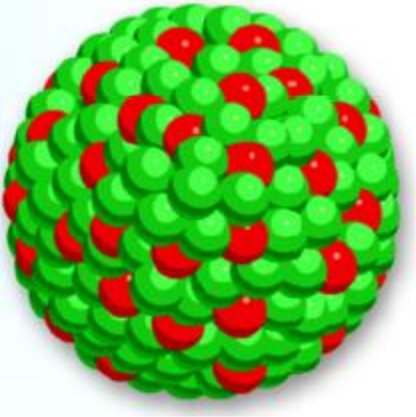
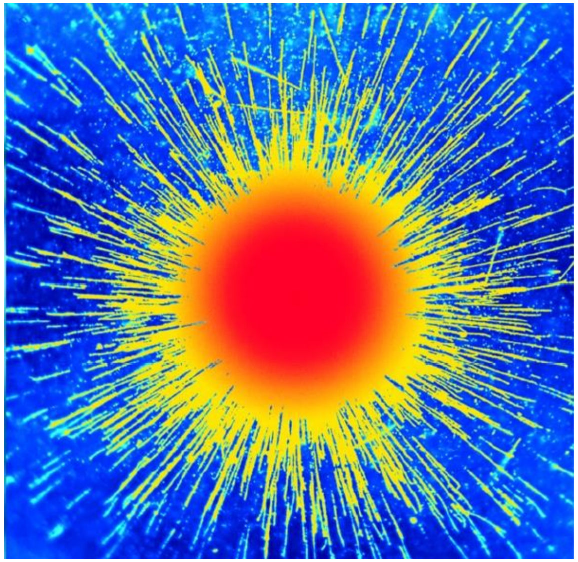


Atoms, Molecules and Ions

2



Atomic structure

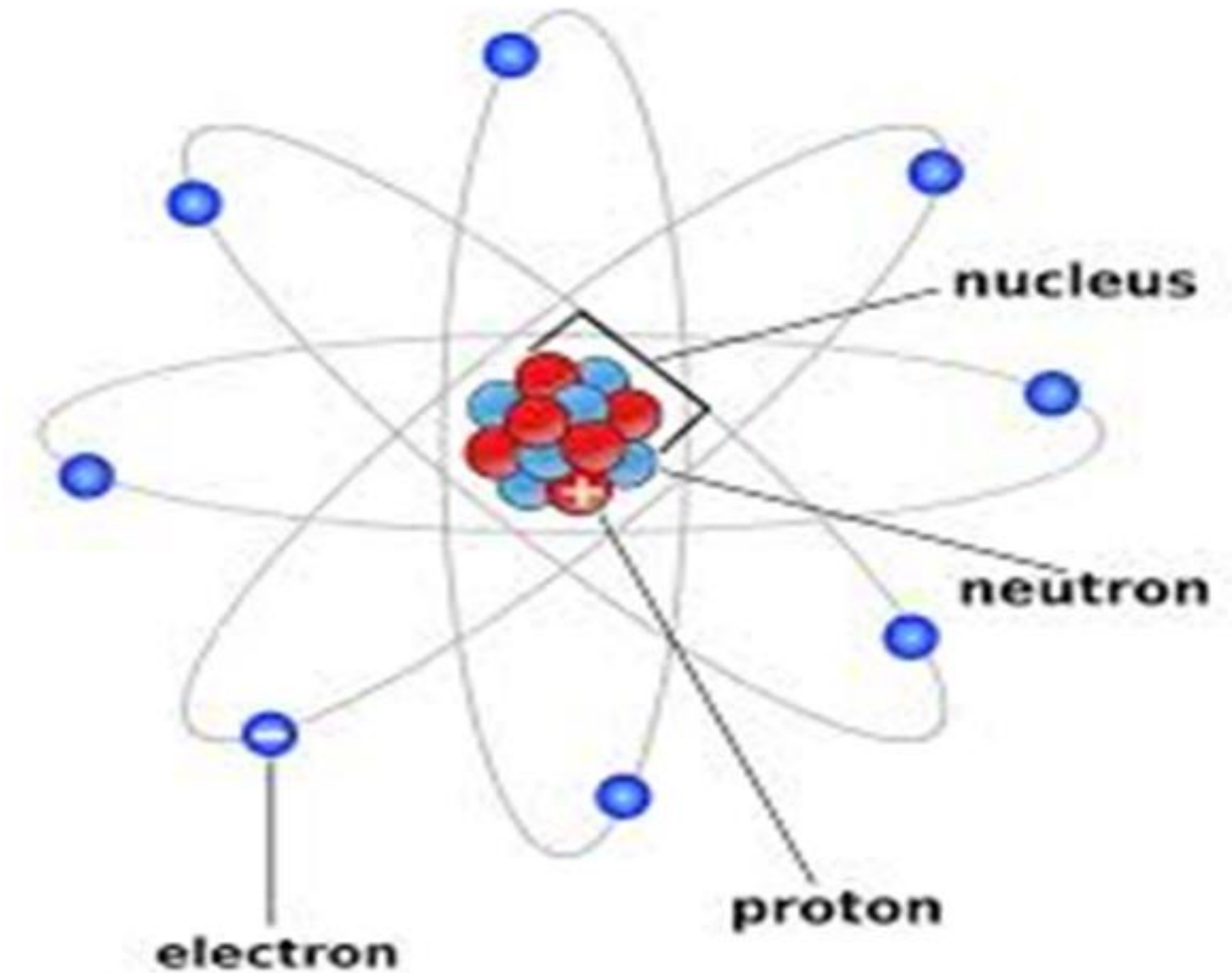


TABLE 2.1 Mass and Charge of Subatomic Particles

Particle	Mass (g)	Charge	
		Coulomb	Charge Unit
Electron*	9.10938×10^{-28}	-1.6022×10^{-19}	-1
Proton	1.67262×10^{-24}	$+1.6022 \times 10^{-19}$	$+1$
Neutron	1.67493×10^{-24}	0	0

*More refined measurements have given us a more accurate value of an electron's mass than Millikan's.

mass p ≈ mass n ≈ 1840 x mass e^-

Atomic number, Mass number and Isotopes

Atomic number (Z) = number of protons in nucleus

Mass number (A) = number of protons + number of neutrons

= atomic number (Z) + number of neutrons

Isotopes are atoms of the same element (X) with different numbers of neutrons in their nuclei

