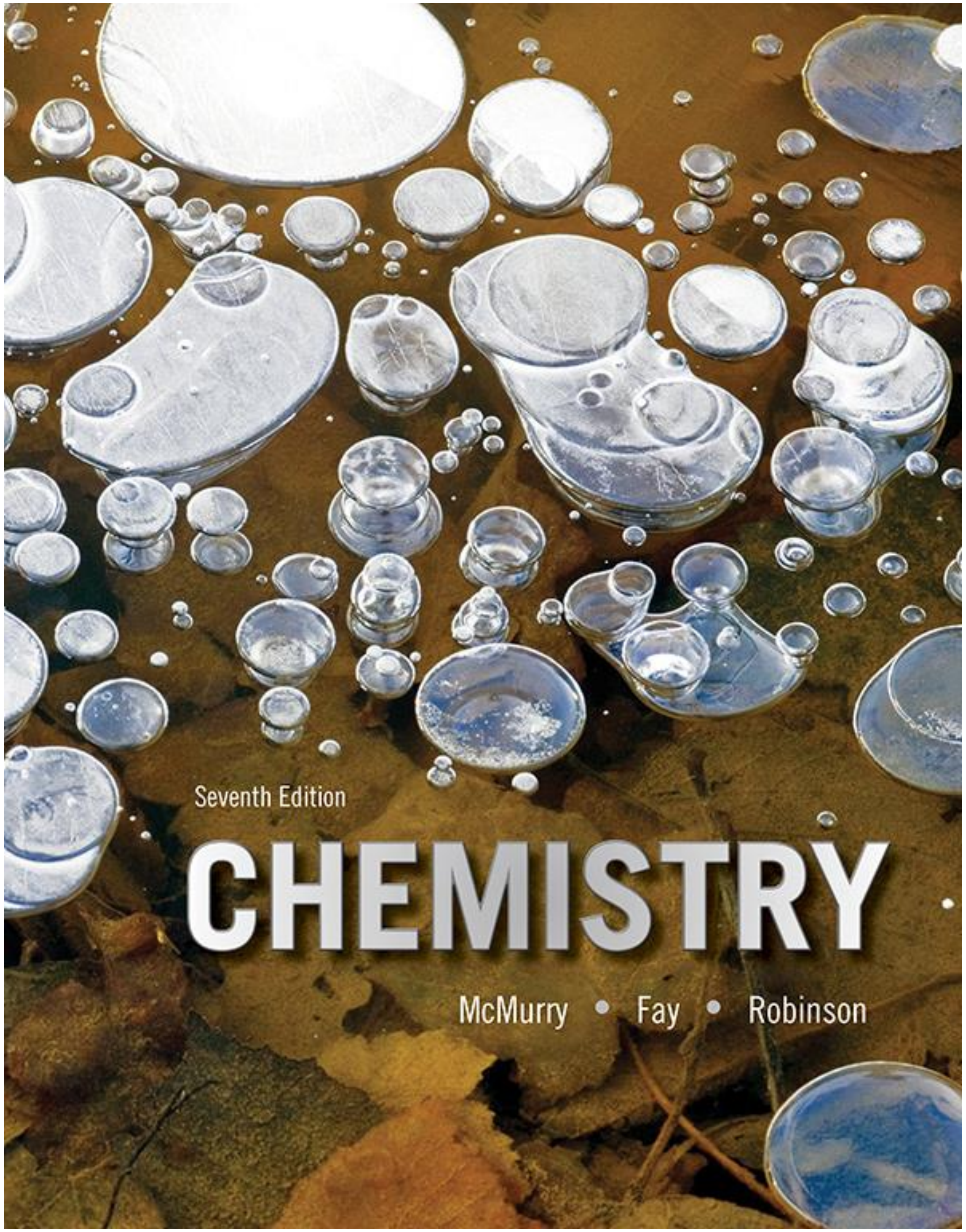

Lecture Presentation

Chapter 2

Atoms, Molecules, and Ions

John E. McMurry
Robert C. Fay

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Chemistry and the Elements

TABLE 2.1 Names and Symbols of Some Common Elements. Latin names from which the symbols of some elements are derived are shown in parentheses.

Aluminum	**Al**	Chlorine	**Cl**	Manganese	**Mn**	Copper (*cuprum*)	**Cu**
Argon	**Ar**	Fluorine	**F**	Nitrogen	**N**	Iron (*ferrum*)	**Fe**
Barium	**Ba**	Helium	**He**	Oxygen	**O**	Lead (*plumbum*)	**Pb**
Boron	**B**	Hydrogen	**H**	Phosphorus	**P**	Mercury (*hydrargyrum*)	**Hg**
Bromine	**Br**	Iodine	**I**	Silicon	**Si**	Potassium (*kalium*)	**K**
Calcium	**Ca**	Lithium	**Li**	Sulfur	**S**	Silver (*argentum*)	**Ag**
Carbon	**C**	Magnesium	**Mg**	Zinc	**Zn**	Sodium (*natrium*)	**Na**

Atomic Number
Chemical symbol

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113	114	115	116	117	118

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Elements and the Periodic Table

Periods: 7 horizontal rows

Groups: 18 vertical columns

- International standard: 1–18
- U.S. system: 1A–8A, 1B–8B

Elements and the Periodic Table

Main Groups

- Columns 1A–2A (2 groups)
- Columns 3A–8A (6 groups)

Transition Metals: 3B–2B (8 groups, 10 columns)

Inner Transition Metals: 14 groups between 3B and 4B

- Lanthanides
- Actinides

Some Chemical Properties of the Elements

Intensive Properties: Independent of sample size

- Temperature
- Melting point

Extensive Properties: Dependent on sample size

- Length
- Volume

Some Chemical Properties of the Elements

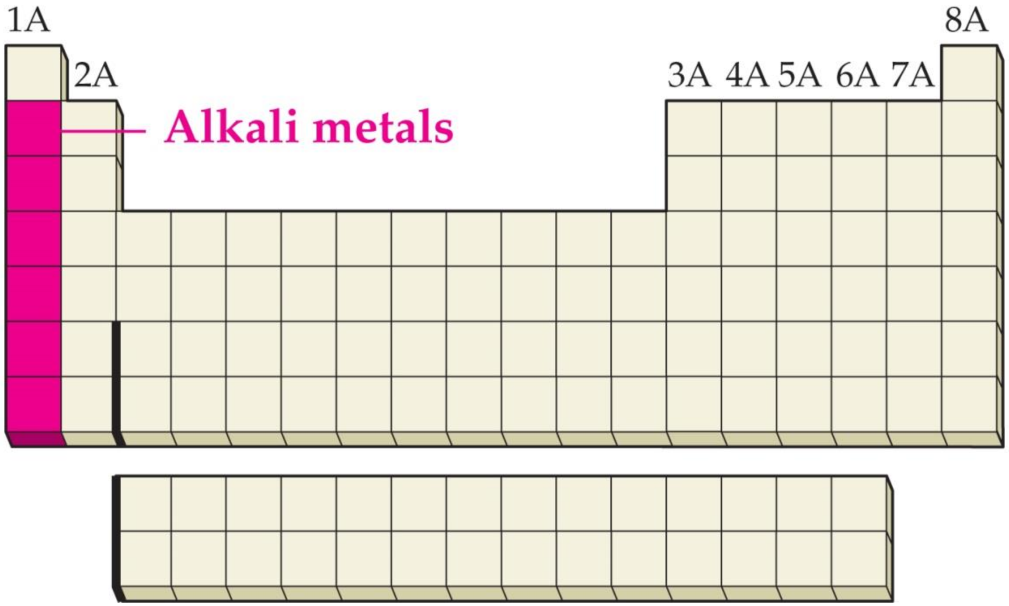
Physical Properties: Characteristics that *do not* involve a change in a sample's chemical makeup

Chemical Properties: Characteristics that *do* involve a change in a sample's chemical makeup

TABLE 2.3 Some Examples of Physical and Chemical Properties

Physical Properties		Chemical Properties
Temperature	Amount	Rusting (of iron)
Color	Odor	Combustion (of gasoline)
Melting point	Solubility	Tarnishing (of silver)
Electrical conductivity	Hardness	Cooking (of an egg)

Some Chemical Properties of the Elements



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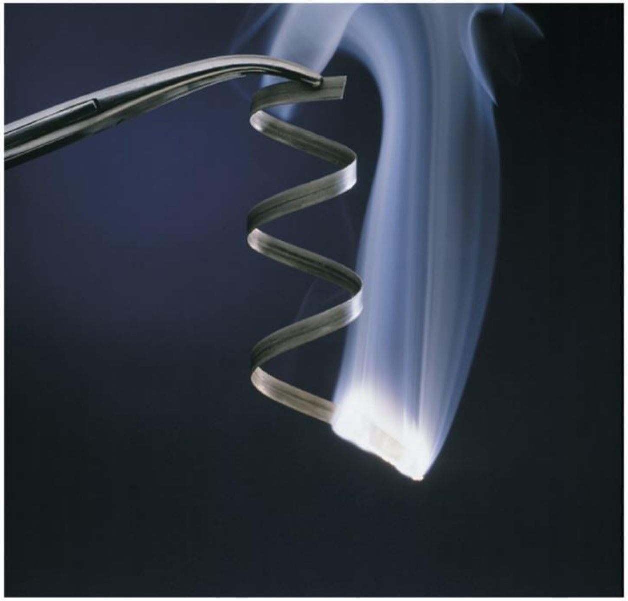
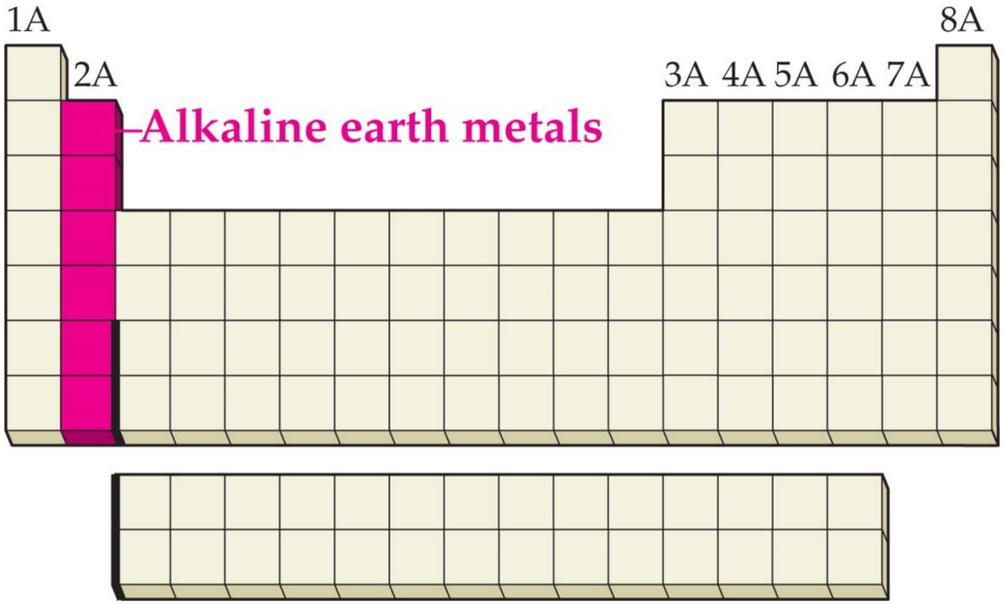
Some Chemical Properties of the Elements





