Chem101 - Lecture 2

Atoms and Molecules

Elements

- Elements are pure substances containing only one kind of atom (homoatomic).
- There are at last count 114 elements. (Your book indicates 112.).
  - 88 of these are naturally occurring.

Elements

- An alphabetic listing of the elements is found inside the back cover of your Textbook.

Elements

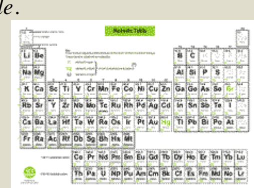
Table 2.1:

The Elements, A to Z

Ac	actinium	Ha	hahnium	Po	polonium
Ag	silver (*argentum*)[a]	He	helium	Pr	praseodymium
Al	aluminum	Hf	hafnium	Pt	platinum
Am	americium	Hg	mercury (*hydrargyrum*)[a]	Pu	plutonium
Ar	argon	Ho	holmium	Ra	radium
As	arsenic	Hs	hassium	Rb	rubidium
At	astatine	I	iodine	Re	rhenium
Au	gold (*aurum*)[a]	In	indium	Rf	rutherfordium
B	boron	Ir	iridium	Rh	rhodium
Ba	barium	K	potassium (*kalium*)[a]	Rn	radon
Be	beryllium	Kr	krypton	Ru	ruthenium
Bi	bismuth	La	lanthanum	S	sulfur
Bk	berkelium	Li	lithium	Sb	antimony (*stibium*)[a]
Br	bromine	Lu	lutetium	Sc	scandium
C	carbon	Lr	lawrencium	Se	selenium
Ca	calcium	Md	mendelevium	Sg	seaborgium
Cd	cadmium	Mg	magnesium	Si	silicon
Ce	cerium	Mn	manganese	Sm	samarium
Cf	californium	Mo	molybdenum	Sn	tin (*stannum*)[a]
Cl	chlorine	Mt	meitnerium	Sr	strontium
Cm	curium	N	nitrogen	Ta	tantalum
Co	cobalt	Na	sodium (*natrium*)[a]	Tb	terbium
Cr	chromium	Nb	niobium	Tc	technetium
Cs	cesium	Nd	neodymium	Te	tellurium
Cu	copper (*cuprum*)[a]	Ne	neon	Th	thorium
Dy	dysprosium	Ni	nickel	Ti	titanium
Er	erbium	No	nobelium	Tl	thallium
Es	einsteinium	Np	neptunium	Tm	thulium
Eu	europium	Ns	neilsbohrium	U	uranium
F	fluorine	O	oxygen	V	vanadium
Fe	iron (*ferrum*)[a]	Os	osmium	W	tungsten (*wolfram*)[a]
Fm	fermium	P	phosphorus	Xe	xenon
Fr	francium	Pa	protactinium	Y	yttrium
Ga	gallium	Pb	lead (*plumbum*)[a]	Yb	ytterbium
Gd	gadolinium	Pd	palladium	Zn	zinc
Ge	germanium	Pm	promethium	Zr	zirconium
H	hydrogen				

Elements

- On the inside of the front cover of you book is a tabular arrangement of the elements.
  - This arrangement is called the *Periodic Table*.



Elements

- On the inside of the front cover of you book is a tabular arrangement of the elements.
  - This arrangement is called the *Periodic Table*.
  - You will learn this semester that there is a great deal of significance to this arrangement.
- The resource page at the Chem101 website provides links for several other periodic tables.

Elements as Pure Substances

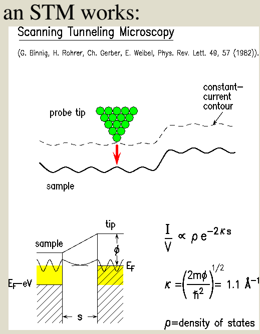
- As pure substances, each element has a well-defined set of physical characteristics.
  - Hydrogen is a clear, colorless, flammable diatomic (H_2) gas.
  - Nitrogen is a clear, colorless, nonflammable diatomic gas (N_2).
  - Sulfur is a yellow, amorphous polyatomic (S_8) solid.
  - Sodium is a highly reactive, soft, metallic solid (Na).
- The web-based periodic tables given on the Resources page list characteristc physical properties of the elements.

