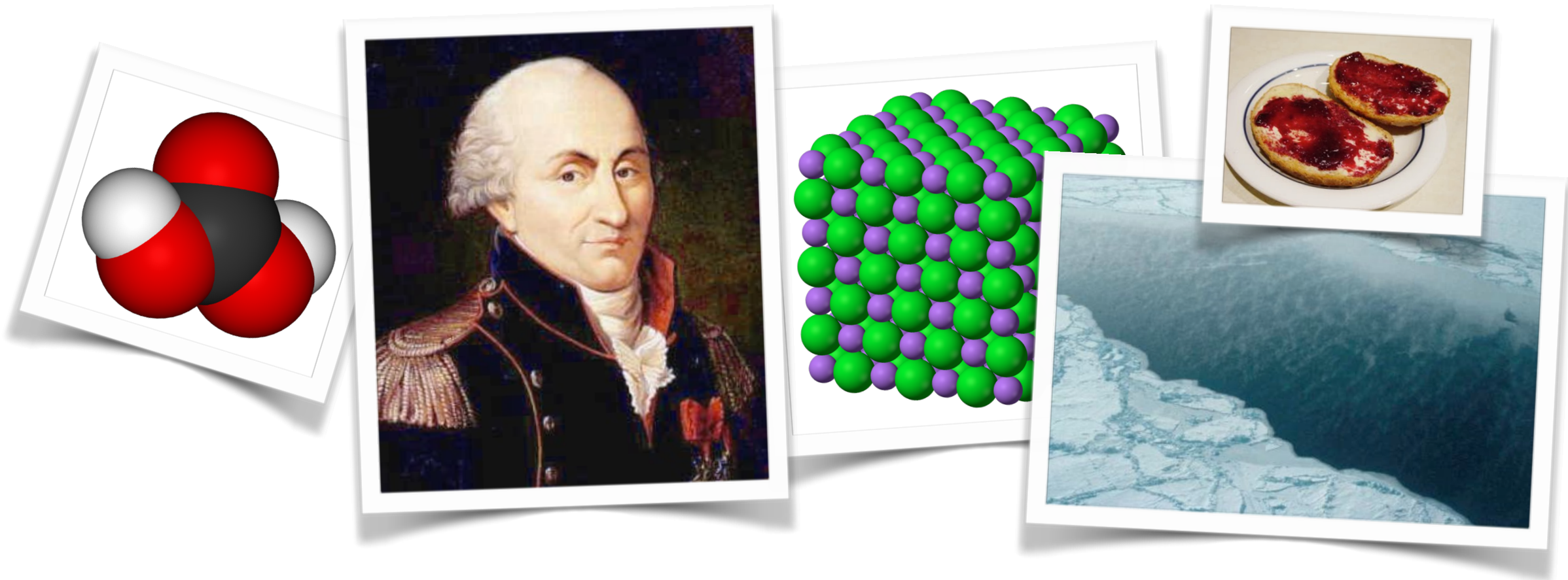
CHEM 100
Principles Of Chemistry



Chapter 3 - Properties of Matter: Opposites Attract

3.1 Properties of Matter: Opposites Attract

- **Matter** occupies space and has mass
- Matter has both chemical and physical properties
- **Chemical properties** are those that involve a substance turning into a different substance
  - Flammability
  - Reactivity with acids
- **Physical properties** are inherent to the substance and do not involve a change to a different substance
  - Density
  - Color
  - Boiling and melting points
  - Electrical conductivity

