CONCEPTS OF BIOLOGY

Chapter 2 CHEMISTRY OF LIFE

PowerPoint Image Slideshow

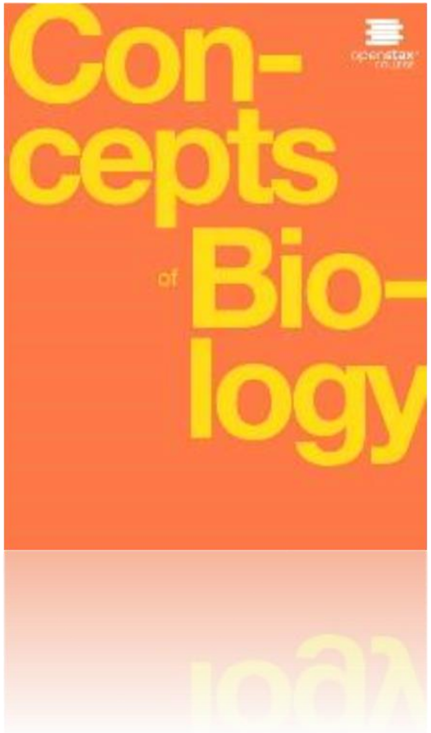

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FIGURE 2.1

Foods such as bread, fruit, and cheese are rich sources of biological macromolecules. (credit: modification of work by Bengt Nyman)

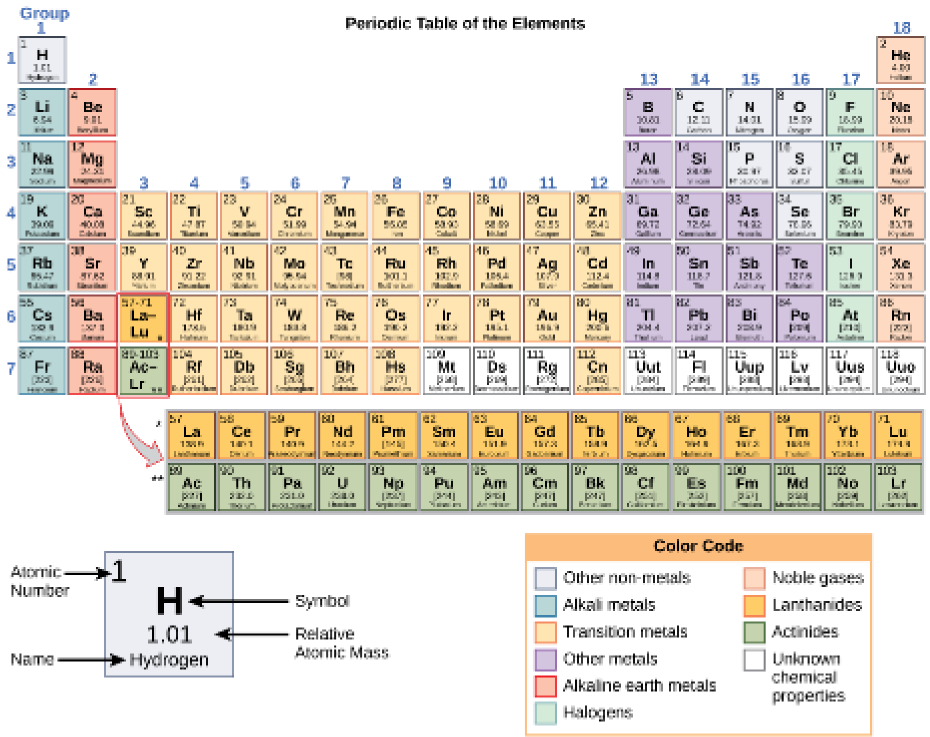
2.1 THE BUILDING BLOCKS OF MOLECULES

- Life is made up of matter and everything is made up of matter
- **Matter** - anything that occupies space and has mass
- All matter is composed of **elements** - substances that cannot be broken down or transformed into other substances

Elements

- A total of 118 elements have been defined
- Only 92 occur naturally, and fewer than 30 are found in living cells
- The remaining 26 elements are unstable and, therefore, do not exist for very long or are theoretical and have yet to be detected
- Each element is designated by it chemical symbol (such as H, N, O, C, and Na) and each possesses unique chemical properties

FIGURE 2.3 – PERIODIC TABLE



Arranged in columns and rows based on the characteristics of the elements, the periodic table provides key information about the elements and how they might interact with each other to form molecules. Most periodic tables provide a key or legend to the information they contain.

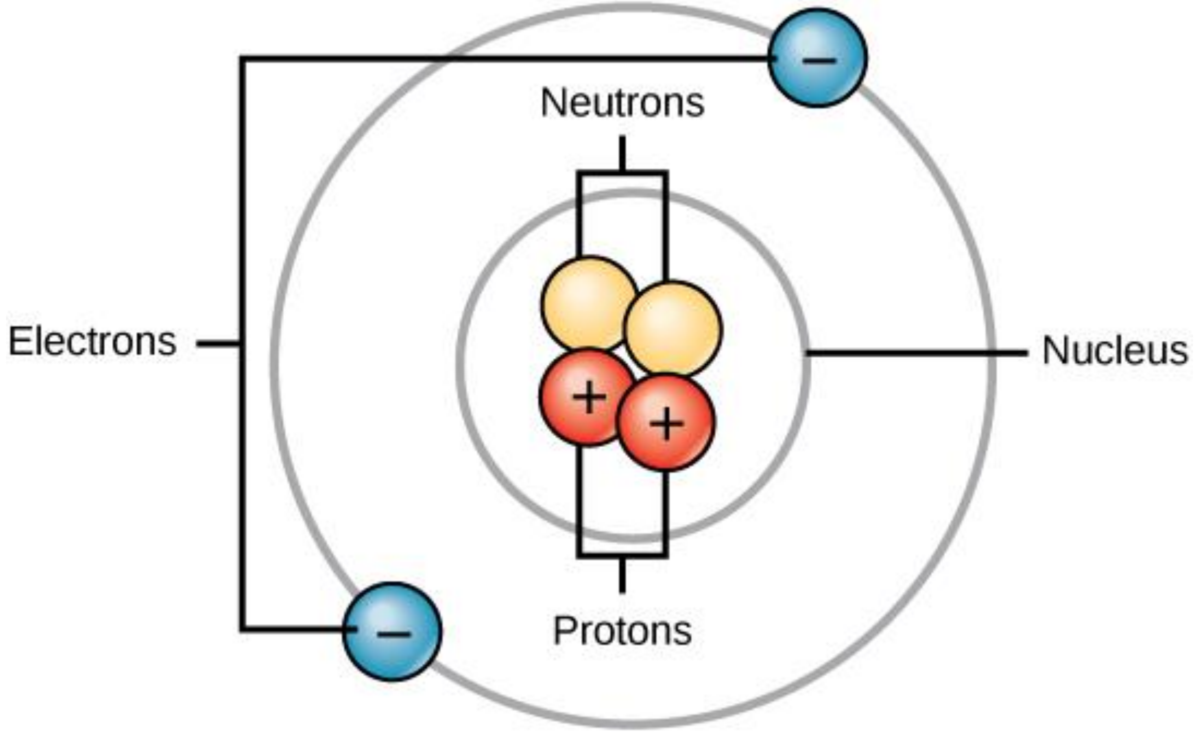
Atoms (1 of 6)

- **Atom** - the smallest component of an element that retains all of the chemical properties of that element
- For example: 1 Hydrogen atom has all the properties of the element hydrogen, such as a gas at room temperature, and it bonds with oxygen to create a water molecule
- A hydrogen atom can be broken down into smaller components called subatomic particles, but these components do not have the properties of hydrogen

Atoms (2 of 6)

- All atoms contain the subatomic particles: protons electrons, and neutrons (H is the exception, lacking neutrons)
- A **proton**:
  - ✓ is a positively charged particle (+1)
  - ✓ located in the nucleus (core) of the atom
  - ✓ has a mass of 1 dalton
- An **electron**:
  - ✓ is a negatively charged particle (-1)
  - ✓ travels in the space around the nucleus
  - ✓ has a negligible mass
- A **neutron**:
  - ✓ does not have a charge (0)
  - ✓ located in the nucleus (core) of the atom
  - ✓ has a mass of 1 dalton

FIGURE 2.2



Atoms are made up of protons and neutrons located within the nucleus, and electrons surrounding the nucleus.