"Seeing" Atoms

- Up until the 1970's no one had ever seen an atom.
  - Atoms were theoretic objects that could explain the properties of matter.
- In 1981, the invention of the *Scanning Tunneling Microscopy* (STM) allowed us to now "see" atoms.
  - The inventors received the Nobel Prize for their invention in 1986.

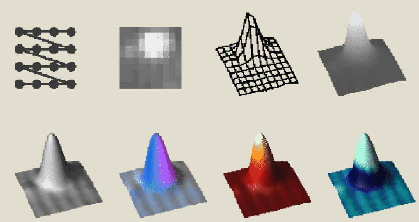
"Seeing" Atoms

- How an STM works:



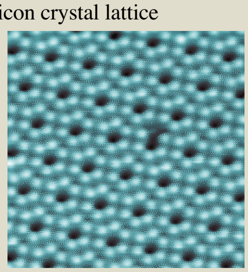
"Seeing" Atoms

- How an STM works:



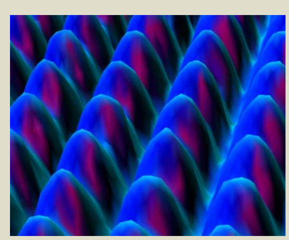
"Seeing" Atoms

- Silicon crystal lattice



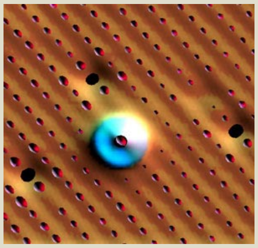
"Seeing" Atoms

- Nickel crystal lattice



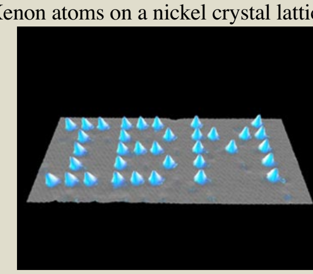
“Seeing” Atoms

- Xenon atom on a nickel crystal lattice



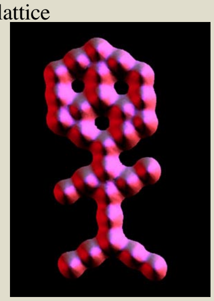
“Seeing” Atoms

- Scientists at IBM have learned how to arrange atoms on a surface.
- Xenon atoms on a nickel crystal lattice



“Seeing” Atoms

- Carbon monoxide molecules on a platinum crystal lattice



Chemical Symbols for Elements

- Each element has a unique one or two character symbol (Table 2.1 and Periodic Table)
  - The first letter of the symbol is always capitalized.
  - The second letter, if there is one, is always lower case.

Chemical Symbols for Elements

- Most of the symbols are derived from the element’s English name:
  - H (Hydrogen), C (Carbon), Ca (Calcium), O (Oxygen), Cl (Chlorine)
- Some of the symbols are derived from the element’s German or Latin name:
  - Au (Gold, *aurum*), Ag (Silver, *argentum*), Na (Sodium, *natrium*), Cu (Copper, *cuprum*), Fe (Iron, *ferrum*)

Compounds

- Compounds are pure substances whose molecules contain more than one type of atom (heteroatomic)
- There are millions of different compounds.

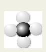
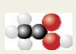
Compounds as Pure Substances

- As pure substances, each compound has a well-defined set of physical characteristics.
  - Dihydrogen oxide (H_2O) is a clear, colorless liquid.
  - Methane (CH_4) is a clear, colorless, flammable gas.
  - Acetic acid ($C_2H_4O_2$) is a crystalline white solid.

Molecular Formulas for Compounds

- Molecular or Chemical formulas are used to indicate the chemical composition of a compound's molecule.
- In a molecular formula, the chemical symbols of all of the elements contained in the compound are listed.
  - Subscripts are used to indicate the numbers of atoms of each element contained in each molecule of the compound.

Molecular Formulas for Compounds

- For example:
  -  The molecular formula for water is H_2O
    Each molecule of water contains two hydrogen (H) atoms and one oxygen (O) atom.
  -  The molecular formula for methane is CH_4
    Each molecule of water contains one carbon (C) atom and four hydrogen (H) atoms.
  -  The molecular formula for acetic acid is $C_2H_4O_2$
    Each molecule of acetic acid contains two carbon (C) atoms, four hydrogen (H) atoms and two oxygen (O) atoms.

