Chapter 2

Are We Alone in the Universe?
Water, Biochemistry, and Cells

1

Are We Alone in the Universe?

- Mars rock landed on Earth about 13,000 years ago
- This meteorite displayed some characteristics that suggest life: fossils, minerals associated with life, and other complex chemicals
- Is this evidence of life?
- How do we know?

2

2.1 What Does Life Require?
A Definition of Life

- There is no simple definition of life
- How can scientists determine if something is living and what characteristics do all living things possess?

3

A Definition of Life

- Some characteristics of living organisms are shared with some non-living things, like fire:
  - Growth (develop and metamorphose)
  - _____ (chemical processes that occur in the cell)
  - Movement
  - Reproduction
  - Response to external environmental stimuli

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A Definition of Life

- All living organisms…
  - contain a common set of biological molecules
  - can maintain _____ (a roughly constant internal environment)

5

A Definition of Life

- Populations of living organisms…
  - can evolve (change in average physical characteristics over time)
- For a planet to support these characteristics, abundant liquid **water** would have to be available

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The Properties of Water

- One reason why water is important to life is that many substances will dissolve in it
  - _____: what is being dissolved
  - _____: what does the dissolving
  - _____: the solute in the solvent

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The Properties of Water

- Dissolving is conducive to chemical reactions
- Chemical reactions occur when the _____ (starting materials) are converted into _____ (end materials)

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The Properties of Water

- Water (H_2O) consists of two hydrogen atoms and one oxygen atom
- _____ are the smallest units into which a substance can be broken down
- Atoms are composed of _____, _____, and _____

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The Properties of Water

- Water's positively charged protons and neutral neutrons make up the _____
- The negatively charged electrons are outside the nucleus in an electron cloud
- Electrons are attracted to the positively charged nucleus

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The Properties of Water

- A _____ consists of two or more atoms held together by chemical bonds
- Chemical bonds occur between two atoms in a molecule that share electrons
- Water is a molecule made up of two hydrogen atoms and one oxygen atom that are bonded together by shared electrons

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The Properties of Water

- Oxygen is more electronegative (electron-pulling) than hydrogen
- The electrons in water spend more time near the nucleus of the oxygen atom than near the nuclei of the hydrogen atoms
- δ^- symbolizes a partial negative charge
- δ^+ symbolizes a partial negative charge

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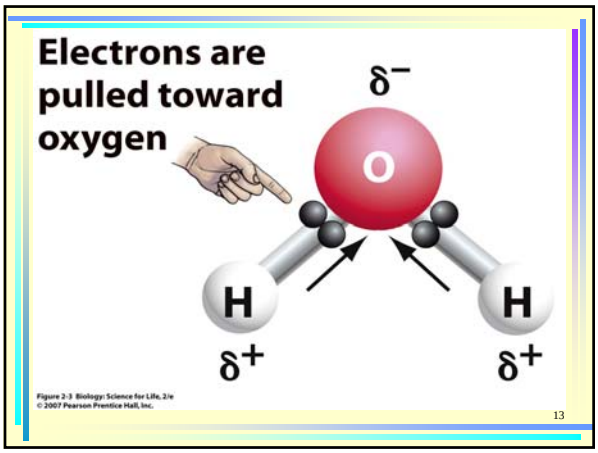
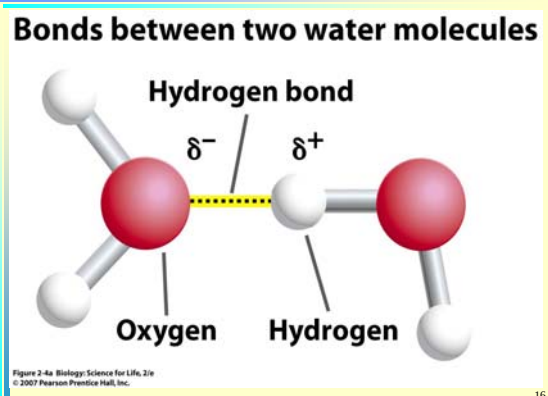


The Properties of Water

- The unequal sharing of electrons makes water a _____ molecule, since different regions (poles) of the molecule have different charges
- When atoms of a molecule carry no charge, they are _____ (do not have differing charges)