Mass Number → $^{A}_{Z}X$ ← Element Symbol

Atomic Number →

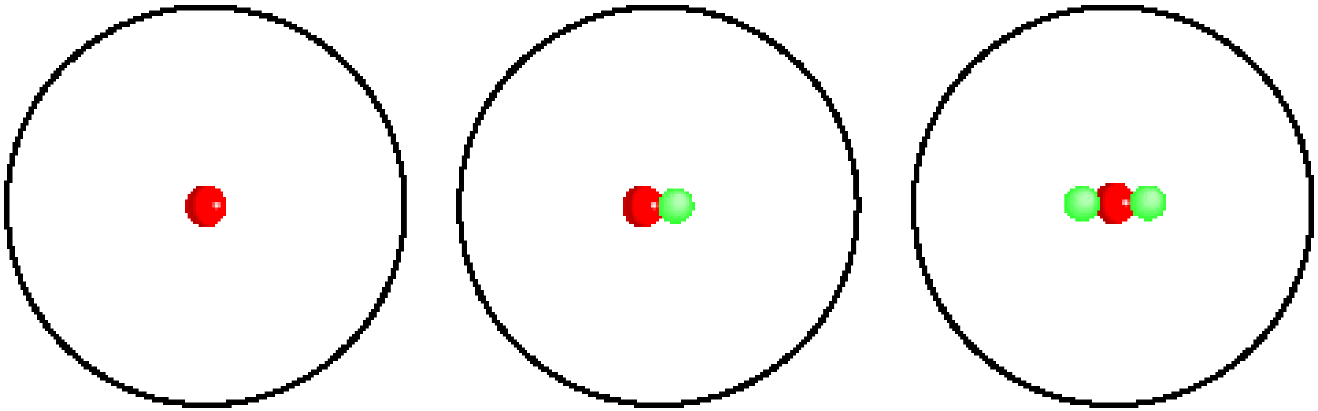
$^{1}_{1}H$ $^{2}_{1}H$ (D) $^{3}_{1}H$ (T)

H isotopes names: hydrogen deuterium tritium

$^{235}_{92}U$ $^{238}_{92}U$

Atomic number, Mass number and Isotopes

The Isotopes of Hydrogen



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

hydrogen deuterium tritium

Atomic number, Mass number and Isotopes

How many protons, neutrons, and electrons are in $^{14}_{6}C$?

6 protons, 8 (14 - 6) neutrons, 6 electrons

How many protons, neutrons, and electrons are in $^{11}_{6}C$?

6 protons, 5 (11 - 6) neutrons, 6 electrons

Atomic number, Mass number and Isotopes

Find number of electrons, protons, and neutrons?

$^{63}_{29}Cu$ $^{239}_{94}Pu$ $^{26}_{13}Al$ $^{17}_{8}O$ $^{202}_{80}Hg$ $^{48}_{22}Ti$

e	29	94	13	8	80	22
p	29	94	13	8	80	22
n	34	145	13	9	122	26

Atomic number, Mass number and Isotopes

EXAMPLE 2.1

Give the number of protons, neutrons, and electrons in each of the following species: (a) $^{20}_{11}Na$, (b) $^{22}_{11}Na$, (c) ^{17}O, and (d) carbon-14.

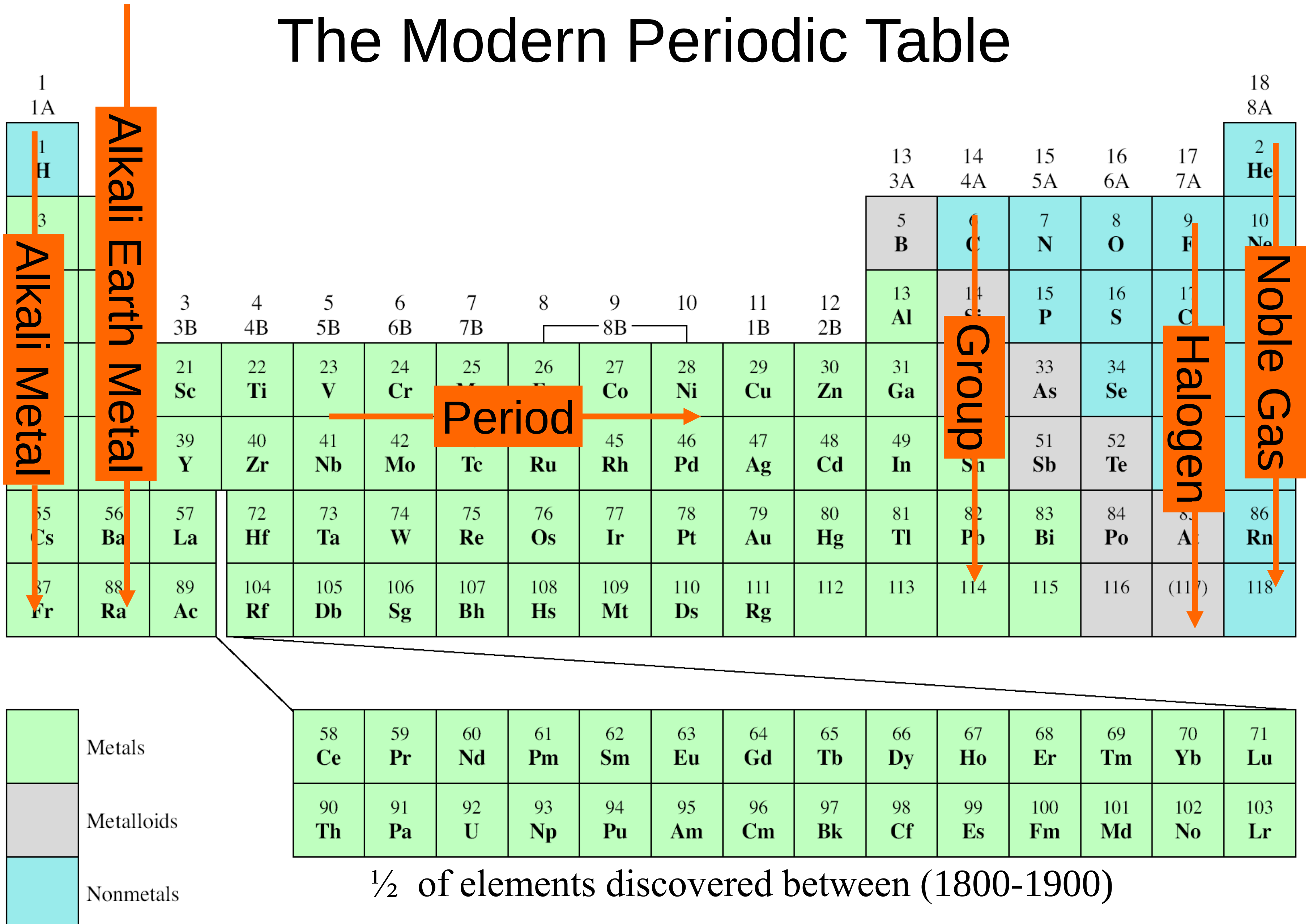
Solution (a) The atomic number is 11, so there are 11 protons. The mass number is 20, so the number of neutrons is 20 − 11 = 9. The number of electrons is the same as the number of protons; that is, 11.

