General Biology

Course No: BNG2003
Credits: 3.00

2. The Chemical Context of Life

2a. Chemical Foundations of Biology

Prof. Dr. Klaus Heese

1

Elements and Compounds

- Matter is made up of elements, substances that cannot be broken down to other substances by chemical reactions

- Matter consists of chemical elements in pure form and in combinations called compounds

- Organisms are composed of matter, which is anything that takes up space and has mass

2

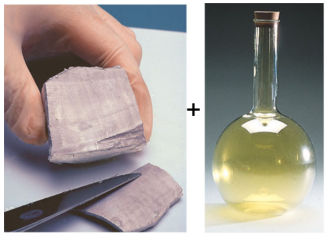
- **A compound**
  - is a substance consisting of two or more elements combined in a fixed ratio
  - has characteristics different from those of its elements

3

- **A compound**
  - is a substance consisting of two or more elements combined in a fixed ratio
  - has characteristics different from those of its elements

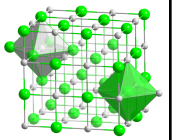
4

- **A compound**
  - is a substance consisting of two or more elements combined in a fixed ratio
  - has characteristics different from those of its elements



5

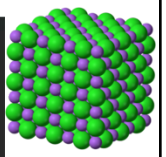
- **a compound**
  - is a substance consisting of two or more elements combined in a fixed ratio
  - has characteristics different from those of its elements



Sodium

Chloride

Sodium Chloride



food preservative
table salt
Ocean

6

Essential Elements of Life

- Essential elements
  - Include Carbon, Hydrogen, Oxygen, and Nitrogen
  - make up 96% of living matter

7

- A few other elements
  - make up the remaining 4% of living matter

Symbol	Element	Atomic Number	Percentage of Human Body Weight
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1

Trace elements (less than 0.01%): boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

8

- The effects of essential element deficiencies

(a) Nitrogen deficiency

(b) Iodine deficiency (---> hypertrophy) Disturbed thyroid function; thyroid synthesizes Iodine-containing hormones such as thyroxine (T4) and T3 ((Tetrajodthyronine, T4) und Trijodthyronine (T3)).

- Trace elements
  - are required by an organism in only minute (tiny, exiguous, diminutive) quantities

9

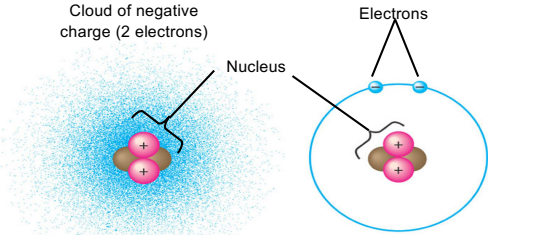
- An element's properties depend on the structure of its atoms
- Each **element**
  - **consists of a certain kind of atom** that is different from those of other elements
- An atom
  - is the smallest unit of matter that still retains the properties of an element
- Atoms of each element
  - Are composed of even smaller parts called subatomic particles

10

- Relevant subatomic particles include
  - Neutrons, which have no electrical charge
  - Protons, which are positively charged
  - Electrons, which are negatively charged
- Protons and neutrons
  - Are found in the atomic nucleus
- Electrons
  - Surround the nucleus in a "cloud"

11

- Simplified models of an atom



(a) This model represents the electrons as a cloud of negative charge, as if we had taken many snapshots of the 2 electrons over time, with each dot representing an electron's position at one point in time.

(b) In this even more simplified model, the electrons are shown as two small blue spheres on a circle around the nucleus.

12

Atomic Number and Atomic Mass

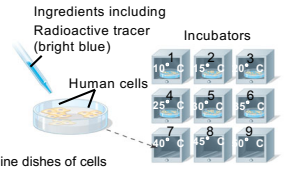
- Atoms of the various elements
  - Differ in their number of subatomic particles
- The atomic number of an element
  - Is the number of protons
  - Is unique to each element
- The mass number of an element
  - Is the sum of protons plus neutrons in the nucleus of an atom
  - Is an approximation of the atomic mass of an atom
- Atoms of a given element
  - May occur in different forms
- Isotopes of a given element
  - Differ in the number of neutrons in the atomic nucleus
  - Have the same number of protons
- Radioactive isotopes
  - Spontaneously give off particles and energy

13

Radioactive isotopes can be used in biology

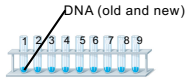
APPLICATION Scientists use radioactive isotopes to label certain chemical substances, creating tracers that can be used to follow a metabolic process or locate the substance within an organism. In this example, radioactive tracers are being used to determine the effect of temperature on the rate at which cells make copies of their DNA.

TECHNIQUE



1 Ingredients for making DNA are added to human cells. One ingredient is labeled with 3H, a radioactive isotope of hydrogen. Nine dishes of cells are incubated at different temperatures. The cells make new DNA, incorporating the radioactive tracer with 3H.

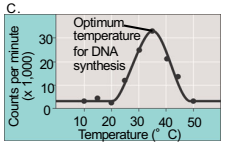
2 The cells are placed in test tubes, their DNA is isolated, and unused ingredients are removed.



14

3 A solution called scintillation fluid is added to the test tubes and they are placed in a scintillation counter. As the 3H in the newly made DNA decays, it emits radiation that excites chemicals in the scintillation fluid, causing them to give off light. Flashes of light are recorded by the scintillation counter.

RESULTS The frequency of flashes, which is recorded as counts per minute, is proportional to the amount of the radioactive tracer present, indicating the amount of new DNA. In this experiment, when the counts per minute are plotted against temperature, it is clear that temperature affects the rate of DNA synthesis—the most DNA was made at 35°C.



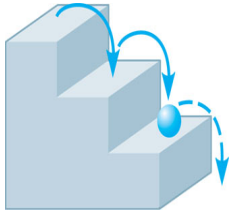
15

The Energy Levels of Electrons

- An atom's electrons vary in the amount of energy they possess
- Energy is defined as the capacity to cause change
- Potential energy is the energy that matter possesses because of its location or structure

16

- The electrons of an atom
  - differ in the amounts of potential energy they possess

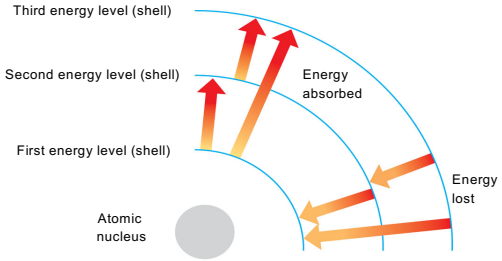


(a)

A ball bouncing down a flight of stairs provides an analogy for energy levels of electrons, because the ball can only rest on each step, not between steps.

17

- Energy levels
  - are represented by electron shells



(b) An electron can move from one level to another only if the energy it gains or loses is exactly equal to the difference in energy between the two levels. Arrows indicate some of the step-wise changes in potential energy that are possible.

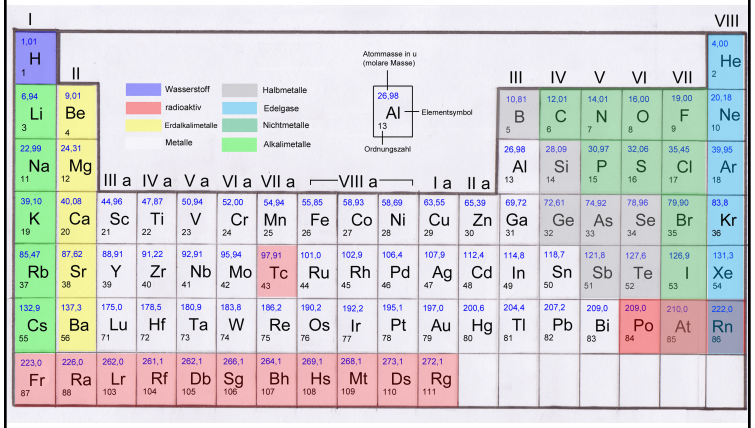
18

Electron Configuration and Chemical Properties

- The chemical behavior of an atom
  - is defined by its electron configuration and distribution
- Valence electrons
  - are those in the outermost, or valence shell
  - determine the chemical behavior of an atom
- An orbital
  - is the three-dimensional space where an electron is found 90% of the time

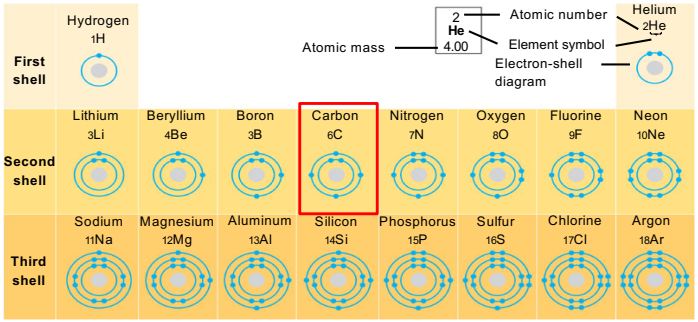
19

The periodic table of the elements



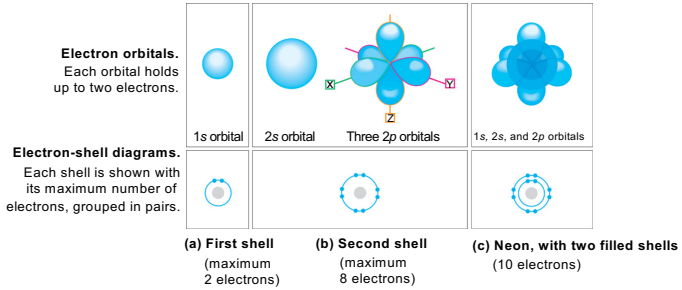
20

- The periodic table of the elements
  - shows the electron distribution for all the elements



21

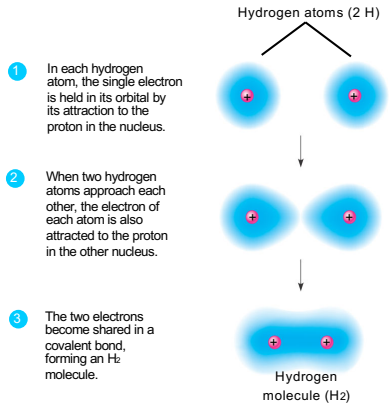
- Each electron shell consists of a specific number of orbitals



22

- The formation and function of **molecules** depend on **chemical bonding** between **atoms**
- A covalent bond is the sharing of a pair of valence electrons

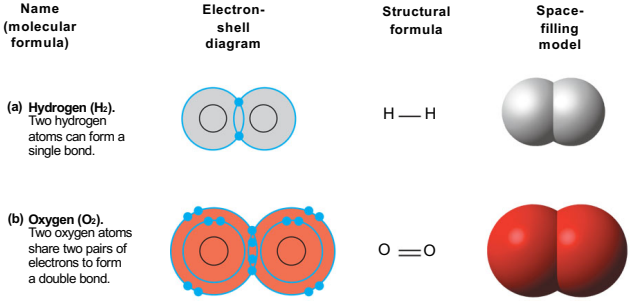
- Formation of a covalent bond



23

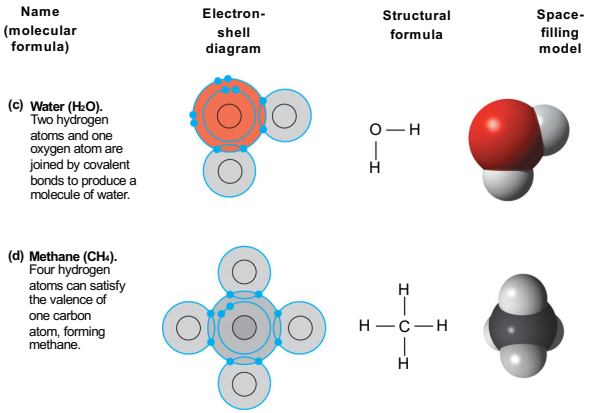
- A **molecule consists** of two or more atoms held together by **covalent bonds**
- A single bond is the sharing of one pair of valence electrons
- A double bond is the sharing of two pairs of valence electrons

- Single and double covalent bonds



24

- Covalent bonding in compounds

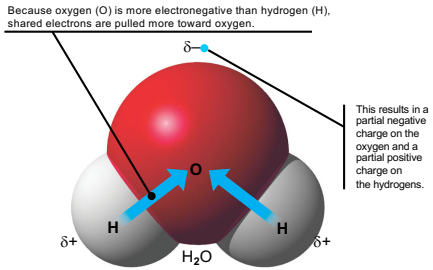


25

- Electronegativity
  - Is the attraction of a particular kind of atom for the electrons in a covalent bond
- The more electronegative an atom
  - The more strongly it pulls shared electrons toward itself
- In a nonpolar covalent bond
  - The atoms have similar electronegativities
  - Share the electron equally

26

- In a polar covalent bond
  - The atoms have differing electronegativities
  - Share the electrons unequally