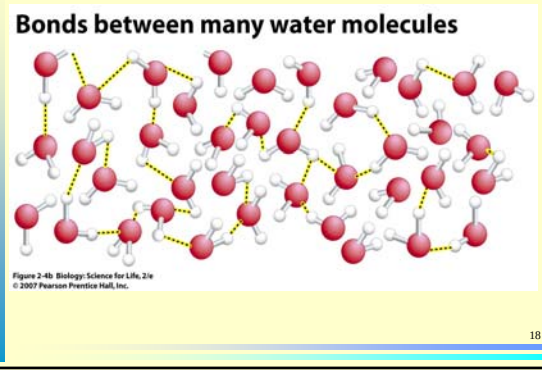
The Properties of Water

- Water molecules tend to orient themselves so that the partially positive charged hydrogen atom of one molecule is near the oxygen atom (with partial negative charge) of another molecule



The Properties of Water

- The weak attraction between the hydrogen atom and the oxygen atom is a _____
- Hydrogen bonding is a type of weak chemical bond occurring between hydrogen and another atom based on the attraction of partial charges for each other



The Properties of Water

- The tendency of water molecules to stick together is called _____
- Cohesion in water is an important property of many biological system – including how many plants use cohesion to transport water from the roots to the leaves

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The Properties of Water

- Salt water is a solution of the salt sodium chloride
- Water is able to dissolve sodium chloride, which is a direct result of its polarity
- Polar molecules are called _____ (water loving) because of their ability to dissolve in water

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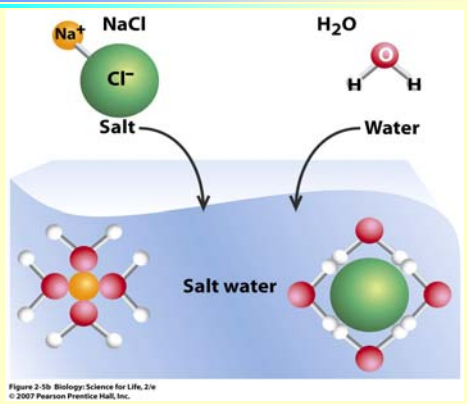

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The Properties of Water

- Salts are produced by the reactions of an _____ (a substance that increases the concentration of hydrogen ions in a solution) with a _____ (a substance that reduces the concentration of hydrogen ions in a solution)
- The _____ is a measure of hydrogen ion concentration

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The Properties of Water

- pH measures the amount of H^+ ions in a solution
- Acids have a lot of H^+ ions in solution
- Bases have less H^+ ions in solution
- The pH scale
  - Low numbers: (1-6) _____
  - 7 is neutral
  - High numbers: (8-14) _____

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The Properties of Water

- Pure water has a pH of 7.0
- Different solutions have different pH values, depending on how many H^+ ions are present

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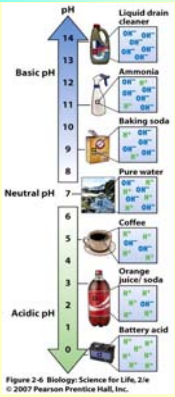

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The Properties of Water

- Nonpolar molecules, such as oil, do not contain charged atoms
- These atoms are called _____ (water hating)

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Organic Chemistry

- All life on Earth is based on the chemistry of the element carbon
- _____ is the chemistry of life
- _____ are chemical substances composed of atoms that cannot be broken down by normal chemical means

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Organic Chemistry

- Elements differ in the number of subatomic particles in their atoms
- All atoms of a particular element have the same number of protons, giving the element its _____
- An atom's _____ is the sum of the number of its protons and neutrons

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Organic Chemistry

- Carbon makes up most of the mass of living organisms
- Carbon is an ideal element as the foundation for life because of its ability to make bonds with up to four other elements
- Carbon has multiple sites for connections that allow carbon-containing molecules to take an almost infinite variety of shapes

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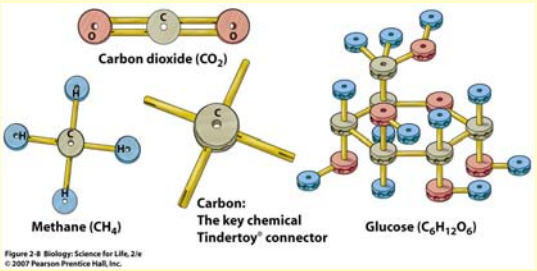

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Organic Chemistry

- The ability of an element to make chemical bonds depends on its electron configuration
- Electrons in the electron cloud exist on different energy levels, or **energy shells**, based on their distance to the nucleus
- The farther out the shell is from the nucleus, the greater the energy