(b) The atomic number is the same as that in (a), or 11. The mass number is 22, so the number of neutrons is 22 − 11 = 11. The number of electrons is 11. Note that the species in (a) and (b) are chemically similar isotopes of sodium.

(c) The atomic number of O (oxygen) is 8, so there are 8 protons. The mass number is 17, so there are 17 − 8 = 9 neutrons. There are 8 electrons.

(d) Carbon-14 can also be represented as ^{14}C. The atomic number of carbon is 6, so there are 14 − 6 = 8 neutrons. The number of electrons is 6.

The Modern Periodic Table



½ of elements discovered between (1800-1900)

Only noble gases exists as single atoms called monoatomic

Group : similar chemical properties

Period : increasing Z

metals ⟶ metalloids ⟶ nonmetals

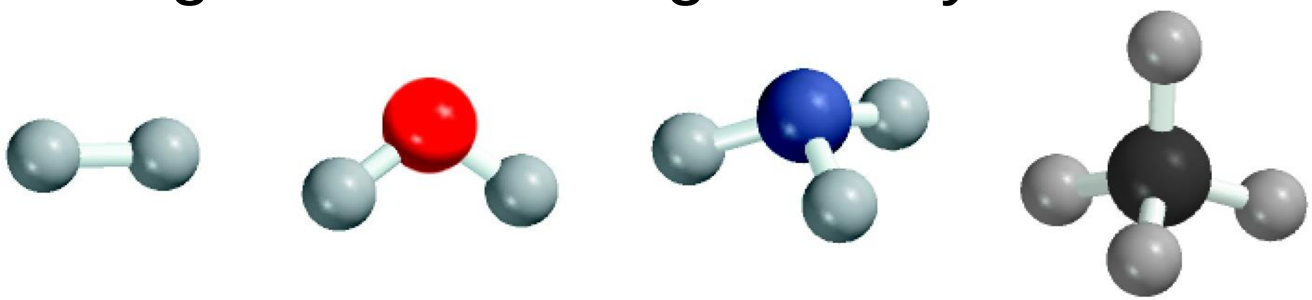
Metals -good conductors of heat and electricity
-occupy most of the table

Nonmetals -Not good conductors of heat and electricity
-only 17 elements

METALLOIDS - INTERMEDIATE BETWEEN METALS AND NON METALS
-ONLY 8 ELEMENTS

Molecules and Ions

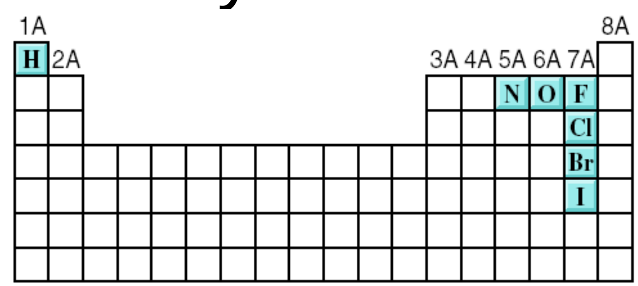
A ***molecule*** is an aggregate of two or more atoms in a definite arrangement held together by chemical forces



H_2 H_2O NH_3 CH_4

A ***diatomic molecule*** contains only two atoms

H_2, N_2, O_2, Br_2, HCl, CO



diatomic elements

A ***polyatomic molecule*** contains more than two atoms

O_3, H_2O, NH_3, CH_4

An ***ion*** is an atom, or group of atoms, that has a net positive or negative charge.

cation – ion with a positive charge

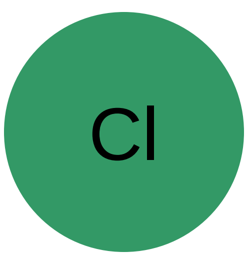
If a neutral atom **loses** one or more electrons it becomes a cation.

11 protons
11 electrons

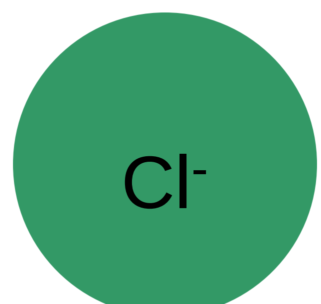
11 protons
10 electrons

anion – ion with a negative charge

If a neutral atom **gains** one or more electrons it becomes an anion.



17 protons
17 electrons



17 protons
18 electrons

A ***monatomic ion*** contains only one atom

Na^+, Cl^-, Ca^{2+}, O^{2-}, Al^{3+}, N^{3-}

A ***polyatomic ion*** contains more than one atom

OH^-, CN^-, NH_4^+, NO_3^-

How many protons and electrons are in $^{27}_{13}Al^{3+}$?

13 protons, 10 (13 – 3) electrons

How many protons and electrons are in $^{78}_{34}Se^{2-}$?

34 protons, 36 (34 + 2) electrons

Chemical Formulas

A ***molecular formula*** shows the exact number of atoms of each element in the smallest unit of a substance

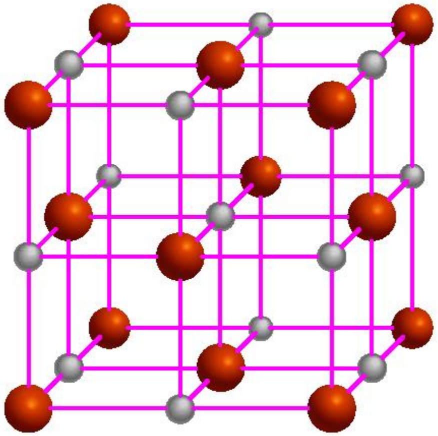
An ***empirical formula*** shows the simplest whole-number ratio of the atoms in a substance

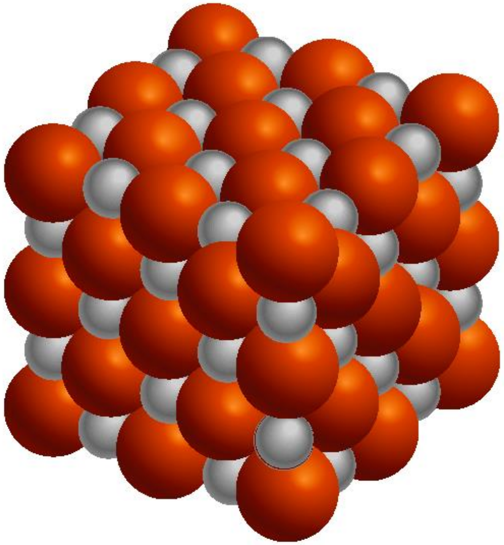
molecular	**empirical**
H_2O	H_2O
$C_6H_{12}O_6$	CH_2O
O_3	O
N_2H_4	NH_2