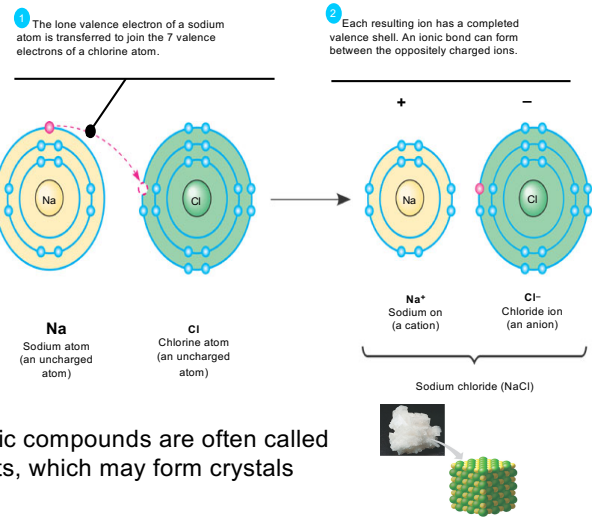
27

Ionic Bonds

- In some cases, atoms strip electrons away from their bonding partners
- Electron transfer between two atoms creates ions
- Ions
  - are atoms with more or fewer electrons than usual
  - are charged atoms
- An anion
  - is negatively charged ions
- A cation
  - is positively charged

28

- **An ionic** bond is an attraction between anions and cations



- Ionic compounds are often called salts, which may form crystals

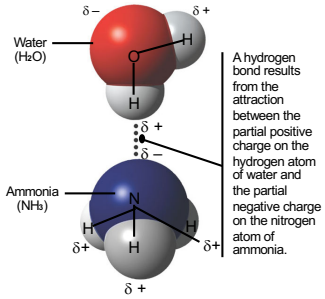
29

Weak Chemical Bonds

- several types of weak chemical bonds are important in living systems

Hydrogen Bonds

- A hydrogen bond forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom



30

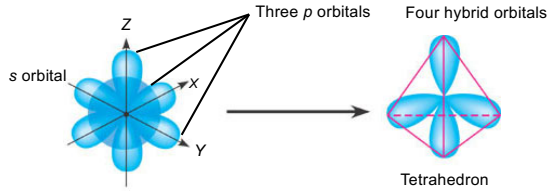
Van der Waals Interactions

- **Van der Waals interactions**
  - occur when transiently positive and negative regions of molecules attract each other
- Weak chemical bonds
  - reinforce the shapes of large molecules
  - help molecules adhere to each other
- Molecular Shape and Function:

  The precise shape of a molecule
  - is usually very important to its function in the living cell
  - is determined by the positions of its atoms' valence orbitals

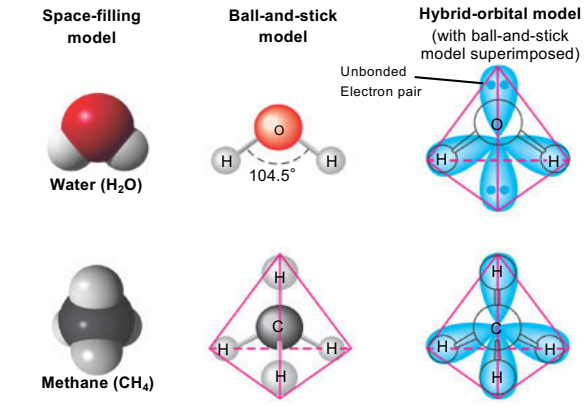
31

- In a covalent bond
  - The *s* and *p* orbitals may hybridize, creating specific molecular shapes



(a) Hybridization of orbitals. The single *s* and three *p* orbitals of a valence shell involved in covalent bonding combine to form four teardrop-shaped hybrid orbitals. These orbitals extend to the four corners of an imaginary tetrahedron (outlined in pink).

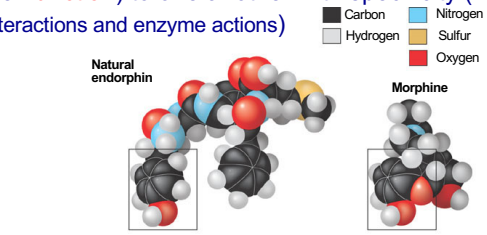
32



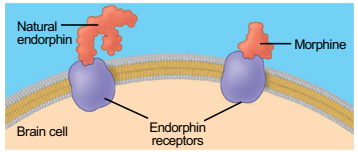
(b) Molecular shape models. Three models representing molecular shape are shown for two examples; water and methane. The positions of the hybrid orbital determine the shapes of the molecules

33

- Molecular shape (i.e. protein structure): Determines how biological molecules (made by covalent bonds) recognize and respond (i.e. function) to one another with specificity (incl. Van der Waals interactions and enzyme actions)



(a) Structures of endorphin and morphine. The boxed portion of the endorphin molecule (left) binds to receptor molecules on target cells in the brain. The boxed portion of the morphine molecule is a close match.



(b) Binding to endorphin receptors. Endorphin receptors on the surface of a brain cell recognize and can bind to both endorphin and morphine.

34

Chemical reactions make and break chemical bonds (ATP ---> ADP + Pi)

- A chemical reaction
  - is the making and breaking of chemical bonds
  - leads to changes in the composition of matter
  - ---> leads to change of structure
  - ---> leads to change of functions

35

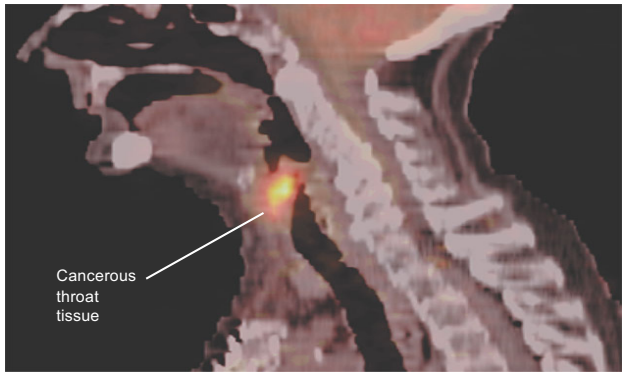
Why do we need to know all this?

Practicable applications:

36

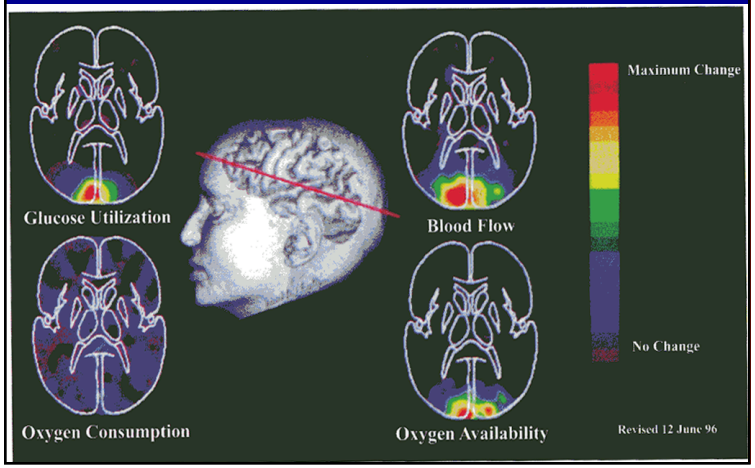
– can be used in biology

In vivo visualizing of human tissue – e.g. cancer detection

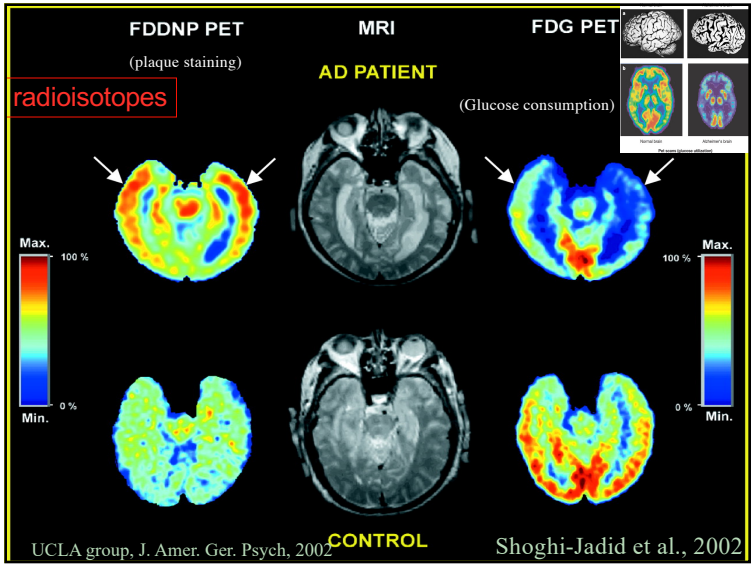


37

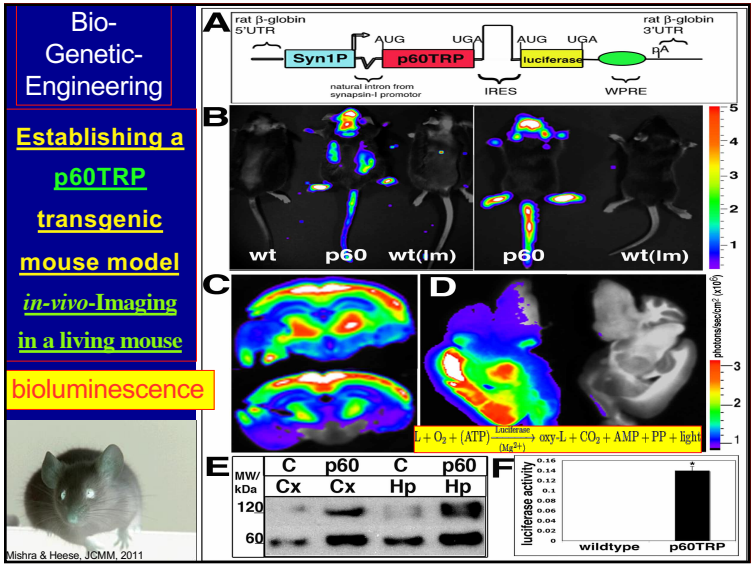
***In vivo* brain function (activity) analysis using imaging technologies such as Positron Emission Tomography (PET)**



38

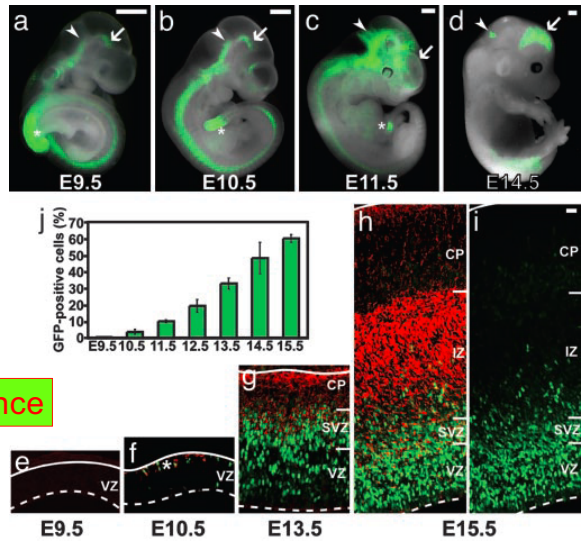


39



40

A Tis21-GFP Knock-In Mouse Reveals Neuron-Generating Progenitors in the Embryonic CNS.

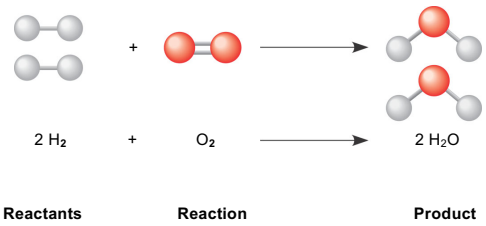


fluorescence

41

- **Chemical reactions** convert reactants to products

An example:



Oxyhydrogen gas, electrolytic gas, detonating gas

See also: http://en.wikipedia.org/wiki/Oxyhydrogen

42

- Photosynthesis is a typical example of a similar chemical reactions used to synthesize ATP in mitochondria: $O_2 + 4\,e^- + 4\,H^+ \longrightarrow 2\,H_2O$

$\Delta G^{o'}$ = -193 kJ/mol

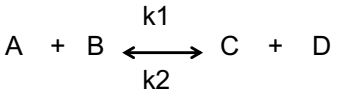
----> Bio-Engineering: Bio-Fuel cells

Gibbs-Energie ΔG used for electrical power/electric current

Understanding photosynthesis provides ideas for the improvement of bio-fuel cells

43

- Chemical equilibrium is reached when the forward and reverse reaction rates are equal
- (---> Biochemistry: thermodynamic; in year-3)



44

General Biology

Course No: BNG2003
Credits: 3.00

2b. Water and the Fitness of the Environment

Prof. Dr. Klaus Heese

1

- The Molecule That Supports All of Life
  - Water is The Biological Medium here on Earth
  - All living organisms require water more than any other substance

2

- Three-quarters of the Earth's surface is submerged in water
- The abundance of water is the main reason the Earth is habitable

3

- Four emergent properties of water contribute to Earth's fitness for life

Cohesion

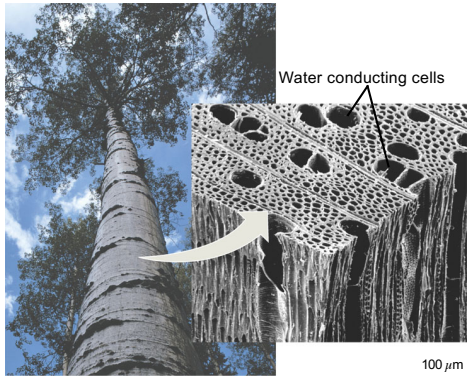
- Water molecules exhibit cohesion
- Cohesion
  - Is the bonding of a high percentage of the molecules to neighboring molecules
  - Is due to hydrogen bonding

4

- Cohesion helps to pull water up through the microscopic vessels of plants (where is the pulling energy force coming from ?)