Atoms (3 of 6)

- When the number of protons (+) is equal to the number of electrons (-), the atom is neutral
- Because protons and neutrons have a mass of 1, the mass of an atom is equal to: the number of protons + the number of neutrons. (Electrons are not factored into the mass because their mass is so small)

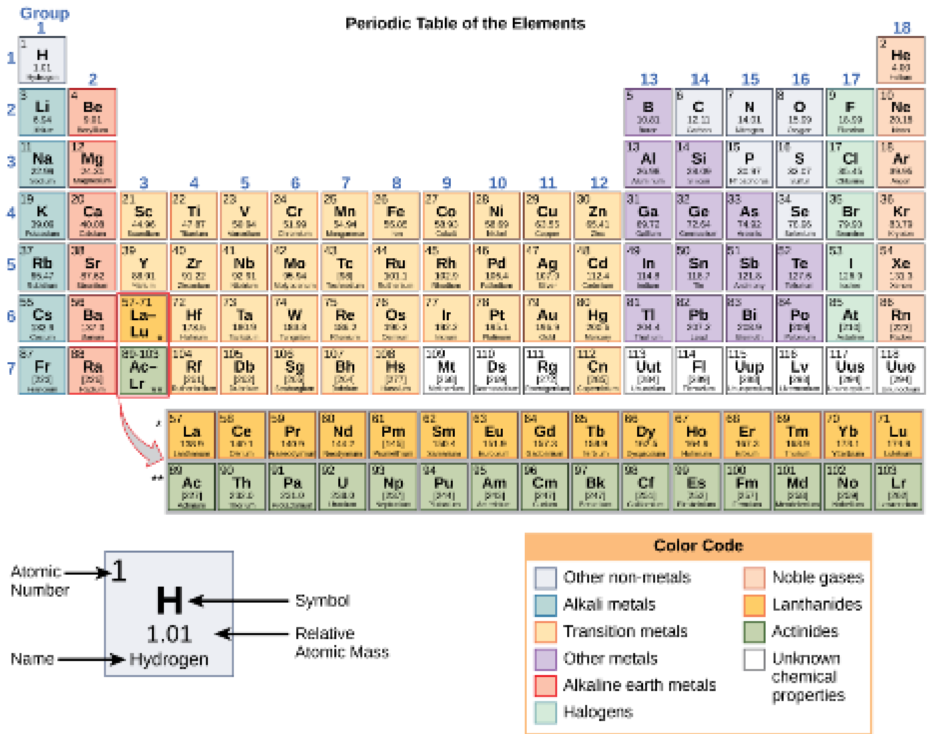
Atoms (4 of 6)

- Every element is unique in its number of protons and neutrons
- **Atomic number** - the number of protons the element's atoms contain
- The **mass number** (or **atomic mass**) - the number of protons plus the number of neutrons for that element
- Therefore, it is possible to determine the number of neutrons by subtracting the atomic number from the mass number

Atoms (5 of 6)

- **Periodic table of elements** - a chart of the elements that includes the atomic number and relative atomic mass of each element
- It also provides key information about the properties of elements, often indicated by color coding
- The arrangement of the table also shows how the electron in each element are organized and provides important details about how atom will react with each other to form molecules

FIGURE 2.3



Arranged in columns and rows based on the characteristics of the elements, the periodic table provides key information about the elements and how they might interact with each other to form molecules. Most periodic tables provide a key or legend to the information they contain.

Atoms 6 of 6

- **Isotopes** - different forms of the same element that have the same number of protons, but a different number of neutrons
- Some elements, such as carbon, potassium and uranium have naturally occurring isotopes
- Some isotopes are unstable and will lose protons, other subatomic particles or energy to form more stable elements; these are called **radioactive isotopes** (or **radioisotopes**)

Isotopes of Carbon

- Carbon-14 has a half-life of ~5730 years. This means that after 5730 years, half of a sample of Carbon-14 will have converted to Nitrogen-14. Scientists use this fact to do carbon dating to reconstruct the ecology and biogeography of organisms living within the past 50,000 years

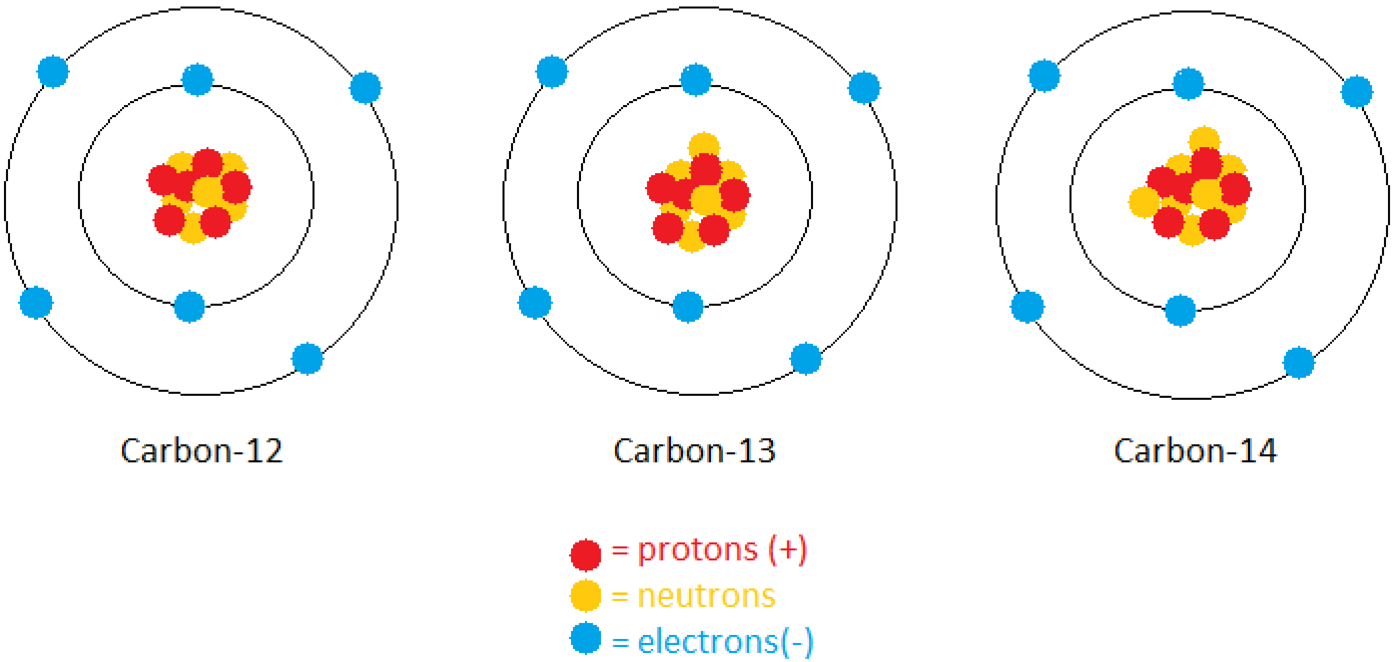


FIGURE 2.4

The age of remains that contain carbon and are less than about 50,000 years old, such as this pygmy mammoth, can be determined using carbon dating. (credit: Bill Faulkner/NPS)

Chemical Bonds (1 of 3)

- How an element interacts with other elements depends on the arrangement of its electrons
- Electrons are arranged in energy levels:
  - The 1st energy level (closest to the nucleus) holds 2 electrons
  - The 2nd and 3rd energy levels hold up to 8 electrons (the **octet rule**)

Chemical Bonds (2 of 3)

- An atom is most stable when the outermost energy shell is full, but not all elements have enough electrons to fill their outermost shells
- **Chemical bonds** – the interactions between two or more atoms that results in the formation of molecules
- An atom can donate, accept, or share electrons with atoms of other elements to fill its outer shell and satisfy the octet rule

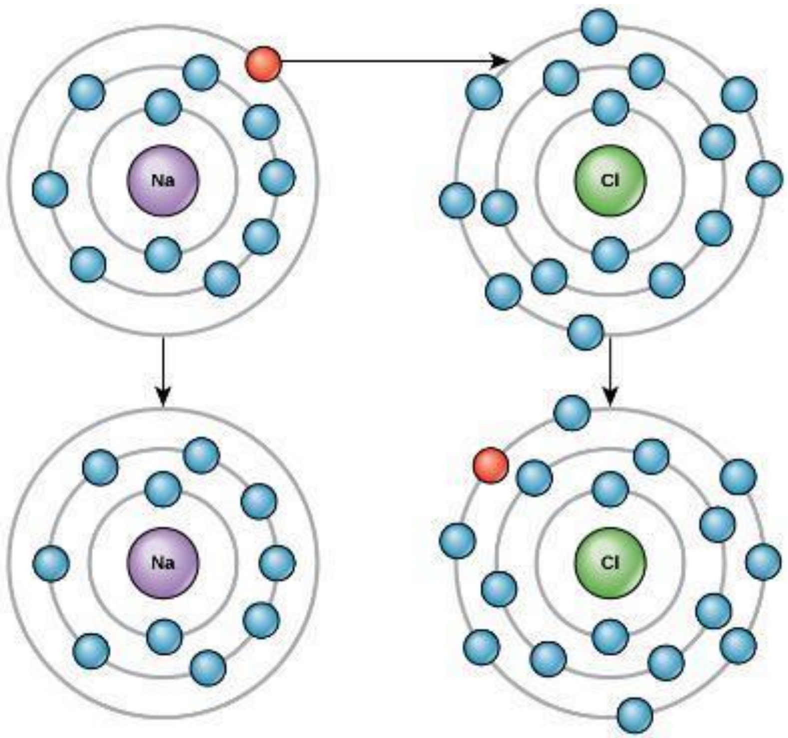
Chemical Bonds (3 of 3)

- There are four types of bonds or interactions:
  - ✓ Ionic
  - ✓ Covalent
  - ✓ Hydrogen
  - ✓ van der Waals interactions

Ionic Bonds

- **Ions** - formed when an atom does not have the same number of protons and electrons
- **Cations** (positive ions) are formed by losing electrons
- **Anions** (negative ions) are formed by gaining electrons
- The movement of electrons from one element to another is referred to as **electron transfer**
- Because opposite charges are attracted, a cation is attracted to an anion; these ions will stay together and form an **ionic bond**

FIGURE 2.5



Elements tend to fill their outermost shells with electrons. To do this, they can either donate or accept electrons from other elements.

