

## GS106 Chemical Bonds and Chemistry of Water

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### I. Introduction

#### A. Hierarchy of chemical substances

1. atoms of elements - smallest particles of matter with unique physical and chemical properties, that still retain the properties of matter
  - a. e.g. hydrogen, oxygen
2. Isotopes of elements
  - a. isotopes of a given element are represented by atoms with the same atomic number, but different numbers of neutrons
  - b. e.g. Oxygen Isotopes
    - (1)  $^{18}\text{O}$  - less common variety of oxygen, 8 protons + 10 neutrons
    - (2)  $^{16}\text{O}$  - most common variety of oxygen, 8 protons + 8 neutrons
3. Ion - charged atomic particle
  - a. atoms that gain or lose electrons, result in net positive or negative charge
    - (1) the number of protons remains unchanged, but the number of electrons changes to result in net charge
  - b. cation - positively charged atoms that lose electrons
    - (1) e.g.  $\text{H}^{+1}$  hydrogen that has lost 1 electron
  - c. anion - negatively charged atoms that gain electrons
    - (1) e.g.  $^{16}\text{O}^{-2}$  Oxygen 16 ion that has gained 2 electrons, 8 protons
  - d. Complex cations and anions - ions comprised of more than 1 element, "compound ions"
    - (1) e.g.  $\text{HCO}_3^-$  bicarbonate anion

### Common Dissolved Ions Found in Natural Waters

$\text{Na}^+$	sodium	$\text{Mg}^{+2}$	magnesium	$\text{Ca}^{+2}$	calcium	$\text{K}^+$	potassium
$\text{Sr}^{+2}$	strontium	$\text{Cl}^-$	chloride	$\text{SO}_4^{-2}$	sulfate		
$\text{Br}^-$	bromide	$\text{Fe}^{+2}$	iron	$\text{Fe}^{+3}$	iron	$\text{HCO}_3^-$	bicarbonate

4. molecules of 1 or more atoms of elements
  - a. e.g. water molecule ( $\text{H}_2\text{O}$ )
  - b. e.g.  $2 \text{H}^{+1} + \text{O}^{-2} = \text{H}_2\text{O}$
5. compounds of elements bonded together
  - a. physical and chemical properties of compounds differ from that of the constituent atoms of elements
  - b. e.g. sodium chloride ( $\text{NaCl}$ )
6. mixtures of unbonded elements and compounds
  - a. e.g. mixture of salt and sugar

## B. Chemical Bonds

1. Atomic Forces that hold atoms together in molecules, or ions in crystals
  - a. atoms form bonds with other atoms to form compounds
  - b. all physical properties of chemical compounds are controlled by the atomic arrangement and bonding characteristics of the component atoms
  - c. bonding between atoms is largely controlled by the electron configuration of the outermost (valence) electron shell
    - (1) bond style is controlled by octet rule - tendency for atoms to attain a stable 8-electron configuration in the outermost valence shell
      - (a) exception to octet rule = hydrogen - tendency towards 2 electrons in outermost shell
    - (2) Note: for the Noble Gases on the far-right column of the periodic chart, the outmost valence shell is full, thus the noble gases are inert (non-reactive)

example of chemical bonding and octet rule:  $\text{Na}^{+1} + \text{Cl}^{-1} \longrightarrow \text{NaCl}$

e.g. NaCl - Na has an atomic no. of 11, and thus contains 11 electrons around the nucleus (2 in first energy level, 8 in second energy level, and 1 in valence or outer energy level); Cl has an atomic no. of 17 and thus 17 electrons about its nucleus (2 in first level, 8 in second level, 7 in outer level). Thus Na needs to lose 1 electron from outer shell to obtain stable configuration, and Cl needs to gain 1 electron in outer shell to obtain stable configuration....tendency for ionic bonding to form NaCl.

## 2. Lewis Electron Dot Models of Atoms

- a. electron dot models represent the configuration of the valence electron shell, or outermost shell
  - (1) outershell electrons are filled 1 by 1 around the nucleus, and then paired to form a "square dance" set



**In-Class Exercise - Using the periodic chart, write the lewis electron dot models for the following atoms:**

K            H            C            Si            Ca            F            O

- b. representing chemical reactions with dot models



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**In-Class Exercise:** write the electron dot models for H and Cl, show the dot-model reaction that forms hydrochloric acid (H + Cl ----- HCl)