Bio-Engineering:

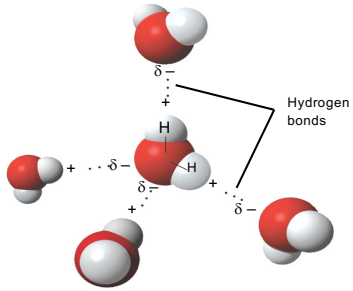
Transport of Photosynthesis products, minerals, etc.



5

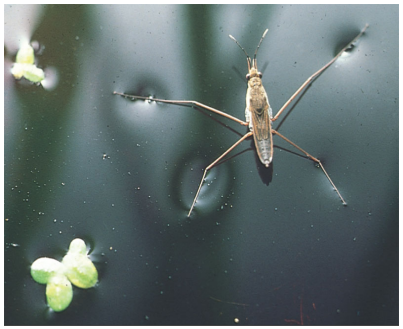
The Polarity of water molecules results in hydrogen bonding

- The water molecule is a polar molecule
- The polarity of water molecules
  - Allows them to form hydrogen bonds with each other (see also dissolving of salts)
  - Contributes to the various properties water exhibits



6

- Surface tension
  - is a measure of how hard it is to break the surface of a liquid
  - is related to cohesion



7

Moderation of Temperature

- Water moderates air temperature
  - By absorbing heat from air that is warmer and releasing the stored heat to air that is cooler

Heat and Temperature

- Kinetic energy
  - Is the energy of motion
- Heat
  - Is a measure of the total amount of kinetic energy due to molecular motion
- Temperature
  - Measures the intensity of heat

8

Water's High Specific Heat

- The specific heat of a substance
  - Is the amount of heat that must be absorbed or lost for 1 gram of that substance to change its temperature by 1ºC
- Water has a high specific heat, which allows it to minimize temperature fluctuations to within limits that permit life
  - Heat is absorbed when hydrogen bonds break
  - Heat is released when hydrogen bonds form

  (see also dissolving of salts)

9

Evaporative Cooling

- Evaporation
  - is the transformation of a substance from a liquid to a gas
- Heat of vaporization
  - is the quantity of heat a liquid must absorb for 1 gram of it to be converted from a liquid to a gas
- Evaporative cooling
  - is due to water's high heat of vaporization
  - allows water to cool a surface

10

Insulation of Bodies of Water by Floating Ice

- Solid water, or ice
  - is less dense than liquid water
  - floats in liquid water
- Since ice floats in water
  - life can exist under the frozen surfaces of lakes and polar seas

11

- The hydrogen bonds in ice
  - Are more "ordered" than in liquid water, making ice less dense

12

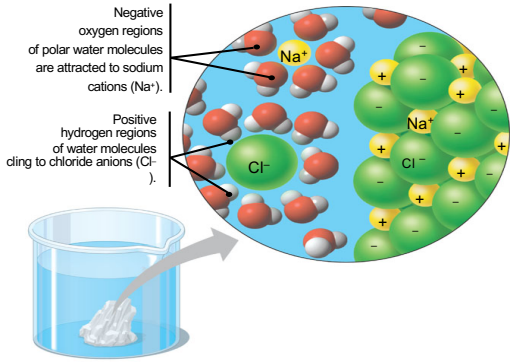
The Solvent of Life

- Water is a versatile solvent due to its polarity
- It can form aqueous solutions

13

Dissolving salt in water

- The different regions of the polar water molecule can interact with ionic compounds called solutes and dissolve them

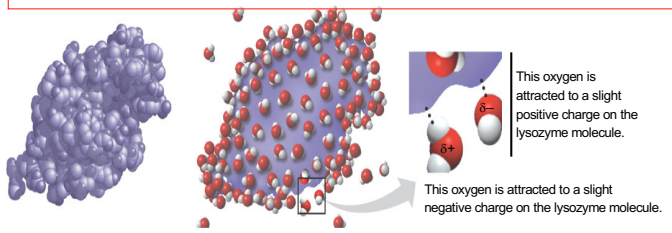


14

- Water can also interact with polar molecules such as proteins

Van der Waals interactions etc ---> protein structure ---> protein function ---> **diseases**

e.g.: AD, PD, HD, Prion



(a) Lysozyme molecule in a nonaqueous environment

(b) Lysozyme molecule (purple) in an aqueous environment such as tears or saliva

(c) Ionic and polar regions on the protein's Surface attract water molecules.

15

Hydrophilic and Hydrophobic Substances

- A hydrophilic substance
  - has an affinity for water
- A hydrophobic substance
  - does not have an affinity for water

16

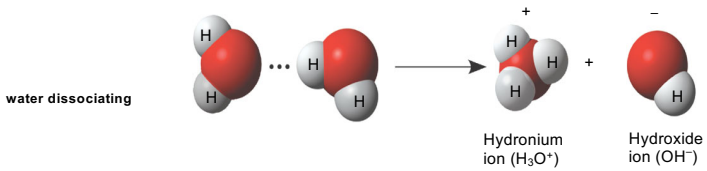
Solute Concentration in Aqueous Solutions

- Since most biochemical reactions occur in water
  - It is important to learn to calculate the concentration of solutes in an aqueous solution
- A mole
  - Represents an exact number of molecules of a substance in a given mass
- Molarity
  - Is the number of moles of solute per liter of solution

17

pH Dissociation of water molecules leads to acidic and basic conditions that affect living organisms

- Water can dissociate
  - into hydronium ions and hydroxide ions
- Changes in the concentration of these ions
  - can have a great affect on living organisms



18

Effects of Changes in pH

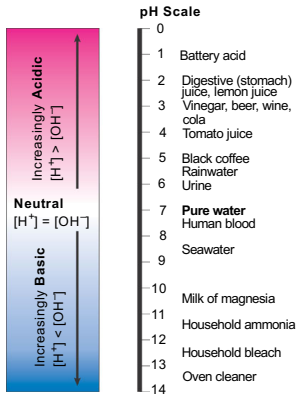
Acids and Bases

- An acid
  - is any substance that increases the hydrogen ion concentration of a solution
- A base
  - is any substance that reduces the hydrogen ion concentration of a solution

19

The pH Scale

- The pH scale and pH values of various aqueous solutions
- The pH of a solution
  - is determined by the relative concentration of hydrogen ions
  - is low in an acid
  - is high in a base



20

Buffers

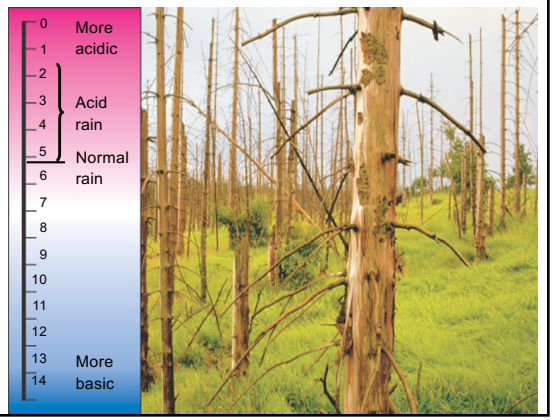
- The internal pH of most living cells
  - must remain close to pH 7
- Buffers
  - are substances that minimize changes in the concentrations of hydrogen and hydroxide ions in a solution
  - consist of an acid-base pair that reversibly combines with hydrogen ions

Which physiological buffer system do you know (in human being)?

21

Ecology: The Threat of Acid Precipitation

- Acid precipitation refers to rain, snow, or fog with a pH lower than pH 5.6 and is caused primarily by the mixing of different pollutants with water in the air
- Acid precipitation can damage life in Earth's ecosystems



22

General Biology

Course No: BNG2003
Credits: 3.00

2c. Carbon and the Molecular Diversity of Life

Prof. Dr. Klaus Heese

1

- Carbon — The Backbone of Biological Molecules
- All living organisms
  - are made up of chemicals based mostly on the element carbon

2

- **Organic chemistry is the study of carbon compounds**
- Organic compounds range from simple molecules to colossal ones
- The concept of vitalism
  - Is the idea that organic compounds arise only within living organisms
  - Was disproved when chemists synthesized the compounds in the laboratory

EXPERIMENT: In 1953, Stanley Miller simulated what were thought to be environmental conditions on the lifeless, primordial Earth. As shown in this recreation, Miller used electrical discharges (simulated lightning) to trigger reactions in a primitive "atmosphere" of H_2O, H_2, NH_3 (ammonia), and CH_4 (methane)—some of the gases released by volcanoes.

RESULTS: A variety of organic compounds that play key roles in living cells were synthesized in Miller's apparatus.

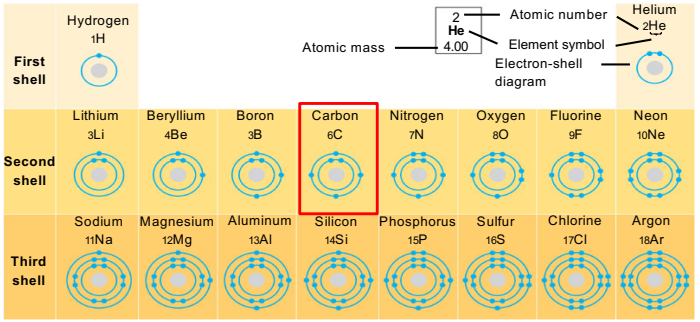
CONCLUSION: Organic compounds may have been synthesized abiotically on the early Earth, setting the stage for the origin of life. (We will explore this hypothesis in more detail in Chapter 26.)

3

- **Carbon** atoms can form diverse molecules by **bonding to four other atoms**
- The Formation of Bonds with Carbon:
- Carbon has four valence electrons
- This allows it to form four covalent bonds with a variety of atoms

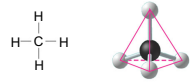
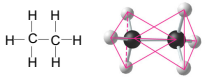
4

- The periodic table of the elements
  - shows the electron distribution for all the elements



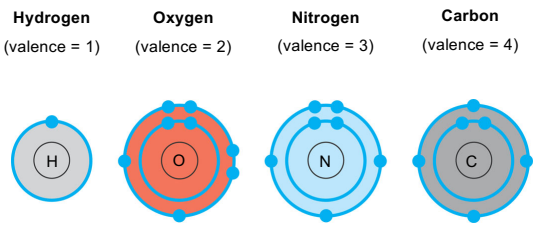
5

- The bonding versatility of Carbon
  - allows it to form many diverse molecules, including carbon skeletons

Name and Comments	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
(a) Methane	CH_4			
(b) Ethane	C_2H_6			
(c) Ethene (ethylene)	C_2H_4			

6

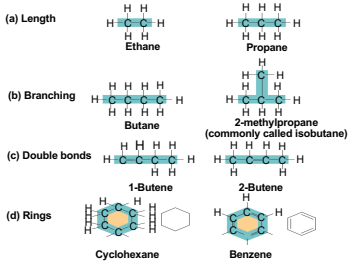
- The electron configuration of carbon
  - gives it covalent compatibility with many different elements



7

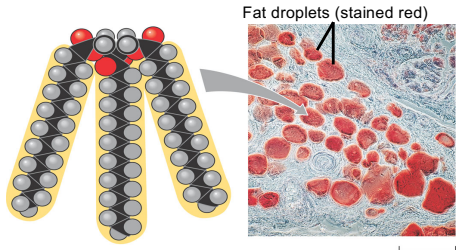
Molecular Diversity Arising from Carbon Skeleton Variation

- **Carbon chains**
  - form the skeletons of most organic molecules
  - vary in length and shape



8

- **Hydrocarbons:** Are molecules consisting of only carbon and hydrogen
  - are found in many of a cell's **organic molecules**



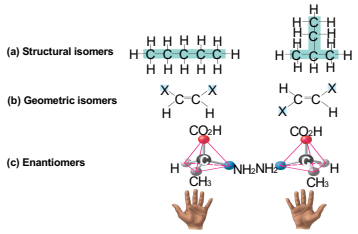
(a) A fat molecule (b) Mammalian adipose cells

9

Isomers

are molecules with the same molecular formula but different structures and properties

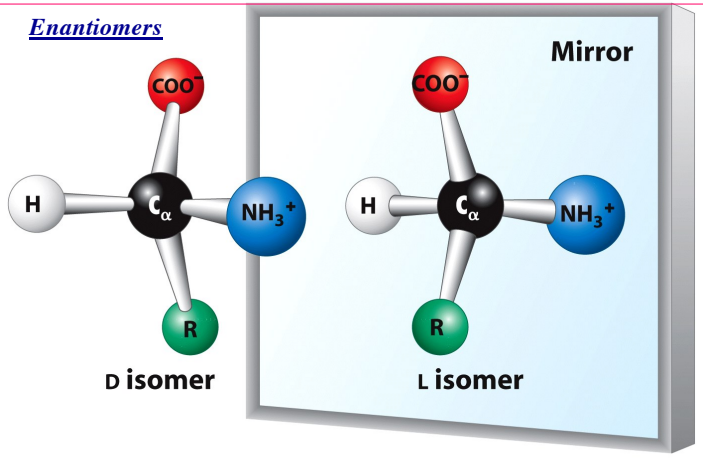
- **three types** of isomers are
  - Structural
  - Geometric
  - Enantiomers



10

Special feature of molecules that define cell (function) which defines life.