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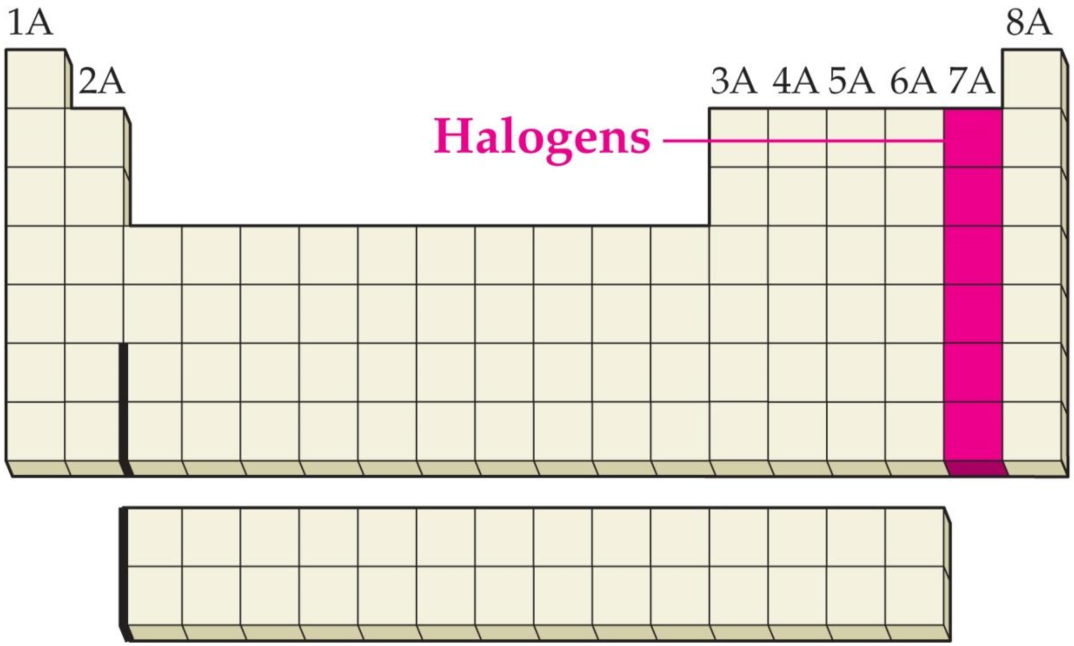
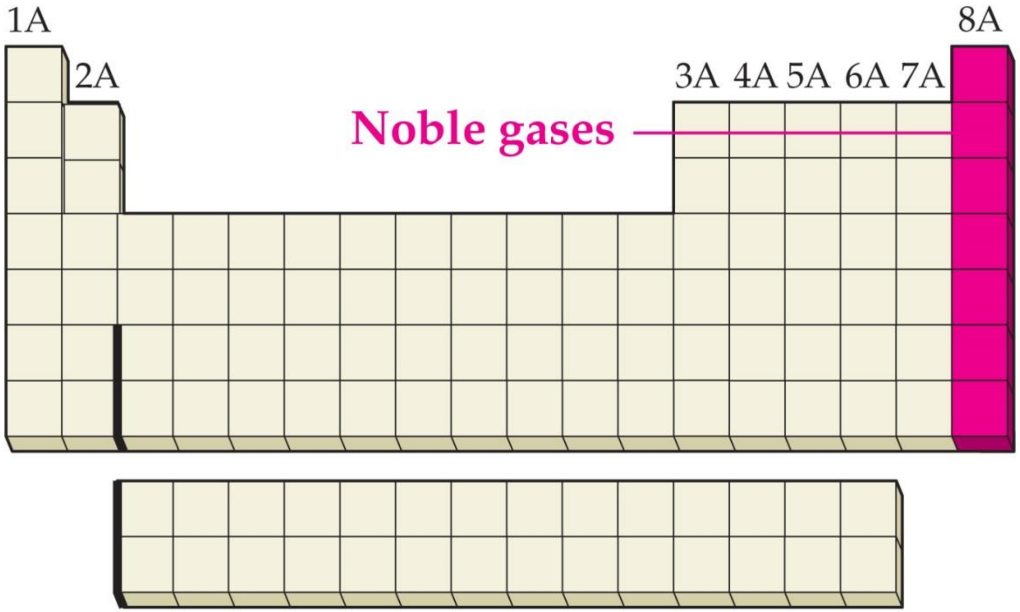
Some Chemical Properties of the Elements

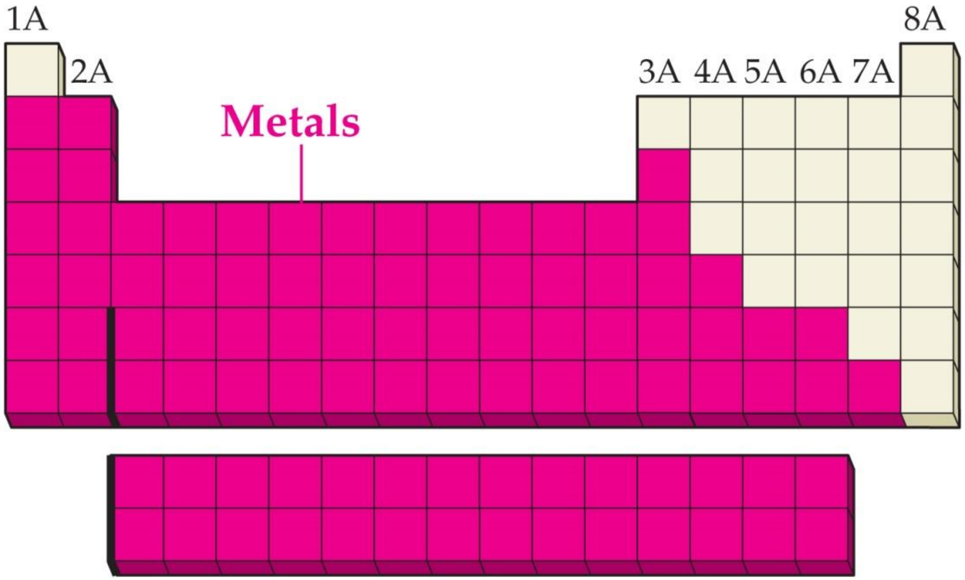


Some Chemical Properties of the Elements



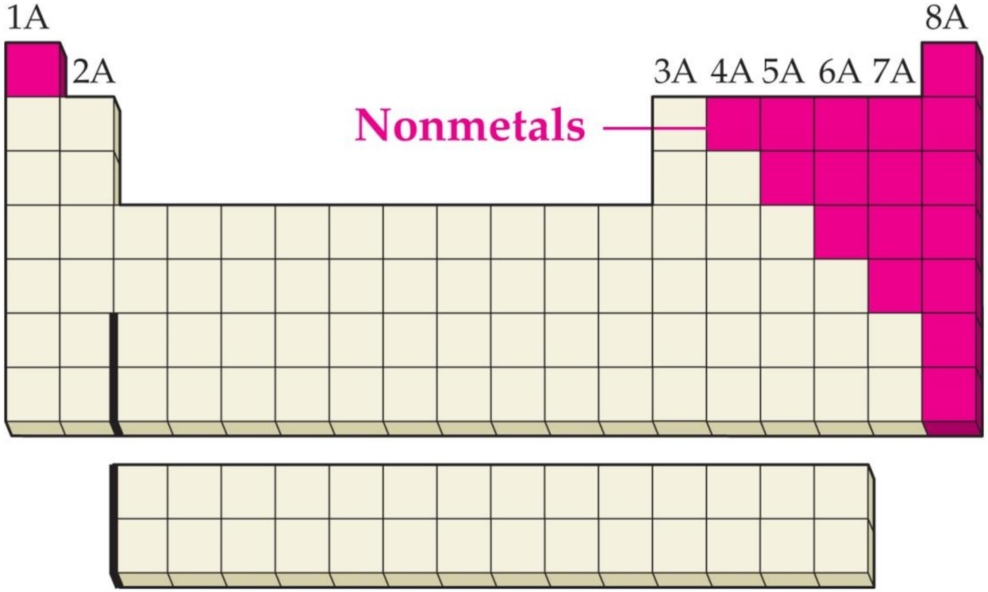
Some Chemical Properties of the Elements

Metals: Left side of the zigzag line in the periodic table (except for hydrogen)



Some Chemical Properties of the Elements

Nonmetals: Right side of the zigzag line in the periodic table



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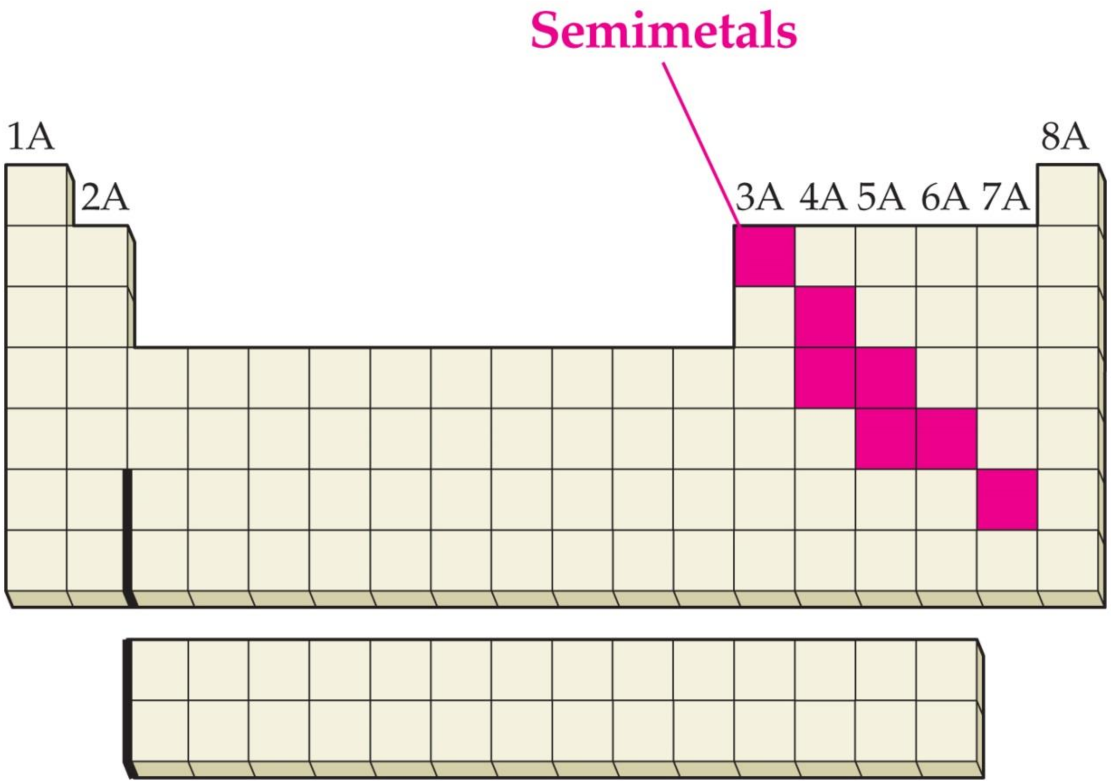
Some Chemical Properties of the Elements

Semimetals (metalloids): Tend to lie along the zigzag line in the periodic table



Conservation of Mass and the Law of Definite Proportions

Law of Conservation of Mass: Mass is neither created nor destroyed in chemical reactions.