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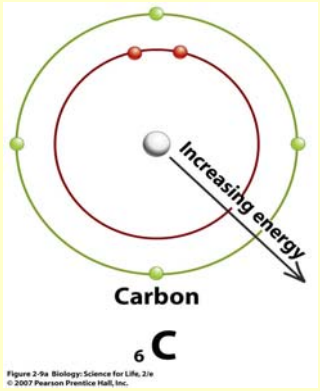

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Organic Chemistry

- Each energy shell can hold a specific maximum number of electrons
- Electrons fill the lowest shell before filling a higher energy-level shell
- Atoms with the same number of electrons in their outermost or _____, exhibit similar chemical behaviors

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Organic Chemistry

- When the valence shell is full of electrons, the atom usually will not form chemical bonds with other atoms
- Atoms that have space in their valence shells, however, will combine with other atoms to form _____

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Organic Chemistry

- Atoms with only 1 or 2 electrons in their valence shell tend to lose electrons and become positively charged ions
- Atoms with 6 or 7 electrons in their valence shell tend to gain electrons and become negatively charged ions
- These two types of atoms often form chemical compounds made up of 2 ions

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Organic Chemistry

- In chemical compounds made up of 2 ions, the electron attraction between the positive and negative ion keeps them together in a loose, _____
- Atoms with 4 or 5 electrons in their valence shells tend to share electrons to complete their valence shells
- This bond type is called a _____

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Organic Chemistry

- Covalent bonds are stronger than ionic bonds
- Covalent bonds will not break apart in water, while ionic bonds will

- Methane (CH_4) is a nonpolar molecule
- Generally, when carbon is bonded to hydrogen (C-H), the bond is nonpolar

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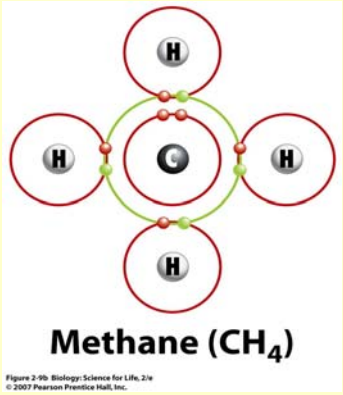

Methane (CH_4)

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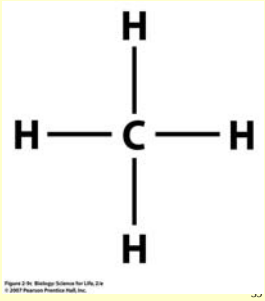
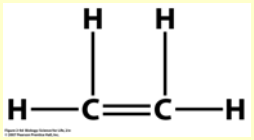
Organic Chemistry

- Carbon atoms are often involved in covalent bonding
- They are symbolized by a short line indicating a shared pair of electrons



Organic Chemistry

- When an element such as carbon enters into bonds involving two *pairs* of shared electrons, this is called a double bond
- A double bond is symbolized by two horizontal lines



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The Structure and Function of Macromolecules

- There are four groups of important macromolecules (large organic molecules) in all living things:
  - _____
  - _____
  - _____
  - _____

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Carbohydrates

- **Carbohydrates** are sugars that are used for energy and structure
- Simple sugars have the ratio of one C to two H to one O (CH_2O)
- An example of this is glucose:

  $C_6H_{12}O_6$

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Carbohydrates

- _____ are simple sugars
  - They are the building blocks of complex carbohydrates
- _____ are two monosaccharides joined together
- _____ are long strings of monosaccharides hooked together

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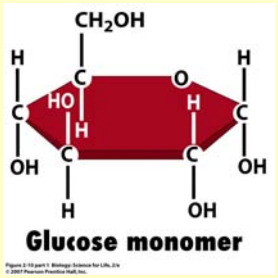
Glucose – A Common Monosaccharide



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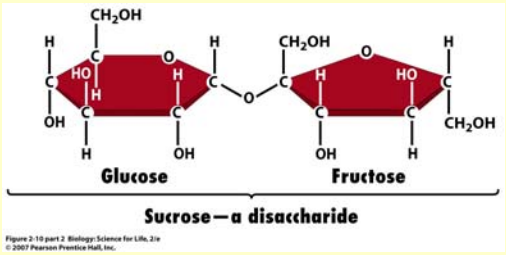
Sucrose (Table Sugar) – a Common Disaccharide Made from Two Monosaccharides