Covalent Bonds (1 of 2)

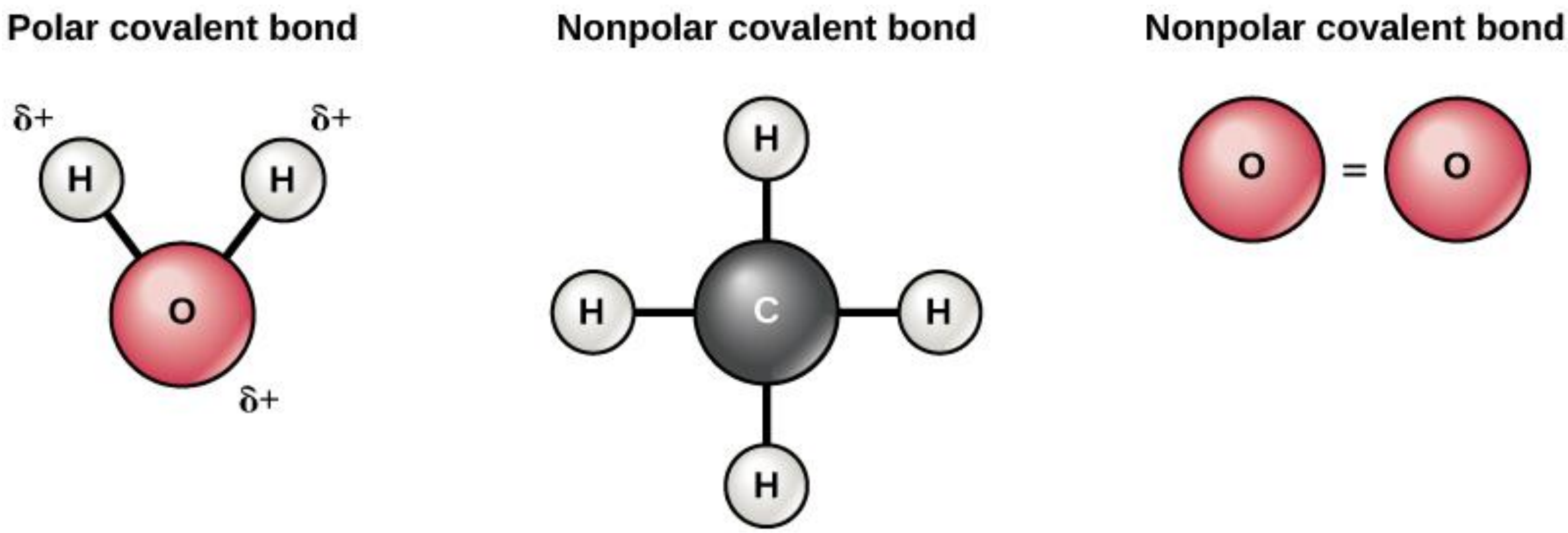
- **Covalent bond -** form when an electron is shared between two atoms
- Covalent bonds are the strongest and most common form of chemical bond in living organisms
- When one pair of electrons are shared, it forms a single covalent bond
- When two pairs of electrons are shared, it forms a double covalent bond
- When three pairs of electrons are shared, it forms a triple covalent bond

$H-H$	$O=O$	$N\equiv N$
strong	stronger	strongest

Covalent Bonds (2 of 2)

- There are two types of covalent bonds: nonpolar covalent bonds and polar covalent bonds
- **Nonpolar covalent bonds** are formed when the electrons are shared equally
- **Polar covalent bonds** are formed when the electrons are not shared equally, they spend more time closer to one nucleus than to the other nucleus. This gives the atom where the electron spends more time a small negative charge, and the atom missing the electron more a small positive charge

FIGURE 2.6

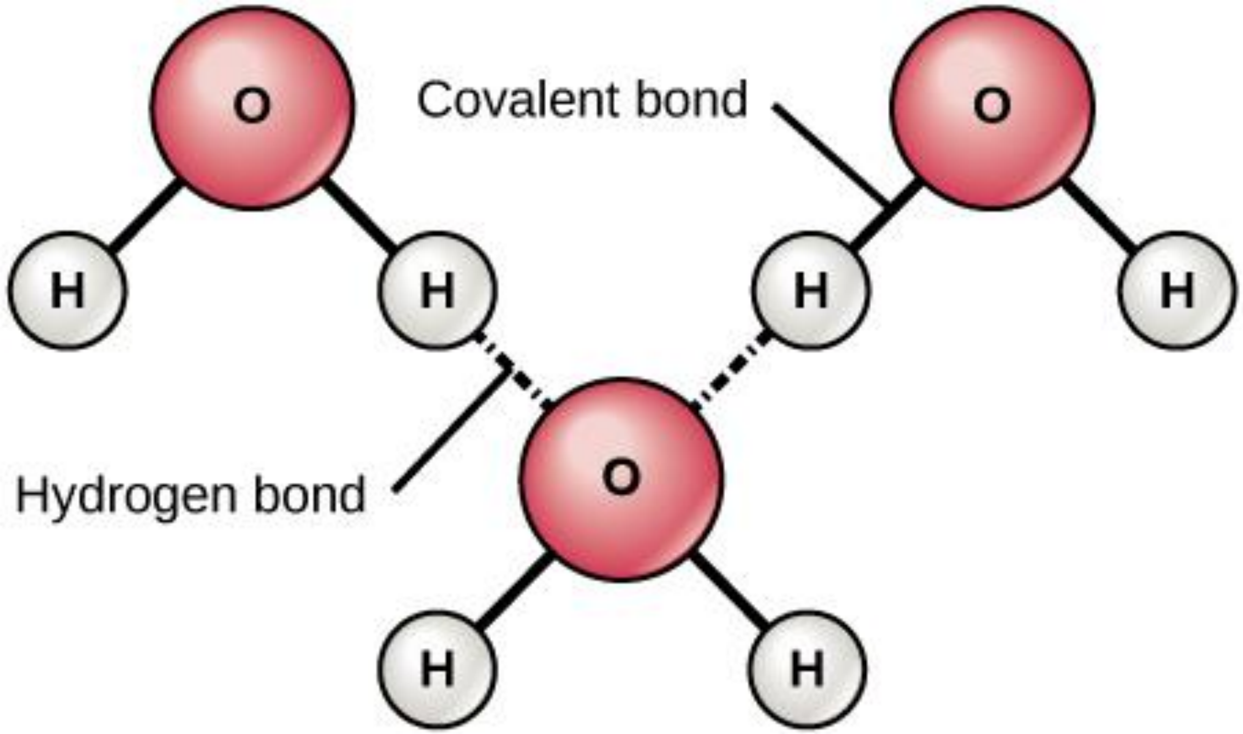


The water molecule (left) depicts a polar bond with a slightly positive charge on the hydrogen atoms and a slightly negative charge on the oxygen. Examples of nonpolar bonds include methane (middle) and oxygen (right).

Hydrogen Bonds

- Weak bonds that occur between the slightly positive hydrogen end and slightly negative end of another molecule
- This bond does not require much energy to break
- Hydrogen bonds give water the unique properties that sustain life

FIGURE 2.7



Hydrogen bonds form between slightly positive (*δ*+) and slightly negative (*δ*–) charges of polar covalent molecules, such as water.

