Atoms

A. Introduction to Chemistry, Atoms and Elements

Importance of Chemistry

Question: If cataclysmic event were to destroy all knowledge of science what would be the most important knowledge to pass on to future generations?

Answer: Everything is made of Atoms.

Atomic Theory is the central theme of chemistry and most important idea in science.

Chemistry is central to science
Chemistry deals with matter (STUFF of the world) and transformations of matter

It is important and essential in physics, biology, geology, dentistry, medicine, nursing, engineering, philosophy, ….etc.

Chemistry is NOT just beakers and test tubes in labs
Chemical processes are going on everywhere all around us and inside us

All the stuff you see around you is made of atoms and you are also made of atoms.

Examples:

Breathing O_2 binds to Fe in Hemoglobin in red blood cells and thousands of other chemical processes going on in our cells and bodies

We get energy from food we eat
sugar + oxygen → carbon dioxide + water + energy

We get energy for industry by combustion
butane + oxygen → carbon dioxide + water +energy

Chemical reaction is: (a balanced chemical equation is shown below)

Reactants → Products
butane + oxygen → carbon dioxide + water + energy
$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ + energy

History of Chemistry

Five Historical Periods related to development of Chemistry

1) Practical Arts – 600 B.C. (ancient to present in some places)
    Chemical Processes were based on experiences
    No theoretical basis or understanding of chemical principles but they knew how to do many chemical processes such as:
    Preparation of dyes and medicines
    Manufacture of pottery
    Production of metals from ores

2) Greek – 600 B.C. to 300 B.C.
    Considered theoretical aspects of chemistry
    Two ideas:
    a) Everything made of earth, fire, air, water, ether (Plato and others)
    b) Matter is made up of atoms (Democritus 5th Century B.C.)

    Wrong idea won out and with it the idea of the transmutation of matter
    (convert lead to gold through some chemical process - WRONG)

3) Alchemy – 300 B.C to 1650 A.D.
    Greek philosophy combined with Egyptian crafts
    Combined chemical processes with astrology, mysticism, and Greek ideas
    Goals of Alchemy:
    1. Transmutation of base metals such as lead into gold
    2. Find elixir of life (make people immortal)

4) Phlogiston – 1650 to 1790 (Wrong Idea)
    Thought heat was a substance called phlogiston that was released by burning

$$\text{wood} \rightarrow \text{ashes} + \text{phlogiston (heat as substance)}$$

5) Modern Chemistry – 1790 to present day
    Antione Lavoisier his work formed the beginning of modern chemistry
    published first real chemistry text *Elementary Treatise on Chemistry* in 1789

    He used quantitative experimentation (such as weighing before and after reaction) and showed gases involved in combustion

$$\text{wood} + \text{oxygen} \rightarrow \text{ashes} + \text{gases} + \text{energy}$$

Modern chemistry makes connection between experiment and theory
Experimental observation $\leftrightarrow$ theory

John Dalton an English School teacher in 1808 reintroduced the ancient idea of Democritus - Atoms are the building blocks of nature!

Chemical reactions involve rearrangement of atoms but atoms are not created or destroyed - This idea of mass not changing is also called "Conservation of Mass"

Chemistry is concerned with structure and transformations of matter on an atomic level. Atoms come together to form compounds and compounds can break apart into atoms or be combined to form new compounds.

Main areas of Chemistry:

- Organic – compounds of carbon (some exceptions CO_2 CO considered inorganic)
- Inorganic – compounds that do not include carbon
- Analytical – composition of matter and mixtures (what is there and how much)
- Physical – applies ideas of math and physics to chemistry
- Biochemistry – chemistry of living things (from bacteria to humans)

Elements and Compounds

- Atoms are building blocks of nature
- Elements – composed of one type of atom
- An element cannot be decomposed into simple substances

~90 natural elements
~110 known elements (some elements don't exist in nature but have been made by combining lighter elements to make heavier ones)
Each elements is assigned a one or two letter chemical symbol – for example:

Found in	**Element**	**Symbol**	**Origin**
cans	Aluminum	Al	English
Hemoglobin, transport oxygen	Iron	Fe	Latin – Ferrum
NaCl salt	Chlorine	Cl	
Coal, diamond	Carbon	C	
H_2S rotten egg	Sulfur	S	
Tin cans	Tin	Sn	Latin – Stannum
Light bulb filament	Tungsten	W	German – Wolfram
Ions in cells	Sodium	Na	
Bones, eggs, $CaCO_3$	Calcium	Ca	

Compounds can be decomposed into elements
Compounds are composed of two or more types of atoms