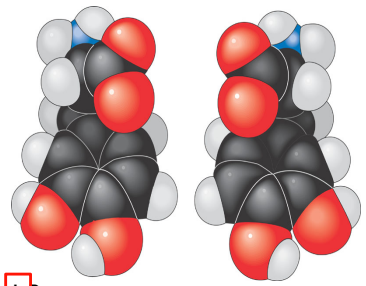
Enantiomers



Enantiomers are chiral molecules that are *mirror images* of one another. Furthermore, the molecules are *non-superimposable* on one another. This means that the molecules cannot be placed on top of one another and give the same molecule.

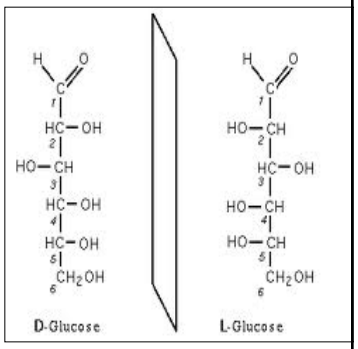
11

- Enantiomers
  - are important in the pharmaceutical industry

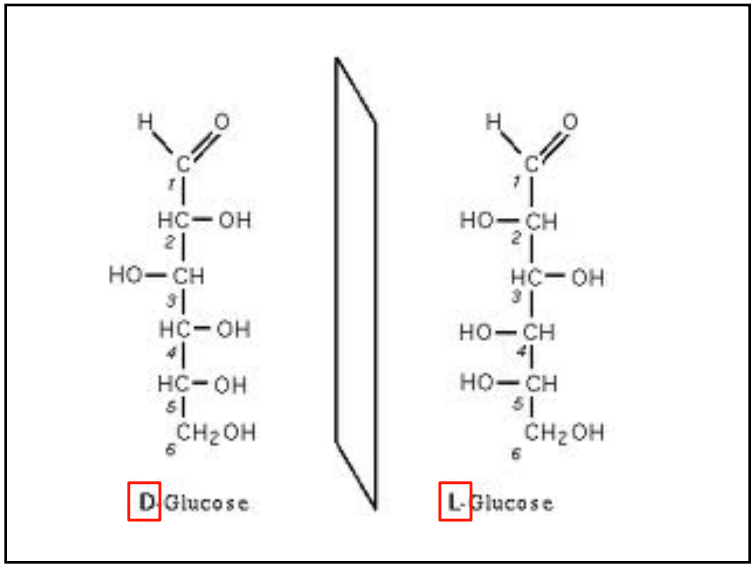


L-Dopa
(effective against Parkinson's disease)

D-Dopa
(biologically inactive)



12



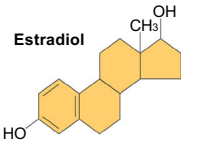
13

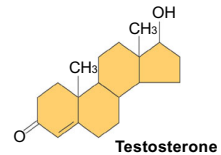
The Functional Groups Most Important in the Chemistry of Life

- Functional groups are the chemically reactive groups of atoms within an organic molecule
- Functional groups are the parts of molecules involved in chemical reactions and give organic molecules distinctive chemical properties


Female lion


Male lion





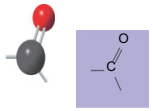
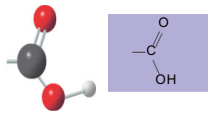
14

The Functional Groups Most Important in the Chemistry of Life

- **Six** functional groups of organic compounds are important in the chemistry of life
  - Hydroxyl
  - Carbonyl
  - Carboxyl
  - Amino
  - Sulfhydryl
  - Phosphate

15

Six functional groups of organic compounds are important in the **chemistry of life**: 1. Hydroxyl, 2. Carbonyl, 3. Carboxyl, 4. Amino, 5. Sulfhydryl, 6. Phosphate

FUNCTIONAL GROUP	HYDROXYL	CARBONYL	CARBOXYL
	 —OH (may be written HO —)		
STRUCTURE	In a hydroxyl group (—OH), a hydrogen atom is bonded to an oxygen atom, which in turn is bonded to the carbon skeleton of the organic molecule. (Do not confuse this functional group with the hydroxide ion, OH^-.)	The **carbonyl group** (>CO) consists of a carbon atom joined to an oxygen atom by a double bond.	When an oxygen atom is double-bonded to a carbon atom that is also bonded to a hydroxyl group, the entire assembly of atoms is called a **carboxyl group** (—COOH).

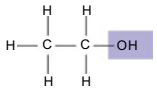
16

Six functional groups of organic compounds are important in the **chemistry of life**: 1. Hydroxyl, 2. Carbonyl, 3. Carboxyl, 4. Amino, 5. Sulfhydryl, 6. Phosphate

NAME OF COMPOUNDS

Alcohols (their specific names usually end in *-ol*)

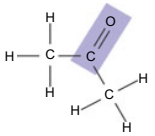
EXAMPLE



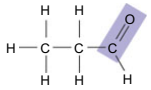
Ethanol, the alcohol present in alcoholic beverages

Ketones if the carbonyl group is within a carbon skeleton

Aldehydes if the carbonyl group is at the end of the carbon skeleton

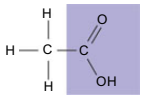


Acetone, the simplest ketone



Propanal, an aldehyde

Carboxylic acids, or organic acids



Acetic acid, which gives vinegar its sour tatste

17

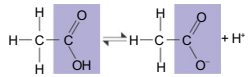
Six functional groups of organic compounds are important in the **chemistry of life**: 1. Hydroxyl, 2. Carbonyl, 3. Carboxyl, 4. Amino, 5. Sulfhydryl, 6. Phosphate

FUNCTIONAL PROPERTIES

- Is polar as a result of the electronegative oxygen atom drawing electrons toward itself.
- Attracts water molecules, helping dissolve organic compounds such as sugars.

- A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal.

- Has acidic properties because it is a source of hydrogen ions. The covalent bond between oxygen and hydrogen is so polar that hydrogen ions (H^+) tend to dissociate reversibly; for example,

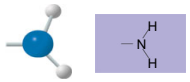


- In cells, found in the ionic form, which is called a carboxylate group.

18

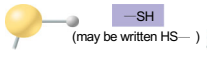
Six functional groups of organic compounds are important in the **chemistry of life**: 1. Hydroxyl, 2. Carbonyl, 3. Carboxyl, 4. Amino, 5. Sulfhydryl, 6. Phosphate

AMINO



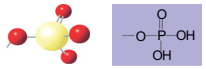
The **amino group** (—NH_2) consists of a nitrogen atom bonded to two hydrogen atoms and to the carbon skeleton.

SULFHYDRYL



The **sulfhydryl group** consists of a sulfur atom bonded to an atom of hydrogen; resembles a hydroxyl group in shape.

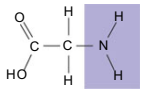
PHOSPHATE



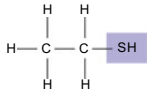
In a **phosphate group,** a phosphorus atom is bonded to four oxygen atoms; one oxygen is bonded to the carbon skeleton; two oxygens carry negative charges; abbreviated $\ominus P\ominus$. The phosphate group (—OPO_3^{2-}) is an ionized form of a phosphoric acid group (—OPO_3H_2; note the two hydrogens).

19

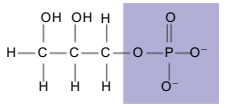
Six functional groups of organic compounds are important in the **chemistry of life**: 1. Hydroxyl, 2. Carbonyl, 3. Carboxyl, 4. Amino, 5. Sulfhydryl, 6. Phosphate



Glycine



Ethanethiol



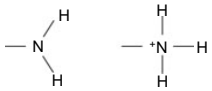
Glycerol phosphate

Because it also has a carboxyl group, glycine is both an amine and a carboxylic acid; compounds with both groups are called amino acids.

20

Six functional groups of organic compounds are important in the **chemistry of life**: 1. Hydroxyl, 2. Carbonyl, 3. Carboxyl, 4. Amino, 5. Sulfhydryl, 6. Phosphate

• Acts as a base; can pick up a proton from the surrounding solution:



(nonionized) (ionized)

• Ionized, with a charge of 1+, under cellular conditions.

• Two sulfhydryl groups can interact to help stabilize protein structure (see Figure 5.20).

• Makes the molecule of which it is a part an anion (negatively charged ion).
Can transfer energy between organic molecules.

21

The Chemical Elements of Life: *A Review*

- The versatility of carbon
  - makes the great diversity of organic molecules

22

General Biology

Course No: BNG2003
Credits: 3.00

2d. The Structure and Function of Macromolecules of a Cell

Prof. Dr. Klaus Heese

1

- The Molecules of Life (the cell)
  - another level in the hierarchy of biological organization is reached when small organic molecules are joined together
  - macromolecules are large molecules composed of smaller molecules and are complex in their structures

2

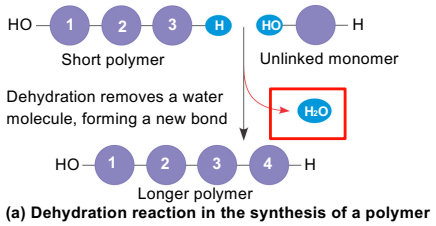
Most macromolecules are **polymers**, built from **monomers**

- Three of the classes of life's organic molecules are polymers
  - Carbohydrates
  - Proteins
  - Nucleic acids
- A **polymer**
  - is a long molecule consisting of many similar building blocks called monomers

3

The Synthesis and Breakdown of Polymers

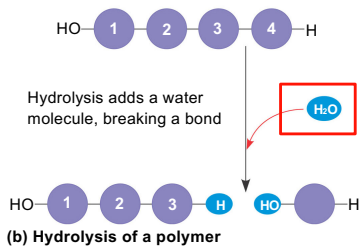
- Monomers form larger molecules by condensation reactions called dehydration reactions



(a) Dehydration reaction in the synthesis of a polymer

4

- **Polymers** can disassemble by
  - Hydrolysis



5

The Diversity of Polymers

- each class of polymer
  - is formed from a specific set of monomers
- although organisms share the same limited number of monomer types, each organism is unique based on the arrangement of monomers into polymers
- an immense variety of polymers can be built from a small set of monomers

6

Carbohydrates

serve as fuel and building material

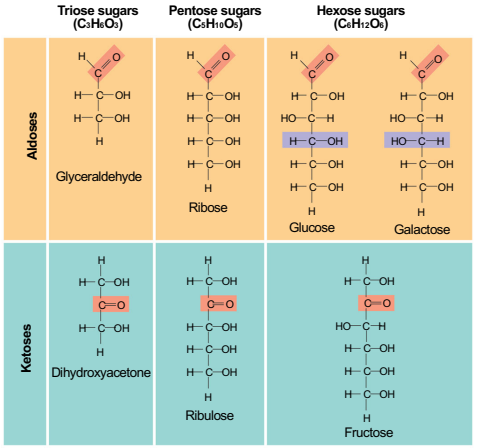
- Carbohydrates
  - include both sugars and their polymers

Sugars

- Monosaccharides
  - are the simplest sugars
  - can be used for fuel
  - can be converted into other organic molecules
  - can be combined into polymers

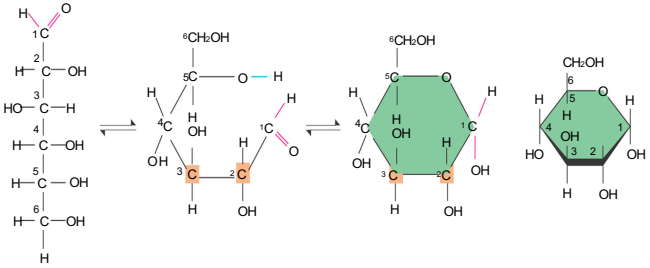
7

- Examples of monosaccharides



8

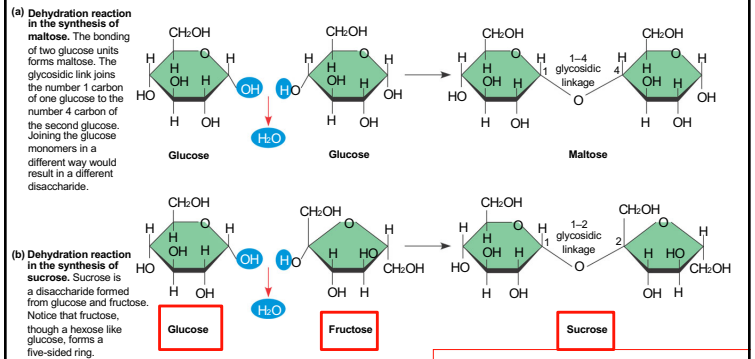
- Monosaccharides
  - may be linear
  - can form rings



(a) Linear and ring forms. Chemical equilibrium between the linear and ring structures greatly favors the formation of rings. To form the glucose ring, carbon 1 bonds to the oxygen attached to carbon 5.