Aqueous solutions of mercury(II) nitrate and potassium iodide will react to form a precipitate of mercury(II) iodide and aqueous potassium iodide.

$$\overbrace{Hg(NO_3)_2(aq) + 2KI(aq)}^{3.25\text{ g} + 3.32\text{ g} = 6.57\text{ g}} \longrightarrow \underbrace{HgI_2(s) + 2KNO_3(aq)}_{4.55\text{ g} + 2.02\text{ g} = 6.57\text{ g}}$$

Conservation of Mass and the Law of Definite Proportions

Known amounts of solid KI and solid $Hg(NO_3)_2$ are weighed and then dissolved in water.

The solutions are mixed to give **solid HgI_2**, which is removed by filtration.

The solution that remains is evaporated to give solid KNO_3. On weighing, the combined masses of the products equal the combined masses of the reactants.

$$3.25\text{ g} + 3.32\text{ g} = 6.57\text{ g}$$

$$Hg(NO_3)_2(aq) + 2KI(aq) \longrightarrow HgI_2(s) + 2KNO_3(aq)$$

$$4.55\text{ g} + 2.02\text{ g} = 6.57\text{ g}$$

Conservation of Mass and the Law of Definite Proportions

Law of Definite Proportions: Different samples of a pure chemical substance always contain the same proportion of elements by mass.

By mass, water is	88.8% oxygen
	11.2% hydrogen

The Law of Multiple Proportions and Dalton's Atomic Theory

Law of Multiple Proportions: Elements can combine in different ways to form different substances, whose mass ratios are small whole-number multiples of each other.

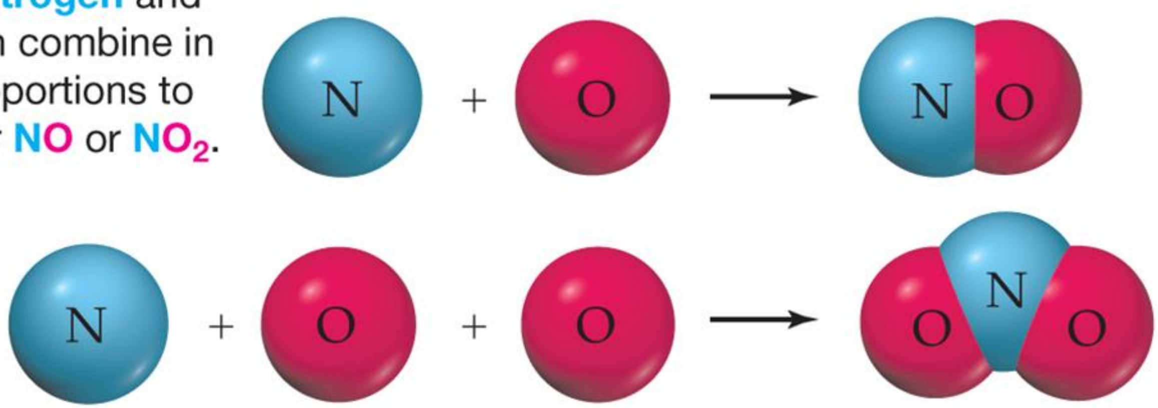
Nitrogen monoxide: 7 grams nitrogen per 8 grams oxygen

Nitrogen dioxide: 7 grams nitrogen per 16 grams oxygen

The Law of Multiple Proportions and Dalton's Atomic Theory

Law of Multiple Proportions: Elements can combine in different ways to form different substances, whose mass ratios are small whole-number multiples of each other.

Atoms of **nitrogen** and **oxygen** can combine in specific proportions to make either **NO** or **NO_2**.



NO_2 contains exactly twice as many atoms of **oxygen** per atom of **nitrogen** as **NO** does.

The Law of Multiple Proportions and Dalton's Atomic Theory

- Elements are made up of tiny particles called **atoms**.

- Each element is characterized by the mass of its atoms. Atoms of the same element have the same mass, but atoms of different elements have different masses.

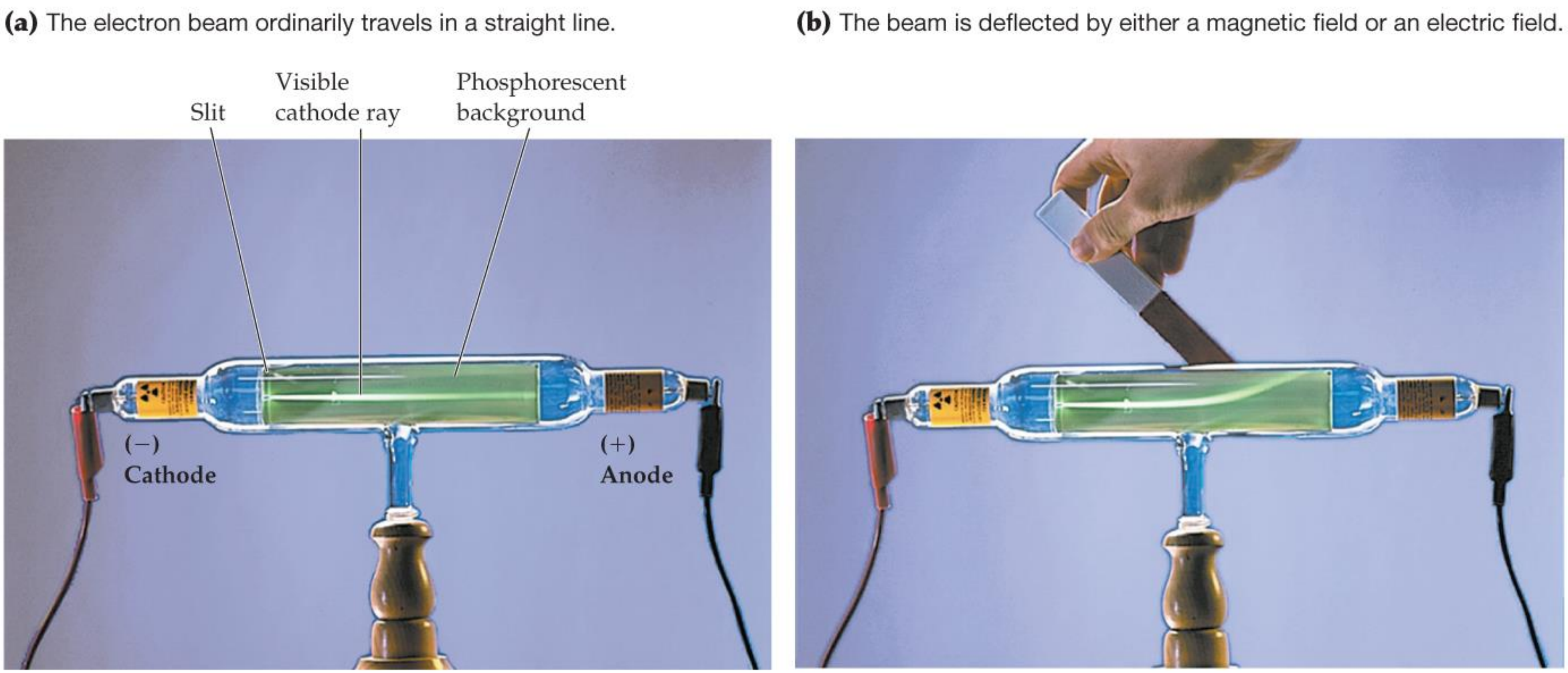
The Law of Multiple Proportions and Dalton's Atomic Theory

- The chemical combination of elements to make different chemical compounds occurs when atoms join in small whole-number ratios.

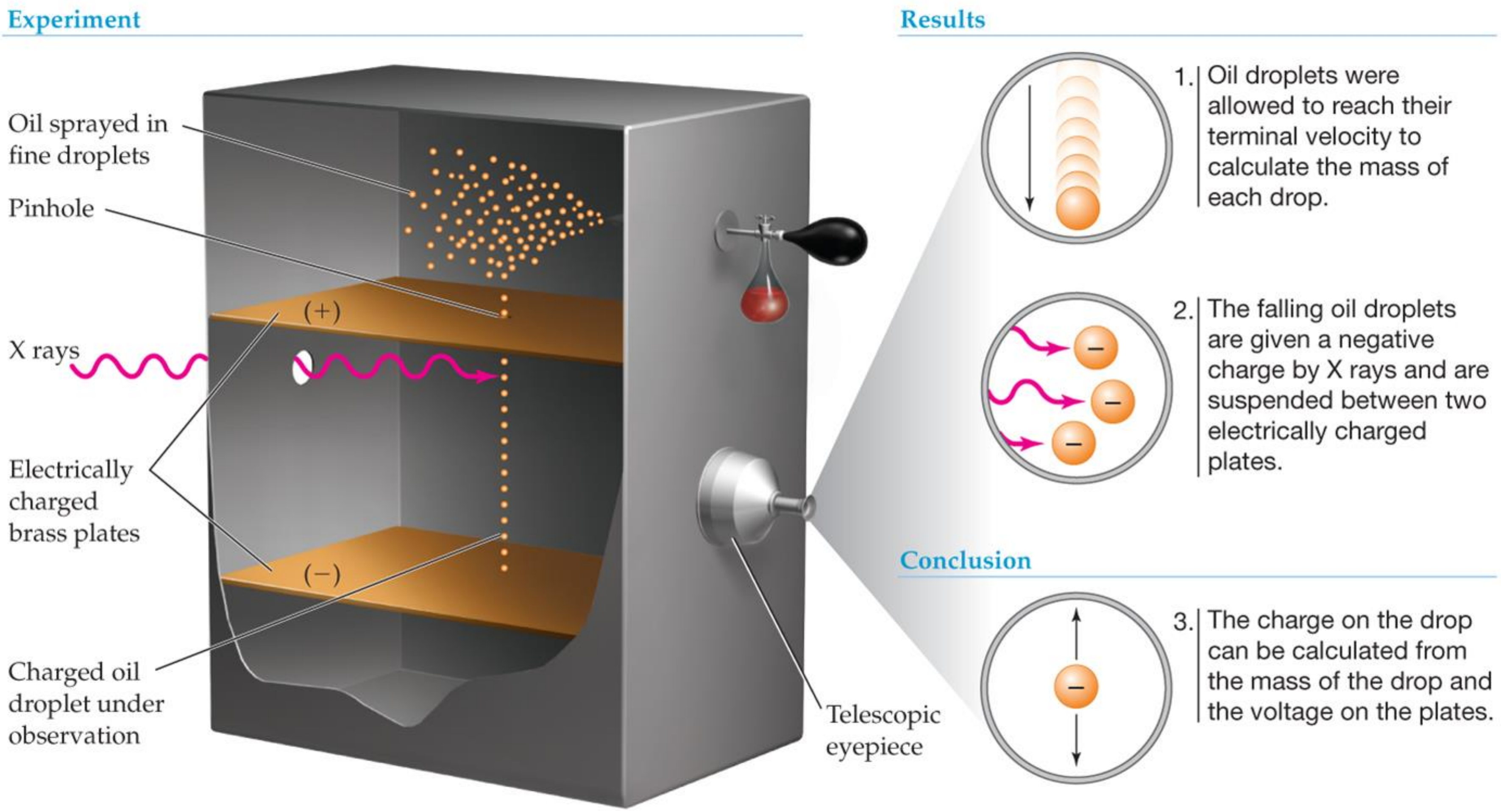
- Chemical reactions only rearrange how atoms are combined in chemical compounds; the atoms themselves don't change.