Some compounds are made of molecules (linked collection of atoms like H_2O)
and some are made of ions (positive and negative charged atoms) NaCl is made of a number Na^+ and Cl^- ions in a three-dimensional array but NOT NaCl molecules

Chemical Reaction shown by balanced chemical equation
Burning natural gas:

Methane	Oxygen	→	Carbon Dioxide	Water
CH_4 +	$2O_2$	→	CO_2 +	H_2O

The number preceding the compound is known as the coefficient

Lighter flame:

Butane	Oxygen	→	Carbon Dioxide	Water
$2C_4H_{10}$ +	$13O_2$	→	$8CO_2$ +	$10H_2O$

The equation is balanced if the number of atoms on
left (reactants) and right (products) are the same

(Reactants)		(Products) for butane lighter reaction
8	C	8
20	H	20
36	O	36

Matter and Changes
Change

One substance converted into another
Rearrangement of matter

1) Physical Change – identity is the same but properties different
   Ex: separate mixture – divide sugar and salt
   Change state – ice → water → steam
   Do NOT create new chemical species

2) Chemical Change – create new chemical species (break and form bonds)
   $2H_20 \rightarrow H_2 + O_2$

Examples:
   Strike a match – chemical change
   Break a match – physical change

Dissolve table sugar – physical change
sucrose molecules($C_{12}H_{22}O_{11}$) spread out in water

Dissolve table salt – chemical change
$NaCl \rightarrow Na^+ + Cl^-$ ions form and spread out in water

Matter is

1) **Pure Substance** (same composition or proportion of elements)
Broken down from compound to element (chemical change)
Can have pure **compound** such as NaCl or H_2O
or pure **element** such as Na Cl_2 H_2 O_2

2) **Mixture** (variable composition) – salt water
Homogenous – same throughout salty water is same throughout
Heterogeneous – not same everywhere oil-water has two different layers

Demo – "Burn Dollar"

Isopropyl alcohol	C_3H_7OH
Water	H_2O

90% isopropyl alcohol, 10 % water will ignite paper and BURN

50% water, 50% isopropyl alcohol will not ignite paper flame but NOT BURN, why?

50% water, 50% isopropyl alcohol is a homogenous mixture and two types of changes are occurring (isopropyl alcohol burns, but water protects paper):

1) Chemical Change: (balanced chemical equation below)

$C_3H_7OH + 9/2O_2 \rightarrow 3CO_2 + 4H_2O$ + light, heat

$2CH_3H_8O + 9O_2 \rightarrow 6CO_2 + 8H_2O$ + light, heat

2) Physical Change: (such as change of state from liquid to gas)

$H_2O\ (\ell) \rightarrow H_20\ (g)$

Reasons for Chemistry
The Fantastic knowledge of chemistry is driven by
a) curiosity and the intellectual satisfaction of understanding our world
b) practical applications wear them, sit on them, eat them, etc

In the Middle Ages Alchemy sought
a) Wealth through Transmutation of Matter–
b) Health through Elixir of Life –

Modern chemistry has achieved much of the above goals of health and wealth by understanding atomic and molecular behavior. (average citizen in America has better health care more comfort than the richest person in the world in Middle Ages)
And the nature of world (atoms and molecules) is more incredible than anything we could imagine.

B. Subatomic Particles and Periodic Table

Dalton Model (1808)
John Dalton (like ancient Greek philosopher Democritus) said atoms are building blocks of nature. But he had no knowledge the internal structure of atoms.

Bohr Model (1913)
Niels Bohr said negative electrons are found in orbits around positive nucleus

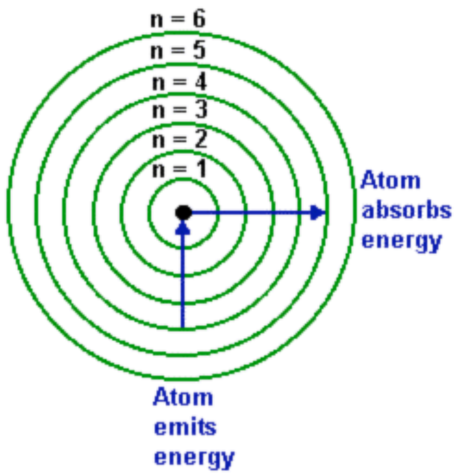
It had been observed that only certain wavelengths of light given off by hot hydrogen so concluded only certain orbits of fixed energy allowed in atom.

Energy in electricity put into hydrogen atoms and only certain colors of light given off.

