Chapter 2: Atomic Theory

“all things are made of atoms - little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into each other”
(Richard Feynman, Six Easy Pieces, 1963)

500 BC: Democritus verses Aristotle

Democritus:
"reality is atoms and empty space"

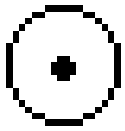
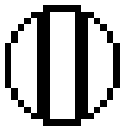
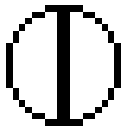
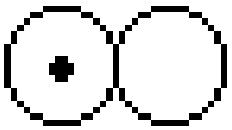
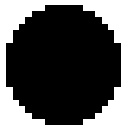
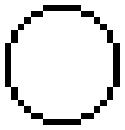
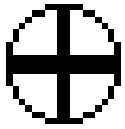
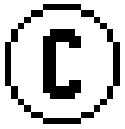
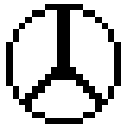
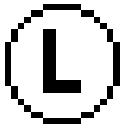
Aristotle:
"matter is infinitely divisible"

Neither were experimentalists
- conclusions based on theory

***atomos* = indivisible**

John Dalton

- > 200,000 weather observations over 46 consecutive years
- Accepted views of Democritus
- Proposed symbols for elements
- Proposed modern atomic theory

 *Hydrogen*	 *Soda*
 *Nitrogen*	 *Water*
 *Carbon*	 *Oxygen*
 *Sulphur*	 *Copper*
 *Phosphorus*	 *Lead*

Why was Dalton sure that atoms were real?

- Elements couldn't be broken down , indivisible atoms
- Elements combined in whole number ratios 2H:O , H_2O
- Brownian motion - random motion of pollen grains on water
- Elements combined in more than 1 set of proportions

Dalton's Atomic Theory (1806)

- All matter is composed of atoms
- Atoms cannot be created or destroyed
- Atoms of a given element are all the same
- Atoms of different elements are different
- Atoms cannot be changed into different atoms

We now know Dalton's ideas were not entirely correct

- atoms are divisible
- atoms can be created
- atoms of a given element can be different
- atoms can be changed into other atoms

Scanning Tunneling Microscope

Rohrer & Binnig
(1981)

Sharp probe (<10^{-9} m) scans sample , map of surface
STM can move atoms about

Inside the atom

Electron

Proton

Neutron

Nucleus

The Discovery of the Electron

William Crookes (1832-1919)

- **Current passed through 2 electrodes**
- **Positive electrode = anode**
  Negative electrode = cathode
- **Tube sealed and evacuated**
- **Glows - cathode rays**

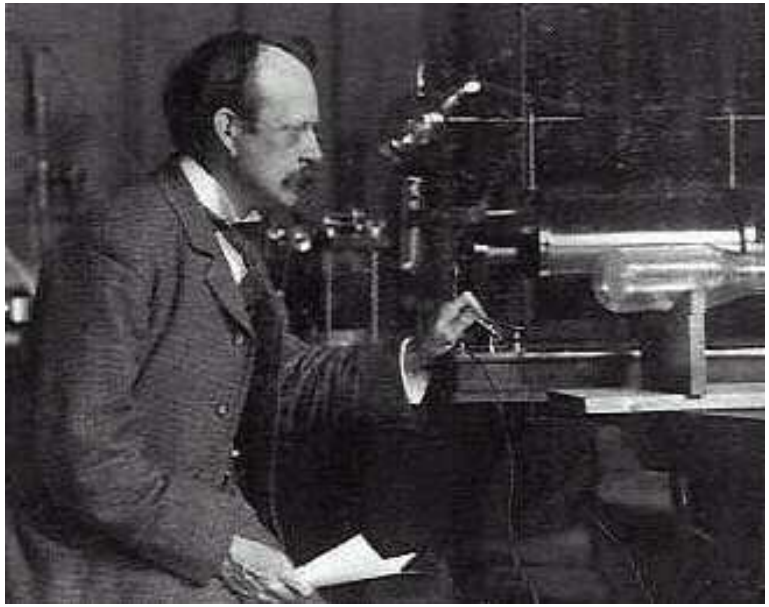
What were the cathode rays?