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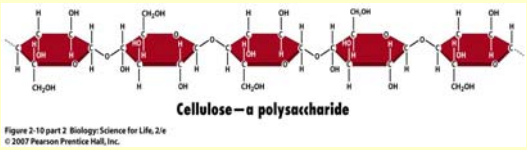
Cellulose – a Polysaccharide Found in Plant Cell Walls as a Structural Component



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Carbohydrates

Carbohydrate summary:

- Carbohydrates include three groups:
  - Monosaccharides – _____
  - Disaccharides – _____
  - Polysaccharides – _____

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Proteins

- **Proteins** are made by connecting different _____ together
- There are 20 amino acids
- There are many combinations of amino acids – so there are many different proteins

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Proteins

- Some proteins are structural
  - Like the proteins found in hair
- Some proteins act as _____
  - Enzymes are proteins that carry out specific chemical reactions in a cell

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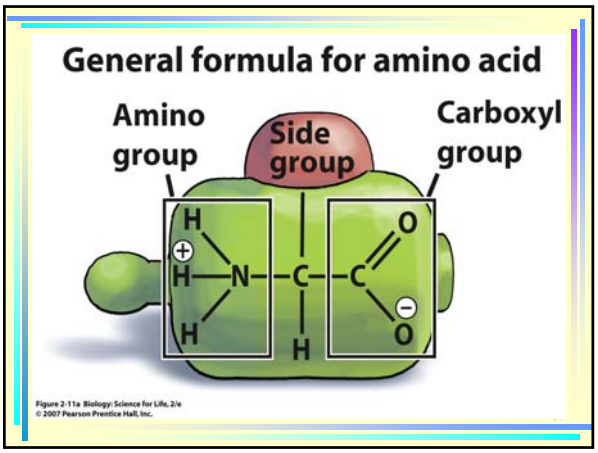

Proteins

- The side group is different for each of the 20 amino acids
- The side groups have different chemical properties – they give the amino acids different properties, like charge or polarity

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Proteins

- Polymers of amino acids are sometimes called polypeptides
- Polypeptides are short chains of amino acids held together by a covalent bond called a _____
- Each different amino acid has a different side group and therefore different behavior
- Long chains of amino acids joined by peptide bonds are called proteins

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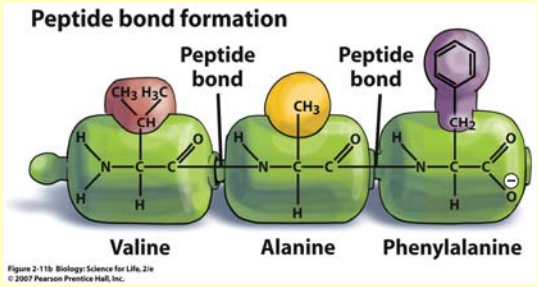

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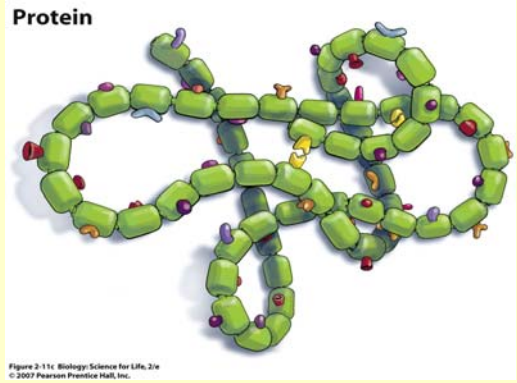

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Proteins

Proteins summary:

- Proteins are:
  - Made of amino acids
  - Can be enzymes or structural
  - Have different properties based on their amino acid content

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Lipids

- **Lipids** are hydrophobic (nonpolar)
- There are three major groups of lipids:
  - _____
  - _____
  - _____

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Lipids

- **Fats** are made of a glycerol molecule and three long _____
- The fatty acid tails are composed of long chains of hydrogen molecules bonded to carbons (lots of non-polar bonds)
- Fats are hydrophobic and store energy

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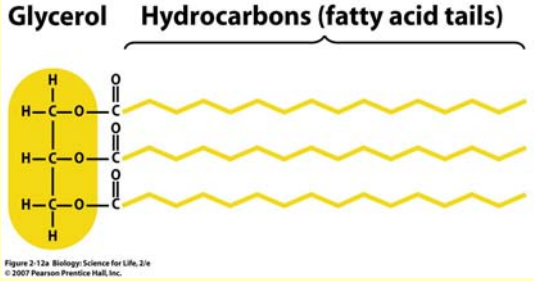
Fat



