slimy to the touch. Very caustic when in contact with organic matter.

Bases in aqueous solutions can dissociate and conduct electricity.

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Electrolyte

An electrolyte consists of free ions and is electrically conductive.

Electrolytes typically are solutions of acids, bases or salts.

When NaCl (salt) is added to water, the individual components dissociate:
$NaCl \rightarrow Na^+ + Cl^-$

The dissociation of NaCl results in a solution that conducts an electric current.

In the body the primary ions of electrolytes are: sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), phosphate (PO_4^{3-}), and hydrogen carbonate (HCO^{3-}).

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Buffer

A buffer is a solution that resists change in its pH when small amounts of an acid or base is added to it or when it is diluted.

Buffers are a mixture of weak acids and it conjugate base or a weak base and its conjugate acid.

$HA \leftrightarrow H^+ + A^-$

More H^+: $HA \leftarrow H^+ + A^-$

Equilibration moves to left, forming more HA and keep H^+ concentration constant.

More OH^-: $HA \rightarrow H^+ + A^-$

Equilibration moves to right, forming more H_2O and keep H^+ concentration constant.

The resistance to changing pH is because of the equilibrium between the weak acid (HA) and its conjugate base (A^-) described by this equation:
$HA + H_2O \rightarrow H_3O^+ + A^-$

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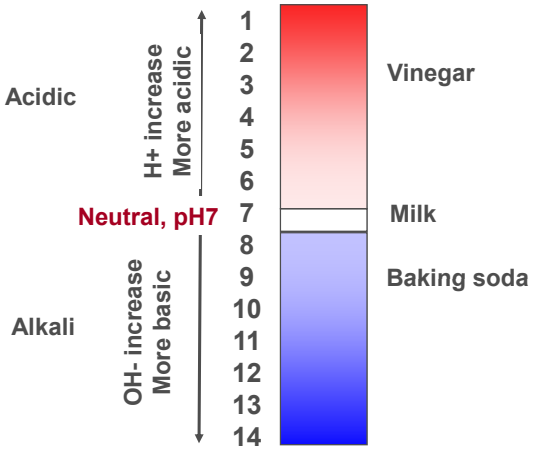
pH

pH represents the concentration of hydrogen ions [H^+] in solution.

pH = -log [H^+]



Neutral, pH7, equal amount of H^+ and OH^- in solution

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Biochemical Reactions

Thermodynamics

Coupled Reactions

Enzymes in Biochemical Reactions

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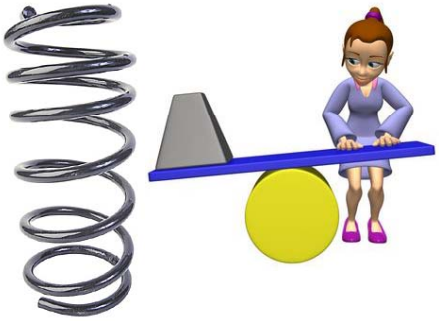
First Law of Thermodynamics

The total energy of a system and its surroundings is constant.

- Energy cannot be created or destroyed.
- Energy can take different forms: heat, light etc.



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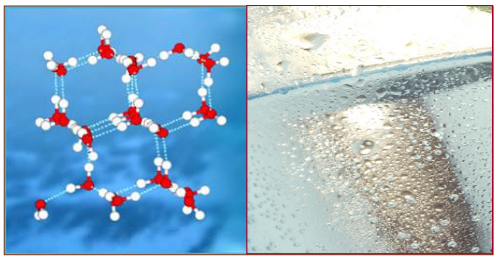
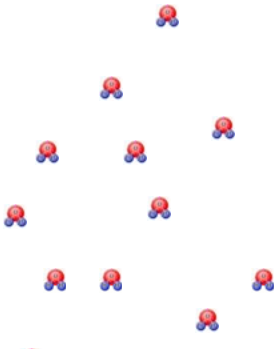
Second Law of Thermodynamics

The total entropy of a system plus its surroundings always increase.



Water molecules are highly ordered in ice (low entropy).