Matter (particles) or energy (light)?

J.J. Thomson

refined previous experiments and designed new ones to uncover the true nature of these mysterious cathode rays

What was Thomson's major discovery?



J.J. Thomson

Showed that the cathode rays could bend in an electric field.

Attracted to a positive field, repelled by a negative field.

Thomson's conclusions (1897)

- **Cathode rays are charged particles, called corpuscles.**

- **Corpuscles are constituents of the atom.**

Proposed (1904) initial model of atom

A sphere full of positive substance mixed with negative electrons "like the raisins in a cake"

1891: "electron"
- coined by G. Johnstone Stoney

1897: George Fitzgerald suggested renaming corpuscles

What is a practical application for the Crookes Tube ?

How could atoms be neutral and be composed of only negative particles?

The search for positive particles was on!

Discovery was a gradual process, normally credited to Ernest Rutherford (1871-1937) after he discovered the nucleus (1911)

Rutherford

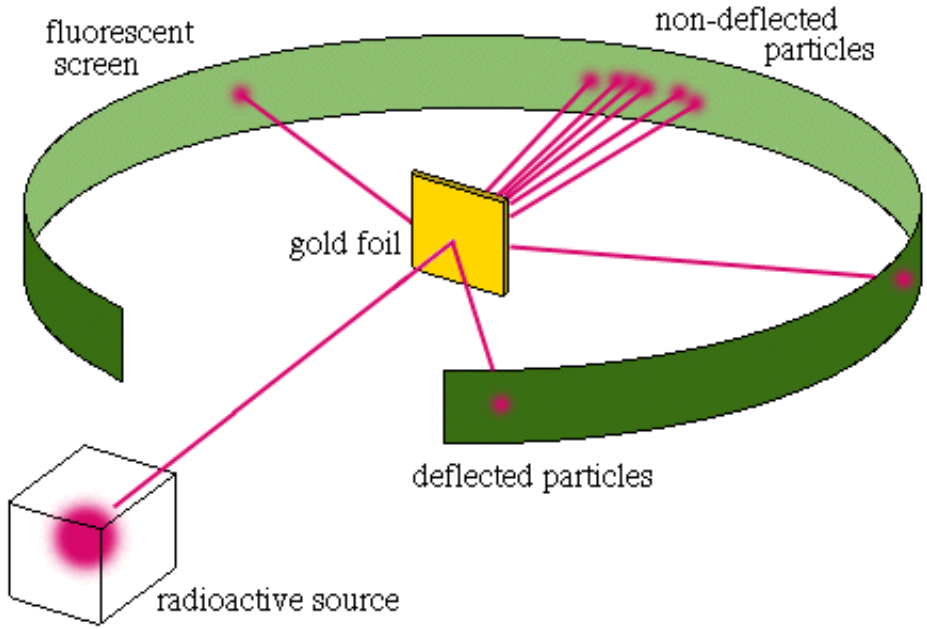
Rutherford

- Born Brightwater, NZ
- Studied Nelson/Canterbury Colleges
- £150/year scholarship Cavendish Lab
- Recent discoveries: electrons, X-rays, radioactivity

Rutherford

- Worked in Thomson’s lab
- Discovered alpha and beta rays
- Professor, McGill University, 1898
- Tested Thomson's hypothesis with the “Gold foil" experiment

The Rutherford scattering experiment



- **Reasoned that if Thomson's model was correct then the mass of the atom was spread out throughout the atom.**

Developed the planetary model of the atom.