Van der Waals Interactions

- Weak attractions between molecules caused by temporary partial charges formed when electrons move around a nucleus
- These weak interactions between molecules are important in biological systems

2.2 WATER

- Why do scientist spend so much time looking for water on other planets?
- It is because water is essential to life
- Water is one of the more abundant molecules in living cells and the one most critical to life
- Approximately 60-70% of your body is made up of water

Water is Polar

- The hydrogen and oxygen atoms within water molecules form polar covalent bonds
- Each hydrogen has a slight positive charge and the oxygen has a slight negative charge
- The opposite charges of water molecules are attracted to one another, and is also attracted to other polar molecules
- When a substance readily forms hydrogen bonds with water, it can dissolve in water and is referred to as **hydrophilic**
- When a substance does not readily form hydrogen bonds with water, it will not dissolve in water and is referred to as **hydrophobic**

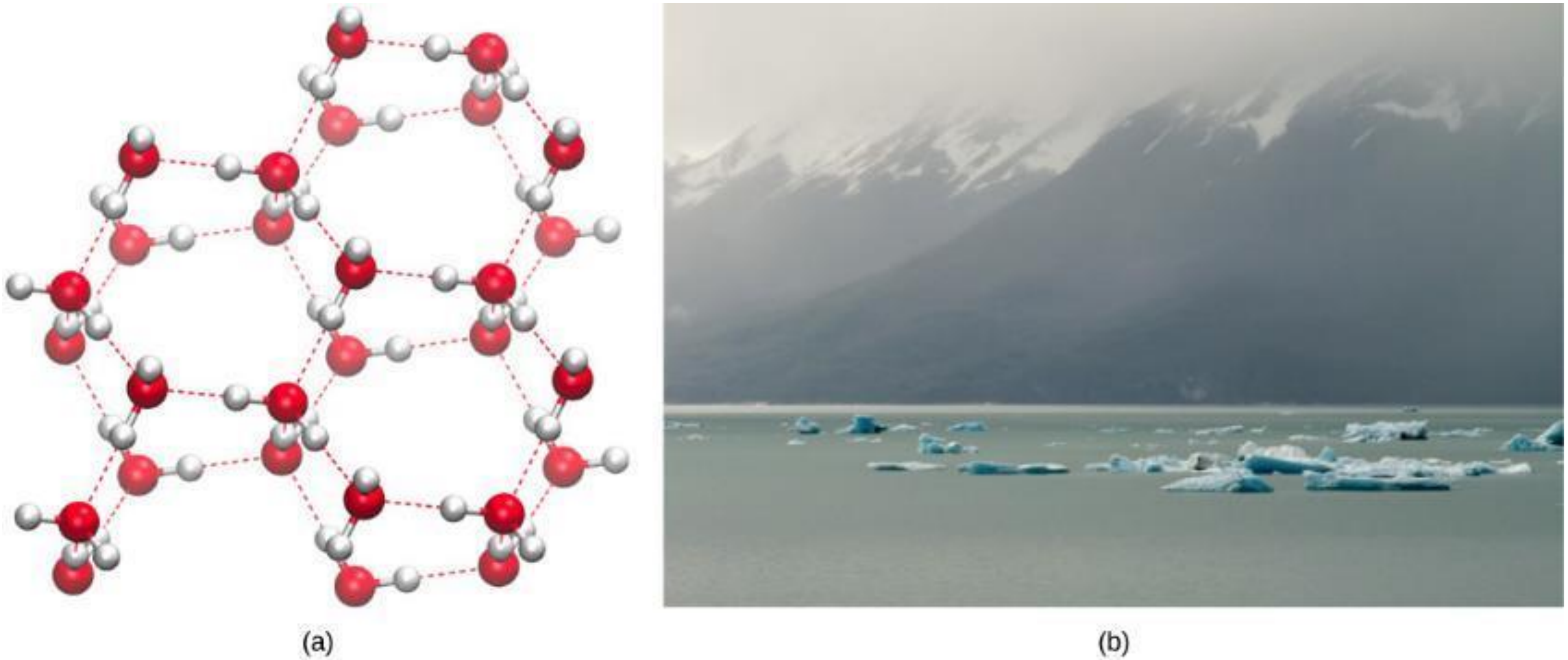
FIGURE 2.8

As this macroscopic image of oil and water show, oil is a nonpolar compound and, hence, will not dissolve in water. Oil and water do not mix. (credit: Gautam Dogra)

Water Stabilizes Temperature

- The hydrogen bonds in water allow it to absorb and release heat energy more slowly than many other substances
- **Temperature** is a measure of the motion (kinetic energy) of molecules
- Water absorbs a great deal of energy before its temperature rises
- As energy input increases, water molecules can be released at the surface, this is called **evaporation**
- Evaporation of sweat allows for cooling of an organism

FIGURE 2.9

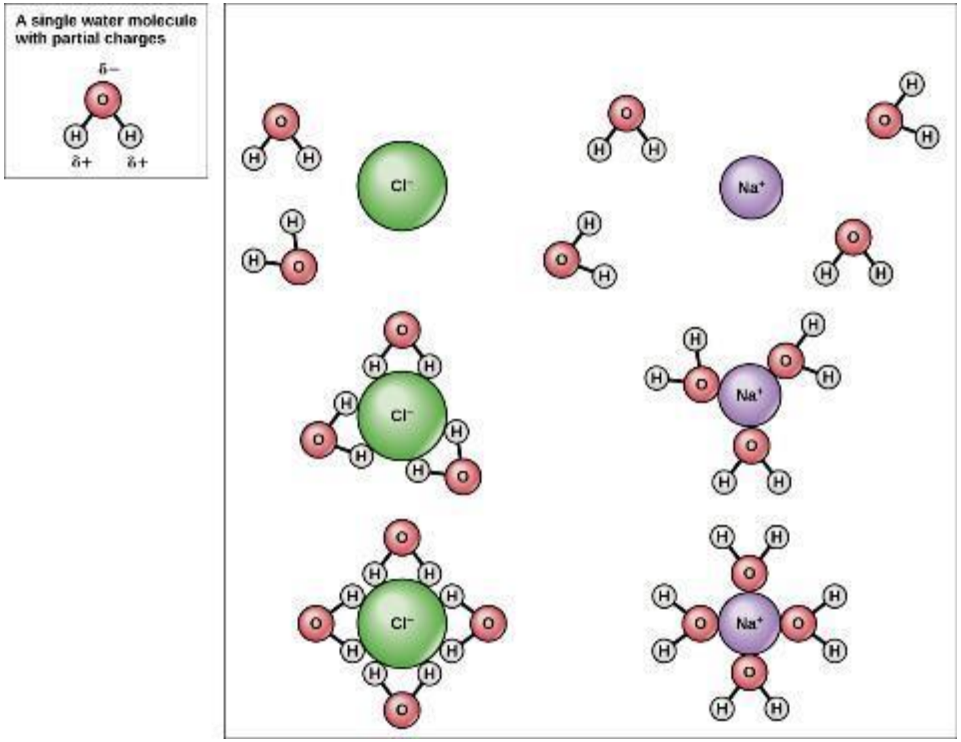


(a) The lattice structure of ice makes it less dense than the freely flowing molecules of liquid water. Ice's lower density enables it to (b) float on water. (credit a: modification of work by Jane Whitney; credit b: modification of work by Carlos Ponte)

Water is an Excellent Solvent

- Because water is polar, ionic compounds and polar molecules can readily dissolve in it
- Water is therefore referred to as a **solvent** - a substance capable of dissolving another substance
- A “sphere of hydration” serves to keep the charged particles separated or dispersed in the water

FIGURE 2.10

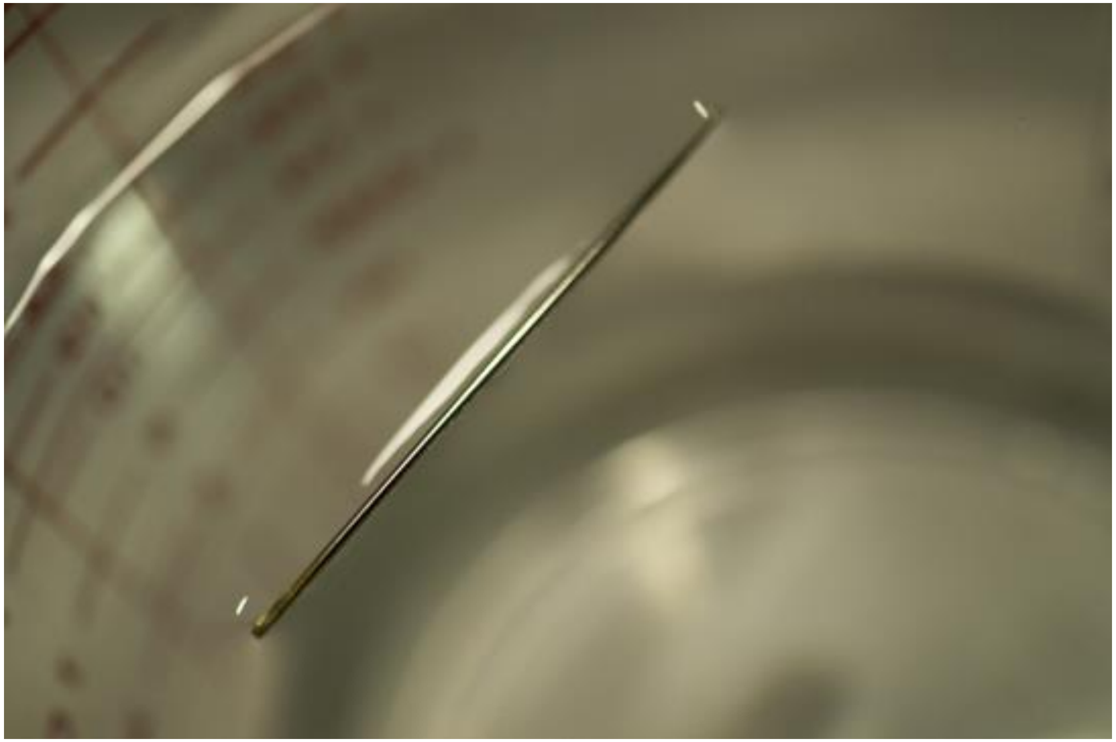


When table salt (NaCl) is mixed in water, spheres of hydration form around the ions.