Exercise 2.5

Determine the number of each type of atom in molecules represented by the following formulas:

a. sulfur trioxide (SO_3)
b. nitric acid (HNO_3)
c. ammonia (NH_3)
d. propane (C_3H_8)

Inside the Atom

- Atoms are the limit of chemical subdivision in matter.
- Each element has a different type of atom.
  - Each with different chemical and physical properties
- To understand how different types of atoms can have different chemical and physical properties, we need to know what atoms are made of.

Inside the Atom

- All atoms are made of three different subatomic particles.
  - These were discovered in the latter part of the 19^{th} and early part of the 20^{th} century.
- The three subatomic particles include:
  - The proton
  - The electron
  - The neutron

Inside the Atom

- Each of these particles have distinguishable physical properties, the important ones being *mass* and *electrical charge*.

Particle	Common Symbols	Characteristic Properties		
		Charge {±}	Mass {g}	Relative Mass
Electron	e^-	1-	9.07 x 10^{-28}	1/1836
Proton	*p*, *p*+, *H*+	1+	1.67 x 10^{-24}	1
Neutron	*n*	0	1.67 x 10^{-24}	1

Inside the Atom

- The protons and neutrons contribute essentially all of the mass to an atom.
- The protons contribute all of the positive charge, while the electrons contribute all of the negative charge.
  - In a neutral atom the net charge is zero, therefore the numbers of protons and electrons are equal.

Particle	Common Symbols	Characteristic Properties		
		Charge {±}	Mass {g}	Relative Mass
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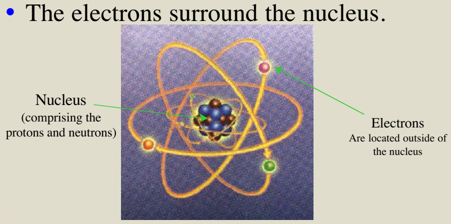
Proton	*p*, *p*+, *H*+	1+	1.67 x 10^{-24}	1
Neutron	*n*	0	1.67 x 10^{-24}	1

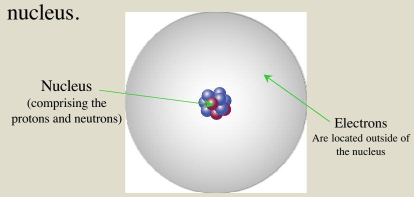
Inside the Atom

- The protons and neutrons are tightly bound together and located in the center of the atom in a region called the nucleus.
- The electrons surround the nucleus.



Inside the Atom

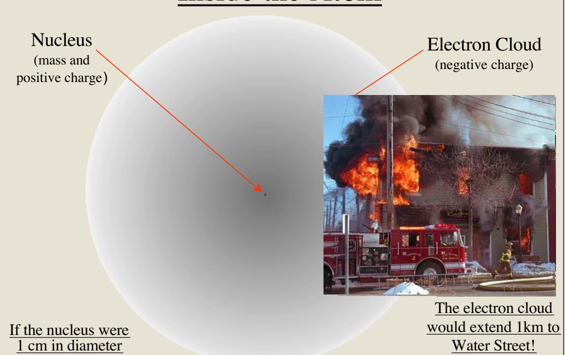
- The popular model of an atom shown on the previous slide is somewhat misleading.
  - The electrons are not hard spheres that whirl about the nucleus, but rather should be thought of as a cloud that surrounds the nucleus.



Inside the Atom

- The popular model of an atom shown on the previous slide is also misleading.
  - The volume occupied by the nucleus, which contains essentially all of the mass, is quite small compare to that occupied by the electrons.
  - The diameter of the nucleus is approximately 1/100,000 the radius of the electron cloud.

Inside the Atom



Inside the Atom

- The number protons an atom contains determines which element it is, this number is called the atomic number and is represented by the letter *Z*.
  - On the periodic table the symbols for the elements are arranged according to their atomic numbers.
- For an electrically neutral atom, the number of electrons is equal the number of protons.

Exercise 2.13

Determine the number of electrons and protons contained in an atom of the following elements:

a. sulfur
b. As
c. element number 24

Isotopes

- The number of neutrons an atom has does not affect its electrical charge,
  - Nor does it affect which element an atom is.
- The number of neutrons in an atom is approximately equal to the number of protons, but it can vary for the different atoms of a given element.