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Lipids

- _____ have a specific structure – four rings arranged in a specific pattern
- Cholesterol, shown in Fig. 2.12b, is a common steroid in animal cells…

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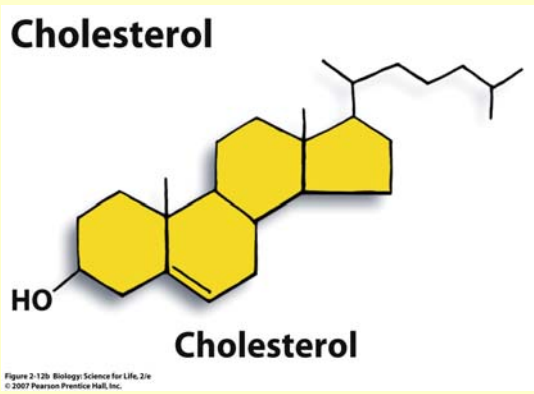
Cholesterol



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Lipids

- _____ are specialized lipids that have a phosphate head, which is hydrophilic, and two fatty acid tails, which are hydrophobic
- Phospholipids are the major component of cell membranes

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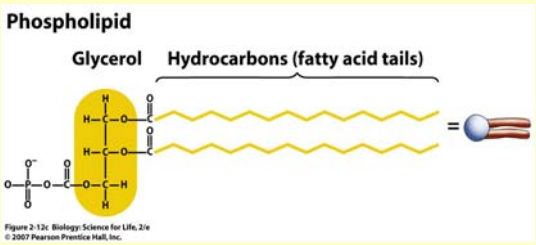

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Lipids

Lipid summary:

- Lipids are:
  - Hydrophobic
  - Fats, steroids, or phospholipids

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Nucleic Acids

- **DNA** (_____) is the molecule that stores genetic information
- Like all **nucleic acids**, DNA is made from long strings of _____
- DNA is made from two strands of nucleotides in a double helix pattern

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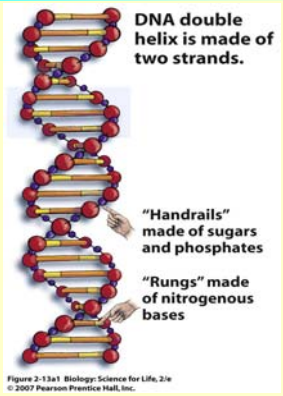

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Nucleic Acids

- Each nucleotide has three parts:
  - A phosphate
  - A sugar (_____ for DNA nucleotides)
  - One of four _____
    - ✓ _____ **(A)**
    - ✓ _____ **(G)**
    - ✓ _____ **(T)**
    - ✓ _____ **(C)**

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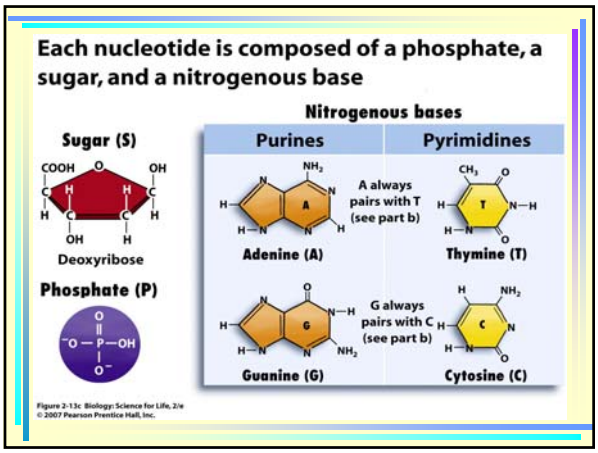

Nucleic Acids

- The nucleotides are hooked together to form long chains
- Each DNA molecule has two strands that are connected by hydrogen bonds between the bases

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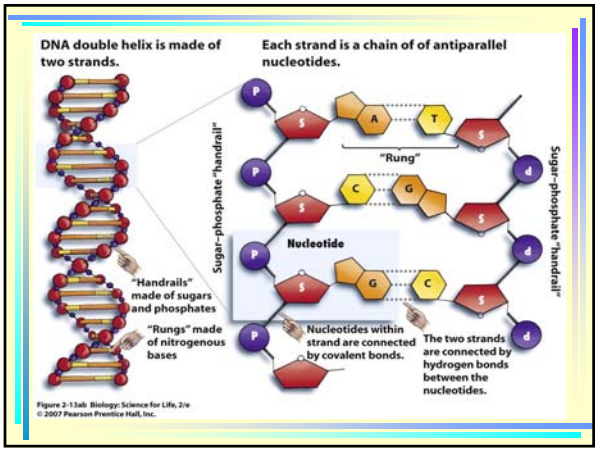