Water is Cohesive

- **Cohesion** - the attraction of water molecules to other water molecules
- Cohesion gives rise to **surface tension** - the capacity of a substance to withstand rupture when placed under tension or stress
- Surface tension allows a scrap of paper, needle, or toothpick to float on top of water
- **Adhesion** - the attraction between water molecules and other molecules
- Adhesion is why water appears slightly higher on the sides of a straw than in the middle

FIGURE 2.11



The weight of a needle on top of water pulls the surface tension downward; at the same time, the surface tension of the water is pulling it up, suspending the needle on the surface of the water and keeping it from sinking. Notice the indentation in the water around the needle. (credit: Cory Zanker)

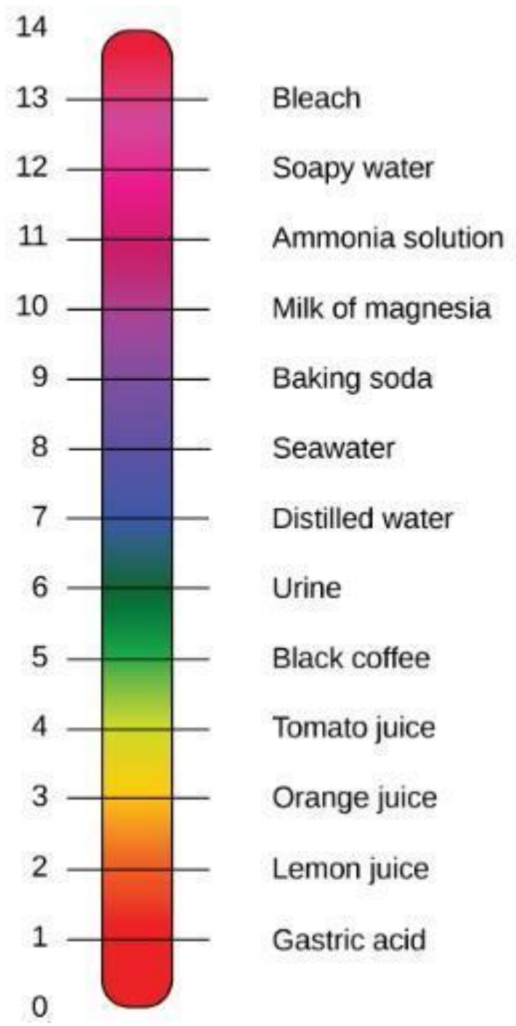
Buffers, pH, Acids and Bases

- The pH of a solution is a measure of its acidity or alkalinity
- A pH test measures the amount of hydrogen ions that exists in a given solution
- The overall concentration of hydrogen ions is inversely related to its pH and can be measured on the pH scale

pH Scale

- The more hydrogen ions present, the lower the pH; the fewer hydrogen ions, the higher the pH
- The pH scale ranges from 0 to 14
- Pure water is neutral (7), neither acidic nor basic
- Anything below 7 is acidic
- Anything above 7 is basic

FIGURE 2.12



The pH scale measures the amount of hydrogen ions (H^+) in a substance. (credit: modification of work by Edward Stevens)

pH Scale

- **Acids** are substances that provide hydrogen ions (H^+) and lower pH
- **Bases** are substances that provide hydroxide ions (OH^-) and raise pH
- Most cells in our bodies operate within a very narrow window of the pH scale, typically ranging only from 7.2 to 7.6
- **Buffers** readily absorb excess H^+ or OH^-, keeping the pH of the body carefully maintained within the proper range

2.3 BIOLOGICAL MOLECULES

- Large molecules necessary for life are built from smaller organic molecules and are called biological macromolecules
- There are four major classes of biological macromolecules:
    - ✓ Carbohydrates
    - ✓ Lipids
    - ✓ Proteins
    - ✓ Nucleic acids
- Biological macromolecules are organic, meaning the contain carbon. In addition, they may contain hydrogen, oxygen, nitrogen, phosphorus, sulfur and additional minor elements

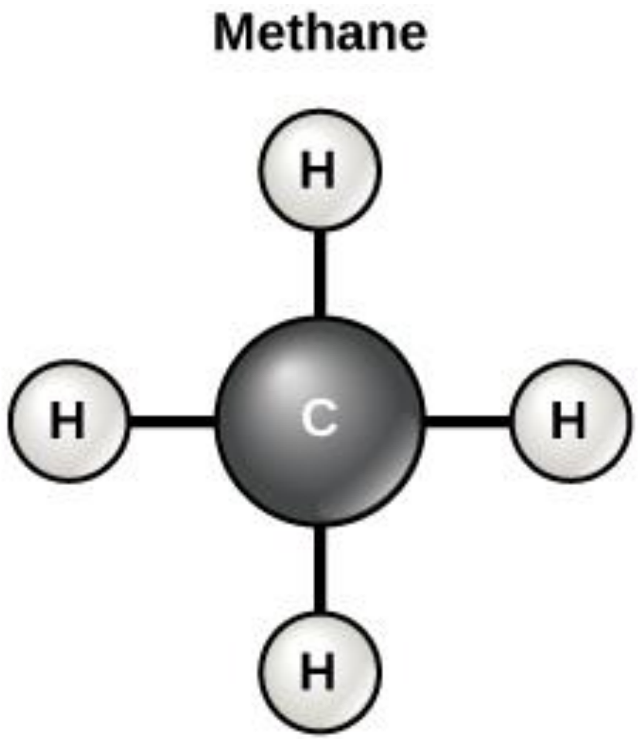
Carbon

- It is often said that life is “carbon-based”
- This means that carbon atoms, bonded with other carbon atoms or other elements form the fundamental components of many, if not most, of the molecules found uniquely in living things

Carbon Bonding

- Carbon contain four electrons in its outer shell
- Therefore, it can form four covalent bonds with other atoms or molecules
- The simplest organic carbon molecule is methane (CH_4), in which four hydrogen atoms bind to a carbon atom

FIGURE 2.13



Carbon can form four covalent bonds to create an organic molecule. The simplest carbon molecule is methane (CH_4), depicted here.

Carbon Molecules

- However, structures that are more complex are made using carbon
- Any of the hydrogen atoms can be replaced with another carbon atom covalently bonded to the first carbon atom
- In this way, long and branching chains of carbon compounds can be made

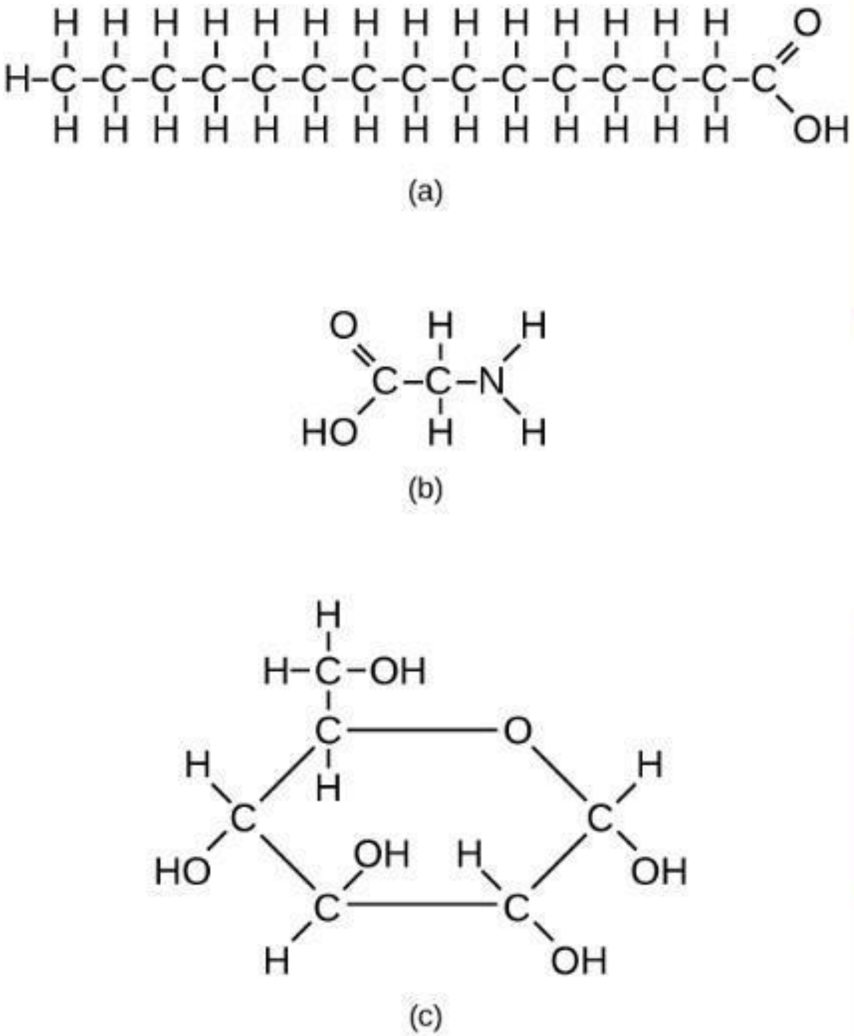
FIGURE 2.14

These examples show three molecules (found in living organisms) that contain carbon atoms bonded in various ways to other carbon atoms and the atoms of other elements.