Nature seems to make jumps, not continuous

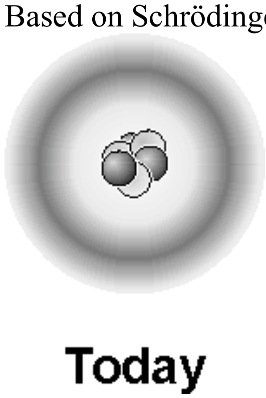
Higher energy orbits at greater distance from nucleus and electrons can move from one level to another. Electrons have to be at some energy level.

Bohr Model shows discrete energy levels – Quantization



(http://library.thinkquest.org/C006669/data/Chem/atomic/bohr.html)

Quantum Mechanical Model (1926)
Schrodinger developed quantum mechanics equations
Developed between about 1900-1930
Treats electron as both wave and as particle
Deals with probability of location (orbitals not orbits)
Orbitals represents clouds of negative charge (like wave) that surround nucleus
Based on Schrödinger Equation



(http://darkwing.uoregon.edu/~ch111/L5.htm)

Subatomic Particles and the Atom

Molecules are composed of Atoms
What are Atoms made of? Do they have an internal structure?

Nucleus is positively charged center of an atom.

Electrons are negatively charged particles with much less mass and located in the region between the nucleus and the edge of the atom

Diameter of Hydrogen 1 x 10^{-10} m = 1A (1 angstrom)
Diameter of Proton 1.2 x 10^{-15} m

Mass of proton/ mass of electron = 1.0073 amu/0.00055 amu = 1831/1 ratio

In Hydrogen Atom- if nucleus is the size of a tennis ball, then atom diameter is 1 mile!

Electrons give an atom its size
Nucleus is made of protons and neutrons and these particles give an atoms its mass

Various types of Hydrogen (different isotopes)
Hydrogen (protium) – 1 proton in nucleus
Deuterium – 1 proton and 1 neutron in nucleus
Tritium – 1 proton and 2 neutrons in nucleus

Isotopes are substances containing the same number of protons but different number of neutrons.

Elements are substances whose atoms are all the same number of protons

Subatomic Particles	**Atomic Mass Unit (u)**	**Relative Charge**
Proton (p)	1.0073	+1
Neutron (n)	1.0087	0
Electron (e-)	0.000546	-1

1g = 6.02 x 10^{23} amu (atomic mass unit sometimes is abbreviated as amu or u) or sometimes called a Dalton Da)

1 amu = 1.66 x 10^{-24}g

Periodic Table gives average mass of individual atoms in atomic mass units (amu) or (g/mol which will be discussed later)

Atomic Symbols for Isotopes

Atomic Number (Z) number of protons in atoms
Mass Number (A) number of protons and neutrons, also known as nucleons

Number of neutrons = A – Z

$^{A}_{Z}X$

A = mass number

Z = atomic number

X = symbol

(http://darkwing.uoregon.edu/~ch111/L5.htm)

Atoms	**# of Protons**	**# of Neutrons**	**# of Electrons**
$^{12}_{6}C$	6 p	6 n	6 e
$^{19}_{9}F$	9 p	10 n	9 e
$^{235}_{92}U$	92 p	143n	92 e
$^{238}_{92}U$	92 p	146n	92 e
Ions			
$^{19}_{9}F^{-}$	9 p	10 n	10 e (gain e to be -)
$^{23}_{11}Na^{+}$	11 p	12 n	10 e (lost e to be +)

For example, to make uranium atomic bomb you have separate radioactive ^{235}U isotopes from nonradioactive from ^{238}U. Done at Oak Ridge in WWII as part of Manhattan Project to make atomic bomb.

Mass number is not the same as the mass (but close) because p and n masses are slightly more than 1 amu. And weight of nucleus not just the sum of weights of protons and neutrons. There is a conversion of part of the mass to energy (called binding energy of nucleus) that holds nucleus together.

Mass is converted to energy in atomic bomb or nuclear reactor is based on Einstein Equation $E= mc^2$ where c is speed of light $3.00x10^8$ m/s. A small amount of mass can release a tremendous amount of energy in these nuclear (not chemical) processes.

<u>Radioactivity</u>

1896 Becquerel stored some uranium ore by some sealed photographic plates.

He discovered that the plates were exposed to something like intense light but plates were protected from light. So something besides light must have gotten to the sealed plates. That something was energetic radioactive particles that could go through the material.

Radioactivity is due to particles thrown out of nucleus.