9

- Disaccharides: Consist of two monosaccharides and are joined by a glycosidic linkage, examples of disaccharides



a product in photosynthesis

10

Polysaccharides

- Polysaccharides
  - are polymers of sugars
  - serve many roles in organisms

Storage Polysaccharides

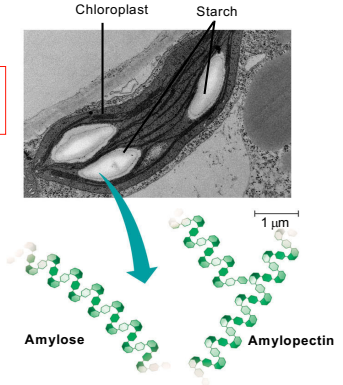
- Starch a product in photosynthesis
  - is a polymer consisting entirely of glucose monomers

11

Starch polymer consisting entirely of glucose monomers

- is the major storage form of glucose in plants

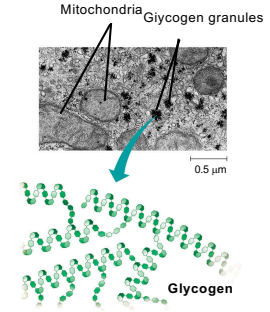
a product in photosynthesis



(a) Starch: a plant polysaccharide

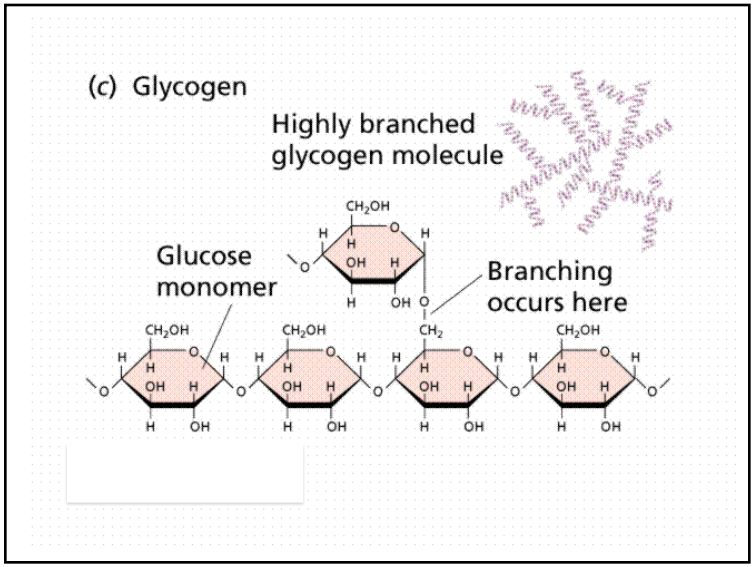
12

- **Glycogen**
  - consists of glucose monomers
  - is the major storage form of glucose in animals



(b) Glycogen: an animal polysaccharide

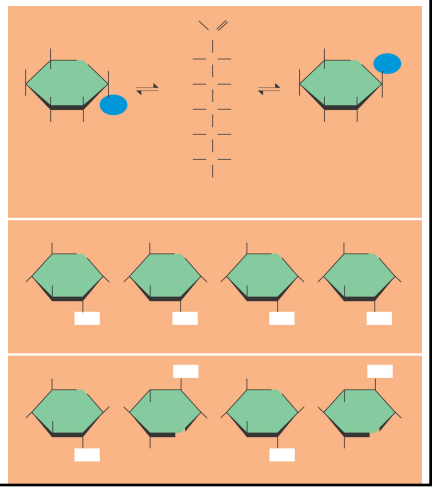
13



14

Structural Polysaccharides

- Cellulose is a **polymer of glucose**, it has different glycosidic linkages than starch



15

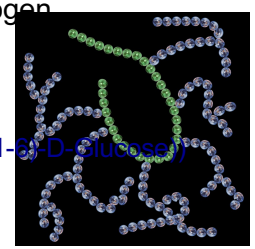
Complex (larger/longer) Carbohydrates

- **polysaccharides**
  - **glycogen** and **starch** (amylose (linear) and amylopectin (branch))
    - built entirely of glucose
  - fiber
    - variety of monosaccharides and other carbohydrate derivatives

16

Glycogen

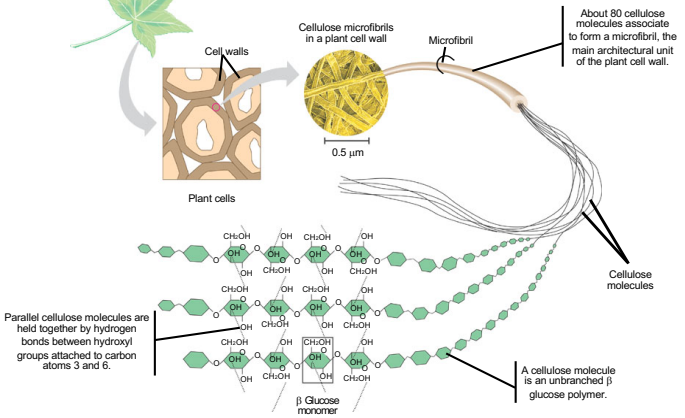
- limited in meat and not found in plants
  - not an important dietary source of carbohydrate
- BUT
  - all glucose is stored as glycogen
  - long chains allow for hydrolysis and release of energy



$\alpha(1\text{-}4)$-D-Glucose and branches at $\alpha(1\text{-}6)$-D-Glucose)

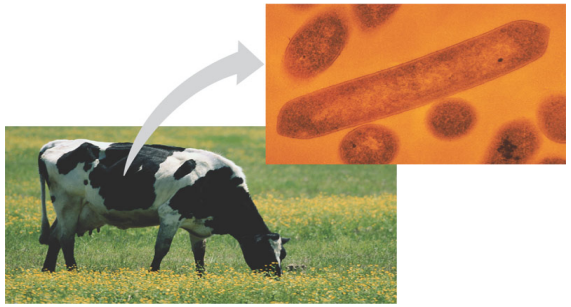
17

- Cellulose (a **polymer of glucose**) is a major component of the tough walls that enclose plant cells



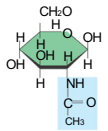
18

- Cellulose is difficult to digest
  - Cows have microbes in their stomachs to facilitate this process



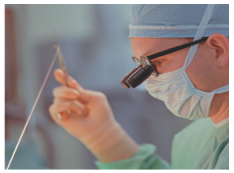
19

- Chitin, another important structural polysaccharide
  - is found in the exoskeleton of arthropods
  - can be used as surgical thread



(a) The structure of the chitin monomer.

(b) Chitin forms the exoskeleton of arthropods. This cicada is molting, shedding its old exoskeleton and emerging in adult form.



(c) Chitin is used to make a strong and flexible surgical thread that decomposes after the wound or incision heals.

20

Lipids

are a diverse group of hydrophobic molecules

Lipids

are the one class of large biological molecules that do not consist of polymers

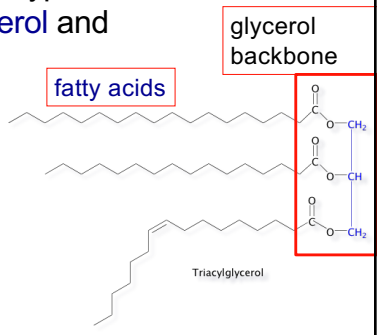
share the common trait of being hydrophobic

21

Fats (lipids)

are constructed from two types of smaller molecules, a single glycerol and usually three fatty acids

- Why are fatty acids important to cells?
  - fuel molecules
    - stored as triacylglycerols
  - building blocks
    - phospholipids
    - glycolipids
  - precursors of hormones and other messengers
  - used to target proteins to membrane sites



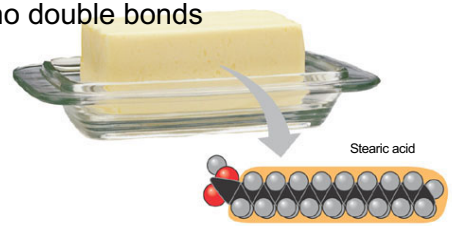
Triglycerides are a highly concentrated store of energy

9 kcal/g *vs* 4 kcal/g for glycogen

Glycogen is also highly hydrated, 2 g H_2O/g glycogen

22

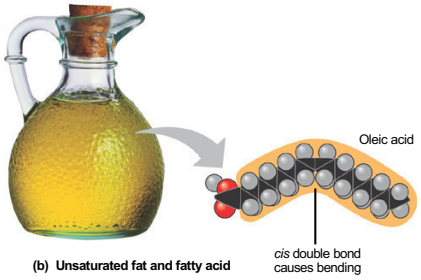
- **Fatty acids**
  - vary in the length and number and locations of double bonds they contain
- **Saturated fatty acids**
  - have the maximum number of hydrogen atoms possible
  - have no double bonds



(a) Saturated fat and fatty acid

23

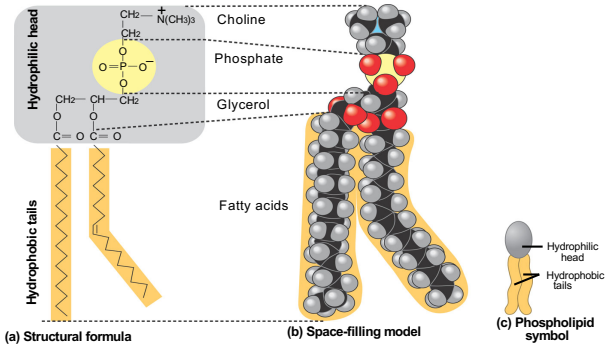
- **Unsaturated fatty acids**
  - have one or more double bonds



(b) Unsaturated fat and fatty acid

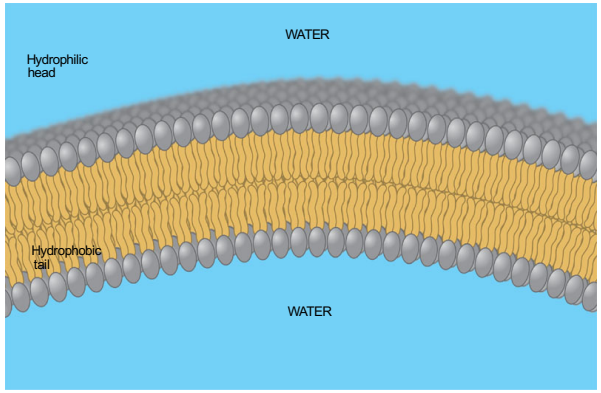
24

- **Phospholipids:** have only two fatty acids and have a phosphate group instead of a third fatty acid
  - Phospholipid structure: they consists of a hydrophilic "head" and hydrophobic "tails"



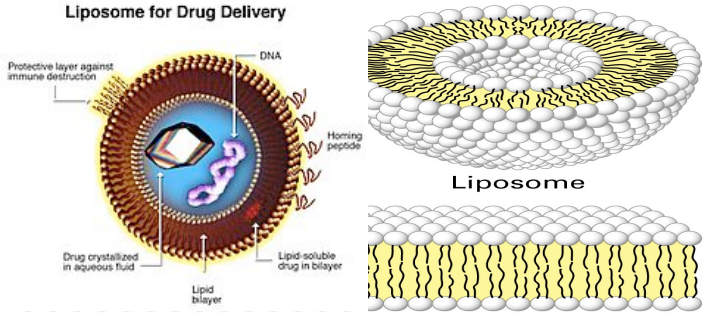
25

- The structure of phospholipids
  - results in a bilayer arrangement found in cell membranes



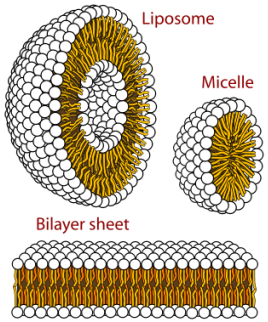
26

Cross-sectional views of the three structures formed by phospholipids in aqueous solutions



The white spheres depict the hydrophilic heads of the phospholipids, and the squiggly black lines (in the yellow regions) represent the hydrophobic tails. Shown are a spherical micelle with a hydrophobic interior composed entirely of fatty acyl chains; a spherical liposome,

27

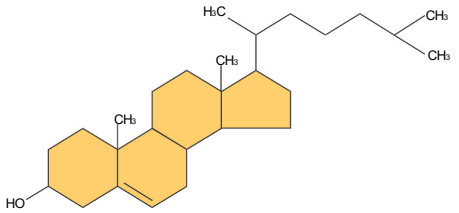


A micelle is an aggregate of surfactant molecules dispersed in a liquid colloid

Micelles are approximately spherical in shape.