When the ice melts the water molecules become more disordered, increased entropy.



Water turns to steam (gas) entropy is at the maximum.

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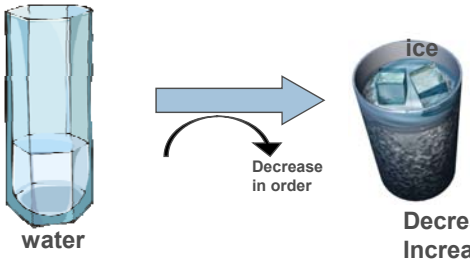
Entropy

Entropy "S"

Entropy is the measure of the degree of randomness or disorder in a system.

The Second Law of Thermodynamics says that the total entropy of a system plus that of its surroundings always increase.

A local increase in order will only occur if entropy in another part of the universe is decreased in an equal or greater amount.



Decrease in entropy
Increase in order.

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Entropy Comparison

Entropy and Matter Comparison

Less Entropy	More Entropy
Solid	Liquid
Liquid	Gas
Solute & Solvent separated	Solution
Small, simple molecule	Large, complex molecule
Less molecules	More molecules

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ΔG vs. Reactions

ΔG (kcal/mol or kJ/mol): the change in "free energy"

- **Spontaneous Reaction**: a naturally occurring reaction that once started will continue to happen without outside intervention.
  ΔG = negative

- **Nonspontaneous Reaction**: an unnatural process that after it is started will NOT continue to happen without outside intervention. A nonspontaneous process only happens when outside action introduces energy to drive the process.
  ΔG = positive

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Coupled Metabolic Reactions

A→B+C
B→D

If ΔG = is negative the reaction can be spontaneous.

The standard free energy change.

Products

$$\Delta G = \Delta G' + RT \ln \frac{[C]\,[D]}{[A]\,[B]}$$

Reactants

A ↔ B + C ΔG°' = + 21 kJ mol-1 (+5 kcal mol-1)
B ↔ D ΔG°' = - 34 kJ mol-1 (-8 kcal mol-1)

A ↔ C + D ΔG°' = - 13 kJ mol-1 (-3 kcal mol-1)

The overall free energy change for the coupled reactions is equal to the sum of the free energy of the individual step.

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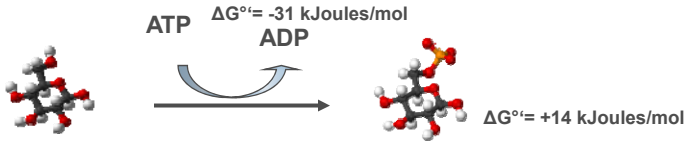
Glycolysis Coupled Reactions



Glucose

Glucose-6-phosphate

First reaction in glycolysis: making glucose-6-phosphate from glucose.

The hydrolysis of ATP to ADP provides the energy by thermodynamic coupling.

ATP + H20 ↔ ADP + Pi	ΔG°'= -31 kJoules/mol
Pi + glucose ↔ glucose-6-phospate + H20	ΔG°'= +14 kJoules/mol
Net Energy Change	ΔG°'= -17 kJoules/mol

Coupled Reactions:
ATP + glucose ↔ glucose-6-phosphate + ADP

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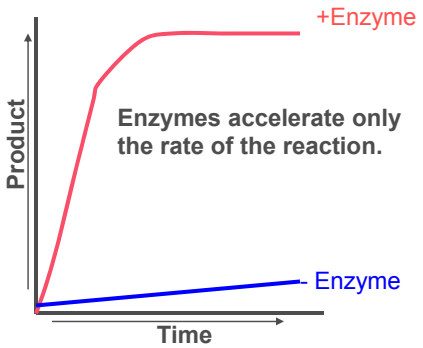
Enzymes Effect Rate Not Equilibrium

- **Enzymes are catalysts.**
- Enzymes do not alter the equilibrium of a chemical reaction.
- Enzymes only effect the rate of a product formation not the amount.

Given an infinite amount of time both +/- reactions would have the same concentration of products to reactants.



