Chemistry 104 Chapter Three PowerPoint Notes

Atomic Structure and the Periodic Table
Chapter 3

Chemistry 104

Professor Michael Russell

Atomic Theory

Chemistry founded on four fundamental assumptions about **atoms** and **matter** which make up the modern **Atomic Theory**:

1. All matter is composed of atoms.
2. The atoms of an element differ from the atoms of all other elements.
3. Chemical compounds consist of atoms combined in specific ratios.
4. Chemical reactions change only the way the atoms are combined in compounds; the atoms themselves are unchanged.

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Atomic Theory

Atoms are composed of tiny **subatomic particles** called **protons, neutrons,** and **electrons.**

Since the masses of atoms are so small, their masses are expressed on a *relative mass scale*. That is, one atom is assigned a mass, and all others are measured relative to it.

Relative atomic mass scale based on carbon atoms with 6 protons and 6 neutrons. This carbon atom is assigned a mass of *exactly* 12 atomic mass units (**amu**). **1 amu = 1.66 * 10^{-24} g**

Mass of proton = 1 amu

Mass of oxygen = 16 amu

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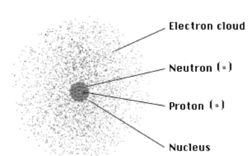
Atomic Theory

Subatomic particles not distributed randomly throughout atoms.

Protons and **neutrons** packed closely together in a dense core called the **nucleus**.

Electrons move about rapidly around core through a large, mostly empty volume of space in atom.



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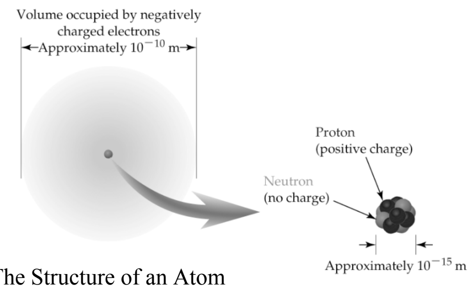
Diameter of a nucleus is only about 10^{-15} m.
Diameter of an atom is only about 10^{-10} m.



The Structure of an Atom

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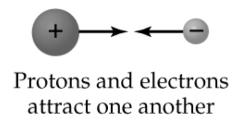
Attraction / Repulsion

Structure of atoms determined by an interplay of different **attractive** and **repulsive forces**.

Unlike charges attract - the *negatively charged electrons* held close to nucleus by attraction to *positively charged protons*



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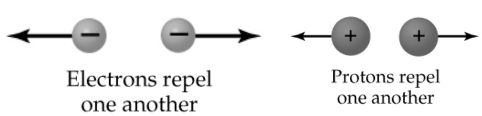
Attraction / Repulsion

Like charges repel each other - *negatively charged electrons* try to get as far apart as possible

Positively charged protons in nucleus also repel, but they are held together by a unique attraction called *nuclear strong force* (Chapter 11)



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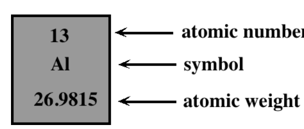
Element and Atomic Number

Atomic Number (Z): Number of protons in an atom

Elements defined by number of protons in the nucleus.

Atoms are neutral overall with no net charge; hence, number of positive protons equals number of negative electrons in the atom.

Mass Number (A): The total number of protons *and* neutrons in an atom.



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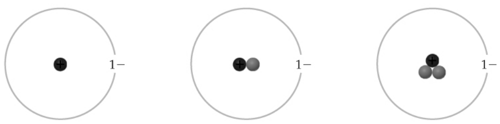
Isotopes and Atomic Weight

Isotopes are atoms with identical atomic numbers (Z) but different mass numbers (A)

Protium, deuterium, and tritium are isotopes of hydrogen.

- Protium: one proton (Z=1) and no neutrons (A=1)
- Deuterium: one proton (Z=1) and one neutron (A=2)



Protium—one proton (●) and no neutrons; mass number = 1

Deuterium—one proton (●) and one neutron (●); mass number = 2

Tritium—one proton (●) and two neutrons (●); mass number = 3

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Atomic and Mass Numbers

Atomic Number, Z

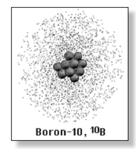
Z = # protons *(defines element)*

Mass Number, A

A = # protons + # neutrons

A boron atom can have
A = 5 p + 5 n = 10 amu

Method to display A, Z and element symbol: A → 10, Z → 5: $^{10}_{5}B$



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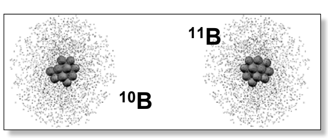
Isotopes Overview

Atoms of the same element (same Z) but different mass number (A).