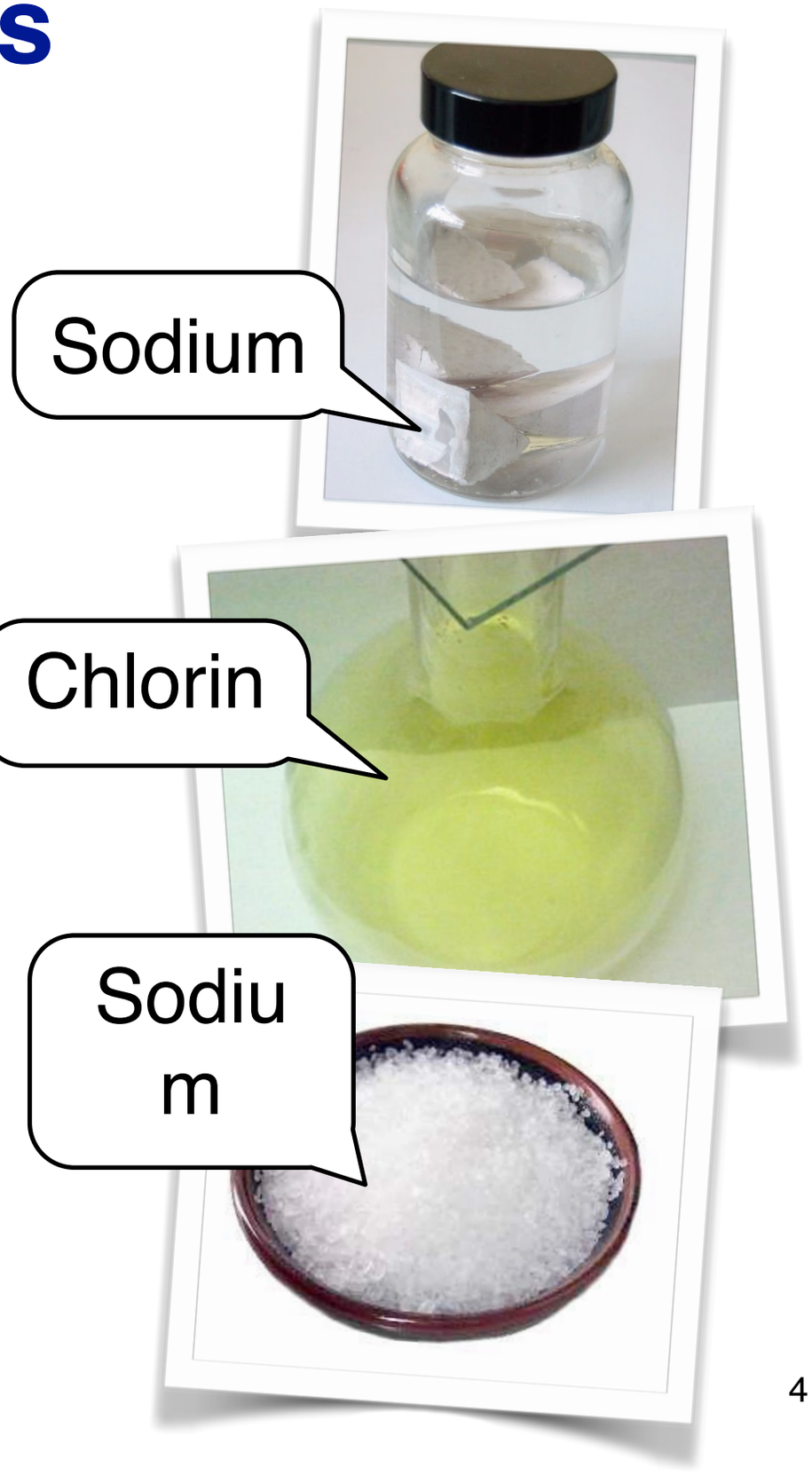
Pure Substances and Mixtures

- Matter is divided into two basic categories:

1. **Pure substances** have a fixed composition and specific properties
   - Aluminum - only aluminum
   - Salt - only sodium and chlorine in fixed ratio
   - Water - only hydrogen and oxygen in fixed ratio
2. **Mixtures** may have a variable composition and properties reflect those of their components
   - Gunpowder - variable amounts of sulfur, saltpeter and charcoal
   - Saltwater - variable amounts of salt and water