Atomic Structure: Electrons

Cathode-Ray Tubes: J. J. Thomson (1856–1940) proposed that cathode rays must consist of tiny, negatively charged particles. We now call them **electrons**.



Atomic Structure: Electrons

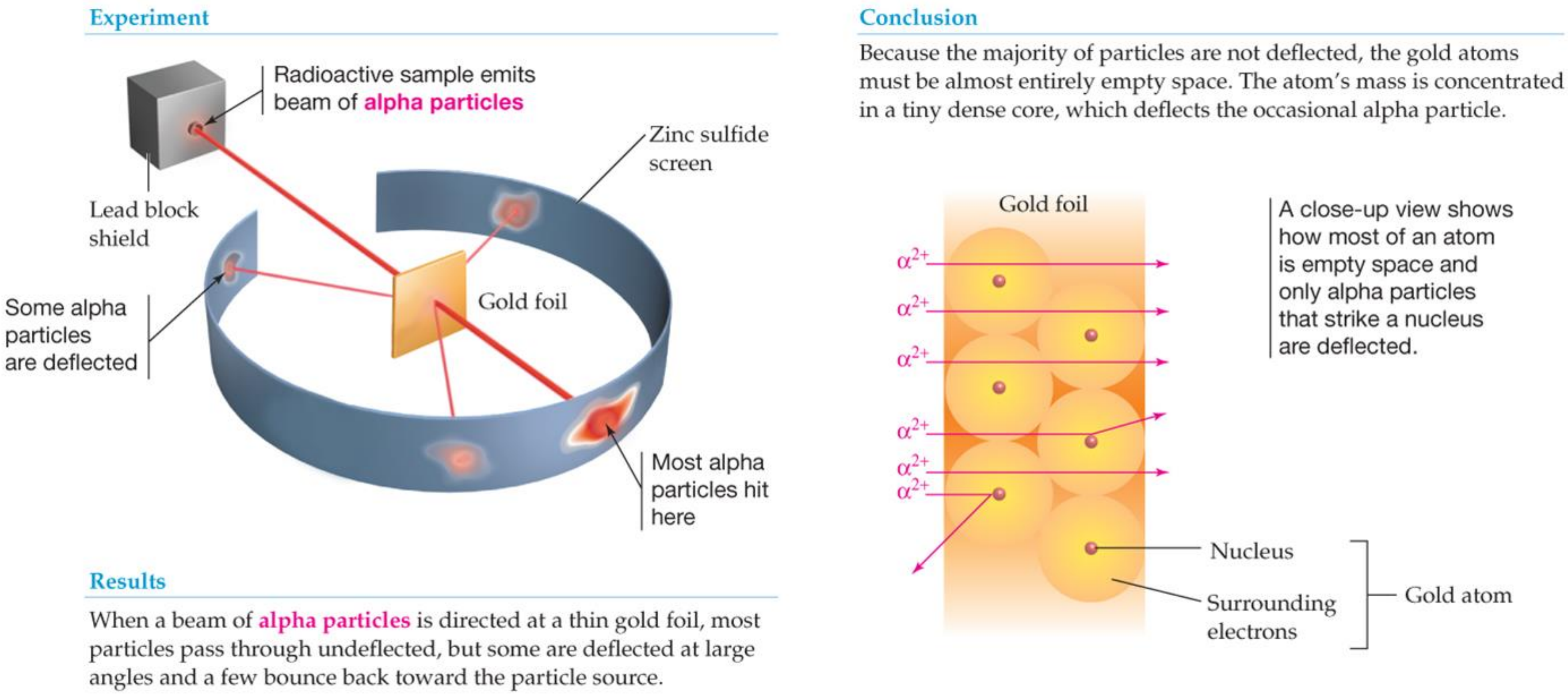


Atomic Structure: Protons and Neutrons

Atomic Nucleus: Ernest Rutherford (1871–1937) bombarded gold foil with alpha particles. Although most of the alpha particles passed through the foil undeflected, approximately 1 in every 20,000 particles was deflected. A fraction of those particles were deflected back at an extreme angle.

Rutherford proposed that the atom must consist mainly of empty space, with the mass concentrated in a tiny central core—the **nucleus**.

Atomic Structure: Protons and Neutrons



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Atomic Structure: Protons and Neutrons

Atomic Structure: Protons and Neutrons

TABLE 2.4 A Comparison of Subatomic Particles

Particle	Mass		Charge	
	Grams	u*	Coulombs	*e*
Electron	$9.109\ 382 \times 10^{-28}$	$5.485\ 799 \times 10^{-4}$	$-1.602\ 176 \times 10^{-19}$	−1
Proton	$1.672\ 622 \times 10^{-24}$	1.007 276	$+1.602\ 176 \times 10^{-19}$	+1
Neutron	$1.674\ 927 \times 10^{-24}$	1.008 665	0	0

*The unified atomic mass unit (u) is defined in Section 2.9.

The mass of the atom is primarily in the nucleus.

Atomic Structure: Protons and Neutrons

TABLE 2.4 A Comparison of Subatomic Particles

Particle	Mass		Charge	
	Grams	u*	Coulombs	*e*
Electron	$9.109\,382 \times 10^{-28}$	$5.485\,799 \times 10^{-4}$	$-1.602\,176 \times 10^{-19}$	-1
Proton	$1.672\,622 \times 10^{-24}$	1.007 276	$+1.602\,176 \times 10^{-19}$	$+1$
Neutron	$1.674\,927 \times 10^{-24}$	1.008 665	0	0

*The unified atomic mass unit (u) is defined in Section 2.9.

The charge of the proton is opposite in sign but equal to that of the electron.

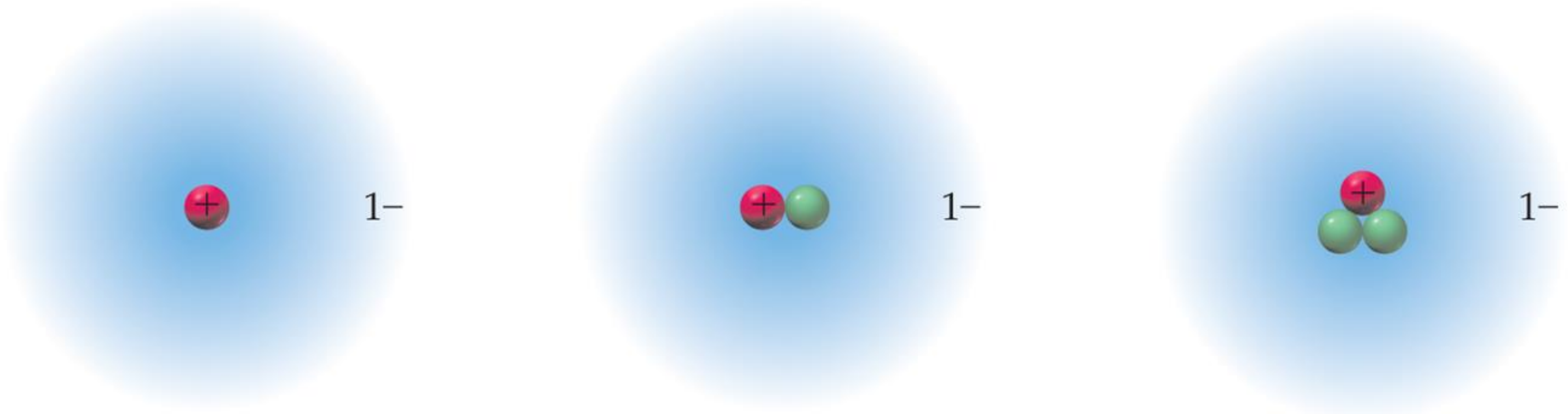
Atomic Numbers

Atomic Number (*Z*): Number of protons in an atom's nucleus, equivalent to the number of electrons around an atom's nucleus

Mass Number (*A*): The sum of the number of protons and the number of neutrons in an atom's nucleus

Isotope: Atoms with identical atomic numbers but different mass numbers

Atomic Numbers



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

Atomic Numbers

Carbon-12:

Mass number

$${}^{12}_{6}\mathrm{C}$$

Atomic number

6 protons
6 electrons
6 neutrons

Carbon-14:

Mass number

$${}^{14}_{6}\mathrm{C}$$

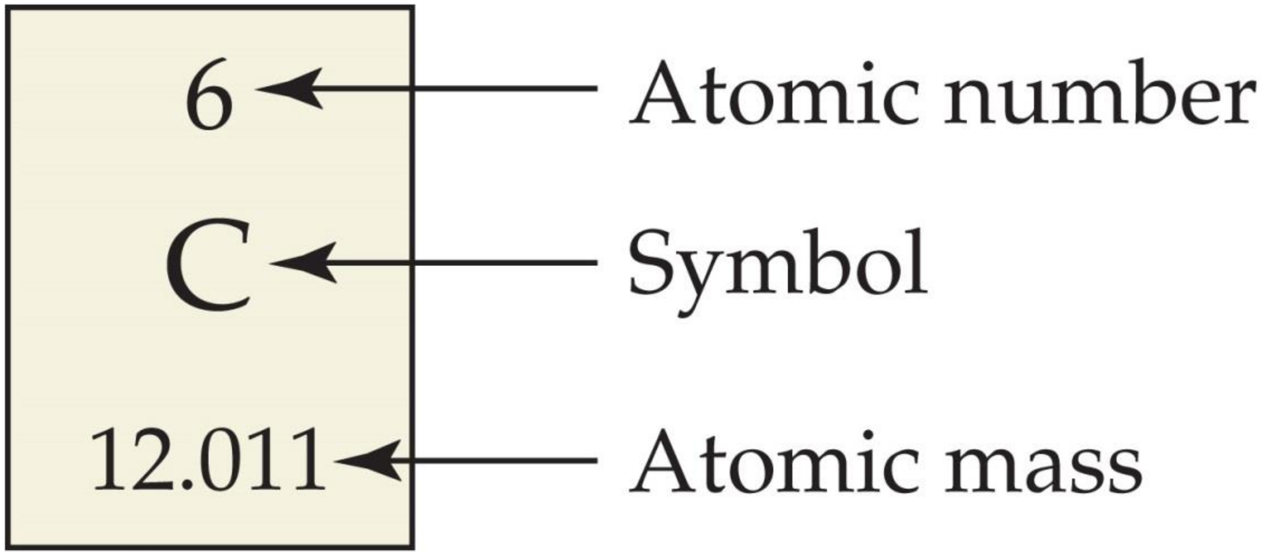
Atomic number

6 protons
6 electrons
8 neutrons

Atomic Masses and the Mole

The mass of 1 atom of carbon-12 is **defined** to be 12 amu.

Atomic Mass: The weighted average of the isotopic masses of the element's naturally occurring isotopes



Atomic Masses and the Mole

Why is the atomic mass of the element carbon 12.01 amu?

Carbon-12: 98.89% natural abundance 12 amu

Carbon-13: 1.11% natural abundance 13.0034 amu

Mass of carbon = (12 amu)(0.9889) + (13.0034 amu)(0.0111)

= 11.87 amu + 0.144 amu

= 12.01 amu

Atomic Masses and the Mole

Avogadro's Number (N_A): One mole of any substance contains 6.022×10^{23} formula units.

