Particles, Atoms, Molecules and Ions

The building blocks of chemistry = electrons, protons, neutrons, molecules and ions

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Composition of Matter

of interest in chemistry

Substance are composed of very small particles, of the approximately the size of 10^{-9} m (very small), referred to as <u>molecules</u> or <u>ions</u>.

The difference between molecules and ions is that the ions have an electrical charge and molecules have no charge.

Molecules can exist by themselves, whereas, since positive and negative charges are strongly attracted, ions normally exist with positive and negative ions togethers in such a way to yield an overall neutral charge. The smallest neutrally charged aggragate of ions is referred to as a <u>formula unit.</u>

Both molecules and ions are composed of <u>atoms</u> which are the smallest units that may be obtained from molecules or atoms using energies that are available by using either chemical or electrochemical methods.

Atoms themselves are composed of subatomic particles called <u>electrons</u>, <u>protons</u> and <u>neutrons</u>. Although protons and neutrons are composed of even smaller particles called “quarks”, this is not a consideration for chemistry.

Definition for the words:

element and compound

The word “element” is used to indicate a number of atoms of the same type. (It normally does not distinguish that it is a mix of isotopes, which will be defined in the next few slides.)

The word “compound” is used to indicate a number of molecules or formula units of the same type.

You could think of these two words as group names like a “pride” (of lions) or a “gaggle” (of geese).

Subatomic particles

Subatomic particles can be classified according to what are referred to as Quantum Numbers.

Quantum Numbers are exact numbers, usually integers but occasionally fractional, which specifies the characteristics of the particle. The following are some subatomic particles of interest in chemistry with the quantum numbers that distinguish them.

	Quantum Numbers:		A physical quantity:
	Charge or Atomic Number	Atomic Mass Number	Particle Mass
Particle name and symbol			
Protons, p^+	+1	1	1.673×10^{-27} kg
Neutrons, n^0	0	1	1.675×10^{-27} kg
Electrons*, e^-	–1	0	9.11×10^{-31} kg
Photons, ν or λ (Ex: light, etc.)	0	0	0.0

* another particle used in some analytical techniques is the positron with quantum numbers of +1 and 0

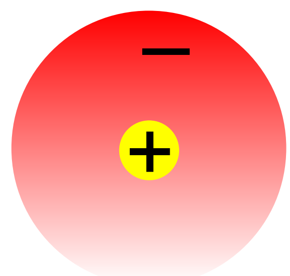
Composition of atoms

Atoms are combinations of these subatomic particles.
The simplest atom: hydrogen

For example the combination of:

1 proton, p^+ and 1 electron, e^-

yields the hydrogen atom



*

The symbol is:

$^{1}_{1}H$

The numbers are: Atomic Mass Number and Atomic Number

* The sizes are not drawn to scale

Composition of atoms

Atoms are combinations of these subatomic particles.
Another type of hydrogen

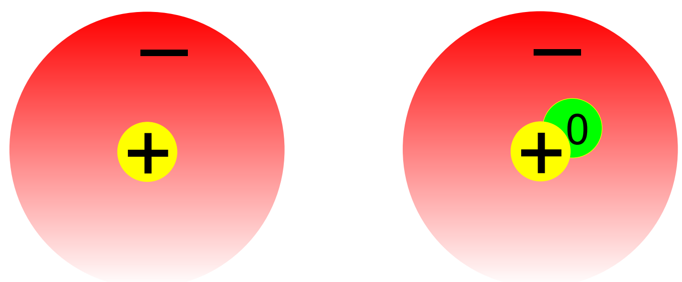
Another example is the combination of:

1 proton, p^+, 1 electron, e^- and 1 neutron, n^0

.

yields another form

of the hydrogen atom



The symbol is:

$^{1}_{1}H$ $^{2}_{1}H$

The numbers are: Atomic Mass Number and Atomic Number

Composition of atoms

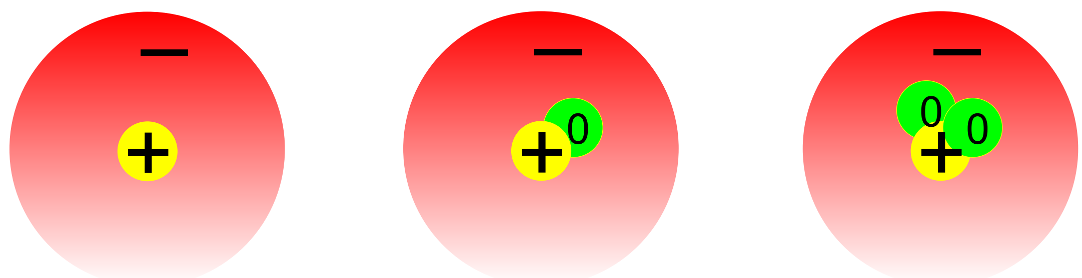
Atoms are combinations of these subatomic particles.
A third type of hydrogen.

There is yet another example for hydrogen that is fairly stable:

1 proton, p^+, 1 electron, e^- and 2 neutrons, n^0
.

yields another form

of the hydrogen atom



The symbol is:

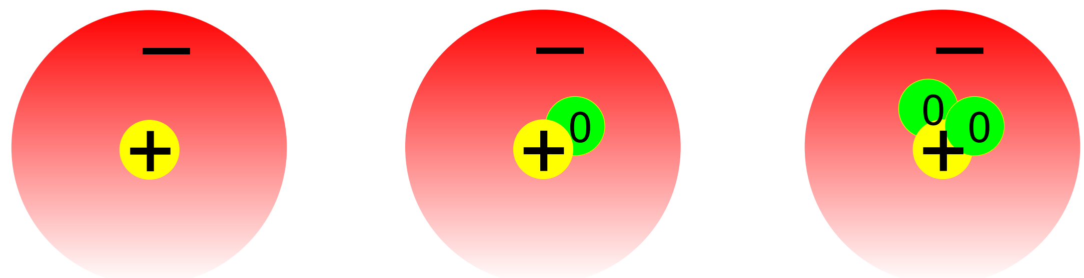
${}^{1}_{1}H$ ${}^{2}_{1}H$ ${}^{3}_{1}H$

The numbers are: Atomic Mass Number and Atomic Number

Composition of atoms

Atoms are combinations of these subatomic particles.
Definition of the word "isotope".

These forms of hydrogen go by the following names:



	$^{1}_{1}H$	$^{2}_{1}H$	$^{3}_{1}H$
These are called:	hydrogen -1	hydrogen-2	hydrogen-3
or symbolized as	H-1	H-2	H-3

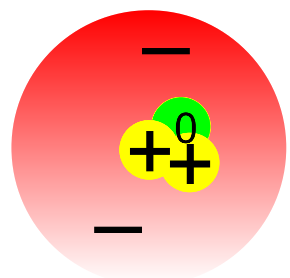
The word "isotope" refers to elements with the same atomic number with differing atomic masses. For the H-2 and H-3 isotopes (only) there are special names: deuterium and tritium

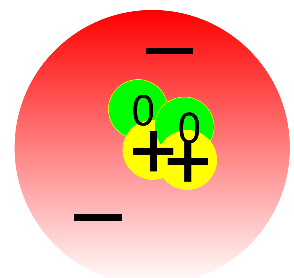
Composition of atoms

Atoms are combinations of these subatomic particles.
The next element is He, and it has two isotopes.

For atomic number 2, there are two stable isotopes:

The atoms that have 2 protons are called helium, with the symbol "He"





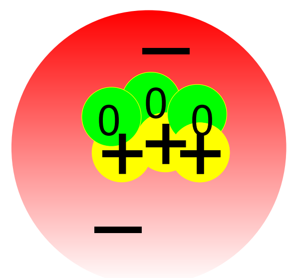
	$^{3}_{2}He$	$^{4}_{2}He$
These are called:	helium-3	helium-4
or symbolized as	He-3	He-4

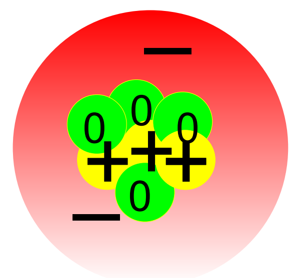
Composition of atoms

Atoms are combinations of these subatomic particles.
..and next, Li - it has two stable isotopes.