Boron-10 has 5 p and 5 n: $^{10}_{5}B$

Boron-11 has 5 p and 6 n: $^{11}_{5}B$



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***Atomic Weight*:** The weighted average mass of an element's atoms in a large sample that includes all naturally occurring isotopes of that atom.

Atomic number and atomic weight displayed in periodic table

13	← atomic number
Al	← symbol
26.9815	← atomic weight

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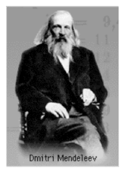
The Periodic Table

Beginning in upper left corner, elements are arranged by increasing atomic number

Seven horizontal rows called ***periods***

Eighteen vertical columns called ***groups***.

Elements in a given group have similar chemical properties (i.e. lithium, sodium, potassium, etc. in group 1A have similar properties)



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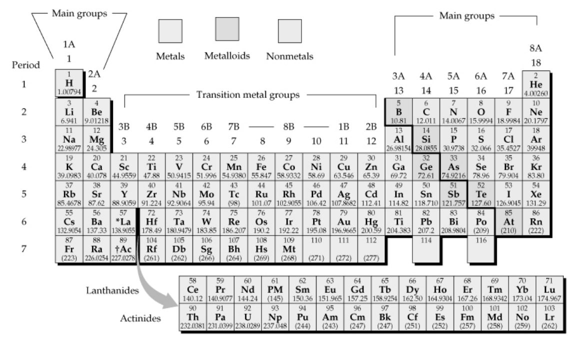

The Periodic Table

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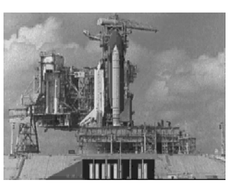
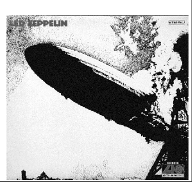
Hydrogen

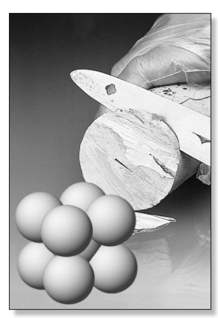


Shuttle main engines use H_2 and O_2



The Hindenburg crash, May 1939.

Group 1A: Alkali Metals



Extreme reactivity with water!

Sodium cut with a knife

MAR ***Solids at room temperature, violently react with water***

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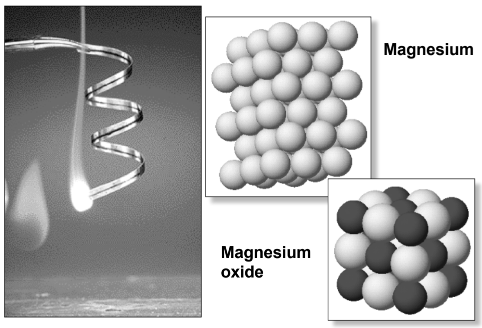
Group 2A: Alkaline Earth Metals



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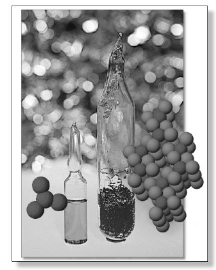
Group 3A: B, Al, Ga, In, Tl

Aluminum



Boron halides, BF_3 & BI_3

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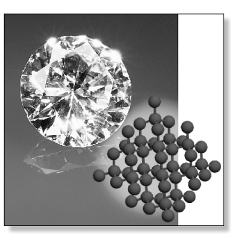
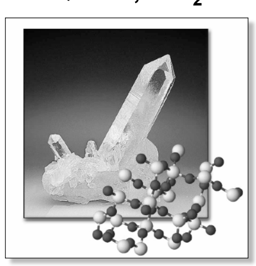
Group 4A: C, Si, Ge, Sn, Pb



Diamond

Quartz, SiO_2



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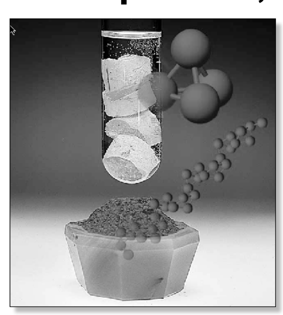
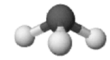
Group 5A: N, P, As, Sb, Bi





Ammonia, NH_3

White and red phosphorus

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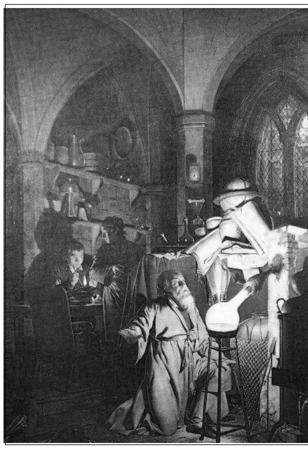