Molar Mass: The mass in grams of one mole of any element. It is numerically equivalent to its atomic mass.

Nuclear Chemistry: The Change of One Element Into Another

Nuclear Equation: A reaction that changes an atomic nucleus

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$$

Carbon-14 nucleus

Nitrogen-14 nucleus

Nuclear Chemistry: The Change of One Element Into Another

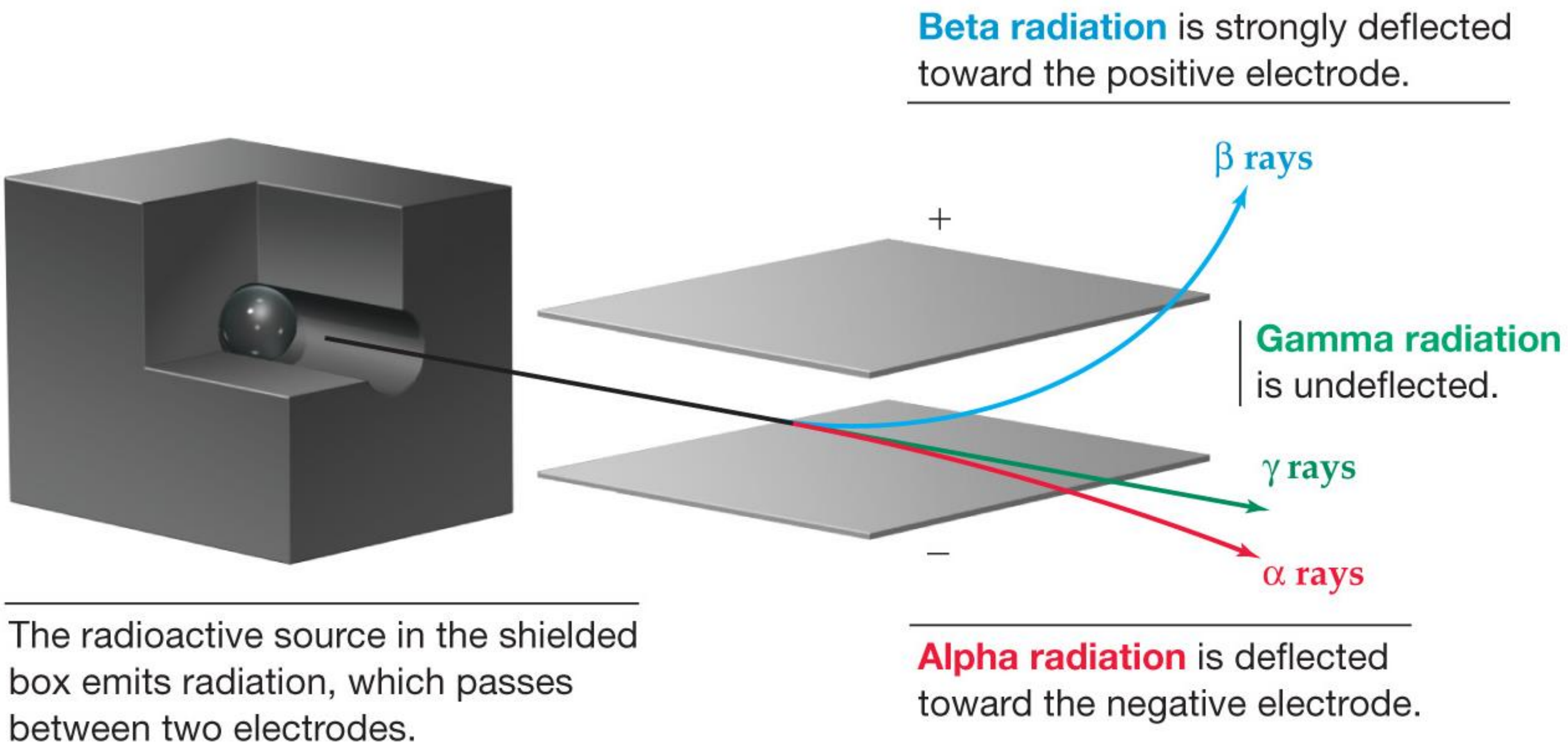
Comparisons between Nuclear and Chemical Reactions

- A *nuclear* reaction changes an atom's nucleus, usually producing a different element. A *chemical* reaction, by contrast, involves only a change in the way that different atoms are combined.

- Different isotopes of an element have essentially the same behavior in *chemical* reactions but often have a completely different behavior in *nuclear* reactions.

- The energy change accompanying a *nuclear* reaction is far greater than that accompanying a *chemical* reaction.

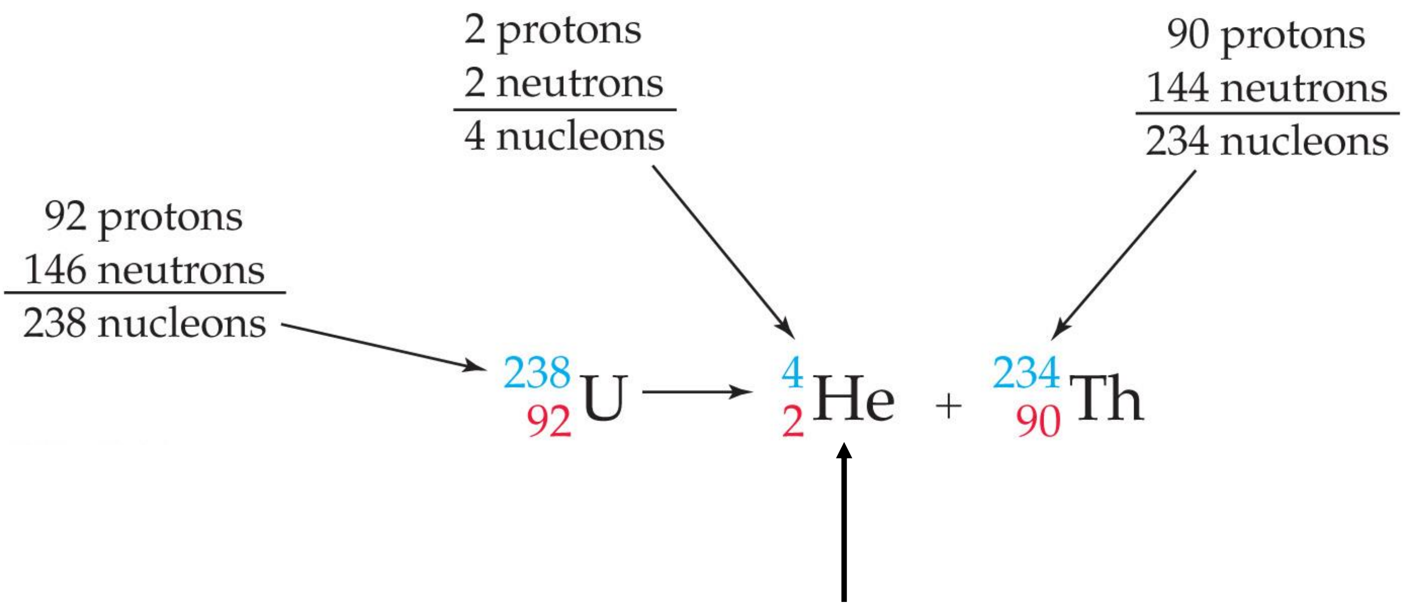
Radioactivity



Radioactivity

Alpha (*α*) Radiation

An alpha particle is a helium-4 nucleus (2 protons and 2 neutrons).



$$^{238}_{92}U \longrightarrow ^{4}_{2}He + ^{234}_{90}Th$$

Alpha particle, *α*

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Radioactivity

Beta (*β*) Radiation

A beta particle is an electron.

53 protons
78 neutrons
131 nucleons

54 protons
77 neutrons
131 nucleons

0 nucleons
but −1 charge

$$^{131}_{53}\mathrm{I} \longrightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e}$$

Beta particle, β^-

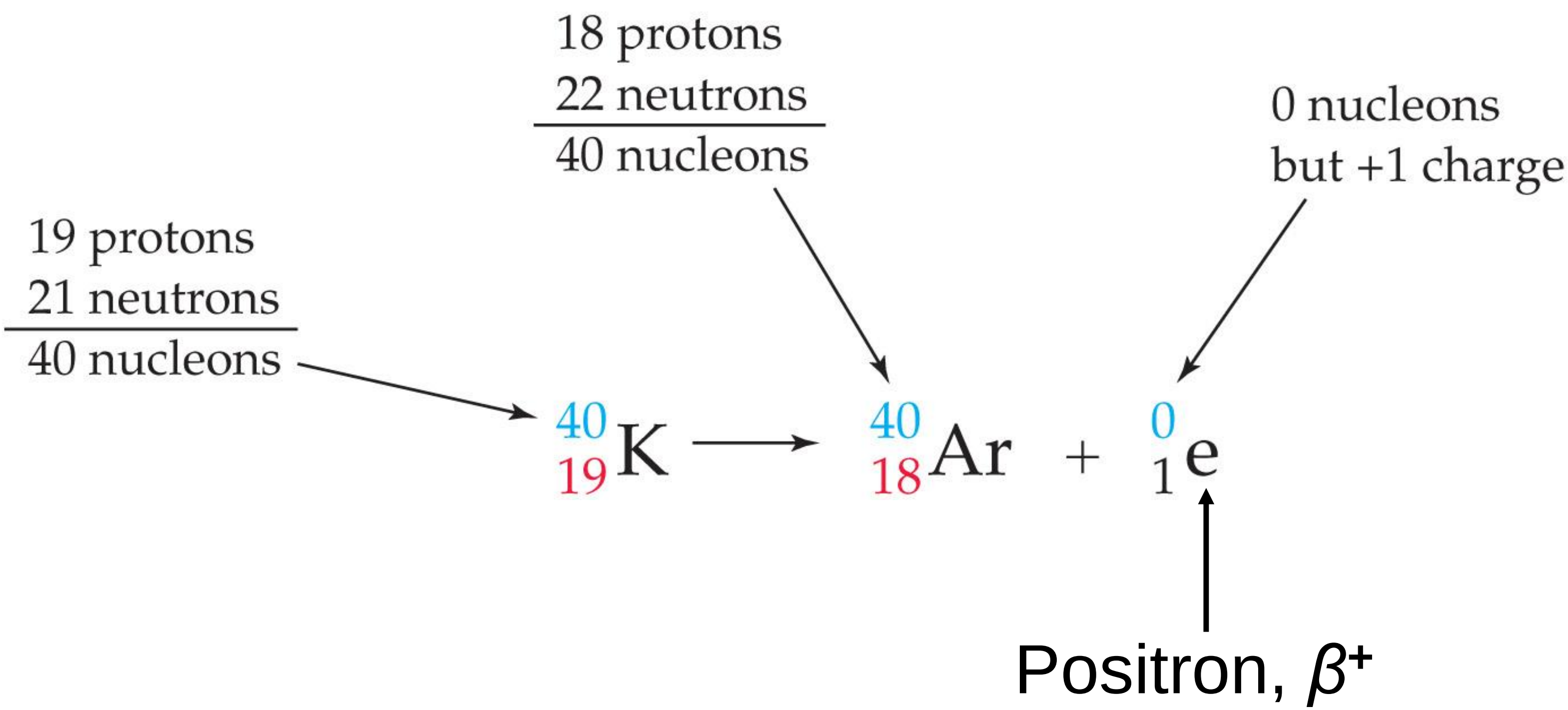
Radioactivity

Gamma (γ) Radiation

A gamma particle is a high-energy photon.