Pure Substances - Elements and Compounds

- Pure substances can be divided into two categories:
- **Elements** are the simplest building blocks of matter
  - There are 118 known
  - They have a unique composition and properties
  - Each has a name and symbol
- **Compounds** contain two or more different elements chemically combined
  - They are formed by chemical reactions
  - Their properties are different



Aluminum	Al
Argon	Ar
Arsenic	As
Barium	Ba
Boron	B
Bromine	Br
Cadmium	Cd
Calcium	Ca
Carbon	C
Chlorine	Cl
Chromium	Cr
Cobalt	Co
Copper*	Cu
Fluorine	F

Gold*	Au
Helium	He
Hydrogen	H
Iodine	I
Iron*	Fe
Lead*	Pb
Lithium	Li
Magnesium	Mg
Manganese	Mn
Mercury*	Hg
Neon	Ne
Nickel	Ni
Nitrogen	N
Oxygen	O

Phosphorus	P
Platinum	Pt
Potassium*	K
Rubidium	Rb
Silicon	Si
Silver*	Ag
Sodium*	Na
Strontium	Sr
Sulfur	S
Tin*	Sn
Titanium	Ti
Uranium	U
Zinc	Zn

Memorize these 41 common chemical element **names** and **symbol**

*Ancient element with symbol from Latin name

Test Yourself: Categorizing Matter

Q Are the following things matter, elements, compounds, pure substances and/or mixtures?

- Iron
  - Matter, element, pure substance
- Lemonade
  - Matter, mixture
- Sodium chloride (salt)
  - Matter, compound, pure substance
- Mercury
  - Matter, element, pure substance
- Air
  - Matter, mixture

Everything with mass and volume is matter

Elements and compounds are pure substances

Mixtures are not pure substances

3.2 How Matter Changes - Chemical Change

- The smallest part of an element is an **atom**
- **Chemical reactions** or **chemical changes** produce new substances by rearranging the way the atoms are connected together
- **Reactants** are starting materials
- **Products** are ending materials
  - Products usually have very different properties than reactants
- Rusting, tarnishing and burning are chemical reactions

How Matter Changes - Physical Change

- **Physical changes** <u>do not</u> produce new substances although the appearance may change
- Ice, water and steam are <u>all the same substance</u>
  - They can be converted from one form to another without chemical reaction
- Dissolving salt in water is a physical change because saltwater has properties like the starting materials
  - Saltwater can be separated simply by boiling

Chemical or Physical Change?

- Chemical changes are often accompanied by heat, light, gas production, color changes, products with different properties
- Physical changes are often achieved by changing temperature or pressure
- **Chemical changes produce new substances; physical changes do not**

3.3 Mixtures

- **Mixtures** have variable composition
- Concrete is a mixture of stones, cement and sand
- The proportions of each component are not fixed
- The properties of the mixture vary with a variation in content