One type of radioacitve particle is alpha particle made of 2p2n (2 protons, 2 neutrons)
Other common radioactive particles shown below

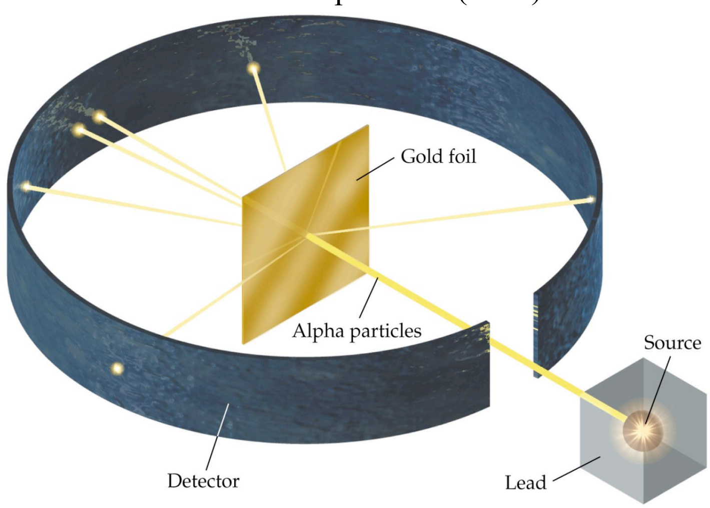
Ray	**Charge**	**Particle**	**Mass (amu)**
Alpha α	+2	2p2n	4
Beta β	-1	e-	0.00055
Gamma γ	0	High energy Electromagnetic Radiation	0

So Dalton not quite right – atoms are made of smaller particles **but atoms are not indestructible** – they can change (not by chemical reactions, but by radioactivity or processes in the nucleus or center of atom).

Radioactive atoms (certain isotopes) can throw off pieces of themselves from the nucleus and even change to different type of atom if number of protons is changed!

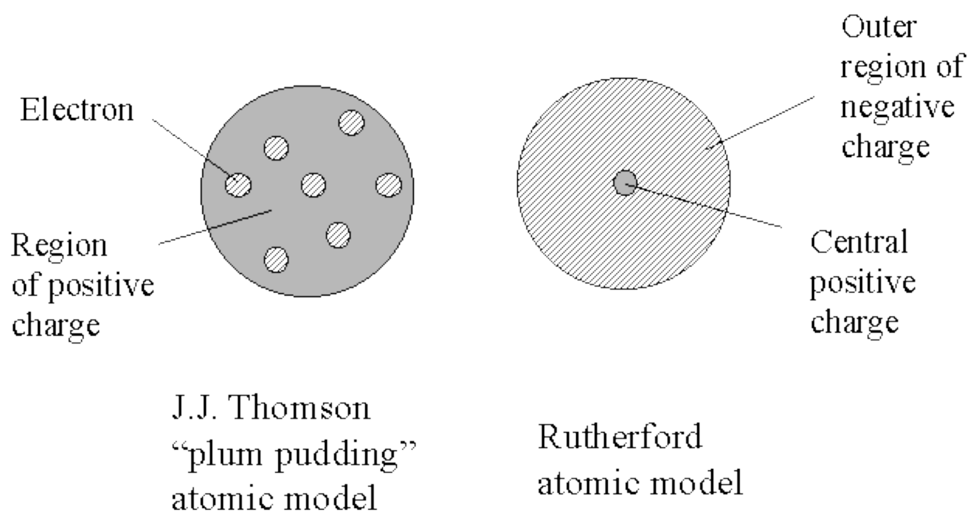
<u>Location of Protons in an Atom</u>

Rutherford's Gold Foil Experiment (1911)



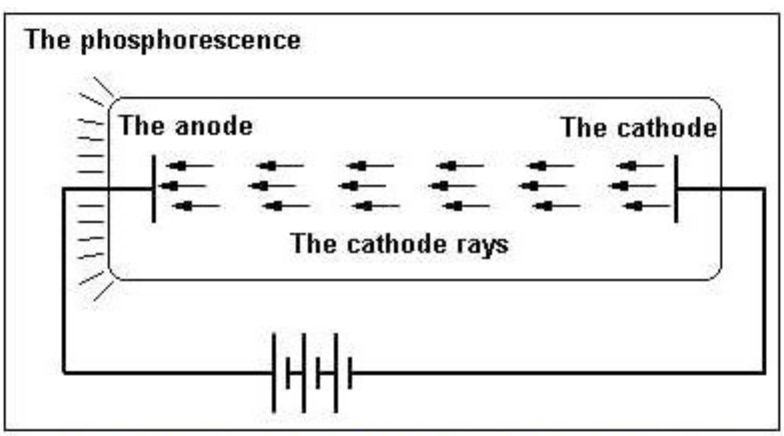
(http://wps.prenhall.com/wps/media/objects/476/488316/ch04.html)

Rutherford concluded that the nucleus is the tiny positively charged, massive center of atoms because positive alpha particles were deflected from their path and would not have been if protons were spread throughout atom (Plum pudding model) as people thought at time.