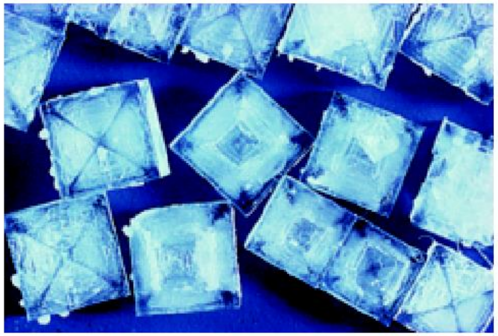
ionic compounds consist of a combination of cations and an anions

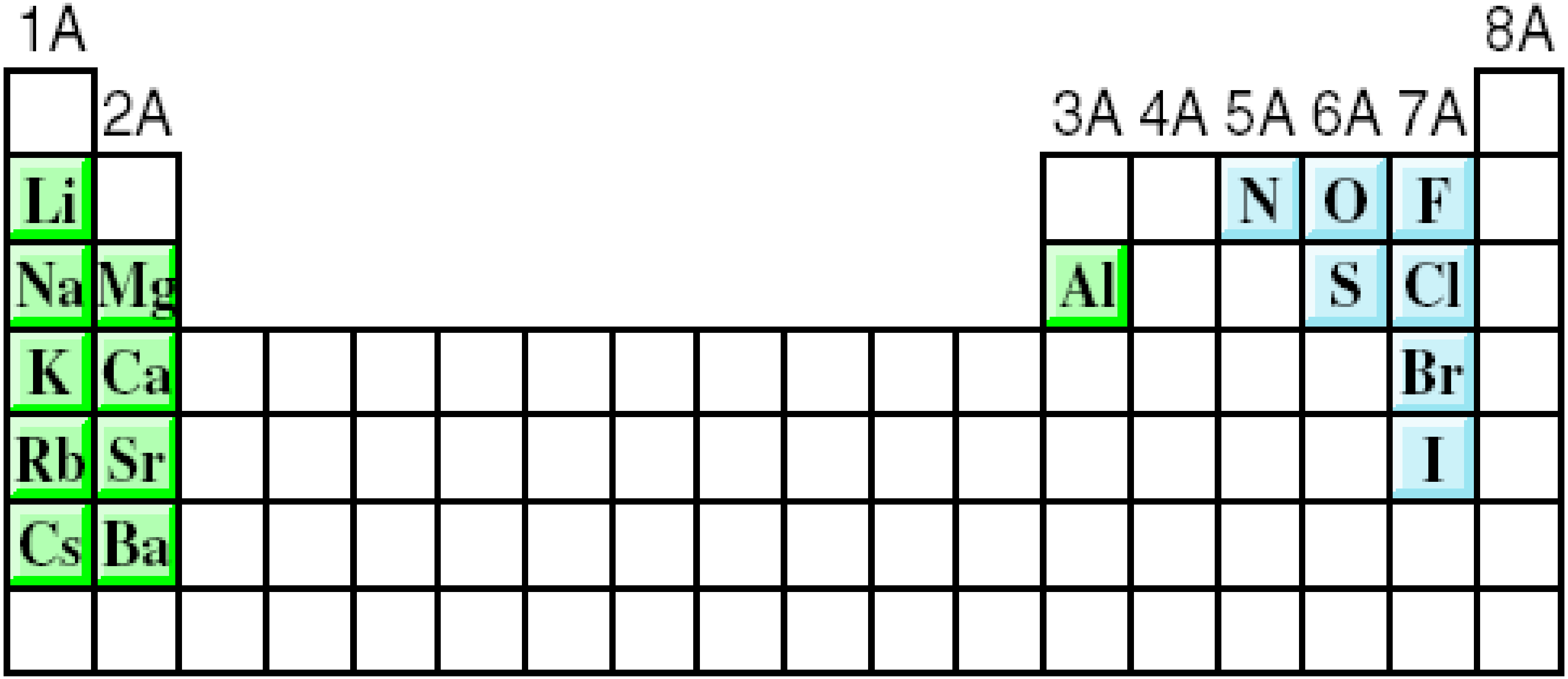
- The formula is usually the same as the empirical formula
- The sum of the charges on the cation(s) and anion(s) in each formula unit must equal zero

The ionic compound NaCl







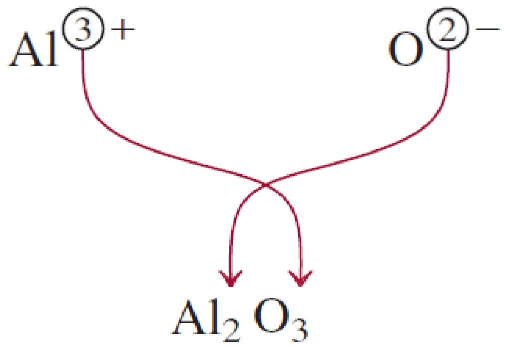


The most reactive **metals** (green) and the most reactive **nonmetals** (blue) combine to form ionic compounds.

- If the charges on the cation and anion are numerically different, we apply the following rule to make the formula electrically neutral:

  The subscript of the cation is numerically equal to the charge on the anion, and the subscript of the anion is numerically equal to the charge on the cation.

Aluminum Oxide. The cation is Al^{3+} and the oxygen anion is O^{2-}.



The sum of the charges is 2(+3) + 3(-2) = 0.
Thus, the formula for aluminum oxide is Al_2O_3.