Isotopes

- The number of neutrons *does* affect an atom's mass.
  - The sum of the number of protons and neutrons an atom contains is called the atom's atomic mass number.
  - The atomic mass number is represented by the letter *A*.
- The different forms of atoms that elements have due to differences in their number of neutrons are called isotopes.

Isotopes

- Each element has its own characteristic number of isotopes and relative abundance of each.
- For example
  - Phosphorus (P) has just one naturally occurring isotope
    - it contains 16 neutrons.
  - Carbon (C) has two naturally occurring isotopes
    - one has 6 neutrons and represents 98.93% of all naturally occurring carbon
    - the other has 7 neutrons and represents the remaining 1.07% of all naturally occurring carbon

Isotopes

- Chlorine (Cl) also has two naturally occurring isotopes:
  - one has 18 neutrons and represents 75.78% of all naturally occurring chlorine
  - the other has 20 neutrons and represents the remaining 24.22% of all naturally occurring chlorine.
- Magnesium (Mg) has three naturally occurring isotopes:
  - one has 12 neutrons and represents 78.99% of all naturally occurring magnesium
  - another has 13 neutrons and represents 10.00% of all naturally occurring magnesium
  - and the last has 14 neutrons and represents the remaining 11.01% of all naturally occurring magnesium.

Isotopes

- The number of naturally occurring isotopes an element has, and their natural abundance, are characteristic properties of each element.
  - They have been determined experimentally.
  - They can be looked up in the *CRC Handbook of Chemistry and Physics*.
  - They can also be found on-line at the *WebElements* web site:

Isotopes

- Some isotopes are radioactive
  - This means that their nuclei are unstable

    They fall apart to produce new elements and in the process release energy

Isotopes

- The convention used to distinguish one isotope of an element from another is modify the element's chemical symbol:

$$^{A}_{Z}E$$

  - Where *E* is the element's chemical symbol,
  - *Z* is the element's atomic number,
  - and *A* is the element's atomic mass number.

Isotopes

- For our previous examples:
  - Phosphorus: $^{31}_{15}P$
  - Carbon: $^{12}_{6}C$ *and* $^{13}_{6}C$
  - Chlorine: $^{35}_{17}Cl$ *and* $^{37}_{17}Cl$
  - Magnesium: $^{24}_{12}Mg$, $^{25}_{12}Mg$ *and* $^{26}_{12}Mg$
- Since an element's atomic number is unique, it is not necessary to include it, for example, for magnesium we can write:
  - Magnesium: ^{24}Mg , ^{25}Mg *and* ^{26}Mg

Isotopes

- Another way to represent the different isotopes of an element is to write out the name of the element followed by the atomic mass number:
  - phosphorus-31
  - carbon-12 and carbon-13
  - chlorine-35 and chlorine-37
  - magnesium-24, magnesium-25 and magnesium-26

Exercise 2.15

Determine the number of protons, number of neutrons, and the number of electrons in atoms of the following isotopes:

a. $^{7}_{3}Li$

b. $^{22}_{10}Ne$

c. $^{44}_{20}Ca$

Exercise 2.17

Write symbols like those given in Exercise 2.15 for the following isotopes:

a. cadmium-110
b. cobalt-60
c. uranium-235

Relative Masses

- The mass of an atom cannot be determined by simply adding up the mass of its constituent protons, neutrons and electrons.
  - This is because some of the mass is converted to energy, which is used to hold the nucleus of the atom together.
- The mass of the atoms for each element must be determined experimentally.

Relative Masses

- By convention, atomic masses are determined by comparing them to the mass of the carbon-12 isotope.
- The unit of mass that is used is called the atomic mass unit and is represented by the symbol *u*.
- The atomic mass unit is equal to exactly 1/12 the mass of the carbon-12 isotope.
  - A carbon-12 atom weighs exactly 12 *u*.

Relative Masses

- The atomic mass is also called the atomic weight.
- The atomic weights of the elements are given on most periodic tables of the elements.
- The atomic weights given reflect weighted average of the masses of the naturally occurring isotopes of an element.
  - For example, the atomic weight given for carbon is 12.01 *u* instead of exactly 12 *u*.
  - This is because naturally occurring carbon comprises
    98.93 % carbon-12 and 1.07% carbon-13.

