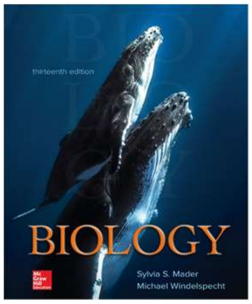


Biology

Sylvia S. Mader
Michael Windelspecht

Chapter 2
Basic Chemistry
Lecture Outline

See separate FlexArt PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.

Search for Life on Other Planets

Precursors to life, methane, ammonia, and hydrocarbons have been found on Titan, a moon of Saturn.

NASA announced a new mission to Europa, a moon of Jupiter, to continue to search for elements that support life.

The finding of water and organic materials on other planets will help us better understand how life originated on Earth.

Outline

2.1 Chemical Elements

2.2 Molecules and Compounds

2.3 Chemistry of Water

2.4 Acids and Bases

2.1 Chemical Elements

Matter refers to anything that has mass and occupies space.

Matter exists in four states: solid, liquid, gas, or plasma.

All matter (both living and nonliving) is composed of basic substances called elements.

Elements

An **element** is a substance that cannot be broken down into substances with different properties; composed of one type of atom.

Ninety-two elements are naturally occurring.

Six elements make up 95% of the body weight of organisms (acronym CHNOPS):

- Carbon
- Hydrogen
- Nitrogen
- Oxygen
- Phosphorus
- Sulfur

Composition of Earth's Crust and Its Organisms

© Design Pics/Don Hammond RF

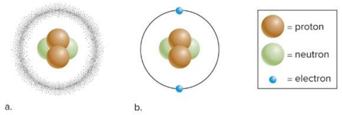
Jump to Composition of Earth's Crust and Its Organisms Long Description

Atoms (1)

An **atom** is the smallest part of an element that displays the property of the element.

- An element and its atoms share the same name.
- Composed of subatomic particles: protons, neutrons, electrons
- Central nucleus
  - **Protons** – positively charged, 1 amu
  - **Neutrons** – no charge, 1 amu
- Orbiting clouds around nucleus (electron shells)
  - **Electrons** – negatively charged, very low mass—negligible in calculations

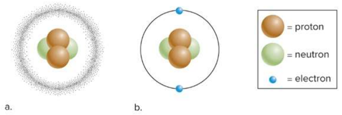
Atoms (2)



Particle	Subatomic Particles Electric Charge	Subatomic Particles Atomic Mass Unit (AMU)	Location
Proton	+1	1	Nucleus
Neutron	0	1	Nucleus
Electron	−1	0	Electron shell

c.

Atoms (3)



Particle	Subatomic Particles Electric Charge	Subatomic Particles Atomic Mass Unit (AMU)	Location
Proton	+1	1	Nucleus
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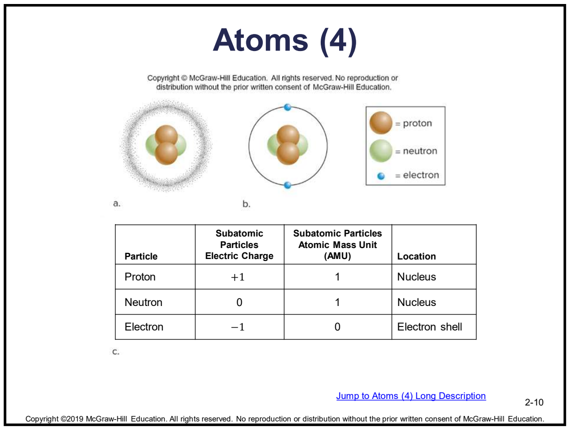
c.

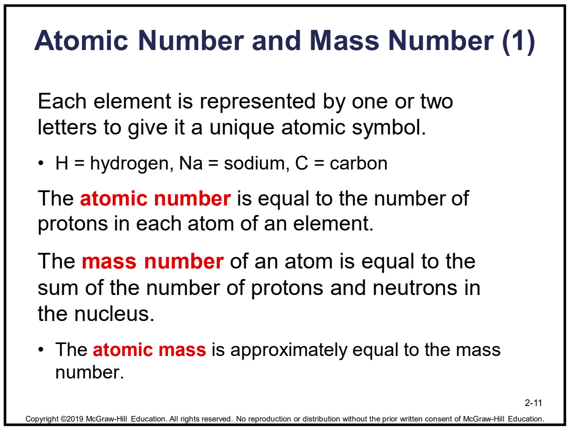


Atoms (4)

Particle	Subatomic Particles Electric Charge	Subatomic Particles Atomic Mass Unit (AMU)	Location
Proton	+1	1	Nucleus
Neutron	0	1	Nucleus
Electron	−1	0	Electron shell

c.