Protons in nucleus, electrons orbited nucleus (like planets around sun)

Neutrons

James Chadwick

(1891-1974)

Problem with the mass of atoms

Hydrogen = 1 proton + 1 electron
Helium … 2 protons + 2 electrons

Extra mass due to .....?? neutrons

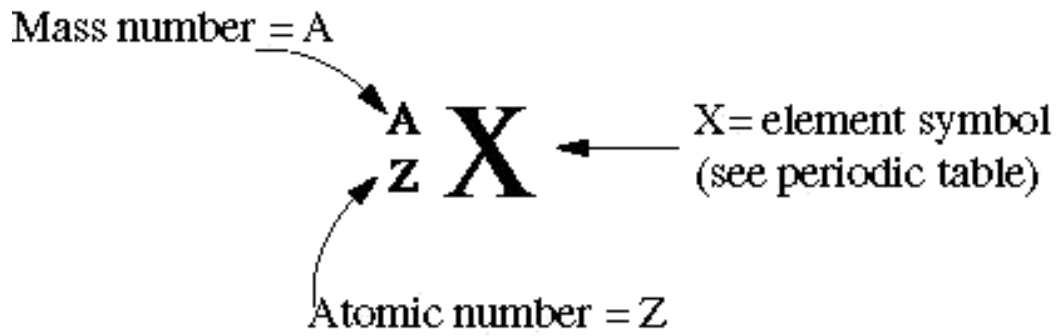
Relative masses:
protons and neutrons equal
electron 1,800 times lighter
Relative size: nucleus small

Large hadron collider

Atomic & Mass Numbers

Atomic number

Number of p^+ (Z)

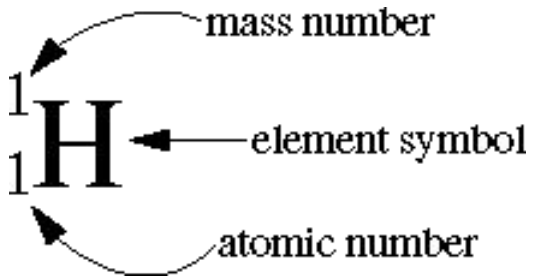


Mass number

Number of p^+ + number of n^0 (A)

$^{23}_{11}Na$ **How many p^+ e^- n^0**

Atomic & Mass Numbers



$^{3}_{1}H$

How many p^+ e^- n^0

Isotopes

Atoms of same element have the same number of protons, but may have different number of neutrons

Gives rise to isotopes

Isotopes are atoms of the same element having different masses

$^{1}_{1}H$

$^{2}_{1}H$
(Deuterium)

$^{3}_{1}H$
(Tritium)

$^{3}_{2}He$

$^{4}_{2}He$

Periodic Table

Mendeleev: 1869

shows all known elements

metals: 80%
non-metals: 15%
metalloids: 5%

metals:
main group
transition
inner transition

Periodic table of elements

	1 1A												13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 **H** 1.00794	2 2A																2 **He** 4.00260
2	3 **Li** 6.941	4 **Be** 9.01218											5 **B** 10.811	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.1797
3	11 **Na** 22.9898	12 **Mg** 24.3050	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 **Al** 26.9815	14 **Si** 28.0855	15 **P** 30.9738	16 **S** 32.066	17 **Cl** 35.4527	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.9381	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.61	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.906	46 **Pd** 106.42	47 **Ag** 107.868	48 **Cd** 112.411	49 **In** 114.818	50 **Sn** 118.710	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.904	54 **Xe** 131.29
6	55 **Cs** 132.905	56 **Ba** 137.327	57 ***La** 138.906	72 **Hf** 178.49	73 **Ta** 180.948	74 **W** 183.84	75 **Re** 186.207	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.967	80 **Hg** 200.59	81 **Tl** 204.383	82 **Pb** 207.2	83 **Bi** 208.980	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226.025	89 **†Ac** 227.028	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Ds** (281)	111 ** (272)	112 ** (285)		114 ** (289)		116 ** (292)		

*Lanthanide series	58 **Ce** 140.115	59 **Pr** 140.908	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.965	64 **Gd** 157.25	65 **Tb** 158.925	66 **Dy** 162.50	67 **Ho** 164.930	68 **Er** 167.26	69 **Tm** 168.934	70 **Yb** 173.04	71 **Lu** 174.967
†Actinide series	90 **Th** 232.038	91 **Pa** 231.036	92 **U** 238.029	93 **Np** 237.048	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Periodic Table