28

- **Steroids**
  - are lipids characterized by a carbon skeleton consisting of four fused rings
- One steroid, cholesterol
  - is found in cell membranes
  - is a precursor for some hormones



29

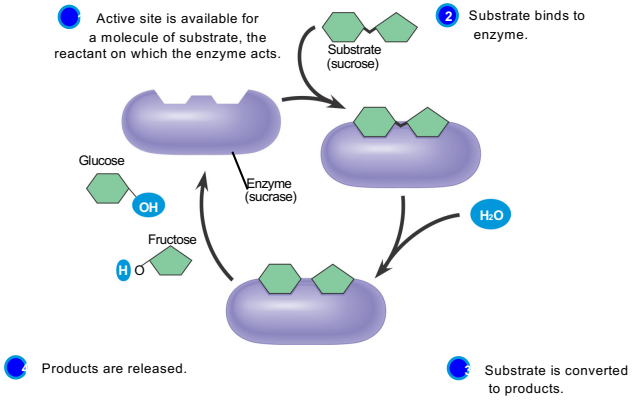
Proteins have many structures, resulting in a wide range of functions

- An overview of protein functions

Type of Protein	Function	Examples
Enzymatic proteins	Selective acceleration of chemical reactions	Digestive enzymes catalyze the hydrolysis of the polymers in food.
Structural proteins	Support	Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin provide a fibrous framework in animal connective tissues. Keratin is the protein of hair, horns, feathers, and other skin appendages.
Storage proteins	Storage of amino acids	Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo. Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds.
Transport proteins	Transport of other substances	Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.
Hormonal proteins	Coordination of an organism's activities	Insulin, a homone secreted by the pancreas, helps regulate the concentration of sugar in the blood of vertebrates.
Receptor proteins	Response of cell to chemical stimuli	Receptors built into the membrane of a nerve cell detect chemical signals released by other nerve cells.
Contractile and motor proteins	Movement	Actin and myosin are responsible for the movement of muscles. Other proteins are responsible for the undulations of the organelles called cilia and flagella.
Defensive proteins	Protection against disease	Antibodies combat bacteria and viruses.

30

- Enzymes
  - are a type of protein that acts as a catalyst, speeding up chemical reactions



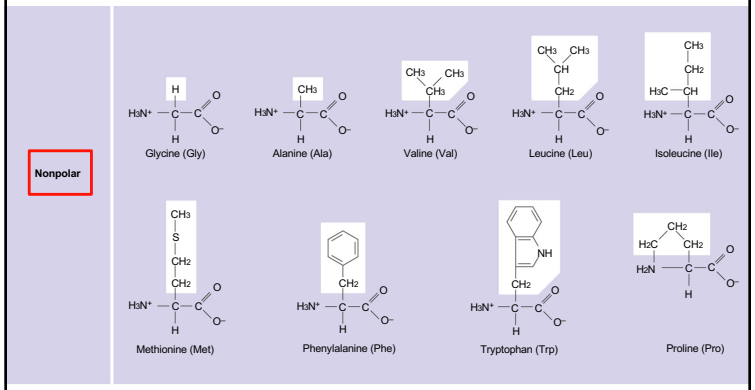
31

Polypeptides

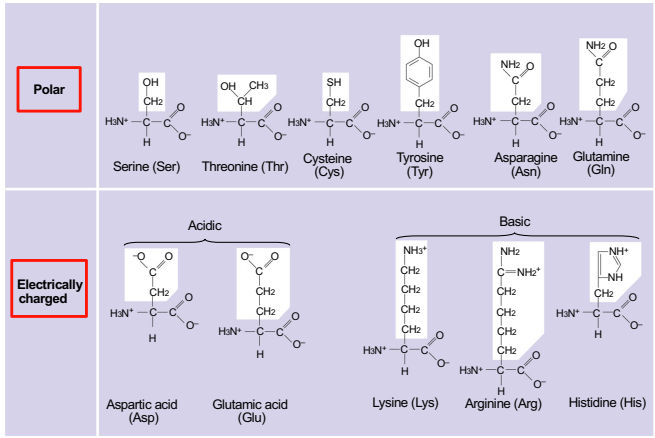
- Polypeptides
  - are polymers of amino acids
- **A *protein* consists of one or more polypeptides**
- ***Amino Acid Monomers***
- Amino acids
  - are organic molecules possessing both carboxyl and amino groups
  - differ in their properties due to differing side chains, called R groups

32

- 20 different amino acids make up proteins

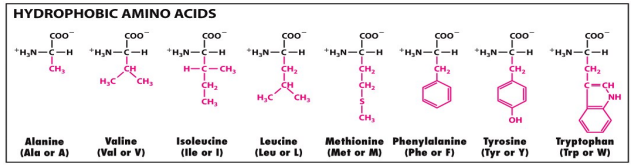


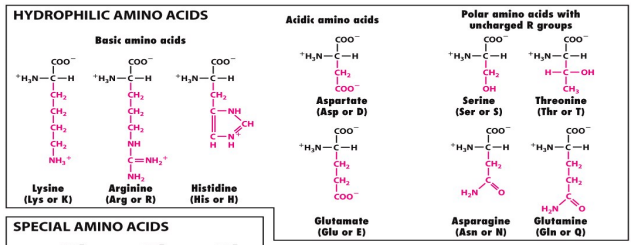
33

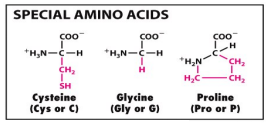


34

Amino Acids





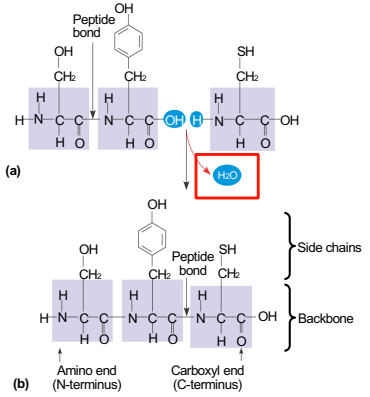


20 different amino acids make up proteins (20 proteinogenic AAs)

35

Amino Acid Polymers

- Amino acids
  - are linked by peptide bonds

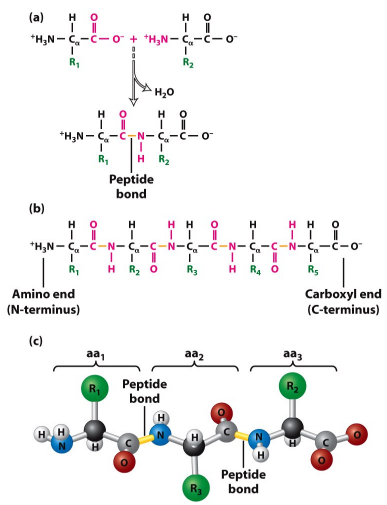


36

Amino acids

Peptides

Proteins



37

Determining the Amino Acid Sequence of a Polypeptide

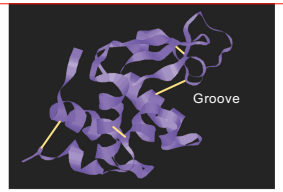
- The amino acid sequences of polypeptides
  - were first determined using chemical means
  - can now be determined by automated machines

38

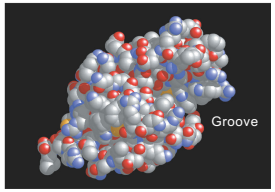
Protein Conformation and Function

- A protein's specific conformation determines how it functions

- two models of protein conformation



(a) A ribbon model

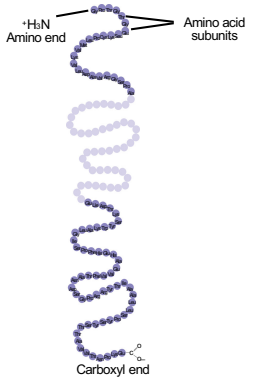


(b) A space-filling model

39

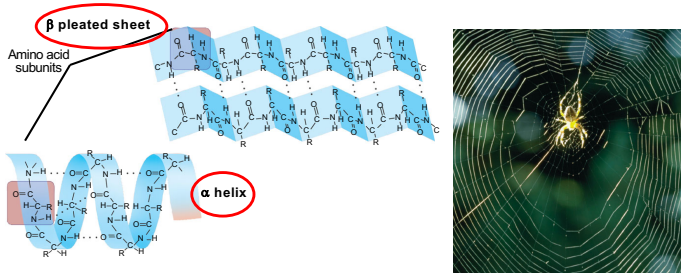
Four Levels of Protein Structure

- **Primary structure**
  - is the unique sequence of amino acids in a polypeptide



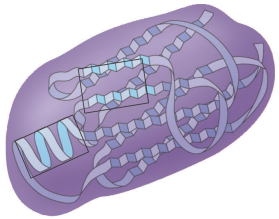
40

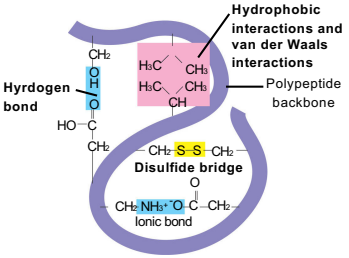
- **Secondary structure**
  - is the folding or coiling of the polypeptide into a repeating configuration
  - includes the α helix and the β pleated sheet



41

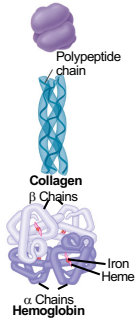
- **Tertiary structure**
  - is the overall three-dimensional shape of a polypeptide
  - results from interactions between amino acids and R groups





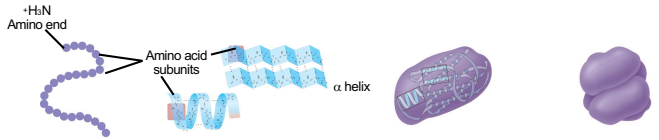
42

- ***Quaternary structure*** is the overall protein structure that results from the aggregation of two or more polypeptide subunits



43

- **The four levels of protein structure**



44

The Protein-Folding Problem

Protein Structure Defines Protein Function

Any disturbance in the protein structure may cause diseases

e.g. Alzheimer's disease, Parkinson Disease, Huntington Disease, Prion disease

Sulistio & Heese, Molecular Neurobiology, 2015

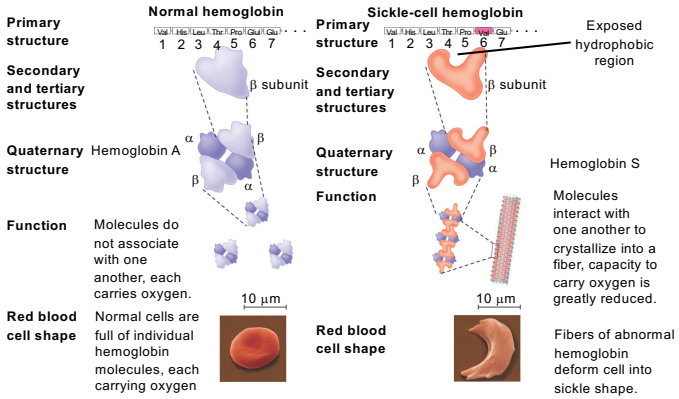
45

Sickle-Cell Disease: A Simple Change in Primary Structure

- Sickle-cell disease
  - results from a single amino acid substitution in the protein hemoglobin

46

- Hemoglobin structure and sickle-cell disease



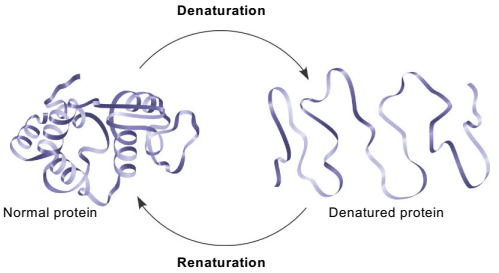
Sickle-cell disease results from a single amino acid substitution in the protein hemoglobin

47

What Determines Protein Conformation?