Jump to Atoms (4) Long Description



Atomic Number and Mass Number (1)

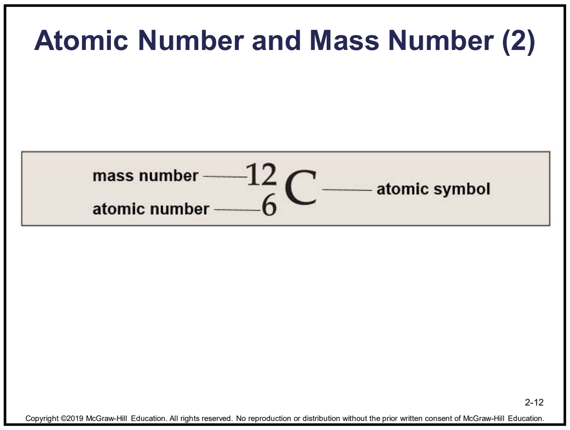
Each element is represented by one or two letters to give it a unique atomic symbol.

- H = hydrogen, Na = sodium, C = carbon

The **atomic number** is equal to the number of protons in each atom of an element.

The **mass number** of an atom is equal to the sum of the number of protons and neutrons in the nucleus.

- The **atomic mass** is approximately equal to the mass number.



Atomic Number and Mass Number (2)

$^{12}_{6}\mathrm{C}$

Periodic Table

Atoms of an element are arranged horizontally by increasing atomic number in rows called periods.

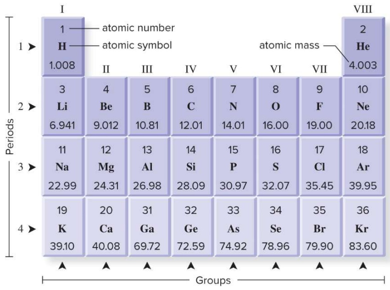
Atoms of an element arranged in vertical columns are called groups.

- Atoms within the same group share the same chemical binding characteristics.
  - Group VIII are the noble gases and are inert.

Atoms shown in the periodic table are electrically neutral.

- Therefore, the atomic number tells you the number of electrons as well as the number of protons.

A Portion of the Periodic Table



	I	II	III	IV	V	VI	VII	VIII
1 ➤	1 H 1.008							2 He 4.003
2 ➤	3 Li 6.941	4 Be 9.012	5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3 ➤	11 Na 22.99	12 Mg 24.31	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4 ➤	19 K 39.10	20 Ca 40.08	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.60

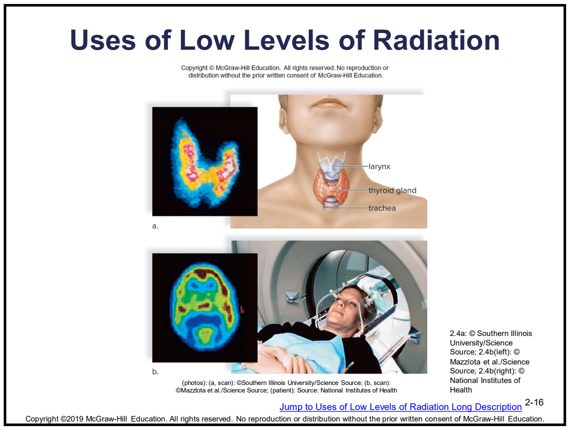
Jump to A Portion of the Periodic Table Long Description

Isotopes

Isotopes are atoms of the same element that differ in the number of neutrons (and therefore different atomic masses).