For atomic number 3, there are two stable isotopes:

The atoms that have 3 protons are called lithium, with the symbol “Li”





$^{6}_{3}\mathrm{Li}$ $^{7}_{3}\mathrm{Li}$

These are called: lithium-6 lithium-7
or symbolized as Li-6 Li-7

Composition of atoms

Atoms are combinations of these subatomic particles.
..and a table of some more stable isotopes.

Here is a table for the first 9 elements:

				average mass (per atom)
Hydrogen	$^{1}_{1}\text{H}$	$^{2}_{1}\text{H}$	$^{3}_{1}\text{H}$	1.67×10^{-24} kg
Helium	$^{3}_{2}\text{He}$	$^{4}_{2}\text{He}$		6.65×10^{-24} kg
Lithium	$^{6}_{3}\text{Li}$	$^{7}_{3}\text{Li}$		1.15×10^{-23} kg
Berium	$^{9}_{4}\text{Be}$			1.50×10^{-23} kg
Boron	$^{10}_{5}\text{B}$	$^{11}_{5}\text{B}$		1.80×10^{-23} kg
Carbon	$^{12}_{6}\text{C}$	$^{13}_{6}\text{C}$		1.99×10^{-23} kg
Nitrogen	$^{14}_{7}\text{N}$	$^{15}_{7}\text{N}$		2.33×10^{-23} kg
Oxygen	$^{16}_{8}\text{O}$	$^{17}_{8}\text{O}$	$^{18}_{8}\text{O}$	2.66×10^{-23} kg
Fluorine	$^{19}_{9}\text{F}$			3.15×10^{-23} kg

Composition of atoms

..but what is that last column labeled “molar mass”?

That last column is the average mass of 6.022×10^{23} atoms of the natural mix of the element. (Masses from previous slide.)

				molar mass
Hydrogen	${}^{1}_{1}H$	${}^{2}_{1}H$	${}^{3}_{1}H$	1.008 g mol^{-1}
Helium	${}^{3}_{2}He$	${}^{4}_{2}He$		4.003 g mol^{-1}
Lithium	${}^{6}_{3}Li$	${}^{7}_{3}Li$		6.941 g mol^{-1}
Berium	${}^{9}_{4}Be$			9.012 g mol^{-1}
Boron	${}^{10}_{5}B$	${}^{11}_{5}B$		10.81 g mol^{-1}
Carbon	${}^{12}_{6}C$	${}^{13}_{6}C$		12.011 g mol^{-1}
Nitrogen	${}^{14}_{7}N$	${}^{15}_{7}N$		14.007 g mol^{-1}
Oxygen	${}^{16}_{8}O$	${}^{17}_{8}O$	${}^{18}_{8}O$	15.998 g mol^{-1}
Fluorine	${}^{19}_{9}F$			18.998 g mol^{-1}

Composition of atoms

Notice that for some of the elements it approximates the atomic mass number, especially those that have only one isotope. For others it's not close to an integer, since it is a weighted average of the natural isotope.

				molar mass
Hydrogen	${}^{1}_{1}H$	${}^{2}_{1}H$	${}^{3}_{1}H$	$1.008\ g\ mol^{-1}$
Helium	${}^{3}_{2}He$	${}^{4}_{2}He$		$4.003\ g\ mol^{-1}$
Lithium	${}^{6}_{3}Li$	${}^{7}_{3}Li$		$6.941\ g\ mol^{-1}$
Berium	${}^{9}_{4}Be$			$9.012\ g\ mol^{-1}$
Boron	${}^{10}_{5}B$	${}^{11}_{5}B$		$10.81\ g\ mol^{-1}$
Carbon	${}^{12}_{6}C$	${}^{13}_{6}C$		$12.011\ g\ mol^{-1}$
Nitrogen	${}^{14}_{7}N$	${}^{15}_{7}N$		$14.007\ g\ mol^{-1}$
Oxygen	${}^{16}_{8}O$	${}^{17}_{8}O$	${}^{18}_{8}O$	$15.998\ g\ mol^{-1}$
Fluorine	${}^{19}_{9}F$			$18.998\ g\ mol^{-1}$