Nucleic Acids

- There is a specific pattern of the bases that connect the two strands
- These are called _____ base pairs and are like the steps (rungs) of a spiral staircase

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Nucleic Acids

- There is a **base-pairing rule**:
  - A always bonds across from T
  - C always bonds across from G
- A and G, called _____, are structures composed of two rings
- C and T are _____ – singled-ringed structures
- A purine always pairs with a pyrimidine and vice versa

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Nucleic Acids

- Because of this, if one strand of DNA is known, the other strand can be deciphered
- If we know that one strand of DNA has the sequence:

  ATCGGCA
- The other side must be:

  TAGCCGT

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Nucleic Acids

- The other parts of the nucleotides – the sugars and phosphates – are connected end to end to form a structure that is like the handrails of a spiral staircase
- Just like your backbone, the **sugar-phosphate backbone** supports and gives shape to the DNA molecule

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Nucleic Acids

Nucleic acids summary:

- DNA carries the genetic information
- DNA is made of nucleotides connected in specific patterns
- DNA is a double helix
- The two complementary strands of DNA are held together by hydrogen bonds

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2.2 Life on Earth

- All living things are made of one or more cells
- There are two major types of cells
  - _____
  - _____

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Prokaryotic and Eukaryotic Cells

- Prokaryotic cells have:
  - _____
  - _____
  - _____
- Prokaryotic cells DO NOT have:
  - _____
  - _____
    (_____)

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Prokaryotic and Eukaryotic Cells

- Bacteria are prokaryotic cells and are much smaller than eukaryotic cells

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Prokaryotic and Eukaryotic Cells

- Eukaryotic cells include animal and plant cells
- Eukaryotic cells have
  - DNA enclosed in a nucleus
  - Compartmentalized specialized structures called _____

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Cell Structure

- All cells are enclosed by a structure called a _____
- The function of the plasma membrane is to control what enters and leaves the cell

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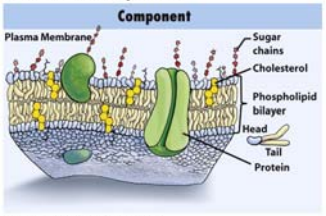
Table 2.4 Cell components

Component	Function
	All cells are surrounded by a plasma membrane. It is composed of a bilayer of phospholipids (tails toward the center), perforated by proteins. Proteins in the bilayer help transport substances across the hydrophobic core of the membrane. Cholesterol in the membranes of animal cells helps maintain the fluidity of the membrane. The sugar chains function as identification tags, marking cells as a particular cell type (liver cell, heart cell, etc.)

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Cell Structure

- All membranes in a cell have similar structural components: phospholipids and proteins
- The phospholipids arrange themselves to form **phospholipid bilayers** with water both on the inside and the outside of the bilayer

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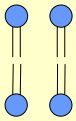
Cell Structure

- Since the phospholipids have two hydrophobic tails at one end and a hydrophilic head at the other end, they tend to gather in a specific arrangement…
  - Two layers with the hydrophilic heads pointing out and the hydrophobic tails on the inside:



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A Fluid Mosaic of Lipids and Proteins

- Because lipids and proteins can move about laterally within the membrane, the membrane is a **fluid mosaic** of lipids and proteins
- Cell membranes are _____
  - Allow some things through but not others

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A Fluid Mosaic of Lipids and Proteins

- Water freely crosses the membranes
  - This can be a problem
    - ✓If too much water enters the cell, it may swell or burst
    - ✓If too much water leaves the cell, it may shrink

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A Fluid Mosaic of Lipids and Proteins

- Some cells (like plant cells and fungal cells) have a _____ outside of the plasma membrane that give the cell structure and protect against water damage
- The cell wall is purely structural and has no control over what enters or leaves the cell

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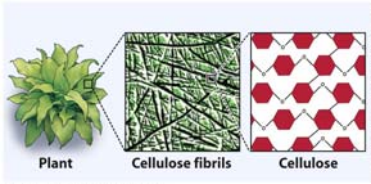
Cell wall



The cell wall is found outside the plasma membrane of plant and bacterial cells. The cell wall in plants is rich in the polysaccharide cellulose. Cellulose is assembled into strong fibrils, and embedded in a matrix.