- Some isotopes spontaneously decay.
  - Radioactive isotopes give off energy in the form of rays and subatomic particles.
  - They can be helpful or harmful.
  - Carbon 14 is an example of a radioactive isotope.
    - Has been used to examine reactions in photosynthesis

${}^{12}_{6}\mathrm{C}$	${}^{13}_{6}\mathrm{C}$	${}^{14}_{6}\mathrm{C}$
Carbon 12	**Carbon 13**	**Carbon 14**

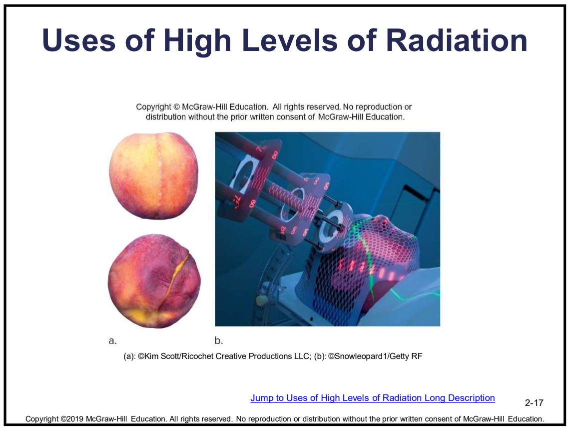


Uses of Low Levels of Radiation

(photos): (a, scan): ©Southern Illinois University/Science Source; (b, scan): ©Mazzlota et al./Science Source; (patient): Source: National Institutes of Health

2.4a: © Southern Illinois University/Science Source; 2.4b(left): © Mazzlota et al./Science Source; 2.4b(right): © National Institutes of Health

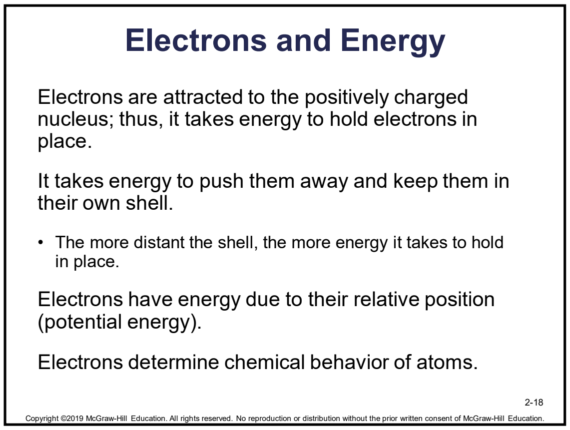
Jump to Uses of Low Levels of Radiation Long Description



Uses of High Levels of Radiation

(a): ©Kim Scott/Ricochet Creative Productions LLC; (b): ©Snowleopard1/Getty RF

Jump to Uses of High Levels of Radiation Long Description



Electrons and Energy

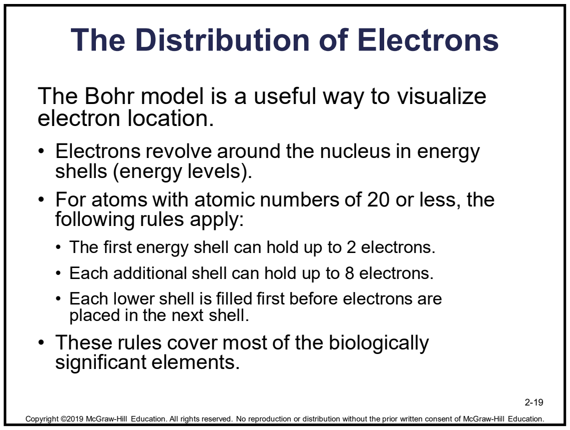
Electrons are attracted to the positively charged nucleus; thus, it takes energy to hold electrons in place.

It takes energy to push them away and keep them in their own shell.

- The more distant the shell, the more energy it takes to hold in place.

Electrons have energy due to their relative position (potential energy).

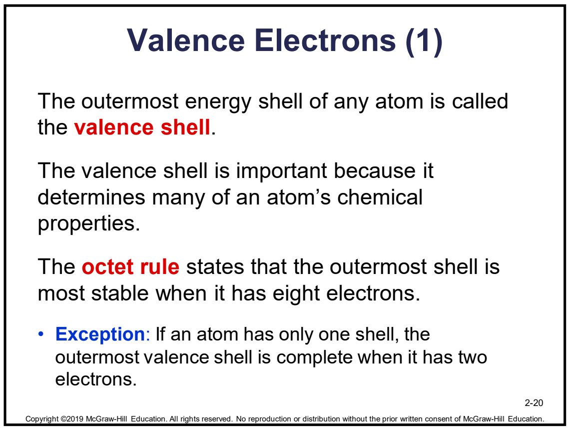
Electrons determine chemical behavior of atoms.