Composition of atoms

However, even for those with one isotope, Be and F, it does not match the atomic mass. This is due to the energy given off to bind the protons and neutrons together. This is the result of the Einstein interconverability of mass and energy ($E = mc^2$).

				molar mass
Hydrogen	${}^{1}_{1}H$	${}^{2}_{1}H$	${}^{3}_{1}H$	$1.008\ g\ mol^{-1}$
Helium	${}^{3}_{2}He$	${}^{4}_{2}He$		$4.003\ g\ mol^{-1}$
Lithium	${}^{6}_{3}Li$	${}^{7}_{3}Li$		$6.941\ g\ mol^{-1}$
Berium	${}^{9}_{4}Be$			$9.012\ g\ mol^{-1}$
Boron	${}^{10}_{5}B$	${}^{11}_{5}B$		$10.81\ g\ mol^{-1}$
Carbon	${}^{12}_{6}C$	${}^{13}_{6}C$		$12.011\ g\ mol^{-1}$
Nitrogen	${}^{14}_{7}N$	${}^{15}_{7}N$		$14.007\ g\ mol^{-1}$
Oxygen	${}^{16}_{8}O$	${}^{17}_{8}O$	${}^{18}_{8}O$	$15.998\ g\ mol^{-1}$
Fluorine	${}^{19}_{9}F$			$18.998\ g\ mol^{-1}$

Composition of atoms

Notice also that the subscript numbers are redundent with the name or the symbol of the element.

				molar mass
Hydrogen	${}^{1}_{1}H$	${}^{2}_{1}H$	${}^{3}_{1}H$	1.008 g mol^{-1}
Helium	${}^{3}_{2}He$	${}^{4}_{2}He$		4.003 g mol^{-1}
Lithium	${}^{6}_{3}Li$	${}^{7}_{3}Li$		6.941 g mol^{-1}
Barium	${}^{9}_{4}Be$			9.012 g mol^{-1}
Boron	${}^{10}_{5}B$	${}^{11}_{5}B$		10.81 g mol^{-1}
Carbon	${}^{12}_{6}C$	${}^{13}_{6}C$		12.011 g mol^{-1}
Nitrogen	${}^{14}_{7}N$	${}^{15}_{7}N$		14.007 g mol^{-1}
Oxygen	${}^{16}_{8}O$	${}^{17}_{8}O$	${}^{18}_{8}O$	15.998 g mol^{-1}
Fluorine	${}^{19}_{9}F$			18.998 g mol^{-1}

Composition of atoms

Since the atomic number and the symbol are redundent, the number is very often left off.

				molar mass
Hydrogen	^{1}H	^{2}H	^{3}H	1.008 g mol^{-1}
Helium	^{3}He	^{4}He		4.003 g mol^{-1}
Lithium	^{6}Li	^{7}Li		6.941 g mol^{-1}
Barium	^{9}Be			9.012 g mol^{-1}
Boron	^{10}B	^{11}B		10.81 g mol^{-1}
Carbon	^{12}C	^{13}C		12.011 g mol^{-1}
Nitrogen	^{14}N	^{15}N		14.007 g mol^{-1}
Oxygen	^{16}O	^{17}O	^{18}O	15.998 g mol^{-1}
Fluorine	^{19}F			18.998 g mol^{-1}

Composition of Molecules and Ions

monoatomic molecules and ions

Some molecules and some ions contain only one atom. These are referred to as monatomic (one atom).

Examples of these are:

for molecules: He, Ne, Ar etc.

for ions: Cr^{3+} , Cl^{-}, I^{-}, etc.

Notice that what the + or – sign indicate is:

+ fewer electrons in the ion as would be found in the atom. That is there are more protons than electrons.

– more electrons in the ion as would be found in the atom. That is there are less protons than electrons.

Composition of Molecules and Ions

polyatomic molecules and ions

Most molecules and ions contain more that one type of atom. These are referred to as polyatomic*.   (* = See footnote.)

Examples of these are:

for molecules: CH_4, CH_3COOH, etc.

for ions: SO_4^{2-} , Hg_2^{2+}, CH_3COO^- etc.