Formula of Ionic Compounds

$2 \times +3 = +6$ — $3 \times -2 = -6$

Al_2O_3

Al^{3+} — O^{2-}

$1 \times +2 = +2$ — $2 \times -1 = -2$

$CaBr_2$

Ca^{2+} — Br^{-}

$2 \times +1 = +2$ — $1 \times -2 = -2$

Na_2CO_3

Na^{+} — CO_3^{2-}

Common Ions Shown on the Periodic Table

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
Li^{+}													**C^{4-}**	**N^{3-}**	**O^{2-}**	**F^{-}**	
Na^{+}	**Mg^{2+}**											**Al^{3+}**		**P^{3-}**	**S^{2-}**	**Cl^{-}**	
K^{+}	**Ca^{2+}**				**Cr^{2+}** **Cr^{3+}**	**Mn^{2+}** **Mn^{3+}**	**Fe^{2+}** **Fe^{3+}**	**Co^{2+}** **Co^{3+}**	**Ni^{2+}** **Ni^{3+}**	**Cu^{+}** **Cu^{2+}**	**Zn^{2+}**				**Se^{2-}**	**Br^{-}**	
Rb^{+}	**Sr^{2+}**									**Ag^{+}**	**Cd^{2+}**		**Sn^{2+}** **Sn^{4+}**		**Te^{2-}**	**I^{-}**	
Cs^{+}	**Ba^{2+}**									**Au^{+}** **Au^{3+}**	**Hg_2^{2+}** **Hg^{2+}**		**Pb^{2+}** **Pb^{4+}**				

Naming Compound

Ionic Compounds

- Often a metal + nonmetal
- Anion (nonmetal), add “ide” to element name

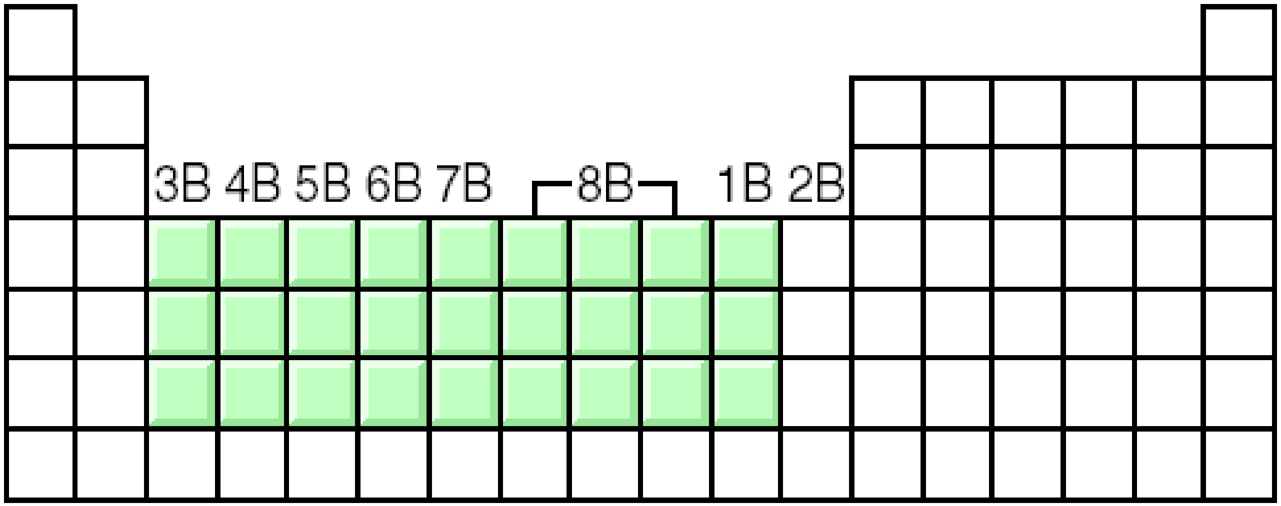
$BaCl_2$	barium chloride
K_2O	potassium oxide
$Mg(OH)_2$	magnesium hydroxide
KNO_3	potassium nitrate

TABLE 2.2 **The "-ide" Nomenclature of Some Common Monatomic Anions According to Their Positions in the Periodic Table**

Group 4A	Group 5A	Group 6A	Group 7A
C carbide (C^{4-})*	N nitride (N^{3-})	O oxide (O^{2-})	F fluoride (F^{-})
Si silicide (Si^{4-})	P phosphide (P^{3-})	S sulfide (S^{2-})	Cl chloride (Cl^{-})
		Se selenide (Se^{2-})	Br bromide (Br^{-})
		Te telluride (Te^{2-})	I iodide (I^{-})

*The word "carbide" is also used for the anion C_2^{2-}.

- Transition metal ionic compounds
  - indicate charge on metal with Roman numerals



$FeCl_2$	2 Cl^- -2 so Fe is +2	iron(II) chloride
$FeCl_3$	3 Cl^- -3 so Fe is +3	iron(III) chloride
Cr_2S_3	3 S^{-2} -6 so Cr is +3 (6/2)	chromium(III) sulfide

If transition metals can form more tha one type of cations we use (–ic) for higher charge and (-ous) for lower charge .

$FeCl_2$ iron(II) chloride becomes ferrous chloride

$FeCl_3$ iron(III) chloride becomes ferric chloride

CuCl cupper(I) chloride becomes cupperous chloride

$CuCl_2$ cupper(II) chloride becomes cupperic chloride

TABLE 2.3 Names and Formulas of Some Common Inorganic Cations and Anions

Cation	Anion
aluminum (Al^{3+})	bromide (Br^-)
ammonium (NH_4^+)	carbonate (CO_3^{2-})
barium (Ba^{2+})	chlorate (ClO_3^-)
cadmium (Cd^{2+})	chloride (Cl^-)
calcium (Ca^{2+})	chromate (CrO_4^{2-})
cesium (Cs^+)	cyanide (CN^-)
chromium(III) or chromic (Cr^{3+})	dichromate ($Cr_2O_7^{2-}$)
cobalt(II) or cobaltous (Co^{2+})	dihydrogen phosphate ($H_2PO_4^-$)
copper(I) or cuprous (Cu^+)	fluoride (F^-)
copper(II) or cupric (Cu^{2+})	hydride (H^-)
hydrogen (H^+)	hydrogen carbonate or bicarbonate (HCO_3^-)
iron(II) or ferrous (Fe^{2+})	hydrogen phosphate (HPO_4^{2-})
iron(III) or ferric (Fe^{3+})	hydrogen sulfate or bisulfate (HSO_4^-)
lead(II) or plumbous (Pb^{2+})	hydroxide (OH^-)
lithium (Li^+)	iodide (I^-)
magnesium (Mg^{2+})	nitrate (NO_3^-)
manganese(II) or manganous (Mn^{2+})	nitride (N^{3-})
mercury(I) or mercurous (Hg_2^{2+})*	nitrite (NO_2^-)
mercury(II) or mercuric (Hg^{2+})	oxide (O^{2-})
potassium (K^+)	permanganate (MnO_4^-)
rubidium (Rb^+)	peroxide (O_2^{2-})
silver (Ag^+)	phosphate (PO_4^{3-})
sodium (Na^+)	sulfate (SO_4^{2-})
strontium (Sr^{2+})	sulfide (S^{2-})
tin(II) or stannous (Sn^{2+})	sulfite (SO_3^{2-})
zinc (Zn^{2+})	thiocyanate (SCN^-)

*Mercury(I) exists as a pair as shown.