The Distribution of Electrons

The Bohr model is a useful way to visualize electron location.

- Electrons revolve around the nucleus in energy shells (energy levels).
- For atoms with atomic numbers of 20 or less, the following rules apply:
  - The first energy shell can hold up to 2 electrons.
  - Each additional shell can hold up to 8 electrons.
  - Each lower shell is filled first before electrons are placed in the next shell.
- These rules cover most of the biologically significant elements.



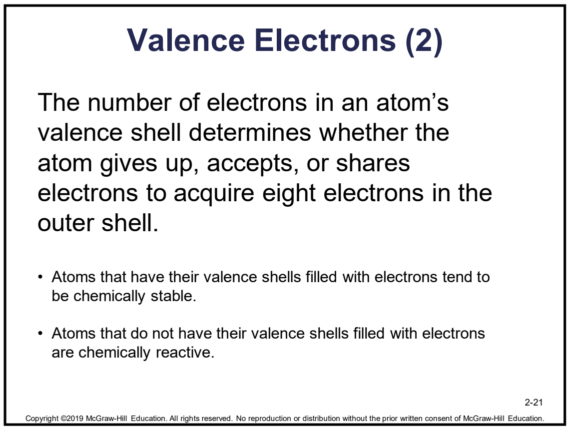
Valence Electrons (1)

The outermost energy shell of any atom is called the **valence shell**.

The valence shell is important because it determines many of an atom’s chemical properties.

The **octet rule** states that the outermost shell is most stable when it has eight electrons.

- **Exception**: If an atom has only one shell, the outermost valence shell is complete when it has two electrons.

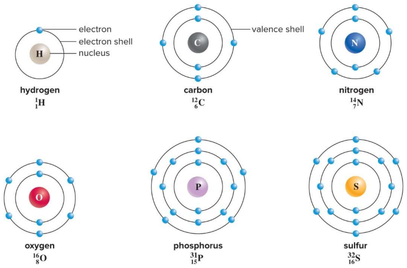


Valence Electrons (2)

The number of electrons in an atom’s valence shell determines whether the atom gives up, accepts, or shares electrons to acquire eight electrons in the outer shell.

- Atoms that have their valence shells filled with electrons tend to be chemically stable.
- Atoms that do not have their valence shells filled with electrons are chemically reactive.

Bohr Models of Atoms



Jump to Bohr Models of Atoms Long Description

2.2 Molecules and Compounds

A **molecule** is two or more elements bonded together.

- It is the smallest part of a compound that retains its chemical properties.
  - $NaCl$, H_2, etc.

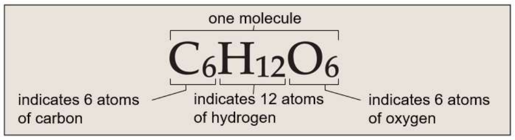
A **compound** is a molecule containing at least two different elements bonded together.

- CO_2, H_2O, $C_6H_{12}O_6$, etc.

A **formula** tells the number of each kind of atom in a molecule.

- $C_6H_{12}O_6$ means there is one molecule of glucose containing 6C,12H, 6O.

Compounds and Molecules



one molecule

$C_6H_{12}O_6$

indicates 6 atoms of carbon

indicates 12 atoms of hydrogen

indicates 6 atoms of oxygen

Chemical Bonding

Bonds that exist between atoms in molecules contain energy.

Bonds between atoms are caused by the interactions between electrons in outermost energy shells.

The process of bond formation is called a **chemical reaction**.

Types of Bonds: Ionic Bonding

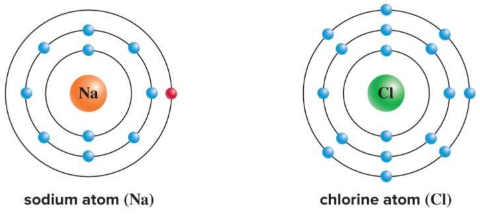
An **ion** is an atom that has lost or gained an electron.