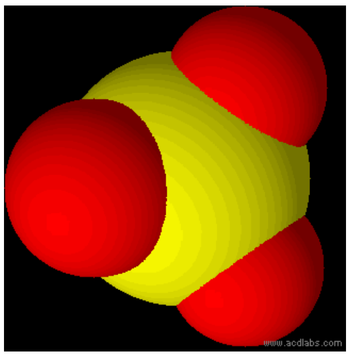
Ions do not occur by themselves but always have counter ions. Positive and negative ions will always be co-accompanied. For example, the negative ion SO_4^{2-} could be accompanied by counter ions such as twice as many Na^+ ions. This gives the formula unit Na_2SO_4. (...or by one Ca^{2+} to give $CaSO_4$.)

*Subscripts indicate the number of atoms in the molecule if more than 1.

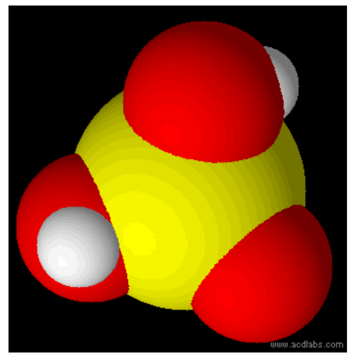
Shapes of Molecules and Ions

What do molecules and ions look like?

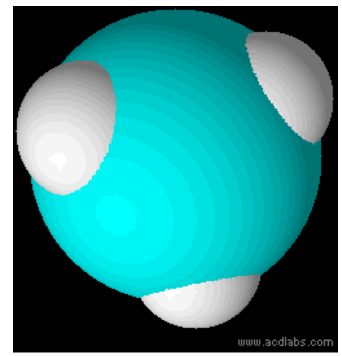
Below are some examples of molecules and ions and what they "look like" if one could see them (colors being arbitrary).



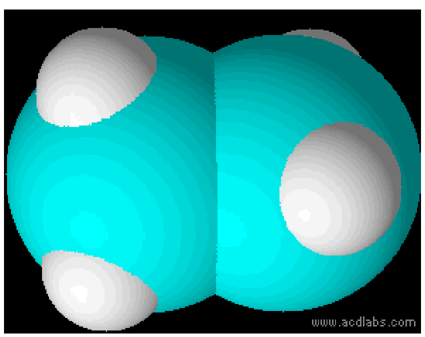
Sulfate ion - SO_4^{2-}



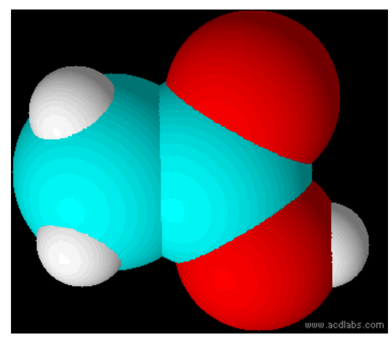
Sulfuric acid - H_2SO_4



Methane - CH_4



Ethane - H_3CCH_3

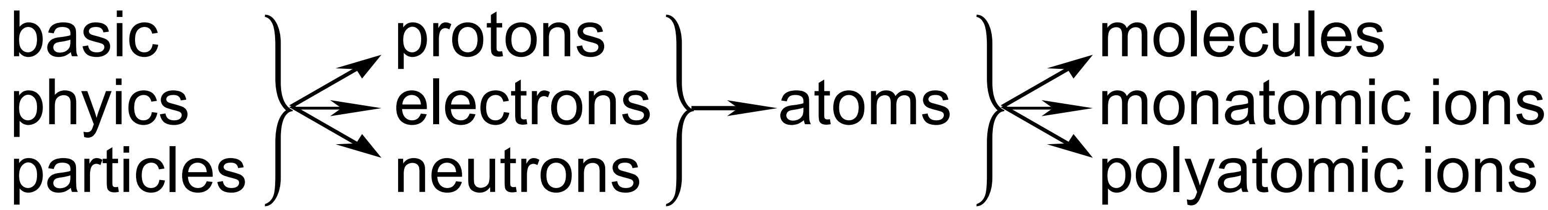


Acetic acid - H_3CCOOH

Summary

polyatomic molecules and ions

Below is a schematics of the buildup of particles leading to compounds



Compounds consist of either molecules or ions.

Elements consist of the same types of atoms.

Particles, Atoms, Molecules and Ions

The End