(a) This molecule of stearic acid has a long chain of carbon atoms.

(b) Glycine, a component of proteins, contains carbon, nitrogen, oxygen, and hydrogen atoms.

(c) Glucose, a sugar, has a ring of carbon atoms and one oxygen atom.



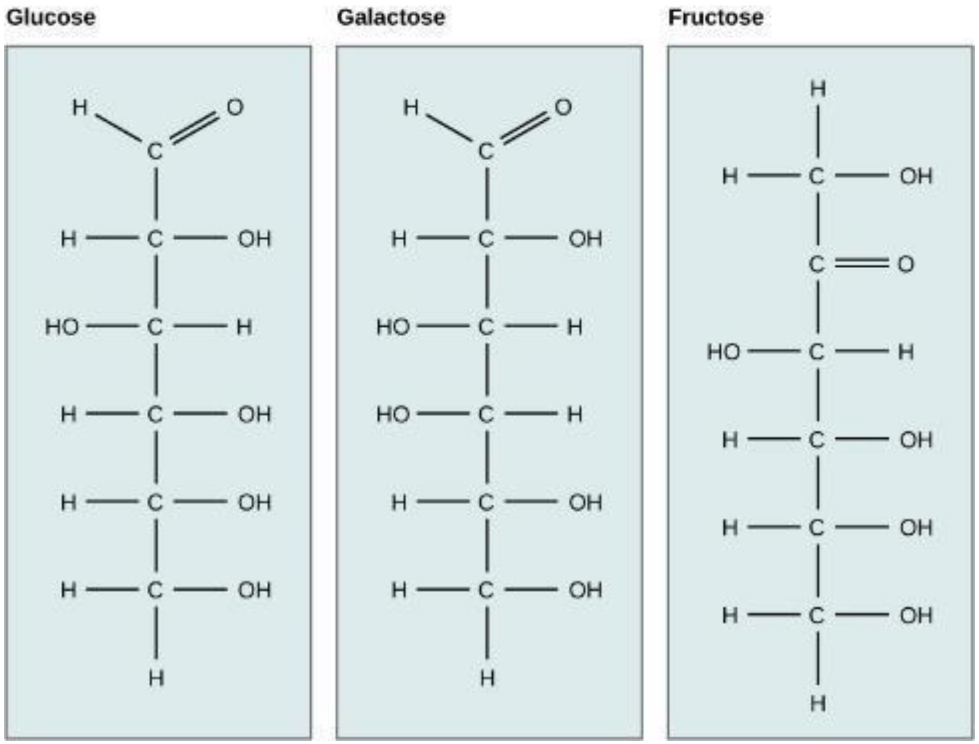
Carbohydrates

- **Carbohydrates** are macromolecules that provide energy to the body and have other important functions in humans, animals and plants
- Can be represented by the formula $(CH_2O)_n$ where n is the number of carbon atoms in the molecule
- Carbohydrates are classified into three subtypes:
  - ✓ Monosaccharides
  - ✓ Disaccharides
  - ✓ Polysaccharides

Monosaccharides

- **Mono** = one; **sacchar** = sweet
- Includes glucose, galactose, and fructose
- Glucose is an important source of energy
- Galactose is part of lactose (milk sugar)
- Fructose is found in fruits
- Glucose, galactose, and fructose all have the same chemical formula ($C_6H_{12}O_6$) but have different structures

FIGURE 2.15



Glucose, galactose, and fructose are isomeric monosaccharides, meaning that they have the same chemical formula but slightly different structures.

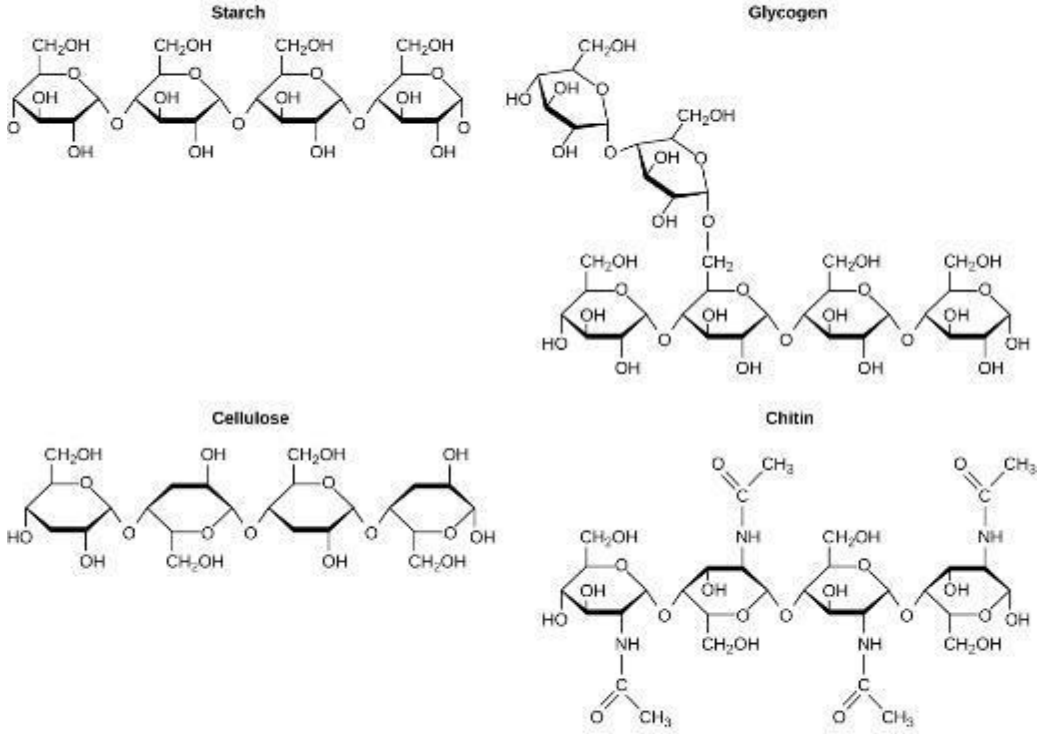
Disaccharides

- **Di** = two
- **Disaccharides** are formed when two monosaccharides are covalently bonded together by a chemical reaction called a dehydration reaction
- Common disaccharides include lactose, maltose and sucrose
- Lactose = glucose + galactose (found in milk)
- Maltose = glucose + glucose (malt sugar)
- Sucrose = glucose + fructose (table sugar)

Polysaccharides

- **Poly** = many
- **Polysaccharides** are long chains of monosaccharides linked by covalent bonds
- Includes starch, glycogen, cellulose and chitin
- Starch is the stored form of sugars in plants
- Glycogen is the stored form of sugars in humans and other vertebrates
- Cellulose makes up the plant cell walls, and provide humans with dietary fiber
- Chitin, a nitrogenous carbohydrate makes up the exoskeleton of arthropods

FIGURE 2.16



Although their structures and functions differ, all polysaccharide carbohydrates are made up of monosaccharides and have the chemical formula $(CH_2O)n$.

Lipids

- **Lipids** are a diverse group of compounds that are united by a common feature – they are hydrophobic ("water-fearing")
- They are insoluble in water because they are nonpolar
- They store energy, provide insulation, and are the building blocks of hormones and plasma membranes
- Includes fats, oils, waxes, phospholipids, and steroids

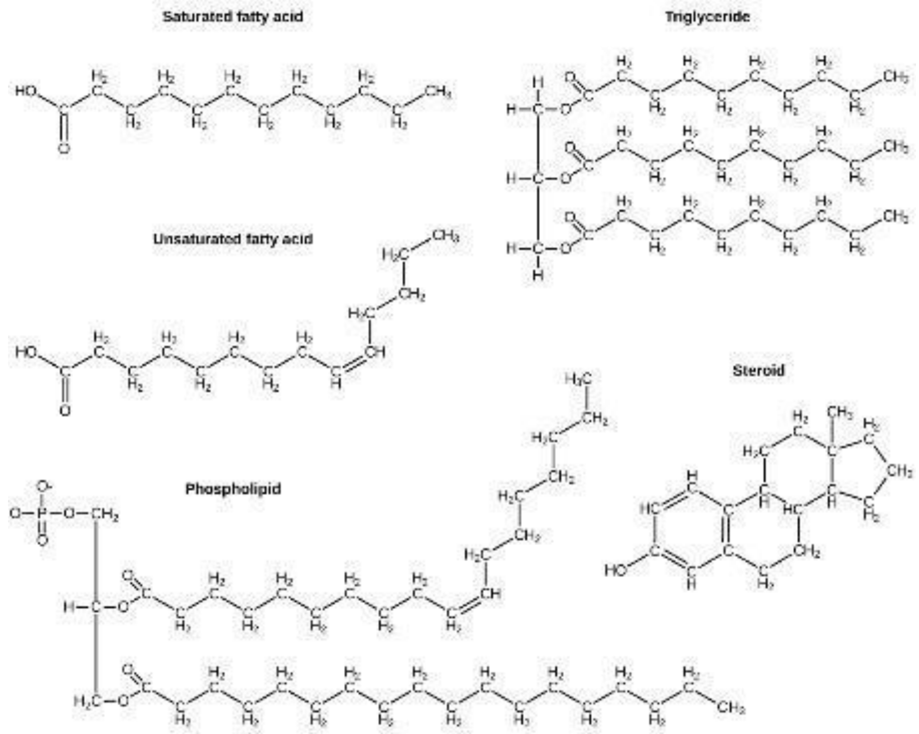
FIGURE 2.17

Hydrophobic lipids in the fur of aquatic mammals, such as this river otter, protect them from the elements. (credit: Ken Bosma)