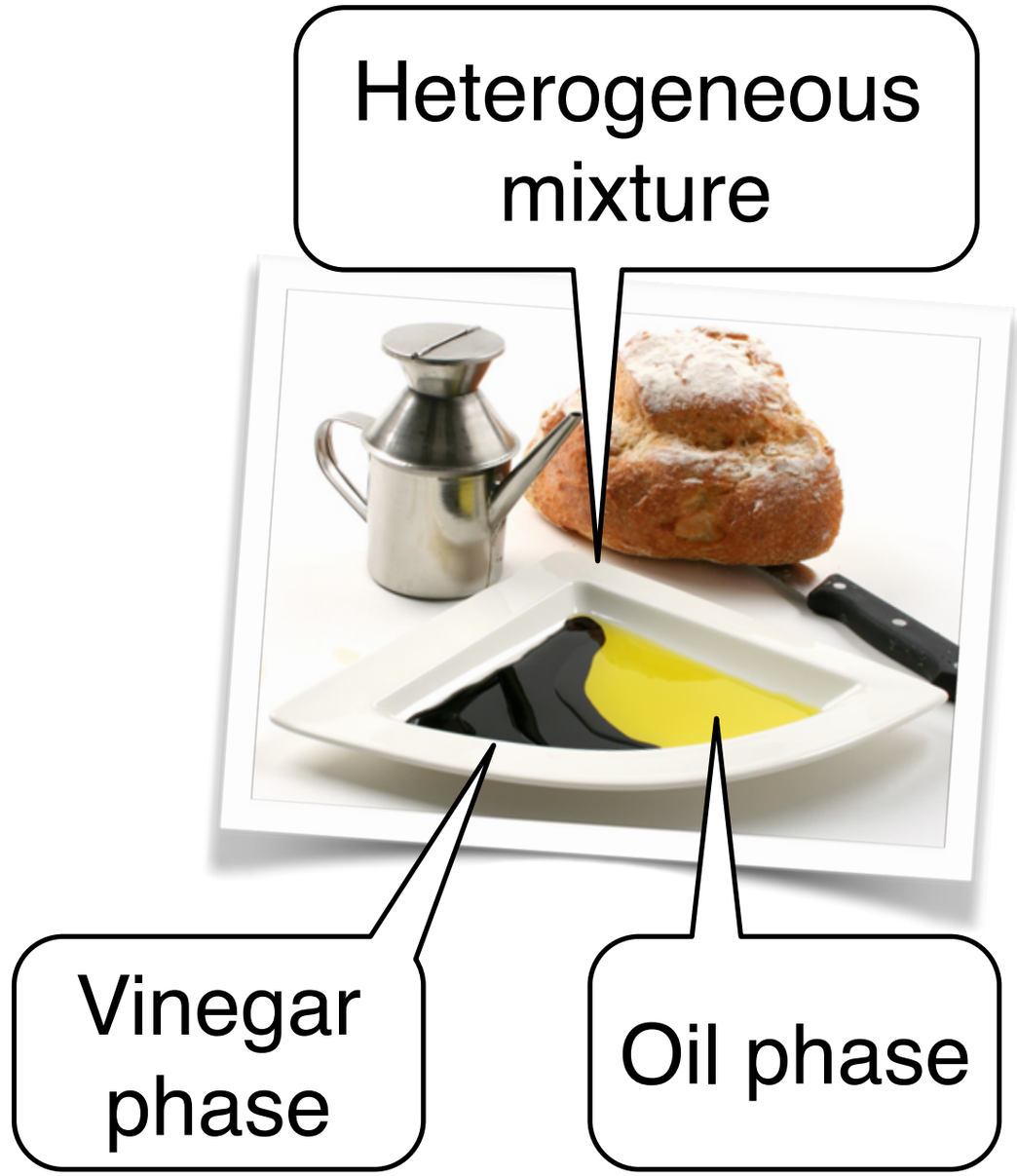
Typical of all mixtures

Homogeneous and Heterogeneous Mixtures

- A mixture with a uniform composition throughout is called a **homogeneous mixture**
- To the unaided eye, it looks the same everywhere
  - Examples include milk, paint, saltwater, metal alloys
- A mixture with a non-uniform composition throughout is called a **heterogeneous mixture**

Heterogeneous Mixtures and Phases

- **Heterogeneous mixtures** have distinct phases
- A **phase** is a portion of a mixture with a specific composition
- Phases may or may not have a different physical state like solid,