- Protein conformation
  - depends on the physical and chemical conditions of the protein's environment
- Denaturation – is when a protein unravels and loses its native conformation

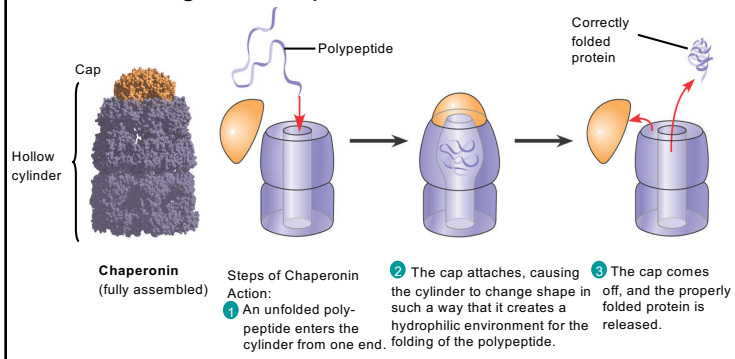
- ***The Protein-Folding Problem***
- most proteins – probably go through several intermediate states on their way to a stable conformation



48

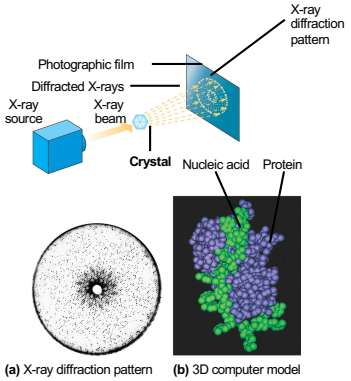
The Protein-Folding Problem

- Chaperonins
  - are protein molecules that assist in the proper folding of other proteins

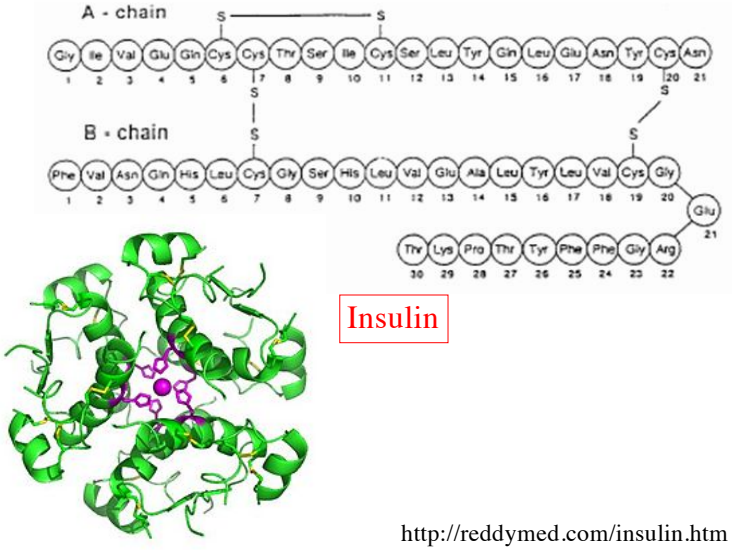


49

- X-ray crystallography
  - is used to determine a protein's three-dimensional structure

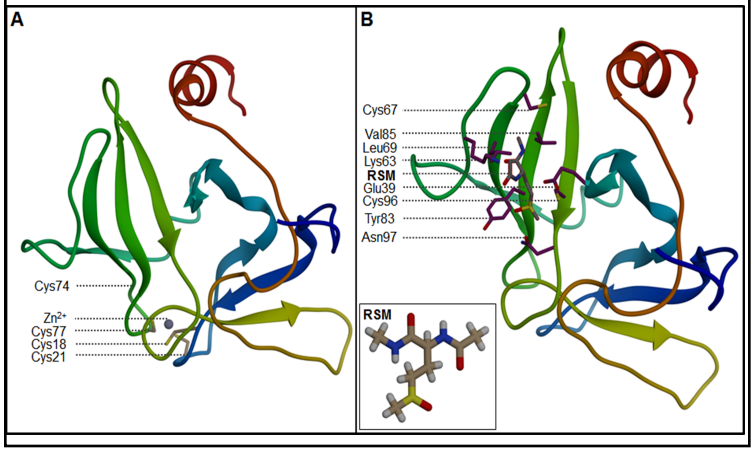


50



51

3D protein structure prediction based on atom-bond infos



52

DNA: The Roles of Nucleic Acids

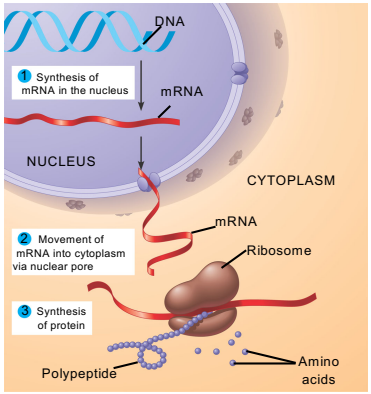
Nucleic acids store and transmit hereditary information

- There are two types of nucleic acids
  - Deoxyribonucleic acid (DNA)
  - Ribonucleic acid (RNA)
- Genes
  - are the units of inheritance
  - program the amino acid sequence of polypeptides = DNA stores information for the synthesis of specific proteins
  - are made of nucleic acids

53

DNA:

- directs RNA synthesis
- directs protein synthesis through RNA



54

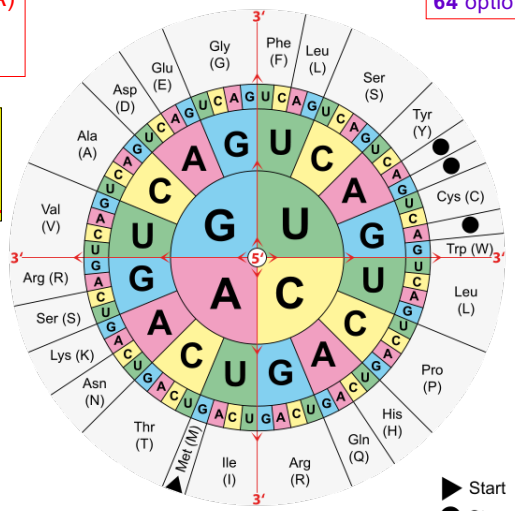
from genes (DNA) to proteins – the genetic code

64 options

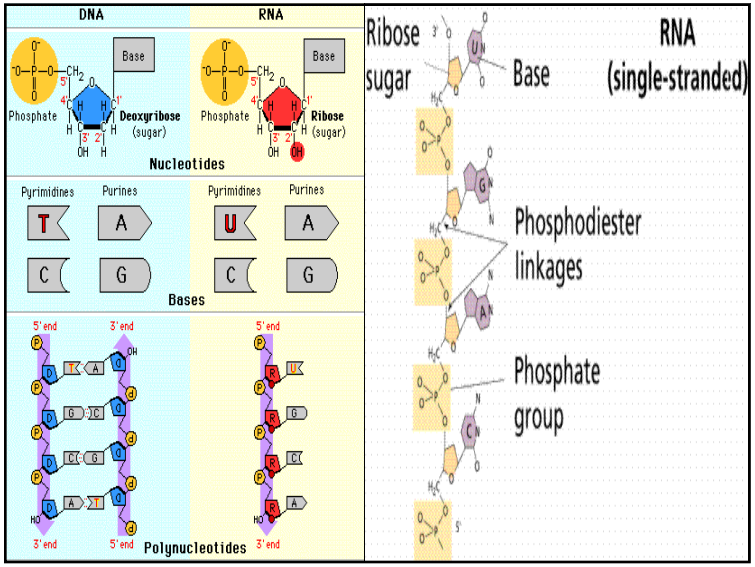
Amino Acids

Genetic Code

read 5' ---> 3'



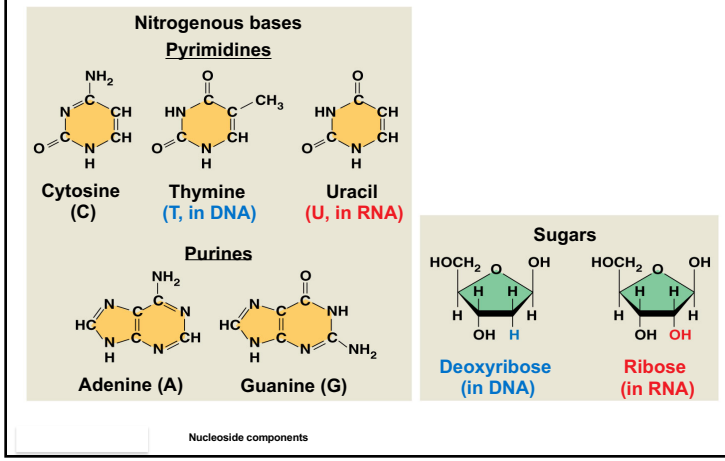
55



56

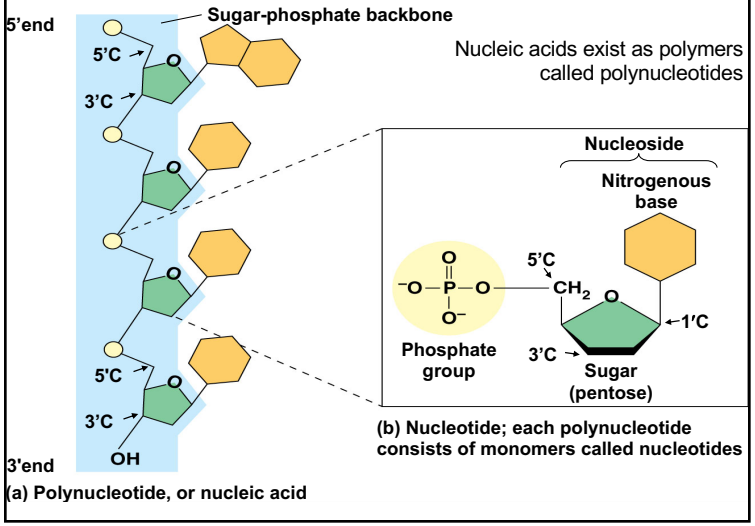
Nucleotide Monomers

- *Nucleotide monomers* are made up of nucleosides and phosphate groups

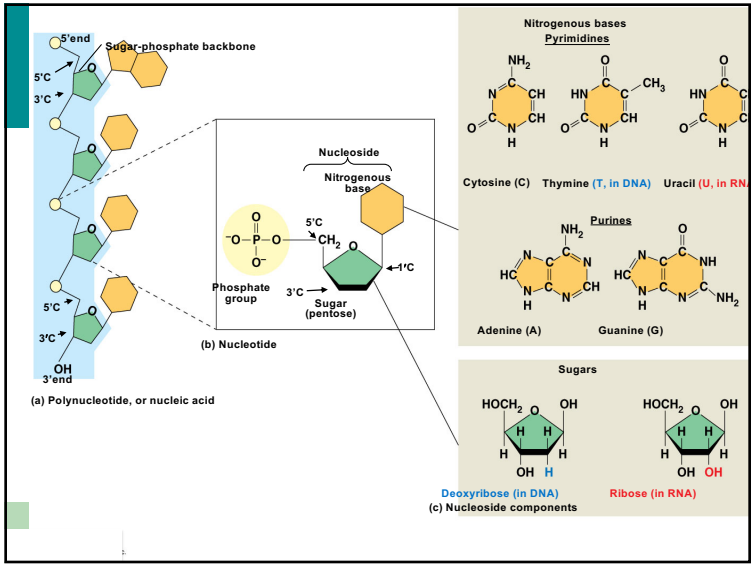


57

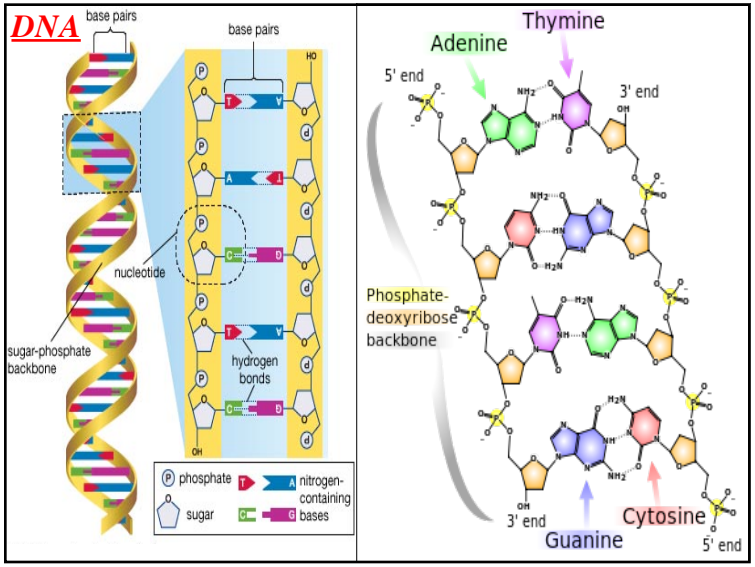
The Structure of Nucleic Acids



58



59



60

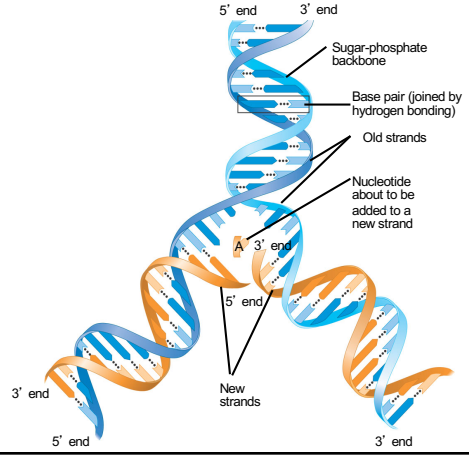
Nucleotide Polymers

- *Nucleotide polymers*
  - are made up of nucleotides linked by the–OH group on the 3´ carbon of one nucleotide and the phosphate on the 5´ carbon on the next
- The sequence of bases along a nucleotide polymer is *unique for each gene*

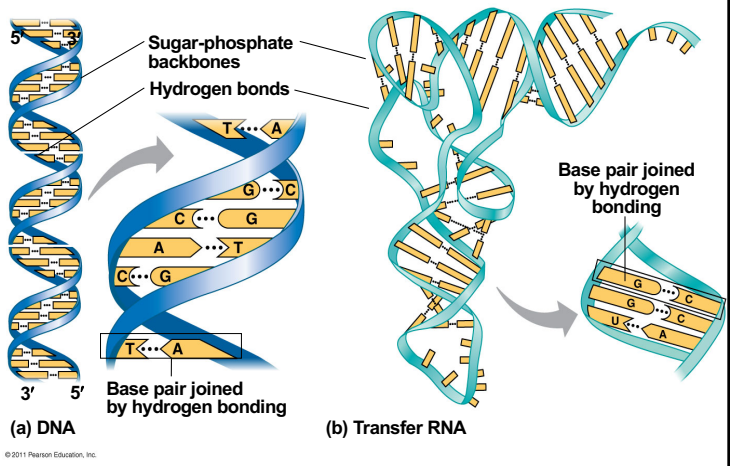
- Cellular DNA molecules
  - have two polynucleotides that spiral around an imaginary axis
  - form a double helix