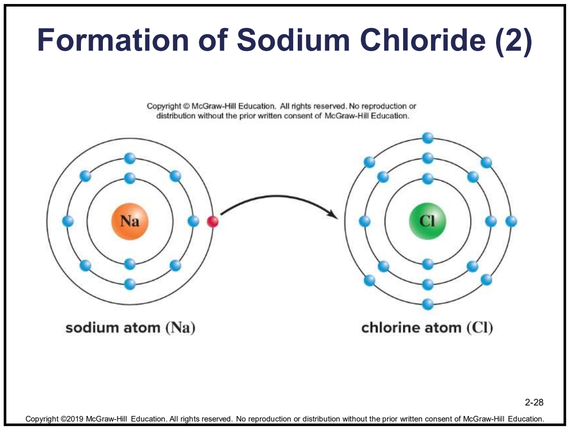
An **ionic bond** forms when electrons are transferred from one atom to another atom and the oppositely charged ions are attracted to each other.

- Example: formation of sodium chloride

Salts are solid substances that usually separate and exist as individual ions in water.

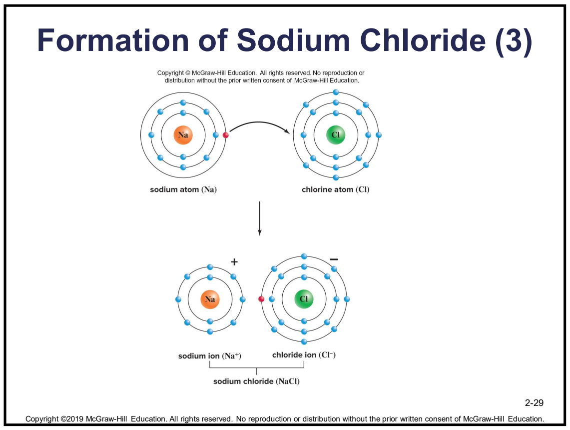
Formation of Sodium Chloride (1)





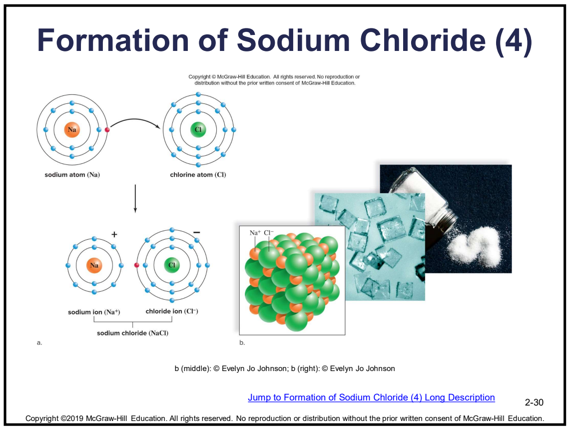
Formation of Sodium Chloride (2)

2-28



Formation of Sodium Chloride (3)

2-29



Formation of Sodium Chloride (4)

b (middle): © Evelyn Jo Johnson; b (right): © Evelyn Jo Johnson

Jump to Formation of Sodium Chloride (4) Long Description

2-30

Types of Bonds: Covalent Bonds (1)

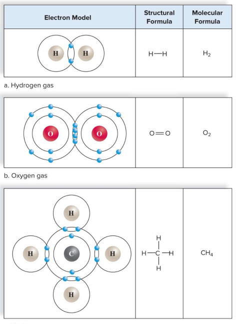
Covalent bonds result when two atoms share electrons so each atom has an octet of electrons in the outer shell.

- Note: In the case of hydrogen, the outer energy shell is complete when it contains two electrons.

In a **nonpolar covalent bond** electrons are **shared equally** between atoms.

- Examples: hydrogen gas, oxygen gas, methane

Covalently Bonded Molecules



a. Hydrogen gas

b. Oxygen gas

c. Methane

Jump to Covalently Bonded Molecules Long Description

Types of Bonds: Covalent Bonds (2)

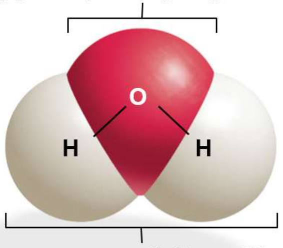
In a **polar covalent bond** electrons are **shared unequally**.

- Example: water

Electronegativity is the ability of an atom to attract electrons towards itself in a chemical bond.

- In water, the oxygen atom is more electronegative than the hydrogen atoms and the bonds are therefore polar.