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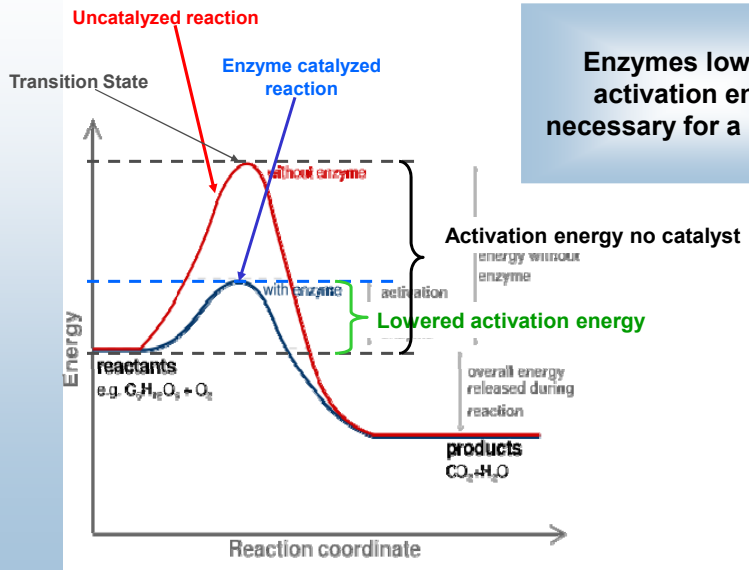
Activation Energy E_a



Enzymes lower the activation energy necessary for a reaction.

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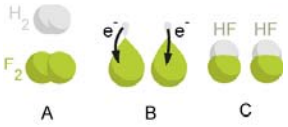
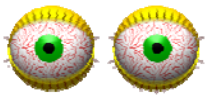
Biochemical Reactions: Types

Oxidation Reduction

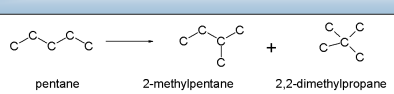


Group Transfer
A-X + B → A + B-X



Formation of :
Ester, Thiol ester, Amide bond.

Isomerization Reaction
Transformation of a molecule into a different isomer.



Hydrolysis:
Esters, Ethers, Amides
A + H_2O → X + Y

Elimination / Addition Reaction
Two substituents are removed from a molecule.
Example: 2 R-OH → R-O-R + H_2O

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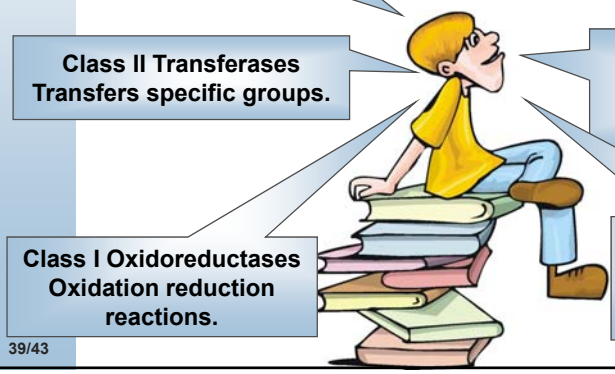
Enzyme Reactions

There are 6 classes or types of enzyme catalyzed reactions.



Class III Hydrolases
Catalyzes hydrolysis reactions.

Class IV Lyases
Catalyzes chemical bond breaking of various types other than hydrolysis and oxidation.

Class II Transferases
Transfers specific groups.

Class V Isomerases
Catalyses the interconversion of polymers.

Class I Oxidoreductases
Oxidation reduction reactions.

Class VI Ligases
Catalyses the joining of two molecules by forming a new chemical bond.

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Learning Summary

Atoms are made up of proton, neutrons and electrons. Atoms combine to create cells and cells make up organisms.

Atoms form bonds making molecules that lead to biochemical macromolecules like: proteins, DNA, saccharides and lipids.

Acids, bases, electrolytes and buffer chemistry are critical to maintaining life. Their chemistries form the foundation for all biochemical reactions.

Biochemical reactions are catalyzed by enzymes (which are usually proteins) that function by lowering the activation energy.

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