61

- The DNA double helix
  - consists of two antiparallel nucleotide strands



62



63

- *The nitrogenous bases in DNA*
  - form hydrogen bonds in a complementary fashion (A with T only, and C with G only)

DNA and Proteins as Tape Measures of Evolution

- Molecular comparisons
  - help biologists sort out the evolutionary connections among species

64

The Theme of Emergent Properties in the Chemistry of Life: *A Review*

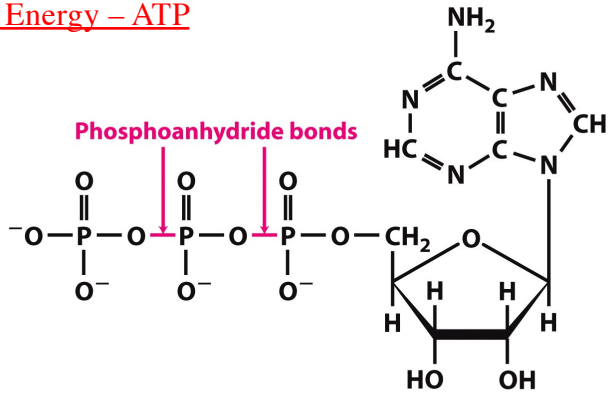
- Higher levels of organization
  - result in the emergence of new properties
- Organization is the key to the chemistry of life
- Amino acid ---> peptide chain ---> 3D-protein ----> cells ---> tissue/organs ----> organisms ----> populations
- <----> Systems Biology

65

Further important large cellular biomolecules

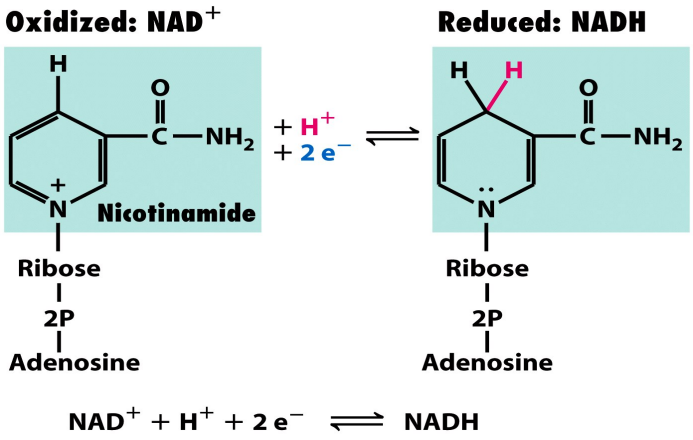
66

Cell Energy – ATP

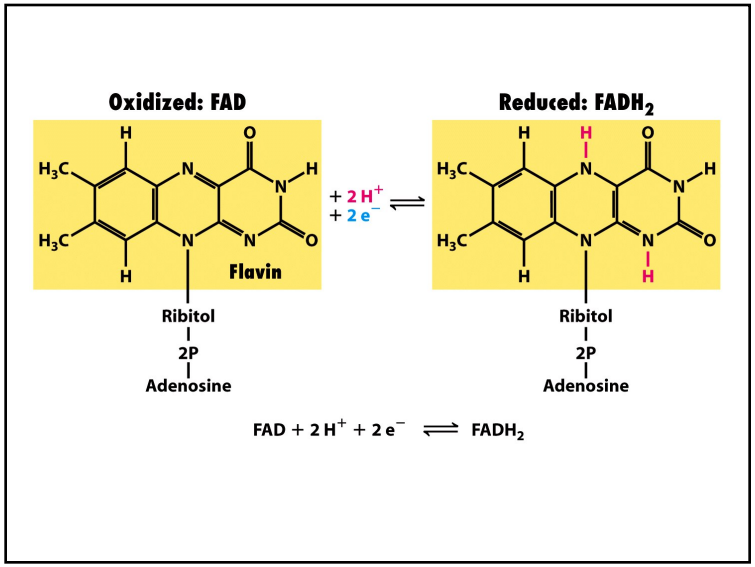


67

Cell Metabolism, Energy & Red-Ox-Reactions

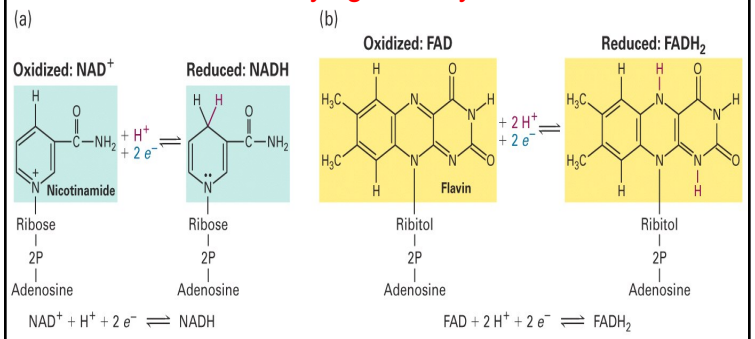


68



69

The Electron Carrying co-enzymes NAD⁺ and FAD



(a) NAD^+ (nicotinamide adenine dinucleotide) is reduced to NADH by addition of two electrons and one proton simultaneously. In many biological redox reactions (e.g., succinate to fumarate), a pair of hydrogen atoms (two protons and two electrons) are removed from a molecule. One of the protons and both electrons are transferred to NAD^+; the other proton is released into solution. (b) FAD (flavine adenine dinucleotide) is reduced to $FADH_2$ by addition of two electrons and two protons. In this two-step reaction addition of one electron together with one proton first generates a short-lived semiquinone interemediae (not shown), which then accepts a second electron and protons.

70

A few universal carriers collect electrons from the stepwise oxidation of various substrates

- Cellular oxidation of a nutrient occurs via stepwise reactions (pathways) for efficient energy transduction.
- NAD^+, $NADP^+$, FAD, and FMN are universal reversible electron carriers (as coenzymes of various enzymes).
- NAD and NADP are dinucleotides able to accept/donate a hydride ion (with $2e^-$) for each round of reduction/oxidation.
- *NAD (as NAD^+) usually acts in oxidations and NADP (as NADPH) in reductions.*

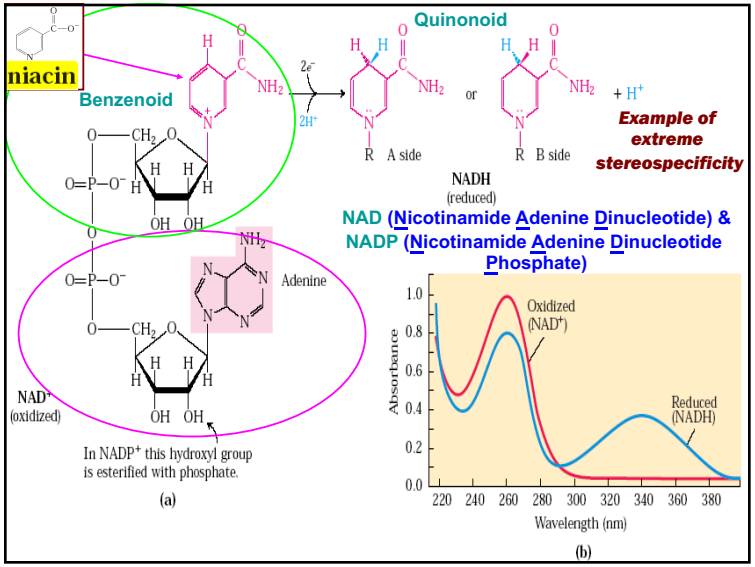
71

- In each specific NAD- or NADP-containing dehydrogenase, the hydride ion is added/taken stereospecifically from one side (A or B) of the nicotinamide ring (*example of extreme stereospecificity*).
- FAD or FMN is able to accept/donate one or two electrons (as hydrogen atom), with absorption maximum for the oxidized and reduced forms being 570 nm and 450 nm respectively (*they also act in such light receptor proteins as cryptochromes and photolyases*).

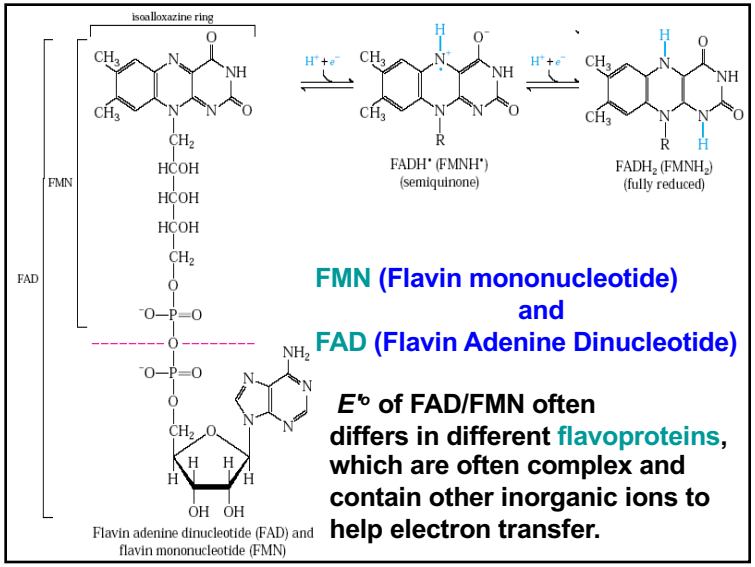
72

- NAD and NADP can easily diffuse out of the enzymes, but FMN and FAD are tightly bound to the enzymes (thus being called *prosthetic groups*, and the complex proteins being called *flavoproteins*).
- NADH and $FADH_2$ will be further oxidized via the respiratory chain for ATP production.
- ADP is commonly present in all these universal electron carriers (as well as in Coenzyme A and ATP).

73



74

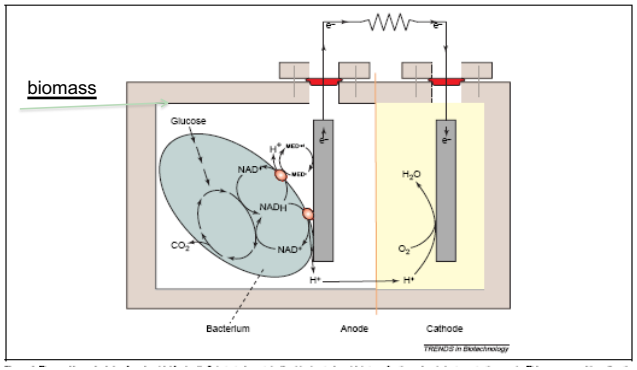


FMN (Flavin mononucleotide) and FAD (Flavin Adenine Dinucleotide)

***E'°* of FAD/FMN often differs in different flavoproteins, which are often complex and contain other inorganic ions to help electron transfer.**

75

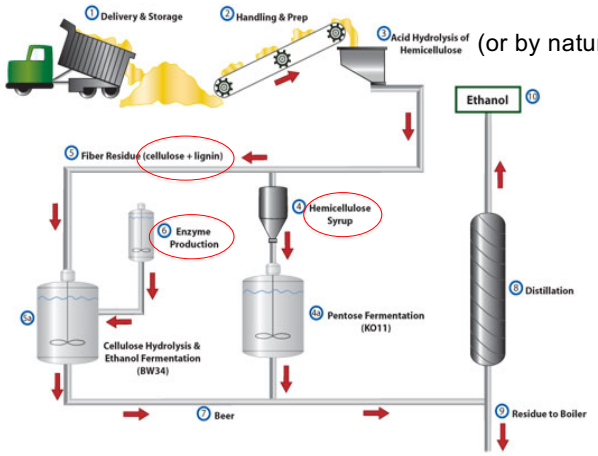
Microbial fuel cells (MFCs)



Electrons flow from an anode through a resistor to a cathode where electron acceptors are reduced. Protons flow across a proton exchange membrane (PEM) to complete the circuit.

76

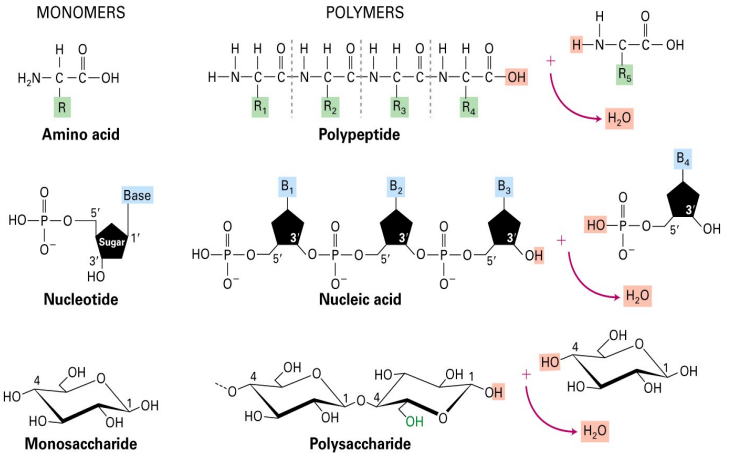
Bio-Engineering: A simplified scheme for the processing of biomass into ethanol



77

Taking-home message:

Essential Bio-Engineering-related Bio-Molecules



78