EXAMPLE 2.5

Name the following compounds: (a) $Cu(NO_3)_2$, (b) KH_2PO_4, and (c) NH_4ClO_3.

Solution

(a) The nitrate ion (NO_3^-) bears one negative charge, so the copper ion must have two positive charges. Because copper forms both Cu^+ and Cu^{2+} ions, we need to use the Stock system and call the compound copper(II) nitrate.

(b) The cation is K^+ and the anion is $H_2PO_4^-$ (dihydrogen phosphate). Because potassium only forms one type of ion (K^+), there is no need to use potassium(I) in the name. The compound is potassium dihydrogen phosphate.

(c) The cation is NH_4^+ (ammonium ion) and the anion is ClO_3^-. The compound is ammonium chlorate.

Practice Exercise Name the following compounds: (a) PbO and (b) Li_2SO_3.

EXAMPLE 2.6

Write chemical formulas for the following compounds: (a) mercury(I) nitrite, (b) cesium sulfide, and (c) calcium phosphate.

Solution

(a) The Roman numeral shows that the mercury ion bears a +1 charge. According to Table 2.3, however, the mercury(I) ion is diatomic (that is, Hg_2^{2+}) and the nitrite ion is NO_2^-. Therefore, the formula is $Hg_2(NO_2)_2$.

(b) Each sulfide ion bears two negative charges, and each cesium ion bears one positive charge (cesium is in Group 1A, as is sodium). Therefore, the formula is Cs_2S.

(c) Each calcium ion (Ca^{2+}) bears two positive charges, and each phosphate ion (PO_4^{3-}) bears three negative charges. To make the sum of the charges equal zero, we must adjust the numbers of cations and anions:

$$3(+2) + 2(-3) = 0$$

Thus, the formula is $Ca_3(PO_4)_2$.

Molecular compounds

- They are usually composed of nonmetallic elements.
- Many molecular compounds are binary compounds.
- Naming binary molecular compounds is similar to naming binary ionic compounds.
- We place the name of the first element in the formula first, and the second element is named by adding *-ide* to the root of the element name.

HCl	hydrogen chloride
HBr	hydrogen bromide
SiC	silicon carbide

– If a pair of elements form more than one compound, use prefixes to indicate number of each kind of atom

Notes in naming compounds with prefixes:

- The prefix "mono-" may be omitted for the first element.
  For example, PCl_3 is named phosphorus trichloride, not monophosphorus trichloride.
- For oxides, the ending "a" in the prefix is sometimes omitted.
  For example, N_2O_4 may be called dinitrogen tetroxide rather than dinitrogen tetraoxide.

TABLE 2.4

Greek Prefixes Used in Naming Molecular Compounds

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

Name the following compounds?

HI	hydrogen iodide
NF_3	nitrogen trifluoride
SO_2	sulfur dioxide
N_2Cl_4	dinitrogen tetrachloride
NO_2	nitrogen dioxide
N_2O	dinitrogen monoxide

EXAMPLE 2.7

Name the following molecular compounds: (a) $SiCl_4$ and (b) P_4O_{10}.

Solution (a) Because there are four chlorine atoms present, the compound is silicon tetrachloride.

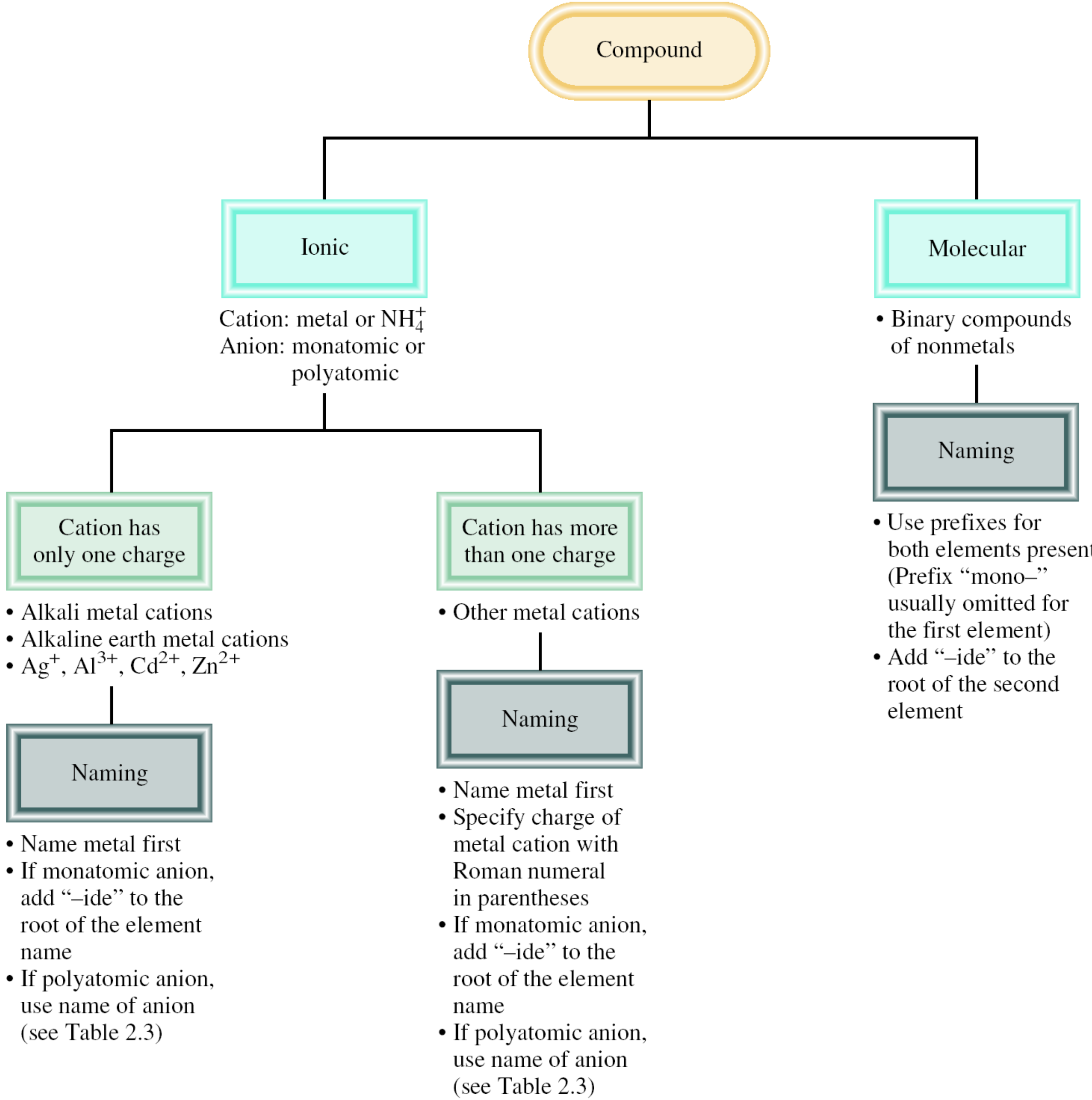
(b) There are four phosphorus atoms and ten oxygen atoms present, so the compound is tetraphosphorus decoxide. Note that the "a" is omitted in "deca."