**Write the electron dot model reaction of Mg + O to form MgO**

**Write the electron dot model reaction for 2 K + O to form K<sub>2</sub>O**

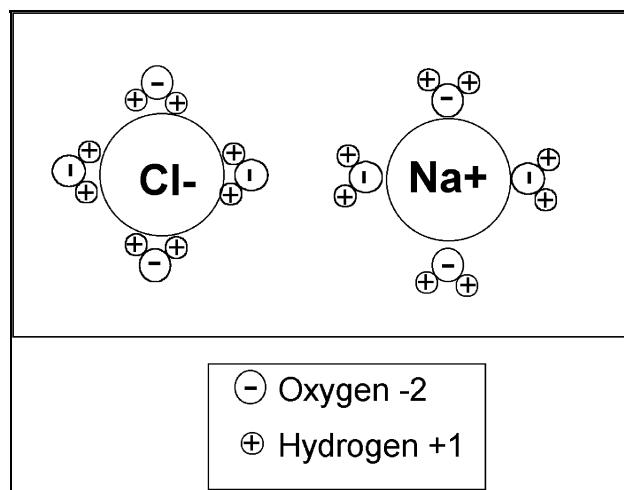
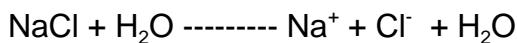
**Write a chemical reaction calcium + choride to form calcim chloride**

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3. Bond Types
  - a. ionic bonds - transfer of electrons between atoms
  - b. covalent bonds - sharing of electrons between atoms
  - c. Metallic bonding - extreme case of electron sharing in which electrons move freely from atom to atom. Metallic bonding accounts for the high electrical conductivity of metals and other special properties.

C. Aqueous Solutions

1. water-based solutions - homogeneous mixture of two or more substances
  - a. homogeneous - mixing throughout with individual ions separated apart from others
2. solute - the substance being dissolved
3. solvent - the substance doing the dissolving
  - a. water is associated with a high degree of dissolving power
4. e.g. saline solution - adding salt to water
  - a. water - dipolar molecule with + and - ends to the molecule
  - b. a "sheath of hydration surrounds the sodium and chlorine atoms to force them apart electrostatically"



- D. Measuring concentrations of solutes in aqueous solutions
1. concentration - measurement of the quantity of solute in a given quantity of solvent (or solution)
    - a. Mass Percent =  $(\text{mass solute} / \text{total mass solution}) * 100\%$

**E.g. if 5 g of NaCl is dissolved in 95 g of water, what is the mass percent of sodium chloride in the solution?**

**conversion factors for mass: 1 gram = 1000 mg, 1 kg = 1000 g, 1 gram = 1,000,000 micrograms**

- (1) percent = "parts per hundred" (%)
- b. Parts per Thousand (o/oo) = grams of solute / liter of water

**Determine the concentration in ppt for a solution of 200 gram dissolved in 2 liters of water?**

**Determine the concentration in ppt for a solution of 2000 mg dissolved in 1 liter of water?**

- c. Parts per Million = milligrams of solute / liter of water

**Determine the concentration in ppm for a solution 20 mg of salt per liter of water?**

**What about 20 kg of salt per liter of water?**

d. Parts per Billion = micrograms of solute / liter of water

**Determine the concentration in ppb for a solution of 200 micrograms of salt dissolved in 3 liters of water?**

**Determine the concentration in ppb for a solution 200 grams of salt dissolved in 4 liters of water?**

e. Molarity = amount of solute in moles / volume of solution in liters

(1) Mole - the amount of a substance that contains exactly the number of elementary entities as there are in carbon-12 atoms in exactly 12 g of carbon-12

(a) Avagadro's number - a constant, the number of carbon-12 atoms contained in 12 g of carbon

$1 \text{ mol } {}^{12}\text{C} = 6.022 \times 10^{23}$   ${}^{12}\text{C}$  atoms = 12.0 gram = the atomic mass of 1 atom of  ${}^{12}\text{C}$

$1 \text{ mol } {}^{16}\text{O} = 6.022 \times 10^{23}$   ${}^{16}\text{O}$  atoms = 15.99 grams = the atomic mass of 1 atom of  ${}^{16}\text{O}$

$1 \text{ mol of NaCl} = 6.022 \times 10^{23}$  NaCl molecules = atomic mass of Na + atomic mass of Cl =  
 $23 + 35 = 58$  grams = the formula weight of 1 molecule of NaCl

**Question: how many atoms are contained in 1 mole of chlorine-35? What is the mass of 1 mole of chlorine 35?**

**Question: if you had 24 grams of  ${}^{12}\text{C}$ , how many moles would you have?**

**Question: if you had 48 grams of  ${}^{16}\text{O}$ , how many moles would you have?**

**Question: What is the molarity of a solution with 75 grams of Cl in 2 liters of water?**

**Question: If you had 236 grams of NaCl, how many moles would you have?**

**Question: What is the molarity of a solution with 236 grams of NaCl dissolved in 4.2 liters of water?**

- f. Molality = amount of solute in moles / mass of solvent (in kilograms)
  - (1) molality differs from molarity in that it is based on mass of solvent, rather than volume, eliminates temperature variation effects on volume of liquids