Groups 1-18:
similar chemical/physical properties

Periods 1-7:
properties change regularly

Special names for groups 1, 2, 17, 18

Molecules and Ions

Molecules:

2 or more atoms bonded together
can be elements or compounds
can be diatomic or polyatomic

Ions:

atoms or molecules with + or -charge
formed by gain/loss of electrons

+ ion = cation **- ion = anion**

Chemical Nomenclature

1. Naming inorganic compounds

2. Writing chemical formulas

Chemical Names and Formulas

H_2O NaCl

both examples of binary compounds

NaCl:
salt **common or traditional name**
sodium chloride **scientific/systematic name**

Binary Compounds

1) Two Non-metals

covalent compounds

electrons shared

Ending of second element changed to end in -ide

Binary Compounds

1) Two Non-metals

CO_2 þ carbon dioxide

CO_2 þ carbon dioxide

Binary Compounds

1) Two Non-metals

PCl_3 þ phosphorus trichloride

PCl_3 þ phosphorus trichloride

Binary Compounds

1) Two Non-metals

N_2O - dinitrogen oxide

N_2O - dinitrogen oxide

Prefixes

1	mono-	6	hexa-
2	di-	7	hepta-
3	tri-	8	octa-
4	tetra-	9	nona-
5	penta-	10	deca-

When it is necessary to specify the number of atoms in a formula, Greek prefixes are used

Fig 2.4, page 46

Writing formulas from names

Phosphorus pentabromide

P 5 Br û PBr_5

Dichlorine heptasulfide

Cl_2S_7

Binary Compounds

2) Metal + Non-metal

Ionic compounds

electrons transferred

Chemical Nomenclature

NAMING IONIC COMPOUNDS

Name the cation first
Name the anion second

Chemical Nomenclature

NAMING IONIC COMPOUNDS

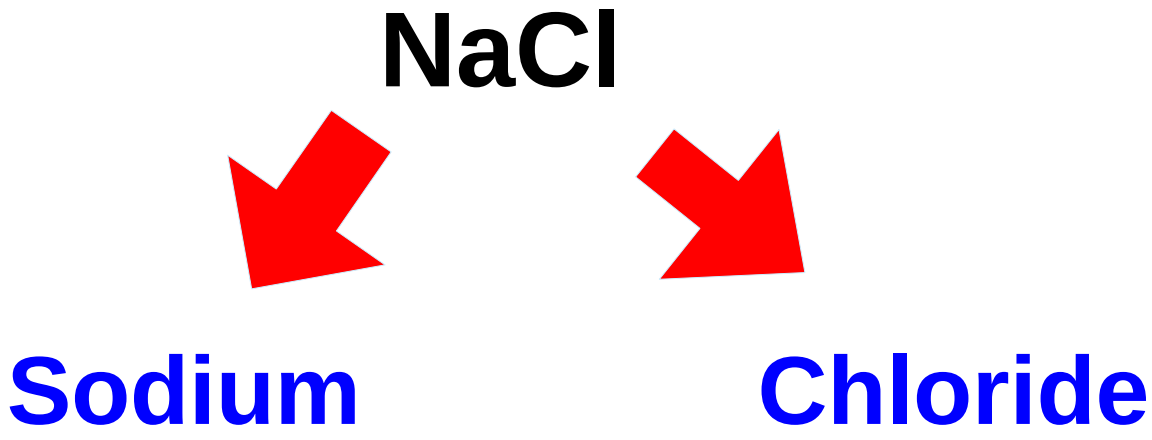
Monoatomic cations take their name from the element name