(http://wine1.sb.fsu.edu/chm1045/notes/Atoms/AtomStr1/Atoms02.htm)

Properties of Electrons
Cathode Ray Tube



The discharge tube used by Plucker for creating the cathode rays.

(http://library.thinkquest.org/19662/low/eng/cathoderays.html)

1860's cathode ray – stream of electrons
TV fluorescent screen uses a beam of electrons to strike dots on screen that emit light when struck by electrons. Beam sweeps across screen and makes light and dark regions as it is rapidly turned on and off.

Beam of charged particles can be deflected by magnet or by charged plates:

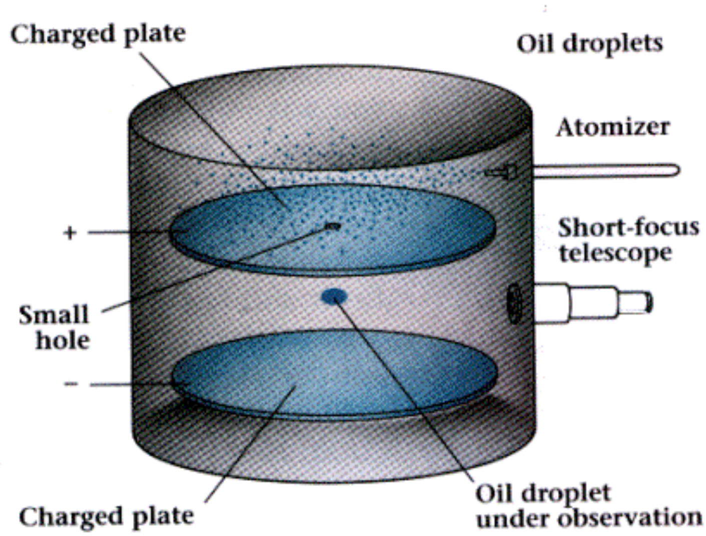
Unlike charges Attract   Like charges Repel

Deflection varies directly with charge
Higher charge = Larger deflection

Deflection varies inversely with mass
Larger mass = Smaller deflection

Using these properties J.J. Thompson (1897) found
Electron = charge/mass ratio for electron = 1.7588 x 10^8 C/g where C is unit of charge called a Coulomb. (Coulomb is the flow of 1 ampere of electrons for 1 second C=A x s)

Mass of electron found by Millikan in experiment with charge on oil drops in 1909



(http://www.compworldnet.com/users/mike/Millikan%20oil_files/image002.gif)

Absolute charge = 1.6022 x 10^{-19} C (coulomb)
Relative charge = -1

Therefore mass of electron

Mass = (charge)(mass/charge) = 9.1096×10^{-28} g

$(9.11 \times 10^{-28}$g$)(6.02 \times 10^{23}$ amu/ 1g$) = 5.5 \times 10^{-4}$ amu = 0.00055 amu

0.000055 amu is only a small part of hydrogen mass so electrons have small mass

DEMO

Cathode Ray Tube:
Cathode ray tube has beam of electrons that can be seen by electrons striking phosphorous coating. Magnet can bend beam.

J.J Thompson used simple device like this to find that electrons were particles with negative charge in 1897.

Lightning:
Negative charges can concentrate in the base of a cloud during the turbulence of a storm. The build up of negative charge may cause negative charge to be repelled at the ground and positive charge builds up. When the difference is great enough, negative electrons travel from the cloud to the ground. After the initial rush of electrons, a flow of negative and positive ions causes the visible aspect of lightning.
http://www.mos.org/sln/toe/lightning.html

(http://www.scopeboy.com/tesla/ol2_6ft1_small.jpg)

Atomic Mass (sometimes called atomic weight)

Remember ions are positive or negative charged particles that can be an atom or molecule:

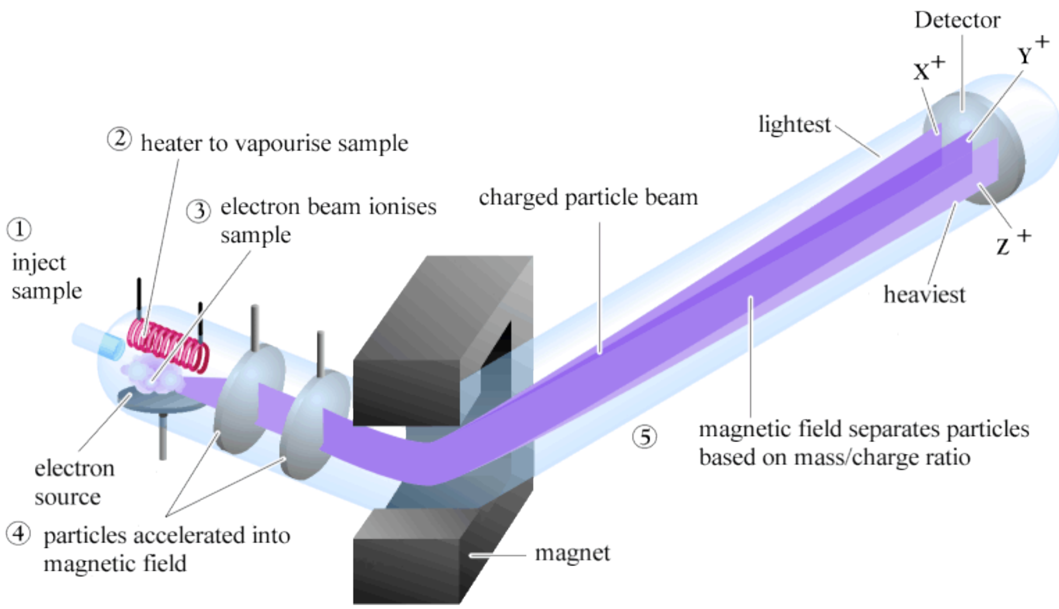
If electrons are added it becomes negative (anion).
If electrons are removed it becomes positive (cation).
In neutral atom or molecule the number of protons and electrons are the same.

Mass Spectrometer (MS) – apparatus used to masses of atoms and molecules. With MS can determine exact masses and thus determine isotopes found in nature.

Mass Spectrometer shown below:

Electron beam knocks electrons off of sample molecule and creates positive ions that are deflected by a magnetic field. The ions are all +1 but if there are different isotopes there are different masses. The lighter the mass, the more the ion is bent by the magnetic field.

Imagine kicking three objects as they roll by: a bowling ball, a basketball, and a ping pong ball – the bowling ball would bend the least. The path of the ping pong ball would bend or curve the most. The magnet does the "kicking" in MS.



(http://www.chem.ucalgary.ca/courses/351/Carey/Ch13/ch13-ms.html)

Below are the results of a Mass Spectrometer Experiment using Cl_2 as the sample:

Mass	**Amounts Observed**
74	Little
72	Some

70	Most

and the reason for above results?

There are two isotopes of Cl ^{35}Cl and ^{37}Cl found in nature
and they can mix together in three ways to make Cl_2. They can combine as
35+35=70 or 35+37=72 or 37+37=74

Determine Average Mass

Very careful measurements determine that the amounts and masses of two isotopes (Isotopes have a different number of neutrons):

75.80% Chlorine-35 with exact mass of 34.969 amu
24.20% Chlorine-37 with exact mass of 36.966 amu

and therefore the average mass (one found on periodic table is)
(.7580)(34.969) + (.2420)(36.966) = 35.45

Remember
Mass Number (A) – Atomic Number (Z) =Number of Neutrons (N)
so for example

Chlorine-35	has 35 – 17 = 18	17p and 18n
Chlorine-37	has 37 – 17 = 20	17p and 20n
Magnesium-24	has 24 – 12 =12	12p and 12n
Magnesium-25	has 25 – 12 = 13	12p and 13n
Magnesium-26	has 26 – 12 = 14	12p and 14n

On Periodic Table the number of protons is given above symbol for element.
Look on Periodic Table and find number of protons in Cl and Mg.

On Periodic Table the masses are given based on natural abundance on earth
and any large number of atoms contains these relative amounts

Example: what is average atomic mass (or atomic weight) of Mg based on percentages given below:

78.99% of ^{24}Mg and 10.00% of ^{25}Mg and 11.01% of ^{26}Mg

avg = 78.99%(24.00) + 10.00%(Mg(25.00) + 11.01%(Mg(26.00)

avg = .7899 (24.00 amu) + .1000 (25.00 amu) + .1101 (26.00 amu)
avg = 24.32 amu

in some problems you might be given exact values for masses and then answer will be slightly different than if you assume whole number values like 24, 25, and 26. Exact values shown below:

avg = .7899(23.99 u) + .1000(24.99 u) + .1101(25.98 u) = 24.31 u
avg = 24.31 amu

On Periodic Table average mass is given below symbol for element.
Look of Periodic Table and find average mass of Mg and Cl

Two kinds of water
Example of isotopes (regular water and heavy water)

Isotopes	% H	% O
$^{1}H_2O$ mass 18 amu	11.19	88.81
$^{2}H_2O$ mass 20 amu	20.12	79.88

Number of H and O atoms same but percent weight composition depends on isotopes, however unless you have separated isotopes by some means we work with natural mixtures of isotopes and so normally (in most chemistry) we use the average found on periodic table.