Phosphorus

Phosphorus first isolated by Brandt from urine (!) in 1669

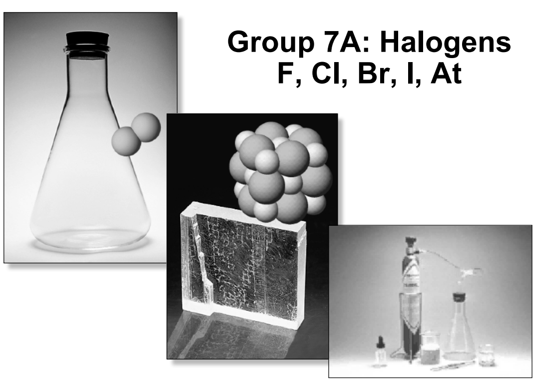
Most chemists' jobs are not so "demanding"!!!

Group 6A: O, S, Se, Te, Po

Sulfuric acid dripping from a cave in Mexico

Sulfur from a volcano

Group 7A: Halogens F, Cl, Br, I, At



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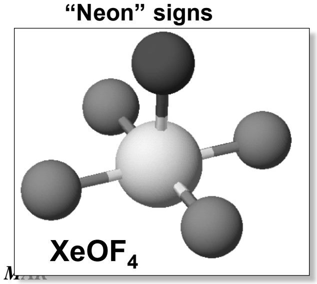
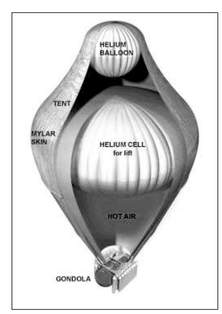
Group 8A: Noble Gases He, Ne, Ar, Kr, Xe, Rn

Lighter than air balloons

"Neon" signs





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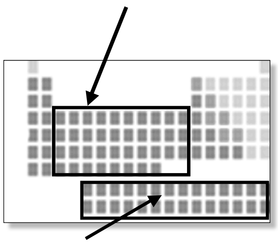
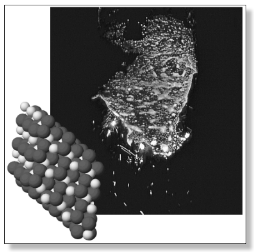
Transition Elements





Iron in air gives iron(III) oxide

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Electronic Structure of Atoms

Quantum mechanical model of atomic structure gives info on electrons

Electrons restricted to moving within a certain region of space in atom - not free to "move about".

Position depends on the amount of energy the electron has.

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Electronic Structure of Atoms

Energies of electrons are quantized, or restricted to having only certain values.

This means that electrons in an atom are grouped around the nucleus into shells.

Within the shells, electrons are further grouped into subshells of four different types, identified as s, p, d, and f, in order of increasing energy

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Shell number:	1	2	3	4
Subshell designation:	*s*	*s* , *p*	*s* , *p* , *d*	*s* , *p* , *d* , *f*

From quantum mechanics we find:

- The first shell has only a *s* subshell
- The second shell has a *s* and *p* subshell
- The third shell has a *s*, *p* and *d* subshell.
- The fourth shell has a *s*, *p*, *d*, and *f* subshell.

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The number of subshells is equal to the shell number (*ex:* shell number 3 has 3 subshells)

Within each subshell, electrons are further grouped into *orbitals*, regions of space within an atom where the electrons are likely to be found. Each orbital holds *two electrons*.

There are different numbers of orbitals within the various subshells:

Shell number:	1	2		3			4			
Subshell designation:	*s*	*s*	*p*	*s*	*p*	*d*	*s*	*p*	*d*	*f*
Number of orbitals:	1	1	3	1	3	5	1	3	5	7

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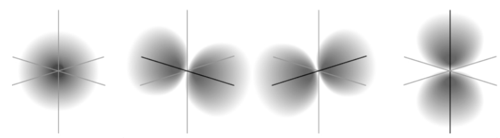
Shapes of Orbitals

Orbitals have different shapes:

- Orbitals in *s* subshells are spherical (a)
- Orbitals in *p* subshells are roughly dumbbell / infinity shaped (b).



(a) (b)

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The overall electron distribution within an atom:

TABLE 3.2 Electron Distribution in Atoms

Shell number:	1	2		3			4			
Subshell designation:	*s*	*s,*	*p*	*s,*	*p,*	*d*	*s,*	*p,*	*d,*	*f*
Number of orbitals:	1	1	3	1	3	5	1	3	5	7
Number of electrons:	2	2	6	2	6	10	2	6	10	14
Total electron capacity:	2	8		18			32			

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Electron Configurations

Electron Configuration: The exact arrangement of electrons in atom's shells and subshells.