Fats (1 of 3)

- A **fat** molecule consists of two main components: glycerol and fatty acids
- Fatty acids may be saturated or unsaturated
- **Saturated fatty acids** are saturated with hydrogen, the number of hydrogen atoms attached to the carbon skeleton is maximized
- **Unsaturated fatty acids** contain a double bond

FIGURE 2.18

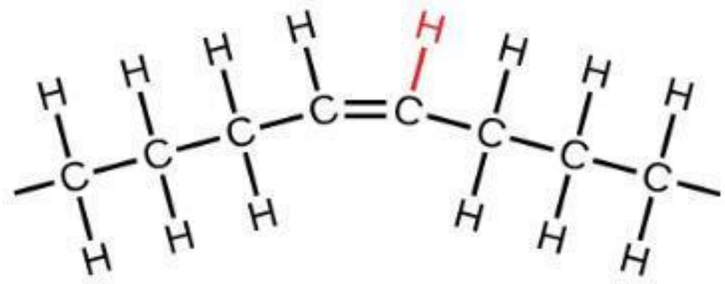


Lipids include fats, such as triglycerides, which are made up of fatty acids and glycerol, phospholipids, and steroids.

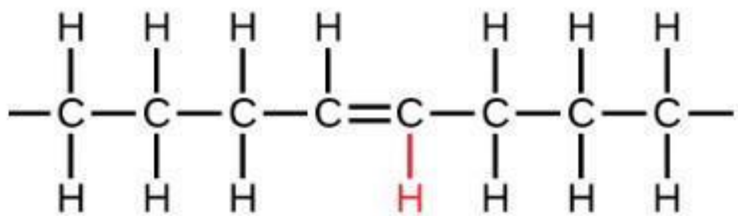
Fats (2 of 3)

- Unsaturated fatty acids are liquid at room temperature and are called **oils**
- Unsaturated fats help to improve blood cholesterol levels, whereas saturated fats contribute to plaque formation in the arteries
- Saturated fats tend to get packed tightly and are solid at room temperature
- **Trans fats** are created by a hydrogenation process the changes the orientation of the molecule, they also increase our LDL or “bad cholesterol”

FIGURE 2.19



cis-fat molecule



trans-fat molecule

During the hydrogenation process, the orientation around the double bonds is changed, making a *trans*-fat from a *cis*-fat. This changes the chemical properties of the molecule.

Fats (3 of 3)

- **Essential fatty acids** are fatty acids that are required but not synthesized by the human body; therefore they must be supplemented through the diet
- There are two known essential fatty acids for humans: omega-3 fatty acid and omega-6 fatty acid
- Omega-3 fatty acids are found in salmon, trout, and tuna; they are important in brain function, normal growth/development, and may prevent heart disease and certain cancers

Phospholipids

- **Phospholipids** are the major constituent of the plasma membrane
- They are composed of two fatty acid chains attached to a glycerol and a phosphate group
- The fatty acid chain is hydrophobic; the phosphate group is hydrophilic
- Cell membranes are a bilayer of phospholipids; the fatty acid regions faces the inside (away from water) while the phosphate groups face either inside or outside the cell (attracted to the water)

Steroids and Waxes (1 of 2)

- Steroids have four carbon rings linked together and several of them (like cholesterol) have a short tail
- Cholesterol is a steroid
- It is synthesized by the liver; and is a precursor of many hormones, of vitamins E and K, and of bile salts
- It is a key component of the plasma membrane of animal cells
- It is necessary for the proper functioning of the body

Steroids and Waxes (2 of 2)

- Waxes are made up of a hydrocarbon chain with an alcohol (-OH) group and a fatty acid
- Includes beeswax and lanolin, as well as the wax coating on plant leaves

Proteins (1 of 6)

- **Proteins** are the most abundant organic molecules in living systems
- They have a diverse range of function, including:
  - They may be structural, regulatory, contractile, or protective
  - They may serve in transport, storage, membranes, toxins or enzymes
- Each cell may contain thousands of different proteins, each with a unique structure and function
- They are polymers of **amino acids**, arranged in a linear sequence

Proteins (2 of 6)

- Proteins are long chains made up of 20 distinct amino acids, that can be in any order and any length
- **Enzymes** are produced by living cells to act as catalysts in biochemical reactions and are usually proteins
- Each enzyme is specific for a substrate (a reactant that binds to an enzyme)
- Enzymes break, rearrange or form chemical bonds
- An example of an enzyme is salivary amylase, which breaks down amylose, a component of starch

Proteins (3 of 6)

- **Hormones** - chemical signaling molecules and are usually proteins or steroids
- Hormones regulate specific physiological processes including growth, development, metabolism and reproduction
- An example of a protein hormone is insulin, which maintains blood glucose levels

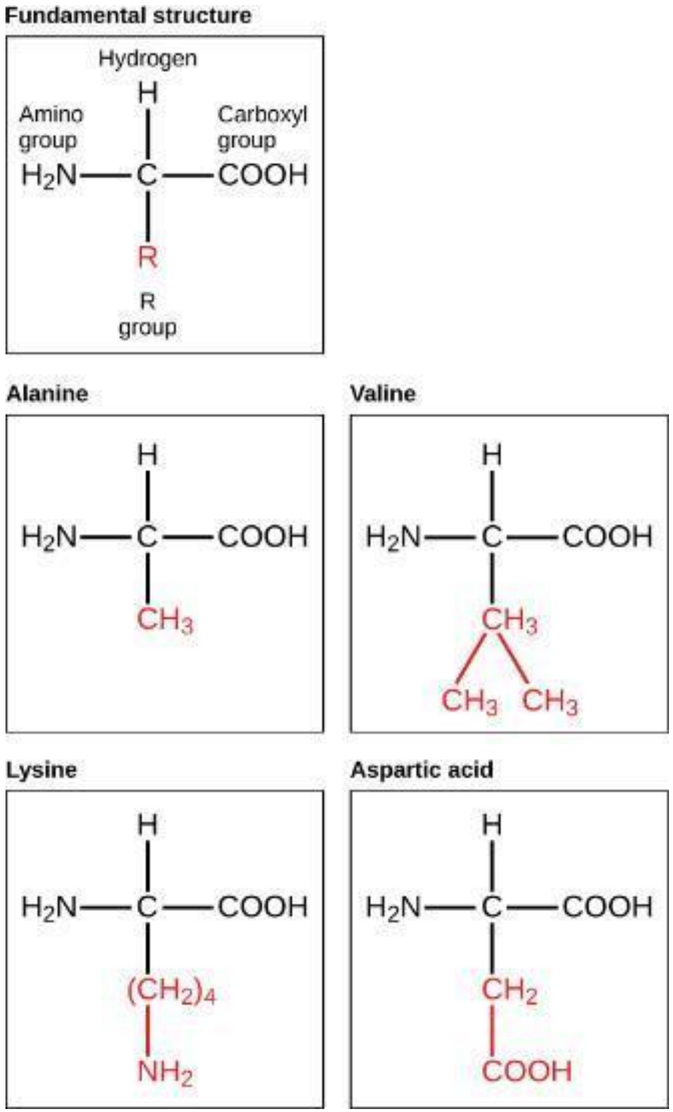
Proteins (4 of 6)

- Proteins have different shapes and molecular weights
- Some are globular (like hemoglobin), whereas others are fibrous (like collagen)
- Protein shape is critical to its function
- Changes in temperature, pH or exposure to chemical may lead to permanent changes in the shape of the protein, leading to loss of function or **denaturation**

Proteins (5 of 6)

- All proteins are made up of different arrangements of the same 20 kinds of amino acids
- **Amino acids** are the monomers that make up proteins
- Each amino acid consists of a central carbon atom bonded to an amino group ($-NH_2$), a carboxyl group ($-COOH$) and a hydrogen atom
- Each amino acid has its own unique R group
- The R group is the only difference in structure between the 20 amino acid; otherwise the amino acids are identical

FIGURE 2.20



Amino acids are made up of a central carbon bonded to an amino group (–NH_2), a carboxyl group (–COOH), and a hydrogen atom. The central carbon's fourth bond varies among the different amino acids, as seen in these examples of alanine, valine, lysine, and aspartic acid.