Positron Emission

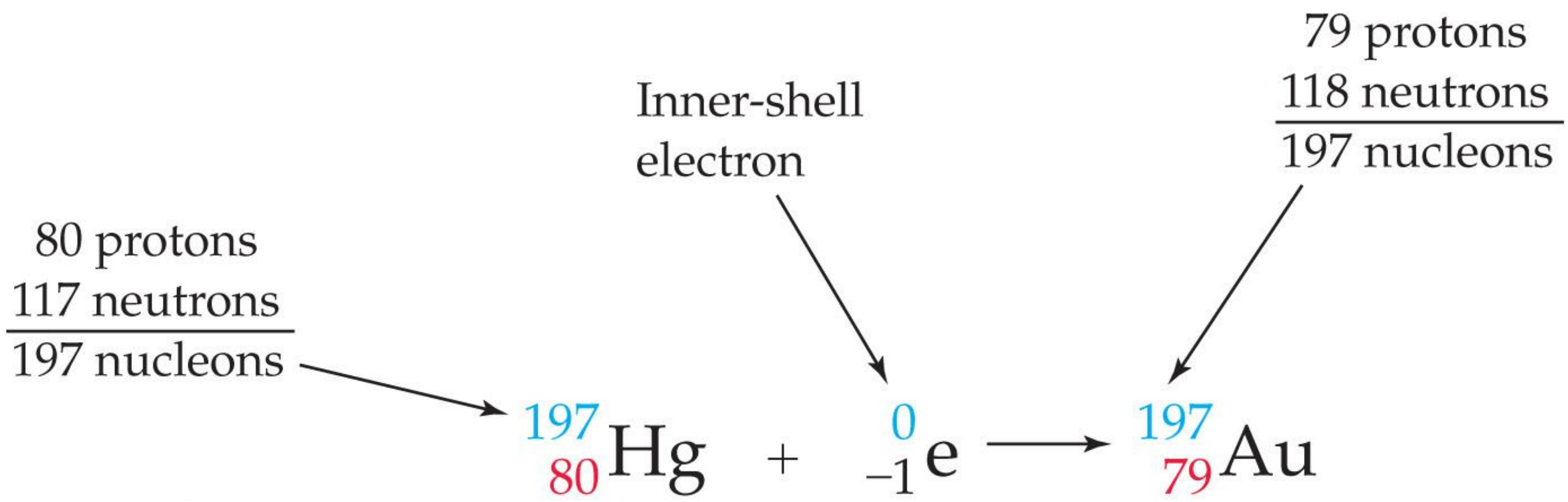
A positron has the same mass as an electron but the opposite charge.



Radioactivity

Electron Capture

A process in which the nucleus captures an inner-shell electron, thereby converting a proton to a neutron

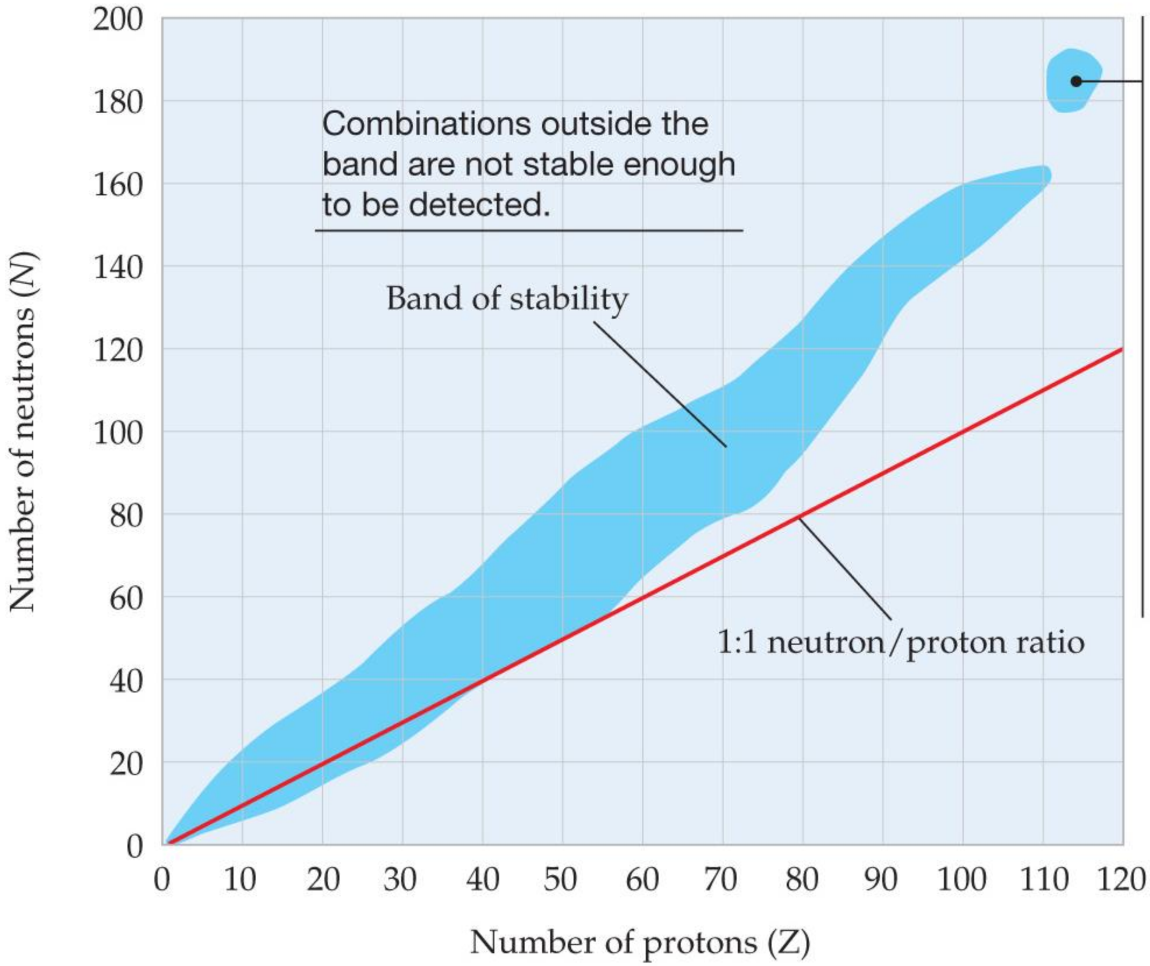


Radioactivity

TABLE 2.2 A Summary of Radioactive Decay Processes

Process	Symbol	Change in Atomic Number	Change in Mass Number	Change in Neutron Number
Alpha emission	${}^{4}_{2}He$ or α	–2	–4	–2
Beta emission	${}^{0}_{-1}e$ or β^-	+1	0	–1
Gamma emission	${}^{0}_{0}\gamma$ or γ	0	0	0
Positron emission	${}^{0}_{1}e$ or β^+	–1	0	+1
Electron capture	E. C.	–1	0	+1

Nuclear Stability



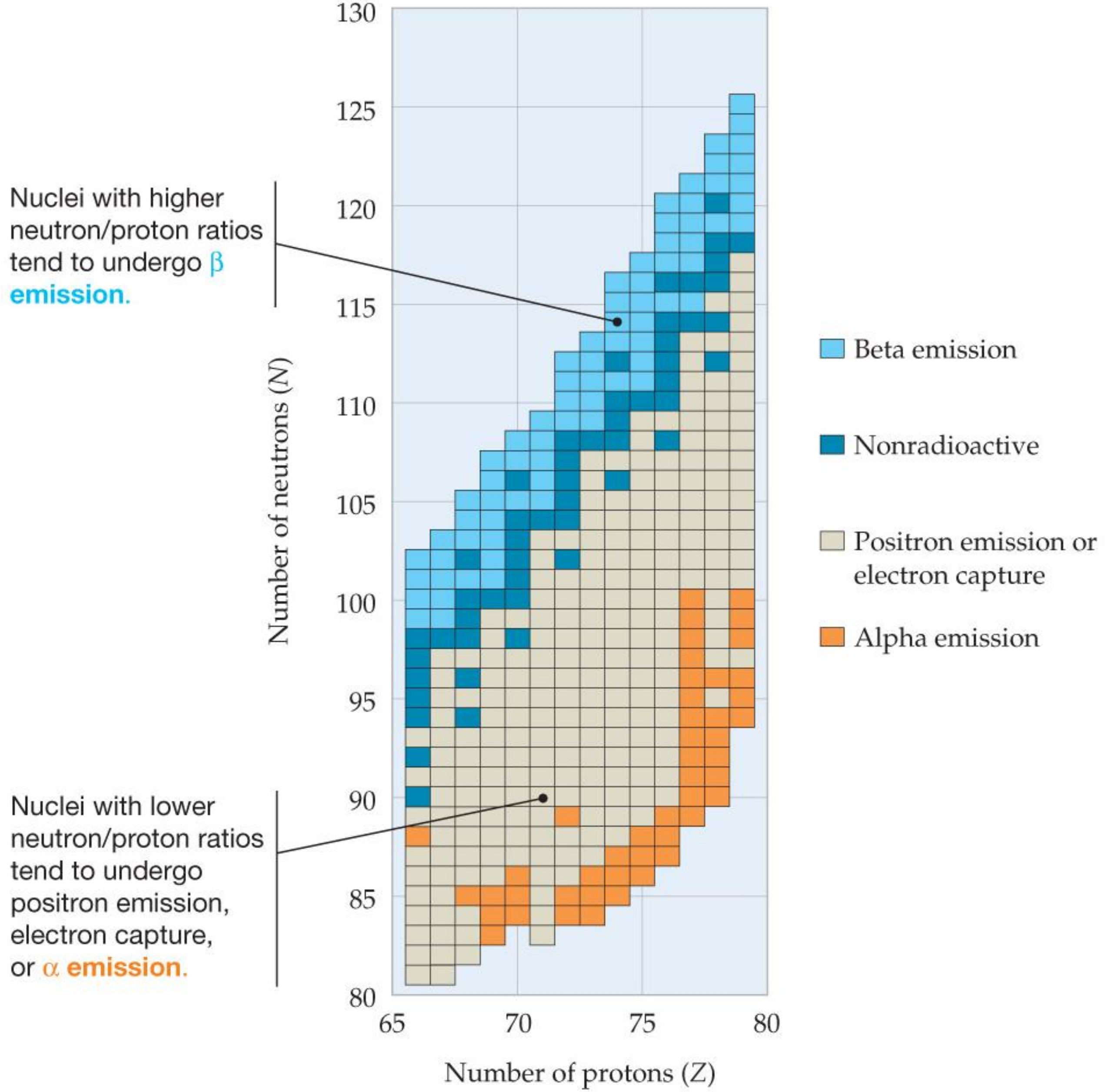
The "island of stability" near 114 protons and 184 neutrons corresponds to a group of superheavy nuclei that are predicted to be radioactive but stable enough to be detected. The first member of this group was reported in 1999.

Nuclear Stability

- Every element in the periodic table has at least one radioactive isotope.
- Hydrogen is the only element whose most abundant stable isotope, hydrogen-1, contains more protons (1) than neutrons (0).