Rules to predict electron configurations:

➲ Electrons occupy the lowest-energy orbitals available, beginning with 1s and continuing in order shown in Figure 3.10 *(page 61, next slide)*

➲ Each orbital holds only two electrons which must have *opposite spin* ("up" and "down")

➲ *If two or more orbitals with the same energy:* each orbital gets one electron before any orbital gets two.

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Notice *order* of electron filling… *important!*
Each orbital holds *only* two electrons

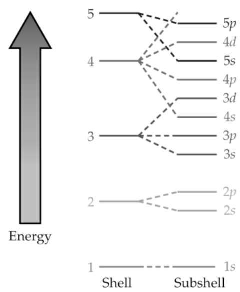

Fig 3.10 Order of Orbital Energy Levels

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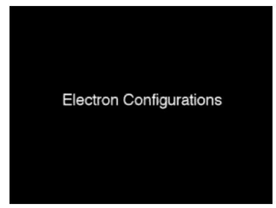
Electron Configurations - *Overview*



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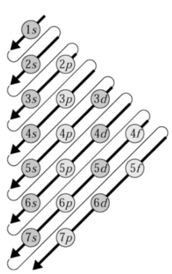
The Aufbau Diagram



Each *s* orbital holds 2 electrons

Each *p* orbital holds 6 electrons

Each *d* orbital holds 10 electrons

Each *f* orbital holds 14 electrons

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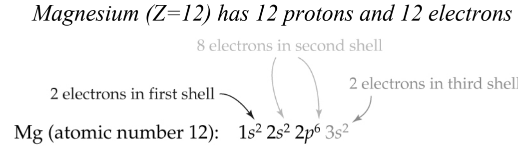
Electronic configuration of Magnesium:

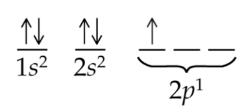
Magnesium (Z=12) has 12 protons and 12 electrons



Electronic configuration of Boron:

Boron (Z=5) has 5 protons and 5 electrons

B $1s^2 2s^2 2p^1$ or



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C $1s^2\,2s^2\,2p^2$ or $\underset{1s^2}{\uparrow\downarrow}$ $\underset{2s^2}{\uparrow\downarrow}$ $\underbrace{\uparrow\ \uparrow\ \_}_{2p^2}$

P $\underset{1s^2}{\uparrow\downarrow}$ $\underset{2s^2}{\uparrow\downarrow}$ $\underbrace{\uparrow\downarrow\ \uparrow\downarrow\ \uparrow\downarrow}_{2p^6}$ $\underset{3s^2}{\uparrow\downarrow}$ $\underbrace{\uparrow\ \uparrow\ \uparrow}_{3p^3}$

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Electron Configurations and the Periodic Table

The periodic table can be divided into four regions or blocks of elements according to the shells and subshells as shown next:

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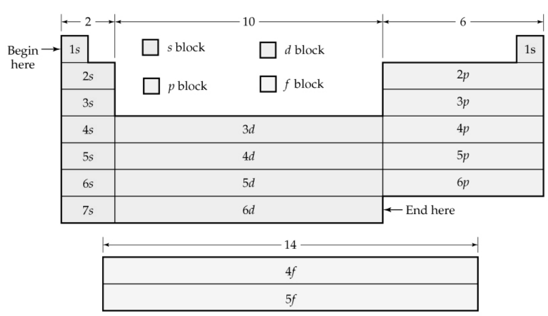

Electron configurations and the periodic table

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Valence Shell and Electrons

Valence Shell: Outermost shell of an atom.

Valence electrons: Electrons in the outermost shell of an atom. These electrons are loosely held and are most important in determining an element's properties and reactivities. *Example:*

P $\underset{1s^2}{\uparrow\downarrow}$ $\underset{2s^2}{\uparrow\downarrow}$ $\underbrace{\uparrow\downarrow\ \uparrow\downarrow\ \uparrow\downarrow}_{2p^6}$ $\underset{3s^2}{\uparrow\downarrow}$ $\underbrace{\uparrow\ \uparrow\ \uparrow}_{3p^3}$

P has five valence electrons ($3s^2 3p^3$) in the 3rd valence shell

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Test Yourself

What is the electron configuration for As? How many valence electrons in As?

What is the electron configuration for Ca? How many valence electrons in Ca?

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End of Chapter 3

To review and study for Chapter 3, look at the "Concepts to Remember" at the end of Chapter Three