**Conversion Factor: 1 liter of water = 1 kg mass of water**

**question: what is the mass of 4.2 liters of water in kg?**

**question: what is the molality of a solution with 236 grams of NaCl dissolved in 4.2 liters of water?**

## II. Physical and Chemical Properties of Water

- A. Can exist in all three physical states: liquid, solid (ice), and gas (water vapor)
- B. Transformation Processes related to energy input and entropy of water: heating of water, > atomic activity of the water molecules, i.e. > vibrational energy of water atoms.
  - 1. ICE -----HEAT----- WATER-----HEAT -----WATER VAPOR  
<32 degrees (32-212) >212 degrees F
- C. Water is one of few earth substances that remains in a liquid state at the operating surface temperatures of the earth.
  - 1. The liquidity of water makes it a dominant and pervasive component of all earth processes
- D. Water has High Heat Capacity- it has a capacity to absorb and hold energy with only a small amount of temperature rise.
  - 1. important for water-based organisms to regulate temperature
  - 2. produces the moderating effects of oceans on climate
    - a. oceans = warm residual heat in winter (warms air temp.)
    - b. oceans = slow rate of heating in summer (cools air temp.)
- E. Water expands in volume when it freezes/ becomes colder, in contrast to majority of substances (which contract when colder)
  - 1. Result Density of ice < Density of water: thus ice floats on water
  - 2. The crystal structure of ice is a hexagonal arrangement of water molecules
    - a. creates increased volume and decrease in density
  - 3. importance: lakes and oceans freeze from top down, life would not be possible if ice was more dense than water (i.e. freezing from bottom to top).

- F. Water strongly influenced by the force of gravity, constantly driven downward, and can possess great erosive/ landscape carving force
- G. Water has property of high surface tension, ability to have strong molecular attractive forces (sticks to itself and electrostatically attracts ionic forms of elements)
1. surface tension - dipolar molecules and hydrogen bonds result in surface tension on top of water mass
    - a. surface tension = intermolecular force
    - b. water surface may support masses of materials
  2. Capillarity- phenomena of water moving upward against the force of gravity, due to strong electrostatic adhesive forces, most notable in narrow, restricted pore spaces where surface to surface contact is high.
- H. Water acts as a "universal solvent" and can dissolve most any substance over time. Water + carbon dioxide forms a mild carbonic acid solution naturally in hydrosphere, as an acid can result in cationic exchange with positive ionic species, and result in chemical breakdown of substances.
1. Bipolar Water Molecule H<sub>2</sub>O
  2. Covalent bonds between hydrogen and oxygen (strong bond, via sharing of electrons)
    - a. Hydrogen: 1 valence electron (atomic no. of 1)
    - b. Oxygen: 6 valence electrons (atomic no. of 8)
- Bipolar Water Molecule**
3. Hydrogen bonds- given a mass of water molecules, the opposite ends will attract molecularly, forming weak hydrogen bonds
    - a. hydrogen bond between molecules is weaker than covalent within molecules
      - (1) water mass is fluid, but molecules are difficult to dissociate
      - (2) the weak hydrogen bonds between molecules allow water flow

- b. Frozen state - water mass is defined by solid, rigid crystalline structure
    - (1) molecular vibrational energy decreases to the point where the hydrogen bonds lock the molecules into a crystalline structure
    - (2) hexagonal crystal lattice with increased volume
    - (3) freezing point at 32 F (0C) for pure water, but supercooling of water is possible in impurities are present (dissolved salt, suspended solids)
  - c. Evaporation - molecular vibrational energy increases, breaks hydrogen bonds between molecules, individual molecules are liberated from water mass
    - (1) evaporation at air-sea interface is at temp. < boiling point

# Overview of Physical Properties of Water

## A. Temperature-Density-Viscosity Relations

Temp. (C)	Density (gm/cm <sup>3</sup> )	Viscosity (centipoises)
5	0.999965	1.5188
10	0.997000	1.3097
15	0.999099	1.1447
20	0.998203	1.0087
25	0.997044	0.8949
30	0.995646	0.8004
35	0.99403	0.7208
100	0.95865	

Note: viscosity is the measure of a fluid's resistance to flow. The higher the viscosity (e.g. molasses), the more sticky and resistant to flow the fluid is.

### *B. Weight Density of Water*

### *C. Boiling Points of Water vs. Elevation (atmospheric pressure)*

Elevation (ft)	Boiling Point (F)
-1000	213.8
0	121
5000	202.9
10,000	193.7

### In-Class Exercise

**How many pounds will 500 gallons of water weigh? Show all of your math work.**

**If someone were to give you 3000 pounds of water, how many gallons would you have?  
How many cubic feet? Show all of your math work.**