Nuclear Stability

- The ratio of neutrons to protons gradually increases, giving a curved appearance to the band of stability.
- All isotopes heavier than bismuth-209 are radioactive, even though they may decay slowly and be stable enough to occur naturally.



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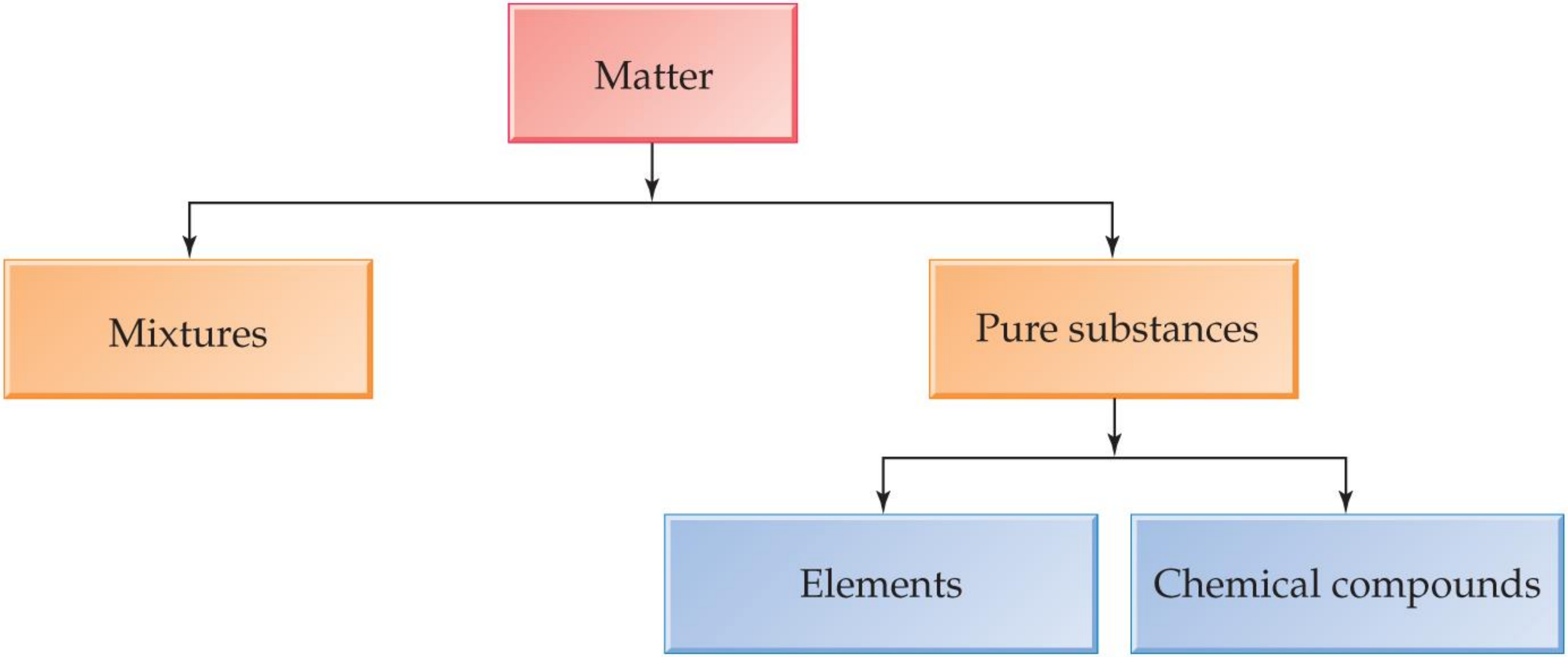
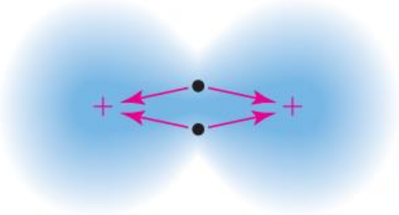
Mixtures and Chemical Compounds



Molecules and Covalent Bonds

Covalent Bond: Results when two atoms share several (usually two) electrons. Typically a nonmetal bonded to a nonmetal.

The two teams are joined together because both are tugging on the same rope.



Similarly, two atoms are joined together when both **nuclei (+)** tug on the same **electrons (dots)**.

Molecules and Covalent Bonds

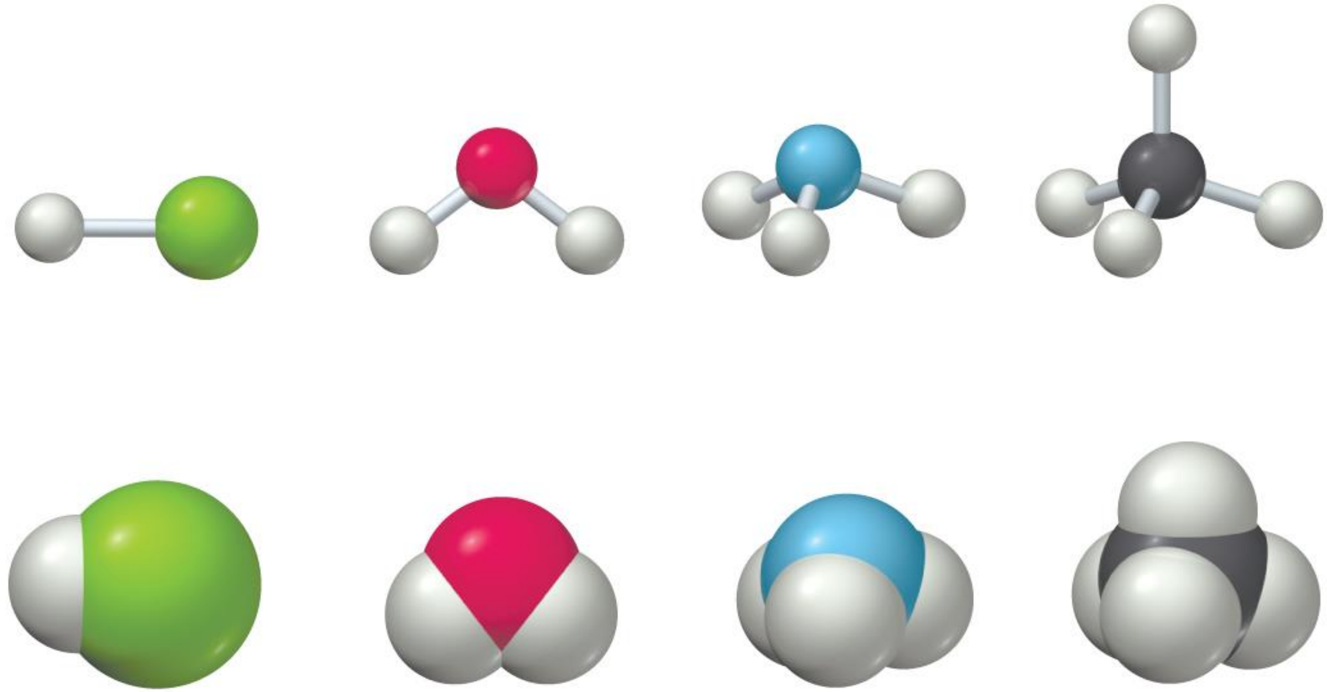
Covalent Bond: Results when two atoms share several (usually two) electrons. Typically a nonmetal bonded to a nonmetal.

Molecule: The unit of matter that results when two or more atoms are joined by covalent bonds.

Molecules and Covalent Bonds

Ball-and-stick models show atoms (spheres) joined together by covalent bonds (sticks).

Space-filling models portray the overall molecular shape but don't explicitly show covalent bonds.



Hydrogen chloride (HCl) | Water (H_2O) | Ammonia (NH_3) | Methane (CH_4)

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Ions and Ionic Bonds

Ionic Bond: A transfer of one or more electrons from one atom to another. A strong electrical attraction between charged particles. Typically a metal bonded to a nonmetal.

Ion: A charged particle

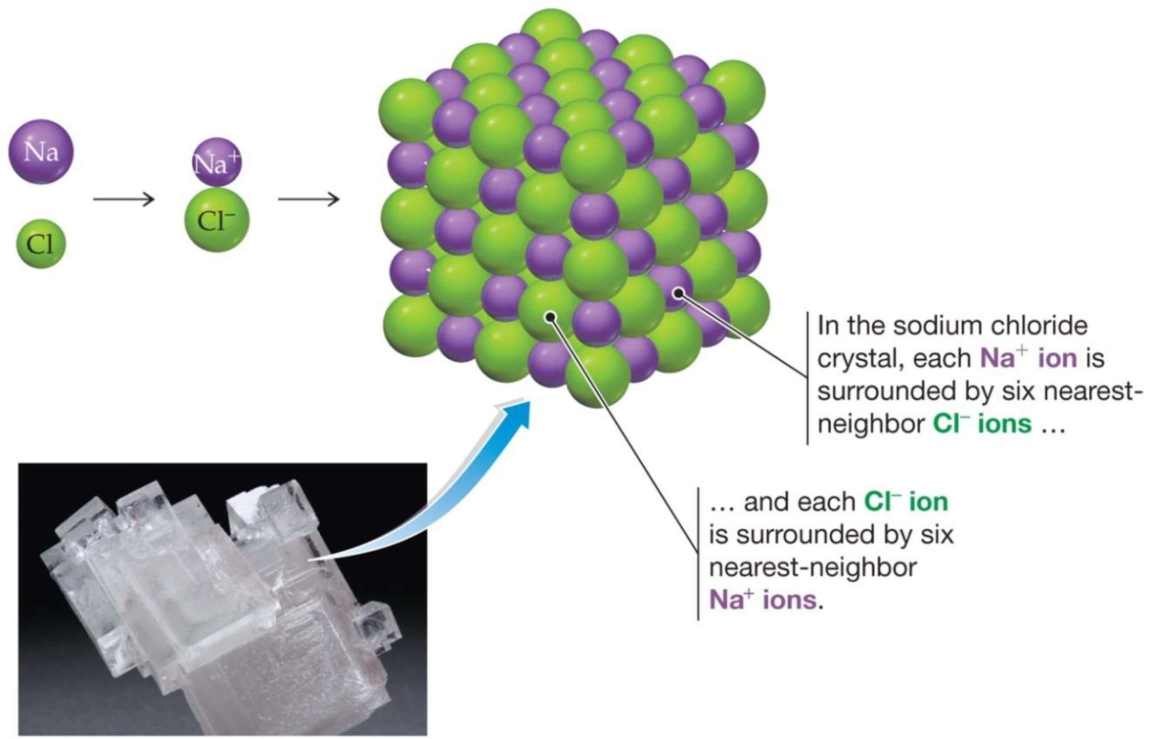
Cation: A positively charged particle. Metals tend to form cations.

Anion: A negatively charged particle. Nonmetals tend to form anions.