Proteins (6 of 6)

- The sequence and number of amino acids ultimately determine a protein's shape, size, and function
- Each amino acid is attached to another amino acid by a covalent bond, known as a **peptide bond**, which is formed by a dehydration reaction
- The term **polypeptide** refers to a polymer of amino acids

Protein Structure (1 of 2)

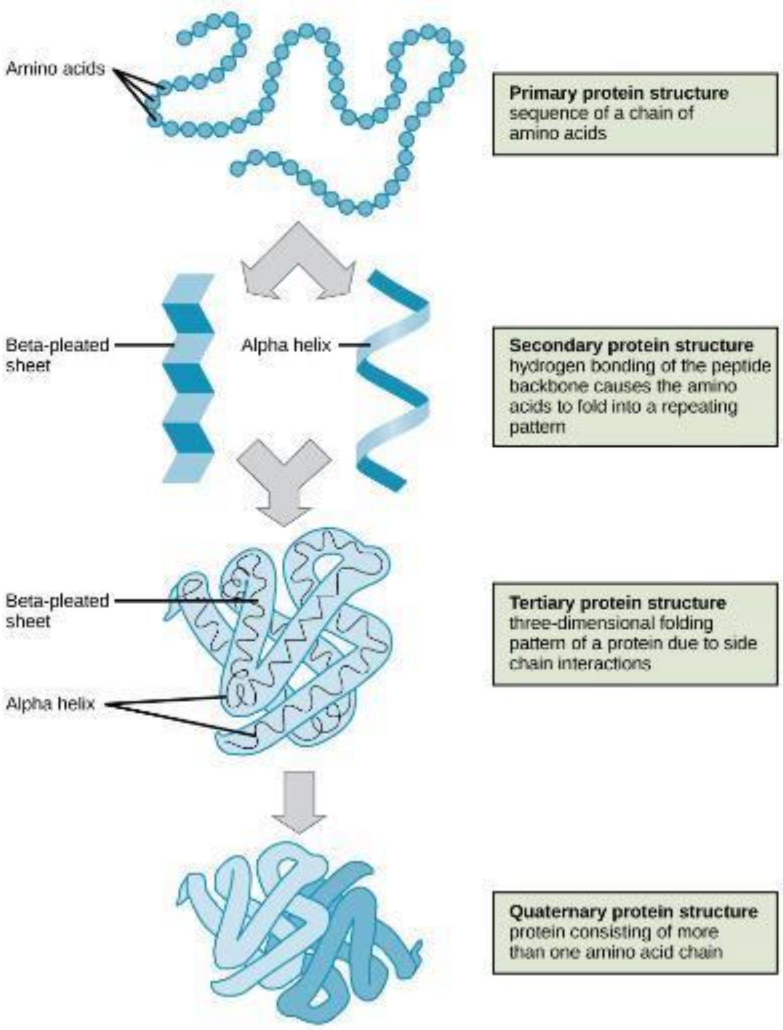
- A protein's shape is critical to its function
- There are four levels to protein structure:
  - ✓ Primary
  - ✓ Secondary
  - ✓ Tertiary
  - ✓ Quaternary

Protein Structure (2 of 2)

- Primary – the unique sequence and number of amino acids (determined by genes)
- Secondary – the folding patterns of the non-R portions of the amino acids; includes the alpha-helix and beta-sheeting
- Tertiary – the unique three-dimensional structure of a polypeptide
- Quaternary – the interaction of several polypeptides (known as subunits)

FIGURE 2.21

The four levels of protein structure can be observed in these illustrations. (credit: modification of work by National Human Genome Research Institute)



Proteins

- Each protein has its own unique sequence and shape
- Changes in temperature, pH, or exposure to chemical may cause the protein structure to change (known as denaturation)
- Denaturation is often reversible, but not always (example, cooking an egg irreversibly denatures the albumin)
- Not all proteins denature at high temperatures; for instance, bacteria that survive in hot springs have proteins that are adapted to function at high temperatures

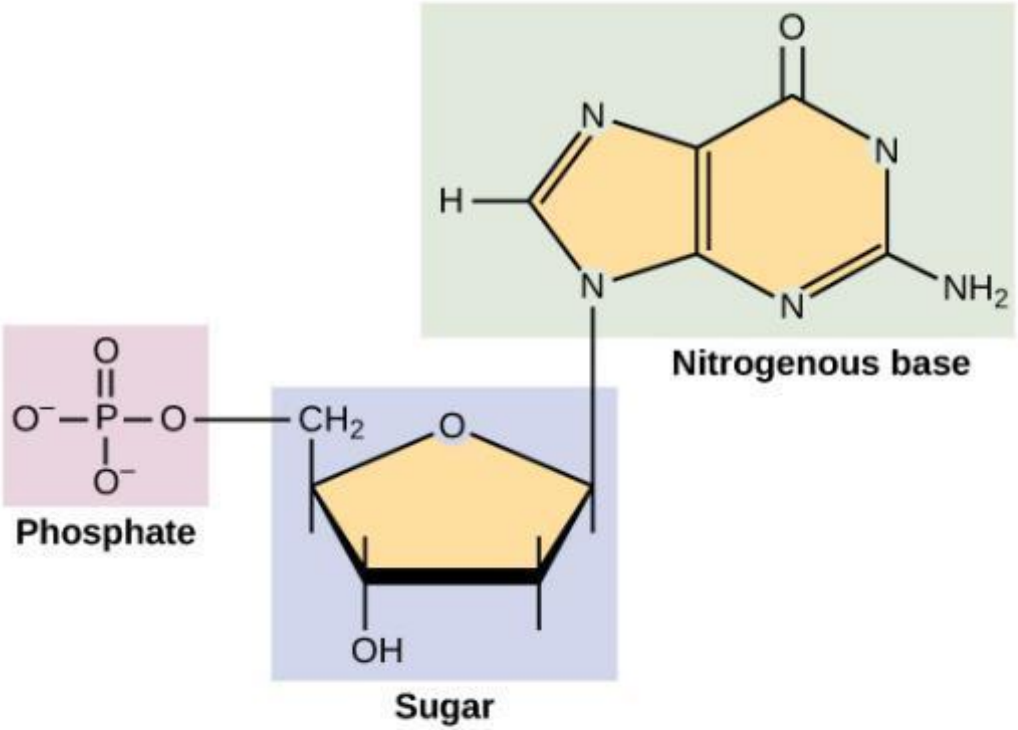
Nucleic Acids (1 of 2)

- **Nucleic acids** are key macromolecules in the continuity of life
- They carry the genetic blueprint of a cell and carry instructions for the functioning of the cell
- The two main types of nucleic acids are:
  - ✓ Deoxyribonucleic acid (DNA)
  - ✓ Ribonucleic acid (RNA)

Nucleic Acids (2 of 2)

- DNA is the genetic material found in ALL living organisms
- RNA is mostly involved in protein synthesis
- DNA never leaves the nucleus of the cell
- DNA and RNA are made up of monomers known as **nucleotides**
- Each nucleotide is made up of: a nitrogenous base, a pentose sugar, and a phosphate group

FIGURE 2.22

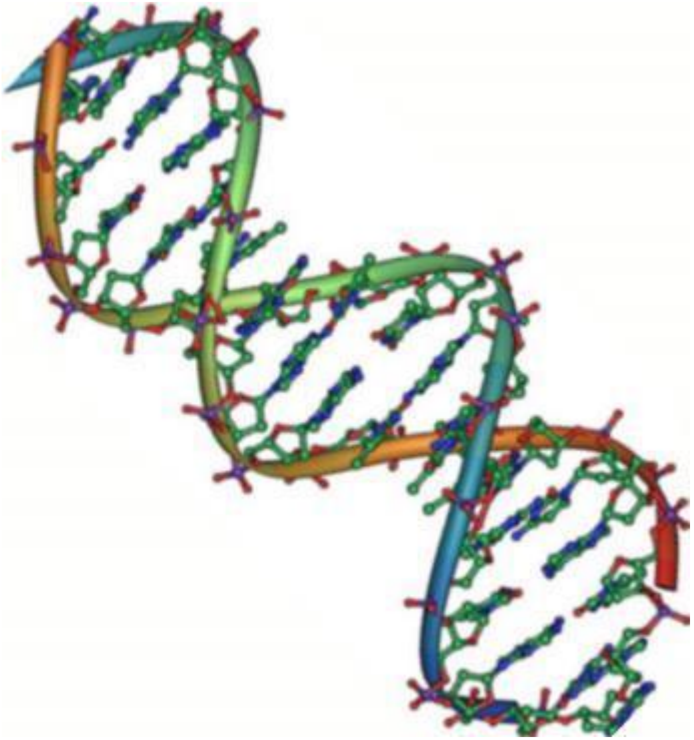


A nucleotide is made up of three components: a nitrogenous base, a pentose sugar, and a phosphate group.

DNA Double-Helical Structure

- DNA has a double-helical structure, composed of two strands (or polymers) of nucleotides
- The strands are formed with bonds between phosphate and sugar groups of adjacent nucleotides
- The two stands are bonded to each other at their bases with hydrogen bonds
- The strands coil about each other along their length, hence the description “double helix”, which means a double spiral

FIGURE 2.23



The double-helix model shows DNA as two parallel strands of intertwining molecules. (credit: Jerome Walker, Dennis Myts)