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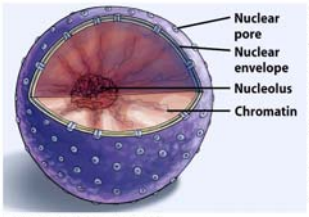
Nucleus

- The nucleus is a membrane structure that encloses the DNA

Nucleus



Eukaryotic cells contain a nucleus. The nucleus is a spherical structure surrounded by two membranes, together called the nuclear envelope. The nuclear envelope is studded with nuclear pores that regulate traffic into and out of the nucleus. Inside the nucleus is chromatin, composed of DNA and proteins. The nucleolus is where ribosomes are produced.

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Cytosol

- The _____ is made up of the watery mixture inside the cell (called the cytosol) and the organelles
- The cytoplasm is contained by the plasma membrane

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Organelles

- Organelles are membrane structures that carry out specific jobs for the cells
- _____ are organelles that carry out the process of aerobic respiration, which converts food energy to ATP, the type of energy a cell can use

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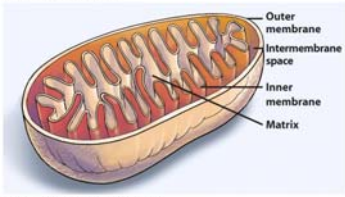
Mitochondrion



Eukaryotic cells contain mitochondria. Mitochondria are energy-producing organelles surrounded by two membranes. The inner and outer mitochondrial membranes are separated by the intermembrane space. The highly convoluted inner membrane carries many of the proteins involved in producing ATP. The matrix of the mitochondrion is the location of many of the reactions of cellular respiration.

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Organelles

- _____ are organelles found in plant cells
  - They can convert sunlight energy into food energy

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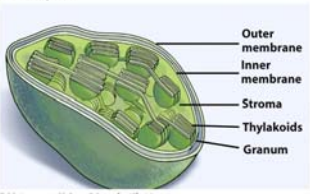
Chloroplast



An important organelle present in plant cells, the chloroplast uses the sun's energy to convert carbon dioxide and water into sugars. Each chloroplast has an outer membrane, an inner membrane, a liquid material called the stroma, and a network of flattened membranes called thylakoids that stack on one another to form structures called grana (singular: granum). Chloroplasts also contain pigment molecules that give green parts of plants their color.

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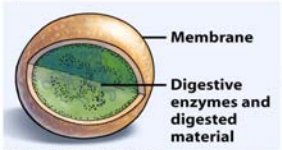
92

Organelles

- _____ are small membrane sacs that contain digestive enzymes that break down food and other materials for the cell

Lysosome



A lysosome is a membrane-enclosed sac of digestive enzymes that degrade proteins, carbohydrates, and fats. Lysosomes roam around the cell, and engulf targeted molecules and organelles for recycling.

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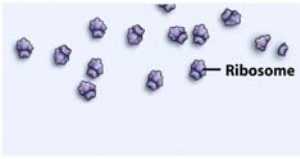
Organelles

- _____ are small structures that act like workbenches
- Proteins are assembled at the ribosomes
- Some ribosomes are free in the cytoplasm and some are bound to a structure called the endoplasmic reticulum

94

Ribosomes



Ribosomes are found in eukaryotic and prokaryotic cells. Ribosomes are built in the nucleus and shipped out through nuclear pores to the cytoplasm, where they are used as work benches for protein synthesis. They can be found floating in the cytoplasm or tethered to the ER.

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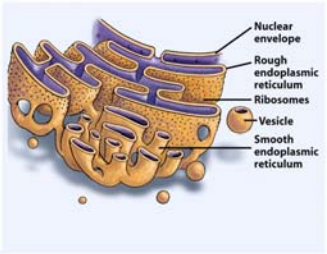
95

Organelles

- Many proteins are assembled on the membranes of the _____ and modified and sorted in a membranous structure called the _____

96

Endoplasmic Reticulum (ER)



The ER is a large network of membranes that begins at the nuclear envelope and extends into the cytoplasm. ER with ribosomes attached is called rough ER. Proteins synthesized on rough ER will be secreted from the cell or will become part of the plasma membrane. ER without ribosomes attached is called smooth ER. The function of the smooth ER depends on cell type but includes tasks such as detoxifying harmful substances and synthesizing lipids. Vesicles are pinched-off pieces of membrane that transport substances to the Golgi apparatus or plasma membrane.

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Golgi Apparatus

The Golgi apparatus is a stack of membranous sacs. Vesicles from the ER fuse with the Golgi apparatus and empty their protein contents. The proteins are then modified, sorted, and sent to the correct destination in new transport vesicles that bud off from the sacs.