Ions and Ionic Bonds

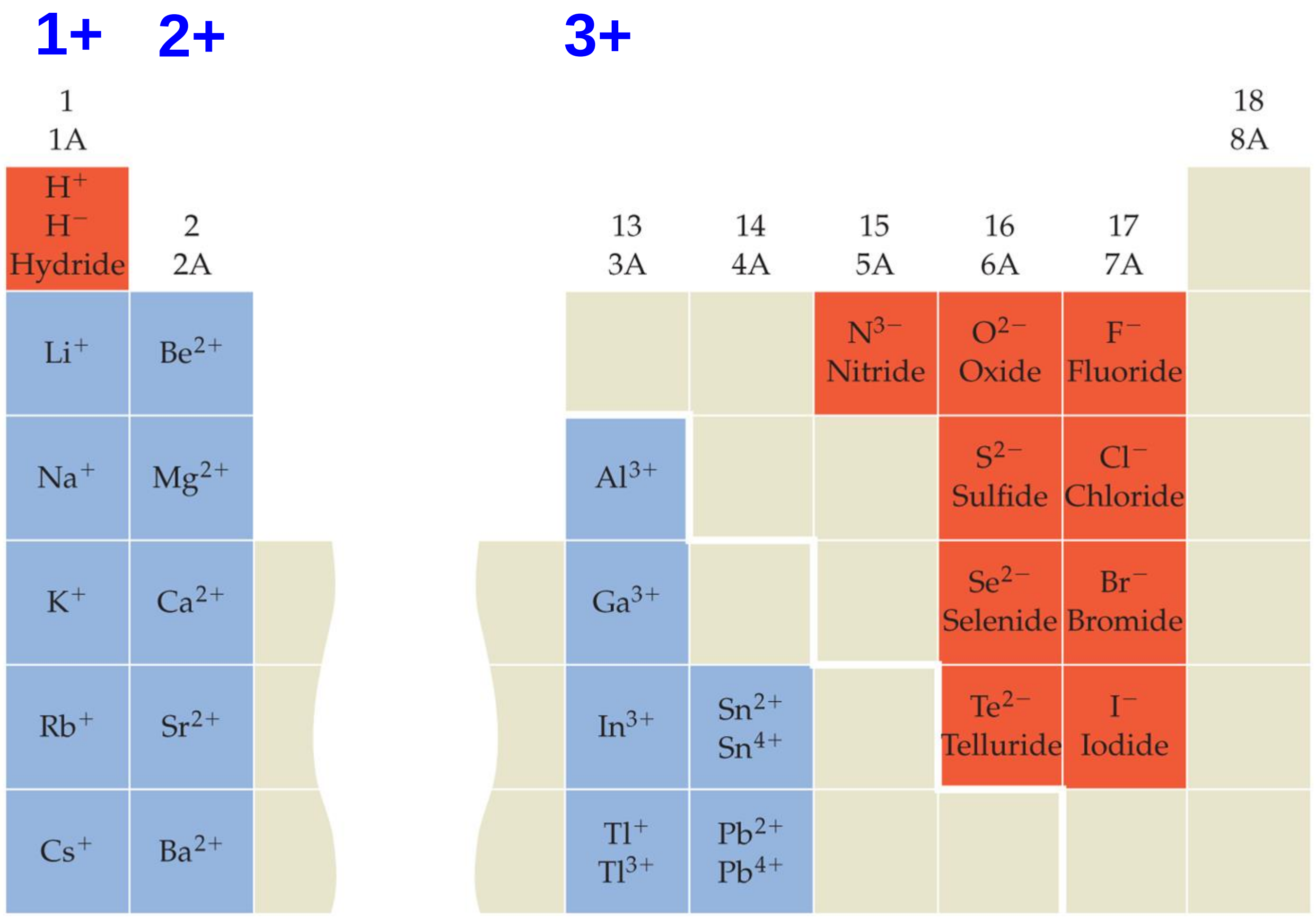
In the formation of sodium chloride, one electron is transferred from the sodium atom to the chlorine atom.

$$Na + \frac{1}{2} Cl_2 \longrightarrow Na^+ + Cl^-$$



Naming Chemical Compounds

Cation Charges for Typical Main-Group Ions



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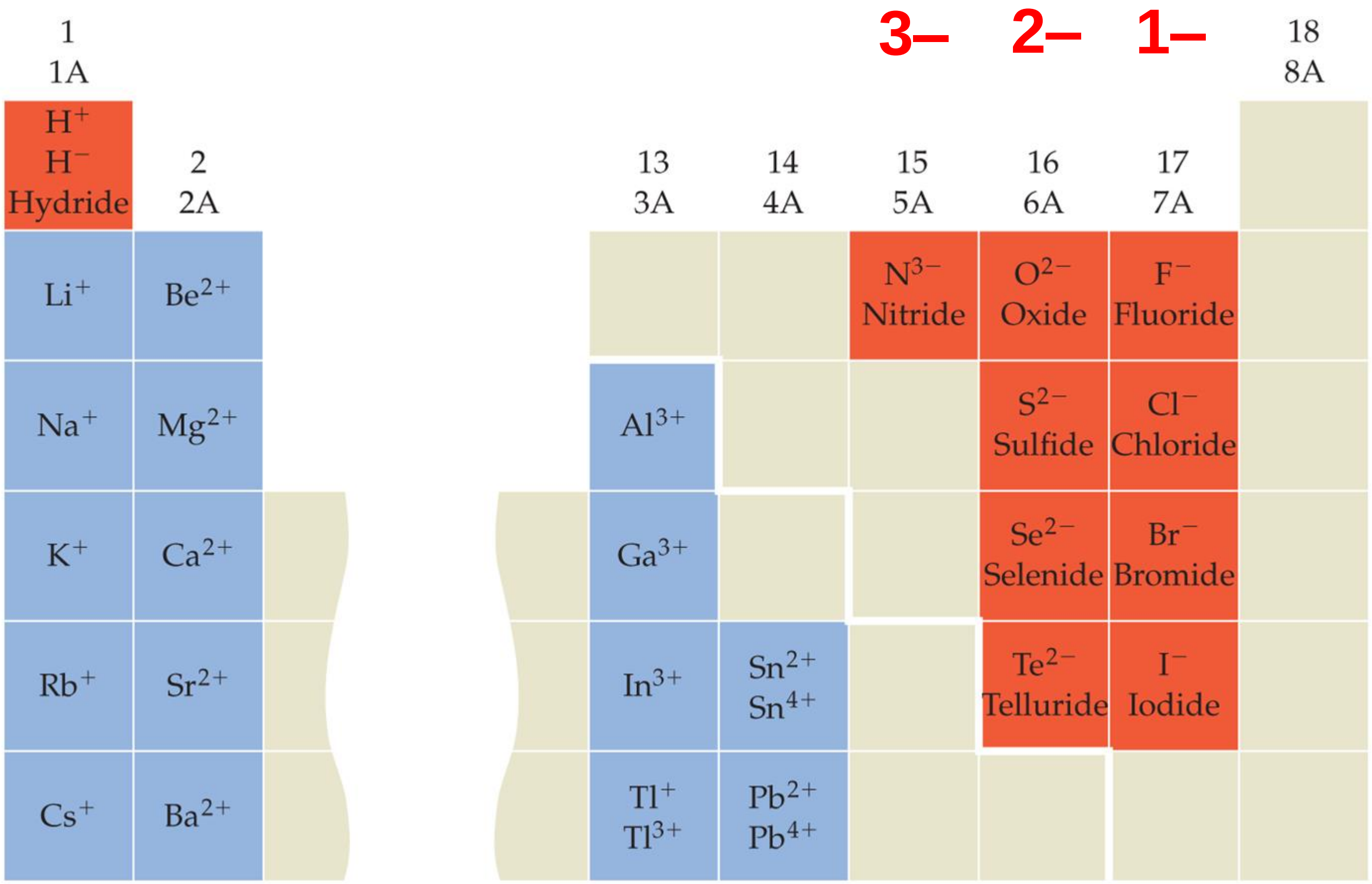
Naming Chemical Compounds

Cation Charges for Typical Main-Group Ions



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Naming Chemical Compounds

Ionic Compound: A neutral compound in which the total number of positive charges must equal the total number of negative charges.

Binary Ionic Compounds

Sodium chloride:	Na^{+}	Cl^{-}	$NaCl$
Magnesium oxide:	Mg^{2+}	O^{2-}	MgO
Aluminum sulfide:	Al^{3+}	S^{2-}	Al_2S_3

Naming Chemical Compounds

Some transition metals form more than one cation.

3	4	5	6	7	8	9	10	11	12
3B	4B	5B	6B	7B	8B	8B	8B	1B	2B
Sc^{3+}	Ti^{3+}	V^{2+} V^{3+}	Cr^{2+} Cr^{3+}	Mn^{2+}	Fe^{2+} Fe^{3+}	Co^{2+}	Ni^{2+}	Cu^{+} Cu^{2+}	Zn^{2+}
Y^{3+}					Ru^{3+}	Rh^{3+}	Pd^{2+}	Ag^{+}	Cd^{2+}
									Hg^{2+} $(Hg_2)^{2+}$

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Naming Chemical Compounds

Use Roman numerals in parentheses to indicate the charge on metals that form more than one kind of cation.

Binary Ionic Compounds

Iron(III) oxide:	Fe^{3+}	O^{2-}	Fe_2O_3
Tin(II) chloride:	Sn^{2+}	Cl^{-}	$SnCl_2$
Lead(II) fluoride:	Pb^{2+}	F^{-}	PbF_2

Naming Chemical Compounds

Binary Molecular Compounds

TABLE 2.6 Numerical Prefixes for Naming Compounds

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

Because nonmetals often combine with one another in different proportions to form different compounds, numerical prefixes are usually included in the names of binary molecular compounds.

Naming Chemical Compounds

$$N_2F_4$$

The prefix is added to the front of each name to indicate the number of each atom.

Dinitrogen **tetra**fluor**ide**

Naming Chemical Compounds

Binary Molecular Compounds

Whenever the prefix ends in *a* or *o* and the element name begins with a vowel, drop the *a* or *o* in the prefix.

N_2O_4	Dinitrogen tetroxide

Whenever the prefix for the **first** element is *mono-*, drop it.

CO_2	Carbon dioxide
CO	Carbon monoxide

Naming Chemical Compounds

TABLE 2.5 Some Common Polyatomic Ions

Formula	Name	Formula	Name
Cation		**Singly charged anions (continued)**	
NH_4^+	Ammonium	NO_2^-	Nitrite
		NO_3^-	Nitrate
Singly charged anions		**Doubly charged anions**	
$CH_3CO_2^-$	Acetate	CO_3^{2-}	Carbonate
CN^-	Cyanide	CrO_4^{2-}	Chromate
ClO^-	Hypochlorite	$Cr_2O_7^{2-}$	Dichromate
ClO_2^-	Chlorite	O_2^{2-}	Peroxide
ClO_3^-	Chlorate	HPO_4^{2-}	Hydrogen phosphate
ClO_4^-	Perchlorate	SO_3^{2-}	Sulfite
$H_2PO_4^-$	Dihydrogen phosphate	SO_4^{2-}	Sulfate
HCO_3^-	Hydrogen carbonate (or bicarbonate)	$S_2O_3^{2-}$	Thiosulfate
HSO_4^-	Hydrogen sulfate (or bisulfate)	**Triply charged anion**	
OH^-	Hydroxide		
MnO_4^-	Permanganate	PO_4^{3-}	Phosphate

Naming Chemical Compounds

Polyatomic Ionic Compounds

Sodium hydroxide:	Na^+	OH^-	$NaOH$
Magnesium carbonate:	Mg^{2+}	CO_3^{2-}	$MgCO_3$
Sodium carbonate:	Na^+	CO_3^{2-}	Na_2CO_3
Iron(II) hydroxide:	Fe^{2+}	OH^-	$Fe(OH)_2$