Types of Bonds: Covalent Bonds (3)



Oxygen is partially negative (δ^-)

Hydrogens are partially positive (δ^+)

2.3 Chemistry of Water (1)

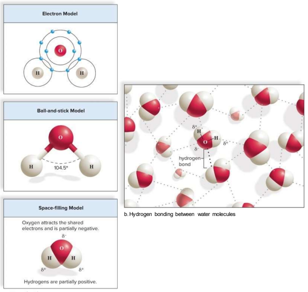
Water is a polar molecule.

- The shape of a water molecule and its polarity make hydrogen bonding possible.
  - This is an example of a structure-function relationship.

A **hydrogen bond** is a weak attraction between a slightly positive hydrogen atom and a slightly negative atom.

- It can occur between atoms of different molecules or within the same molecule.
- A single hydrogen bond is easily broken, while multiple hydrogen bonds are collectively quite strong.
- It helps to maintain the proper structure and function of complex molecules such as proteins and DNA.

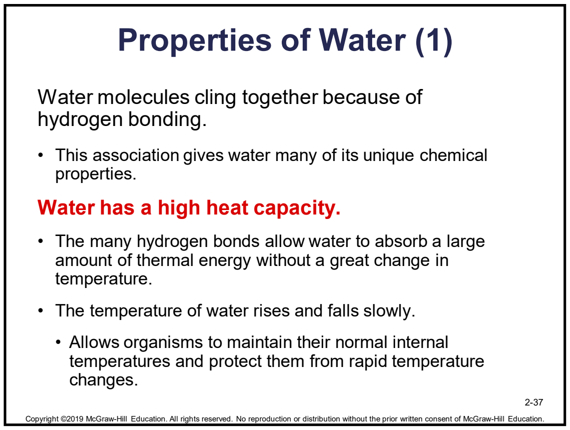
2.3 Chemistry of Water (2)



b. Hydrogen bonding between water molecules

a. Water (H_2O)

Jump to 2.3 Chemistry of Water (2) Long Description



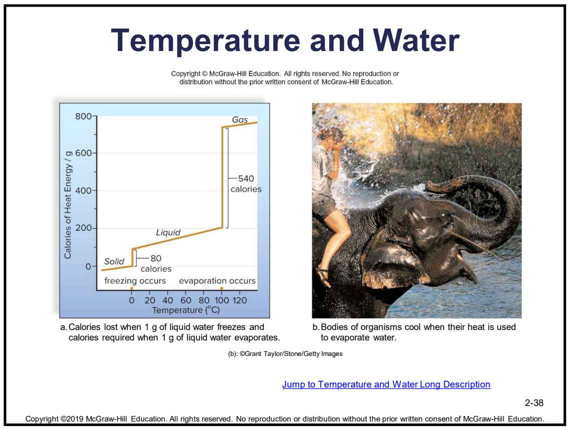
Properties of Water (1)

Water molecules cling together because of hydrogen bonding.

- This association gives water many of its unique chemical properties.

Water has a high heat capacity.

- The many hydrogen bonds allow water to absorb a large amount of thermal energy without a great change in temperature.
- The temperature of water rises and falls slowly.
  - Allows organisms to maintain their normal internal temperatures and protect them from rapid temperature changes.



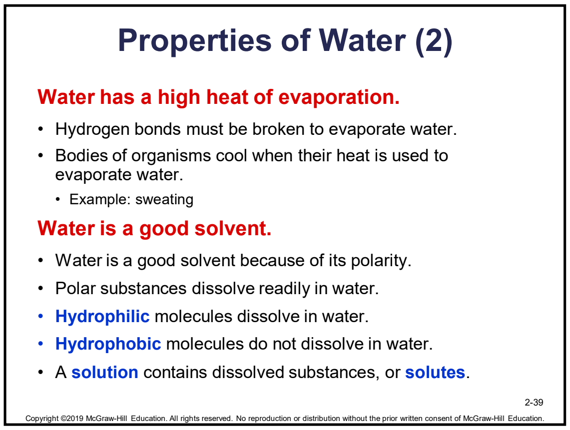
Temperature and Water

a. Calories lost when 1 g of liquid water freezes and calories required when 1 g of liquid water evaporates.

b. Bodies of organisms cool when their heat is used to evaporate water.