Relative Masses

- Chlorine has two naturally occurring isotopes: chlorine-35 (75.53%) and chlorine-37 (24.47%).
  - The atomic weight for chlorine-35 is 34.97 *u*.
  - The atomic weight for chlorine-37 is 36.97*u*.
- The average atomic weight for chlorine is

$$\frac{(75.53)(34.97u) + (24.47)(36.97u)}{100} = 35.45u$$

- This is the mass reported for chlorine on the periodic table.

Exercise 2.38

Calculate the atomic weight of boron on the basis of the following percent composition and atomic weights of the naturally occurring isotopes. Compare the calculated value with the atomic weight listed for boron in the periodic table.

boron-10 = 19.78% (10.0129 *u*)

boron-11 = 80.22% (11.0093*u*)

The Mole

- The *atomic mass unit* is a very small unit of mass.
  - For example: 1 *g* of carbon-12 weighs 5.0×10^{23} *u*
- In the lab we typically use *grams* as our unit of mass.

The Mole

- A mole is defined as
  - The number of atoms of an element who's mass in *grams* is numerically equal to the atom's mass in atomic mass units.
  - This number is the same for all elements
- For example:
  - The mass of 1 *mole* of carbon is 12.01 *g*.
  - The mass of 1 *mole* of chlorine is 35.45 g.

The Mole

- The number of atoms in a mole of atoms is 6.022×10^{23} $mole^{-1}$ (*per mole*).
  - This number is called Avogadro's number.
  - You can have a mole of any object, like 1 *dozen* (12) or 1 *gross* (144), it is just a number.

The Mass of a Mole of Molecules.

- Pure substances are made of molecules.
- The mass of a mole of molecules is called the molar mass or molecular weight.
- The molecular weight for a compound can be determined from its chemical formula and the atomic weights of its constituent atoms.

The Mass of a Mole of Molecules.

- To determined the molecular weight of H_2O:
  - O: $\left(\frac{1\ mol\ \mathrm{O}}{1\ mol\ \mathrm{H_2O}}\right)\left(\frac{16.00\ g\ \mathrm{O}}{1\ mol\ \mathrm{O}}\right) = \left(\frac{16.00\ g\ \mathrm{O}}{1\ mol\ \mathrm{H_2O}}\right)$
  - H: $\left(\frac{2\ mol\ \mathrm{H}}{1\ mol\ \mathrm{H_2O}}\right)\left(\frac{1.008\ g\ \mathrm{H}}{1\ mol\ \mathrm{H}}\right) = \left(\frac{2.016\ g\ \mathrm{H}}{1\ mol\ \mathrm{H_2O}}\right)$
- Added together these give the molecular weight for H_2O:

$$\left(\frac{16.00\ g\ \mathrm{O}}{1\ mol\ \mathrm{H_2O}}\right) + \left(\frac{2.016\ g\ \mathrm{H}}{1\ mol\ \mathrm{H_2O}}\right) = \left(\frac{18.02\ g\ \mathrm{H_2O}}{1\ mol\ \mathrm{H_2O}}\right)$$

Exercise 2.29

Determine the molecular weights of the following in *u*:

a. oxygen (O_2)
b. carbon monoxide (CO)
c. chloric acid ($HClO_3$)
d. glycerine ($C_3H_8O_3$)
e. sulfur dioxide (SO_2)

Exercise 2.44

Write three relationships (equalities) based on the mole concept for each of the following elements (See section 2.7 for some examples):

a. bromine
b. carbon
c. silver

Exercise 2.46

Use a factor derived from the relationships written in Exercise 2.44 and the factor-unit method to determine the following (The factor-unit method is discussed in *Study Skills 2.1* .):

a. The mass in grams of one bromine atom
b. The number ot grams of carbon in 2.75 *mol* of carbon
c. The total mass in grams of one-half Avogadro's number of silver atoms

Exercise 2.57

Urea (CH_4N_2O) and ammonium sulfate ($N_2H_8SO_4$) are both used as agricultural fertilizers. Which one contains the higher mass percentage of nitrogen?