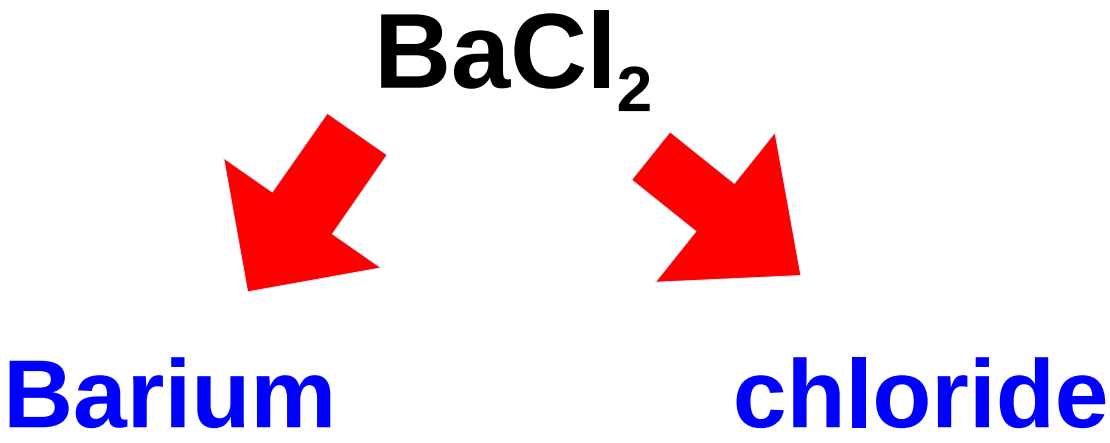
Monoatomic anions take their names from the first part of the element name and then add "-ide"

Chemical Nomenclature

NAMING IONIC COMPOUNDS

Cation	Name	Anion	Name
Na^{+}	Sodium	Cl^{-}	Chloride
Al^{3+}	Aluminum	O^{2-}	Oxide


NaCl
Sodium
Chloride



Note: no prefixes

cation + anion = neutral ionic compound

cation	anion	compound
Ca^{+2}	Cl^{-1}	$CaCl_2$
Ba^{+2}	O^{-2}	BaO
K^{+1}	S^{-2}	K_2S
Fe^{+3}	Br^{-1}	$FeBr_3$
Cr^{+3}	O^{-2}	Cr_2O_3

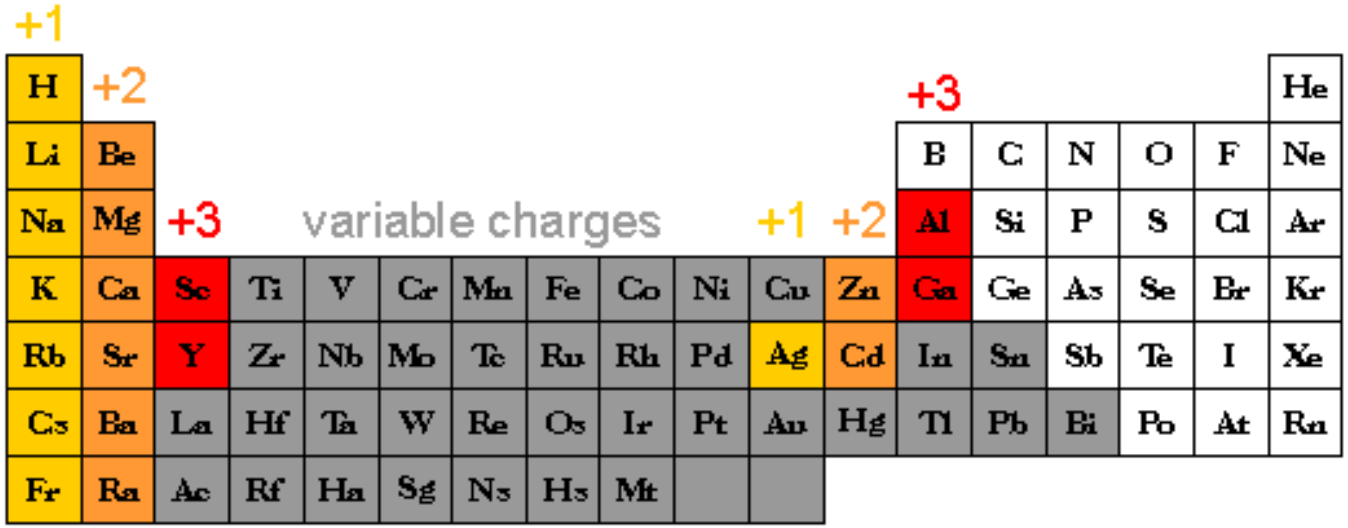
Name the following.....