Relative Weights

Prior to Mass Spectrum how did scientists 200 years ago determine relative atomic weights?

Used:
1) Law of definite proportions – compound is the same proportion by mass ratio
Water = 88.8% Oxygen and 11.27% Hydrogen

2) Law of multiple proportions – compound is always the same proportion by number ratio H_2O_1 2/1=H/O

assume H is 1 and set two ratios equal to each other and solve for unknown mass

1O/2H = 88.8/11.2
O/H = 2 (8/1)
O = 16 (H) or 16 (1.0) = 16.0 for oxygen

and Carbon Monoxide (CO) is 57.1% oxygen and 42.9% carbon by mass then

C/O = (42.9/57.1)
C = (42.9/57.1) (O)

C = (42.9/57.1) (16.0) = 12.0

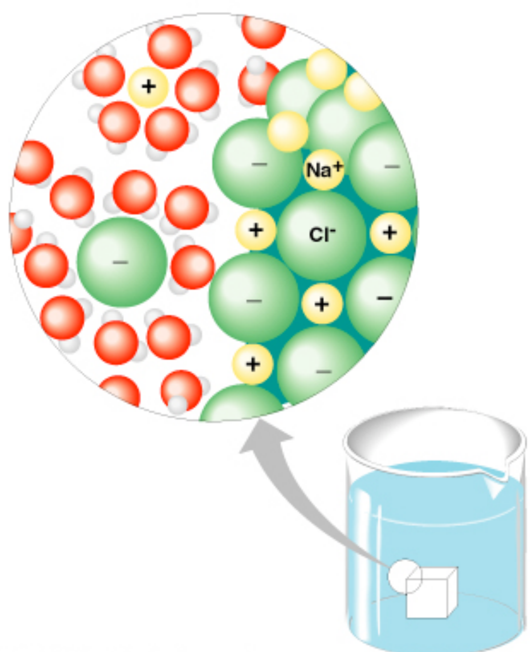
So to determine the relative weights then need both:
(1) Combining ratio by mass
(2) Combining ration by number

This has been done for you in Modern scale of atomic mass
Reason we say atomic mass is even if you are weightless in orbit, you still have mass - resistance to change in momentum (or movement) is mass

On Periodic Table below symbol for element are atomic mass
Atomic mass are not rounded numbers but are averages for each type of element based on natural abundance of isotopes

Compound Formulas
Molecules are particles formed from two or more atoms (H_2O for example)

But compounds are not always made of molecules
NaCl is an array of charged particles (ions)



(http://fig.cox.miami.edu/~cmallery/150/chemistry/chem.htm)

Ions are positive or negative atoms or molecules

The compound formula is a shorthand notation that tells us the whole number combining ratio of different elements:

Example:
water is made of individual H_2O molecules
sodium chloride is made of a large number of Na^+ and Cl^- ions held together by electrostatic attraction

Compound	Molar Formula	Empirical Formula (simplest ratio)
Methane	CH_4	CH_4
Carbon Dioxide	CO_2	CO_2
Glucose (sugar)	$C_6H_{12}O_6$	CH_2O
Hydrazine	N_2H_4	NH_2
Sodium Chloride	NaCl	NaCl
Barium Chloride	$BaCl_2$	$BaCl_2$
Sodium Peroxide	Na_2O_2	NaO

Methane, Carbon dioxide, Glucose, Hydrazine are all composed of molecules

Sodium chloride, Barium chloride and Sodium peroxide are all composed of ions
NaCl ---> made of many ions but ratio is Na^+ and Cl^-
$BaCl_2$ ---> made of many ions but ratio is Ba^{2+} and $2Cl^-$
Na_2O_2 ---> made of many ions but ratio is $2Na^+$ and O_2^{2-}

Compound Formula (molar formula) – <u>actual ratio</u> of atoms in a unit of substance

Empirical Formula – <u>simplest ratio</u> based on molecular formula or true formula

<u>Writing Elements in Formulas:</u>
When referring to pure elements in chemical equations use single symbol,
Ex: Iron (Fe), Copper (Cu), Magnesium (Mg)

but if one of the elements below write as shown below
7 Elements occur as diatomic molecules KNOW THESE!!!