(b): ©Grant Taylor/Stone/Getty Images

Jump to Temperature and Water Long Description



Properties of Water (2)

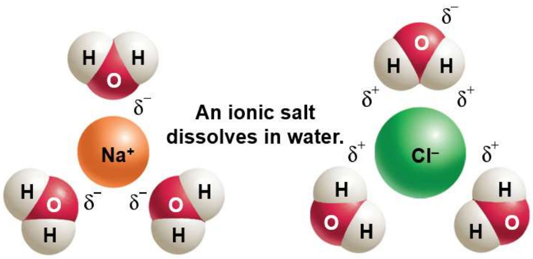
Water has a high heat of evaporation.

- Hydrogen bonds must be broken to evaporate water.
- Bodies of organisms cool when their heat is used to evaporate water.
  - Example: sweating

Water is a good solvent.

- Water is a good solvent because of its polarity.
- Polar substances dissolve readily in water.
- **Hydrophilic** molecules dissolve in water.
- **Hydrophobic** molecules do not dissolve in water.
- A **solution** contains dissolved substances, or **solutes**.

Water as a Solvent

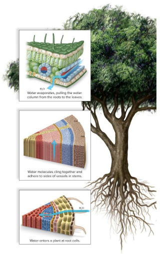


Properties of Water (3)

Water molecules are cohesive and adhesive.

- **Cohesion** is the ability of water molecules to cling to each other due to hydrogen bonding.
  - Water flows freely
  - Surface tension
- **Adhesion** is the ability of water molecules to cling to other polar surfaces.
  - Due to water's polarity
  - Capillary action
- Cohesion and adhesion account for water transport in plants as well as transport in blood vessels.

Water as a Transport Medium



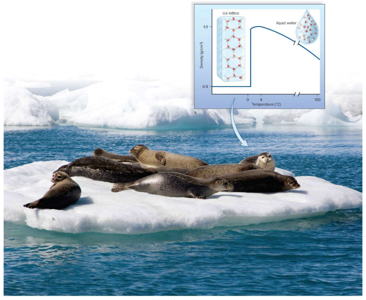
Jump to Water as a Transport Medium Long Description

Properties of Water (4)

Frozen water (ice) is less dense than liquid water.

- At temperatures below 4 degree Celsius, hydrogen bonds between water molecules become more rigid but also more open.
- Water expands as it reaches 0 degree Celsius and freezes.
- Ice floats on liquid water.
  - Without this property, ice would sink and oceans would freeze solid, instead of from the top down.
  - Ice acts as an insulator on top of a frozen body of water.

Ice Is Less Dense than Water



(photo): ©Stockcam/Getty RF

Jump to Ice Is Less Dense than Water Long Description

2.4 Acids and Bases

pH is a measure of hydrogen ion concentration in a solution.

When water ionizes or dissociates, it releases an equal number of hydrogen (H^+) ions and hydroxide (OH^-) ions.

Acids are substances that dissociate in water, releasing hydrogen ions.

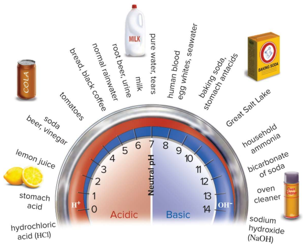
Bases are substances that either take up hydrogen ions (H^+) or release hydroxide ions (OH^-).

The pH Scale (1)

The **pH scale** is used to indicate the acidity or basicity (alkalinity) of a solution.

- Values range from 0 to 14
  - 0 to <7 = Acidic
  - 7 = Neutral
  - >7 to 14 = Basic (or alkaline)
- Logarithmic scale
  - Each unit change in pH represents a 10-fold change in H^+ concentration.
  - pH of 4 is 10× as acidic as pH of 5
  - pH of 10 is 100× more basic than pH of 8

The pH Scale (2)



Jump to The pH Scale (2) Long Description

Buffers and pH

A **buffer** is a chemical or a combination of chemicals that keeps pH within normal limits.

Health of organisms requires maintaining the pH of body fluids within narrow limits.

- Human blood is normally pH 7.4 (slightly basic).
  - If blood pH drops below 7.0, acidosis results.
  - If blood pH rises above 7.8, alkalosis results.
  - Both are life-threatening situations.
- The body has built-in mechanisms to prevent pH changes.
  - Example: carbonic acid buffer dissociates and re-forms to reduce changes in pH