EXAMPLE 2.8

Write chemical formulas for the following molecular compounds: (a) carbon disulfide and (b) disilicon hexabromide.

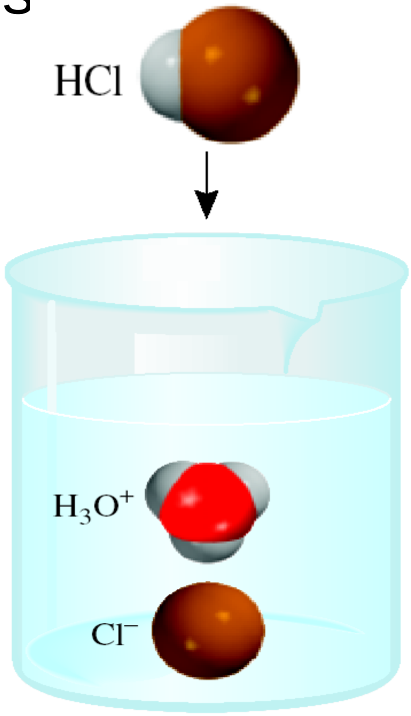
Solution (a) Because there are two sulfur atoms and one carbon atom present, the formula is CS_2.

(b) There are two silicon atoms and six bromine atoms present, so the formula is Si_2Br_6.


Compound
Ionic
Cation: metal or NH_4^+
Anion: monatomic or polyatomic
Cation has only one charge
• Alkali metal cations
• Alkaline earth metal cations
• Ag^+, Al^{3+}, Cd^{2+}, Zn^{2+}
Naming
• Name metal first
• If monatomic anion, add "–ide" to the root of the element name
• If polyatomic anion, use name of anion (see Table 2.3)
Cation has more than one charge
• Other metal cations
Naming
• Name metal first
• Specify charge of metal cation with Roman numeral in parentheses
• If monatomic anion, add "–ide" to the root of the element name
• If polyatomic anion, use name of anion (see Table 2.3)
Molecular
• Binary compounds of nonmetals
Naming
• Use prefixes for both elements present (Prefix "mono–" usually omitted for the first element)
• Add "–ide" to the root of the second element

Acids

- An ***acid*** can be defined as a substance that yields hydrogen ions (H^+) when dissolved in water.



For example: HCl gas and HCl in water

- Pure substance, hydrogen chloride
- Dissolved in water (H_3O^+ and Cl^-), hydrochloric acid

- Anions whose names end in “-ide” form acids with a “hydro-” prefix and an “-ic” ending.

HCl	hydrogen chloride
HCl	hydrochloric acid

Some Examples of acids

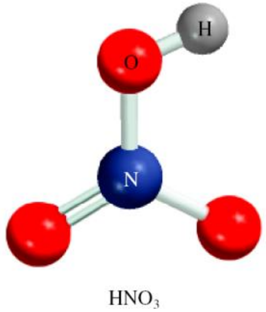
TABLE 2.5 Some Simple Acids

Anion	Corresponding Acid
F^- (fluoride)	HF (hydrofluoric acid)
Cl^- (chloride)	HCl (hydrochloric acid)
Br^- (bromide)	HBr (hydrobromic acid)
I^- (iodide)	HI (hydroiodic acid)
CN^- (cyanide)	HCN (hydrocyanic acid)
S^{2-} (sulfide)	H_2S (hydrosulfuric acid)

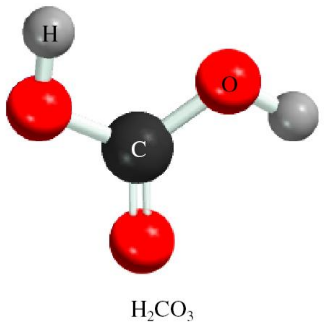
Naming Oxoacids and Oxoanions

An ***oxoacid*** is an acid that contains hydrogen, oxygen, and another element.

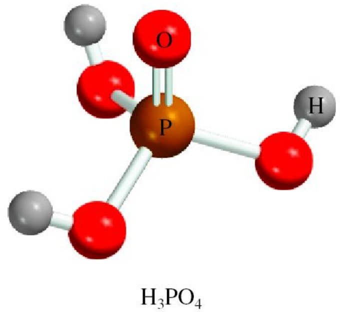
nitric acid



carbonic acid



phosphoric acid



The formulas of ***oxoacids*** are usually written with the H first, followed by the central element and then O.

H_2CO_3 (carbonic acid), $HClO_3$ (chloric acid),

HNO_3 (nitric acid), H_3PO_4 (phosphoric acid),

H_2SO_4 (sulfuric acid)

Two or more *oxoacids* have the same central atom but *a different number of O atoms*; the following rules to name these compounds.

1. **Addition of one O atom to the "-ic" acid**: The acid is called "per . . -ic" acid. (--ate)

$HClO_3$	chloric acid
$HClO_4$	perchloric acid

2. **Removal of one O atom from the "-ic" acid**: The acid is called "-ous" acid. (--ite)

HNO_3	nitric acid
HNO_2	nitrous acid

3. **Removal of two O atoms from the "-ic" acid:** The acid is called "hypo . . . -ous" acid.

$HBrO_3$	Bromic acid
HBrO	hypobromous acid.

- **The rules for naming *oxoanions, anions of oxoacids*, are as follows:**

1. When all the **H ions are removed** from the **"-ic" acid**, the anion's name ends with **"-ate."**
2. When all the **H ions are removed** from the **"-ous" acid**, the anion's name ends with **"-ite."**
3. The names of anions in which one or more but not all the hydrogen ions have been removed must indicate the number of H ions present.