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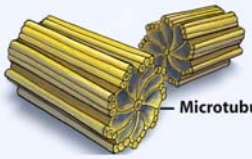
98

Organelles

- Some subcellular structures help cells divide and maintain their shape
- _____ are involved in moving genetic material around when a cell divides

99

Centrioles



Centrioles are barrel-shaped rings composed of nine microtubule triplets. Microtubules help move chromosomes around when a cell divides. Centrioles are involved in microtubule formation during cell division and the formation of cilia and flagella.

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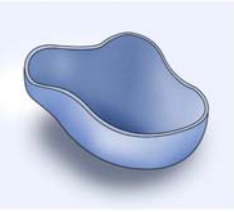
100

Organelles

- Some subcellular structures are found in certain types of cells only
- In addition to cell walls, the plant cell also has a _____, a membrane sac
  - Contains water soluble materials like sugars and pigments
  - Vacuoles can also help control water pressure and help to keep the plants rigid and vertical

101

Central vacuole



Plant cells also have membrane-bound, fluid filled vacuoles that can occupy as much as 90 percent of a cell's total volume. The plant vacuole contains a variety of dissolved molecules, including sugars and pigments that give color to flowers and leaves. Vacuoles also function to maintain pressure inside individual cells which helps support the upright plant.

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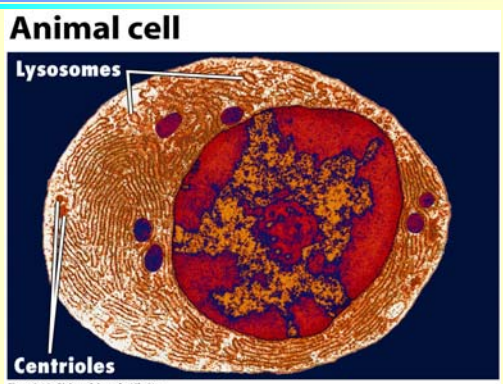
Organelles

- Differences in organelles in animal and plant cells can be seen with proper magnification…

103



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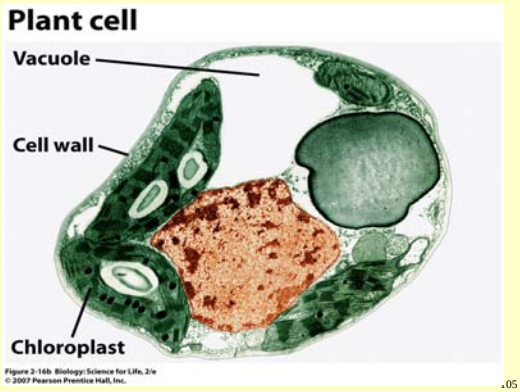


105

The Tree of Life and Evolutionary Theory

- The number of different types of living organisms, or **species**, on Earth today is probably around 10 million, although some biologists believe there may be 100 million

106

Theory of Evolution

- While the diversity of species is great, so are the number of similarities among all living things:
  - Basic biochemistry: carbohydrates, lipids, proteins, and nucleic acids
  - All consist of cells surrounded by a plasma membrane
  - All eukaryotic cells contain nearly the same suite of organelles

107

Theory of Evolution

- The best explanation for these shared characteristics is called “the unity of life”
- Biologists believe all living organisms had a common ancestor 4 billion years ago

108

Theory of Evolution

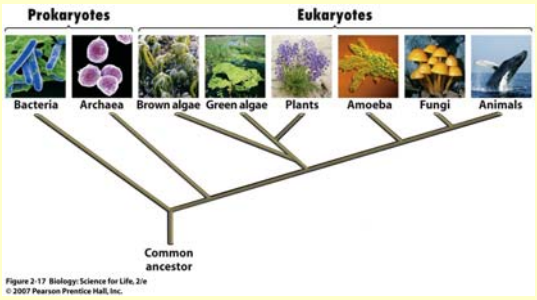
- Differences in species came about through responses to environmental changes (natural selection) and to chance
- These ideas are the essence of the **theory of evolution**, which underlies the entire science of biology

109

Theory of Evolution

- Modern organisms can be arranged on a "tree of life" that reflects their basic unity and relationships
- The common ancestor is the trunk of the tree of life
- Living organisms can be grouped into three large groups: 2 prokaryotic (*Bacteria* and *Archaea*) and 1 eukaryotic

110



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