Hydrogen $\mathbf{H_2}$
Nitrogen $\mathbf{N_2}$
Oxygen $\mathbf{O_2}$
Fluorine $\mathbf{F_2}$
Chlorine $\mathbf{Cl_2}$
Bromine $\mathbf{Br_2}$
Iodine $\mathbf{I_2}$

Example: if Sodium is combined with chlorine to form Sodium chloride
write $2Na + Cl_2 \rightarrow 2NaCl$
elements → compounds

Sometimes exceptions such as Sulfur (S_8) and Phosphorous (P_4)
but we will ignore these exceptions and just write as S and P

Elements Properties

Most Metals: Ductile
Malleable
Luster
Good conductor of heat
Good conductor of electricity

Metalloids = Semi-metals
Have some of these properties but not all

Nonmetals have none of these properties

Metalloids:
Boron (B)
Silicon (Si) (used in semiconductors, electronics)
Germanium (Ge)
Arsenic (As)
Antimony (Sb)
Tellerium (Te)
Pollonium (Po)
Astatine (At)

Range of Reactivity: Na (never free in Nature) ---> Au (free in nature)

Melting Point range: Hg (-39^oC) ---> W (3400^oC)

Carbon
- Diamond
- Graphite
- Bucky Ball
- Nanotubes

Diatomic
Br_2 = red liquid
I_2 = purple solid

Periodic Table

Russian – Dmitri Mendeleev (1869)

German – Julius Meyer

Similar Properties occur at periodic intervals based on atomic weights

Really organized now by Atomic Number
Based on X-ray experiments of Henry Moseley

Modern:
Periodic law: elements arranged increasing atomic number
Periodic repetition of physical and chemical properties
Elements in same group (column) have similar properties

The Periodic Table is the most useful aid chemists have

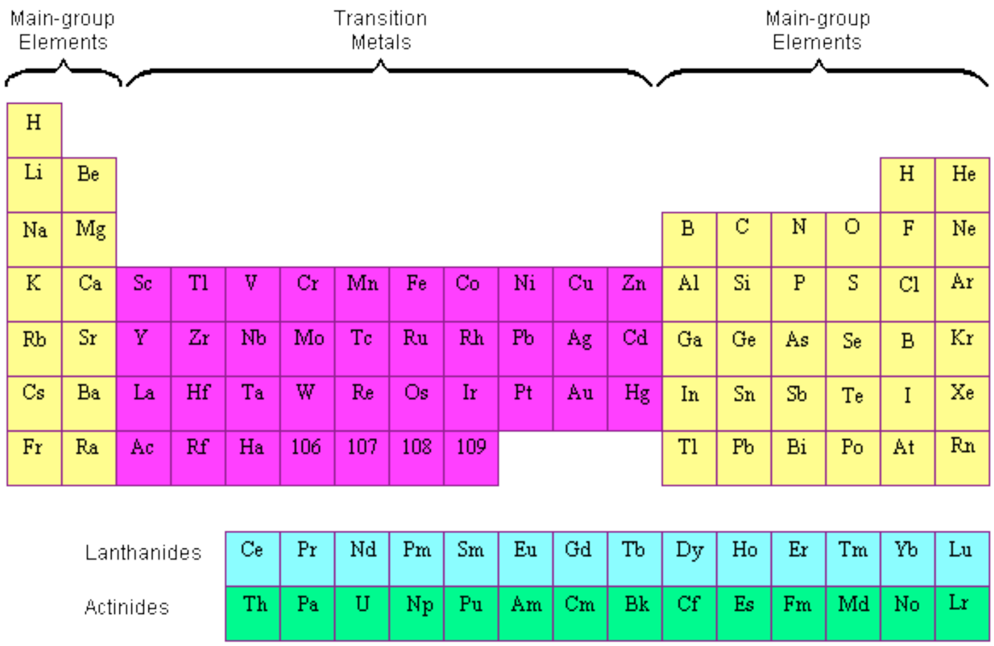
Groups → are 1-18 or older system IA –VIIIA and IB - VIIIB

Period = horizontal row 1 through 7

Group = vertical column
Groups → are 1-18 or older system IA –VIIIA and IB - VIIIB

Groups with special names

1	IA	Alkali Metals
2	IIA	Alkaline Earth Metals
17	VIIA	Halogens
18	VIIIA	Noble Gases (Inert)



(http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch12/trans.html)

Compounds

Ionic (made of ions)
Composed of a Metal and a Nonmetal
One element from the left of the and one from the right of the Periodic Table
NaCl Fe_2O_3 Mg_3N_2

On the left side of Periodic Table metals lose electrons (become +)
to left of metalloids are metals

On the right side of Periodic Table nonmetals receive electrons (become -)
to right of metalloids are nonmetals

Covalent (made of molecules or networks of atoms)
Composed of a Nonmetal and a Nonmetal
Both come from right side of periodic table (hydrogen is considered nonmetal)
HCl CO_2 PI_3