Li_2O	Lithium oxide
ZnO	Zinc oxide
$AlCl_3$	Aluminum chloride
Ba_3N_2	Barium nitride

Some metal cations have fixed charge

Some have variable charge

Elemental Cations



Fe^{2+} iron(II) ion
Fe^{3+} iron(III) ion
K^{+} potassium ion
Al^{3+} aluminum ion
Ba^{2+} barium(II) ion

Indicate the charge with a Roman numeral...

...unless the element forms only one cation.

Fig 2.10, page 39

Variable charge metal ions to know:

Cobalt:	**Co^{2+}**	**Co^{3+}**
Iron:	**Fe^{2+}**	**Fe^{3+}**
Chromium:	**Cr^{2+}**	**Cr^{3+}**
Lead:	**Pb^{2+}**	**Pb^{4+}**
Tin:	**Sn^{2+}**	**Sn^{4+}**
Copper:	**Cu^{+}**	**Cu^{2+}**
Gold:	**Au^{+}**	**Au^{3+}**

Name the following.....

CuO	Copper(II) oxide
$FeCl_3$	Iron(III) chloride
Cr_2O_3	Chromium (III) oxide

Ammonium ion NH_4^+

Won't use -ic and -ous endings

Total charge cation = total charge anion

ZnO	$Zn^{2+}\ O^{2-}$
$AlCl_3$	$Al^{3+}\ (Cl^{-})_3$
Ba_3N_2	$(Ba^{2+})_3\ (N^{3-})_2$

Monatomic Cation Charges

Gp 1: +1 Li^+ Na^+ K^+

Gp 2: +2 Mg^{2+} Ba^{2+} Ca^{2+}

Others: Al^{3+} Zn^{2+} Ag^+

Monatomic Anion Charges

Gp 17:	-1	F^-	Cl^-	Br^-
Gp 16:	-2	O^{2-}	S^{2-}	
Gp 15:	-3	N^{3-}	P^{3-}	
Others:		H^-		

Common Polyatomic Ions

NH_4^+	ammonium
NO_3^-	nitrate
SO_4^{2-}	sulfate
CO_3^{2-}	carbonate
PO_4^{3-}	phosphate
OH^-	hydroxide
CN^-	cyanide
$C_2H_3O_2^-$	acetate
HCO_3^-	hydrogen carbonate

Also need to be able to name an ionic compound from its chemical formula

Name the following.....

$NaOH$	sodium hydroxide
$Ca(CN)_2$	calcium cyanide
K_2SO_4	potassium sulfate
$Pb(CO_3)_2$	lead(IV) carbonate

Give formulas for the following.....

lithium nitrate $LiNO_3$

sodium sulfate Na_2SO_4

iron(II) carbonate $FeCO_3$

To name a compound

1. **Is it ionic or covalent ?**
2. **If ionic, does it contain a metal that can have variable charges ?**

Chemical Nomenclature

ACIDS

all acids contain hyrdogen

They produce the hydrogen ion H^+ when dissolved in water

ACIDS

Two types

1. **Binary acids**
   hydrogen + nonmetal

2. **Oxoacids**
   hydrogen + nonmetal + oxygen

Name the following.....

HCl	**hydrogen chloride**
HBr	**hydrogen bromide**
H_2S	**hydrogen sulfide**

when added to water the hydrogen forms ions: H^+ ions

name changes from -ide to -ic

HCl in water.....

called hydrochloric acid

hydro means water

Name the following.....

H_2SO_4 hydrogen sulfate ?

sulfuric acid

HNO_3 nitric acid

Also know: H_3PO_4 = phosphoric acid

$HC_2H_3O_2$ = acetic acid

Bases

hydroxides

carbonates

oxides

bicarbonates

ammonia

Common Names

dry ice

baking soda

marble

laughing gas

gypsum

saltpeter