For example:

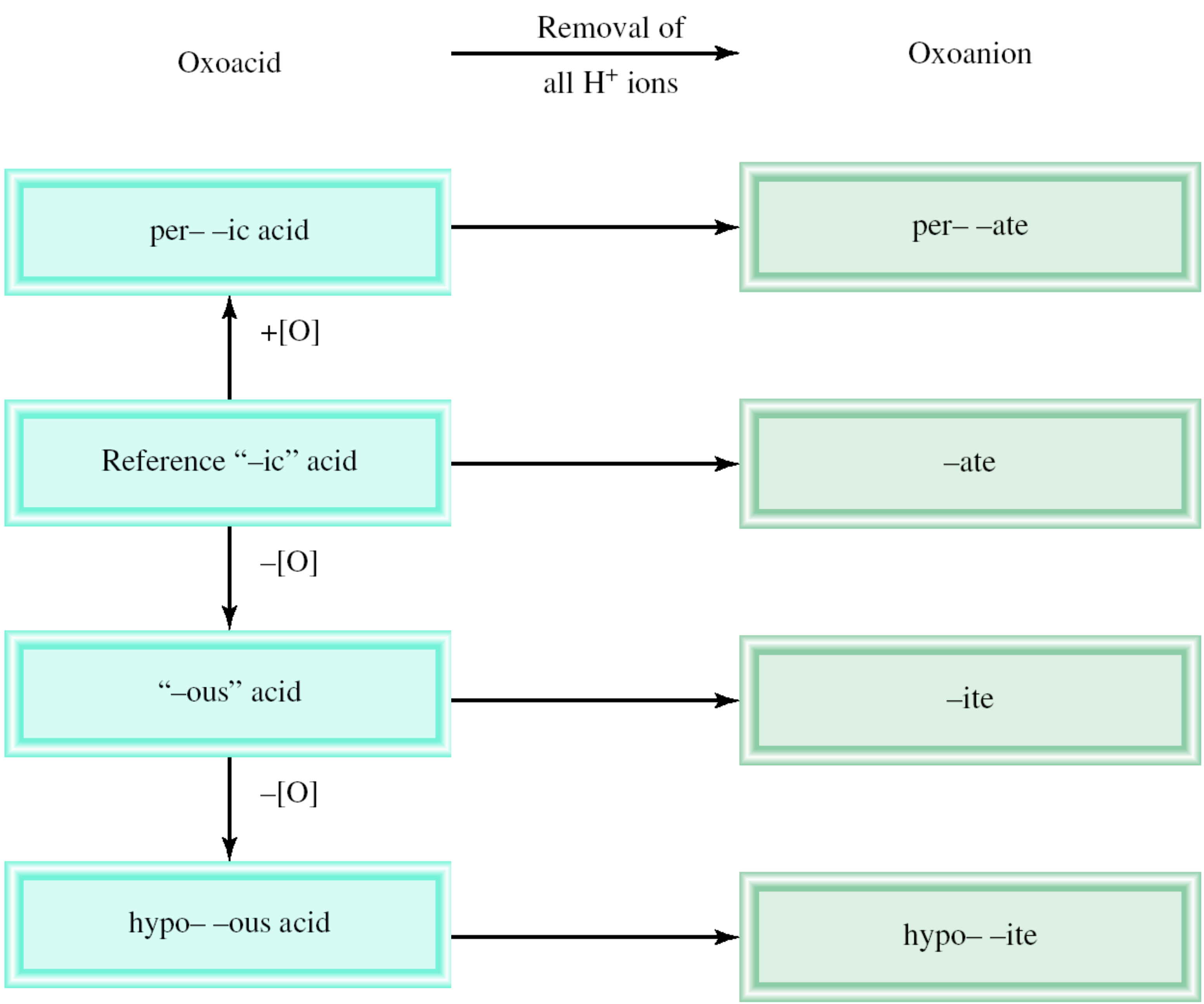
– H_3PO_4	phosphoric acid
– $H_2PO_4^-$	dihydrogen phosphate
– HPO_4^{2-}	hydrogen phosphate
– PO_4^{3-}	phosphate

TABLE 2.6 **Names of Oxoacids and Oxoanions That Contain Chlorine**

Acid	Anion
$HClO_4$ (perchloric acid)	ClO_4^- (perchlorate)
$HClO_3$ (chloric acid)	ClO_3^- (chlorate)
$HClO_2$ (chlorous acid)	ClO_2^- (chlorite)
$HClO$ (hypochlorous acid)	ClO^- (hypochlorite)

parent acid for all halogenic acids is

HXO_3 Halogenicic acid


Oxoacid
Removal of
all H+ ions
Oxoanion
per– –ic acid
per– –ate
+[O]
Reference "–ic" acid
–ate
–[O]
"–ous" acid
–ite
–[O]
hypo– –ous acid
hypo– –ite

EXAMPLE 2.9

Name the following oxoacid and oxoanion: (a) H_3PO_3 and (b) IO_4^-.

Solution (a) We start with our reference acid, phosphoric acid (H_3PO_4). Because H_3PO_3 has one fewer O atom, it is called phosphorous acid.

(b) The parent acid is HIO_4. Because the acid has one more O atom than our reference iodic acid (HIO_3), it is called periodic acid. Therefore, the anion derived from HIO_4 is called periodate.

Bases

A ***base*** can be defined as a substance that yields hydroxide ions (OH^-) when dissolved in water.

$NaOH$	sodium hydroxide
KOH	potassium hydroxide
$Ba(OH)_2$	barium hydroxide

Hydrated compounds

Hydrates are compounds that have a specific number of water molecules attached to them.

$BaCl_2 \cdot 2H_2O$	barium chloride dihydrate
$LiCl \cdot H_2O$	lithium chloride monohydrate
$MgSO_4 \cdot 7H_2O$	magnesium sulfate heptahydrate
$Sr(NO_3)_2 \cdot 4H_2O$	strontium nitrate tetrahydrate

$CuSO_4 \cdot 5H_2O$ →

← $CuSO_4$

TABLE 2.7 Common and Systematic Names of Some Compounds

Formula	Common Name	Systematic Name
H_2O	Water	Dihydrogen monoxide
NH_3	Ammonia	Trihydrogen nitride
CO_2	Dry ice	Solid carbon dioxide
$NaCl$	Table salt	Sodium chloride
N_2O	Laughing gas	Dinitrogen monoxide
$CaCO_3$	Marble, chalk, limestone	Calcium carbonate
CaO	Quicklime	Calcium oxide
$Ca(OH)_2$	Slaked lime	Calcium hydroxide
$NaHCO_3$	Baking soda	Sodium hydrogen carbonate
$Na_2CO_3 \cdot 10H_2O$	Washing soda	Sodium carbonate decahydrate
$MgSO_4 \cdot 7H_2O$	Epsom salt	Magnesium sulfate heptahydrate
$Mg(OH)_2$	Milk of magnesia	Magnesium hydroxide
$CaSO_4 \cdot 2H_2O$	Gypsum	Calcium sulfate dihydrate