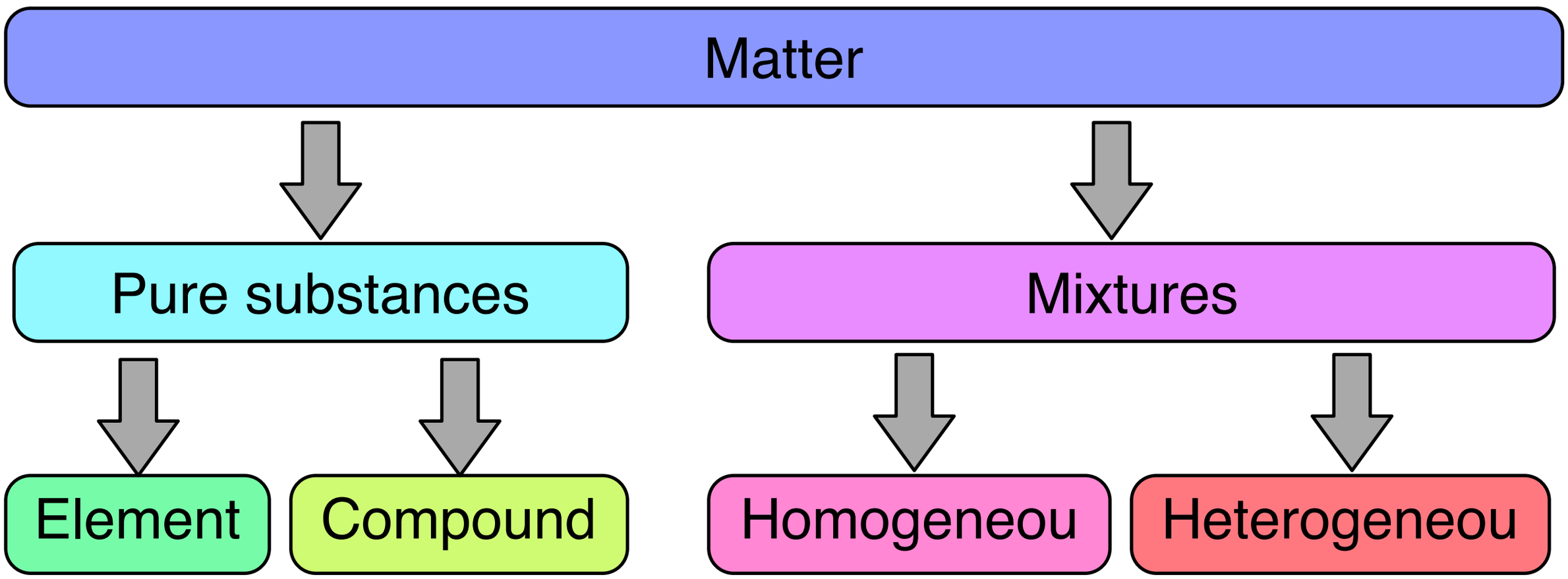
Test Yourself: Mixtures

Q Are the following homogeneous or heterogeneous mixtures and how many phases are present?

- Butter
  - Homogeneous mixture, one phase
- Ice water
  - Heterogeneous mixture, two phases
- Air
  - Homogeneous mixture, one phase
- Toast with butter and jelly
  - Heterogeneous mixture, three phases

Homogeneous mixtures are always one phase

Classification of Matter



All matter fits into one of these four categories

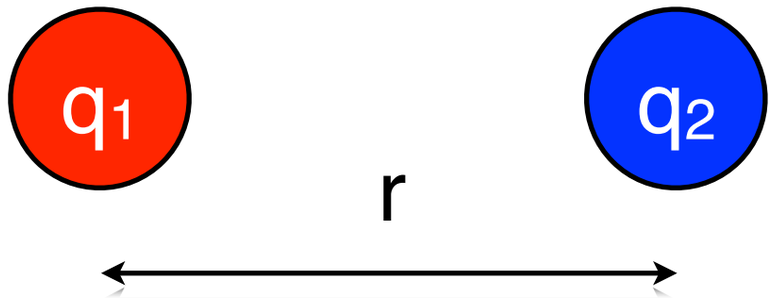
3.5 Atomic Structure

- **Electric charge** is a property of matter
- It may build up on an object as **static electricity**
  - The shock when touching a metal door handle in winter
- It may move from one place to another as **electrical current**
  - Lightning or charge flowing through a light bulb
- Charge comes in **positive**

Electric Charges and Coulomb's Law

- **Opposite varieties** of electric charge **attract**
- The **same varieties** of electric charge **repel**
- The **electrostatic force** F between two charges is given by **Coulomb's law**

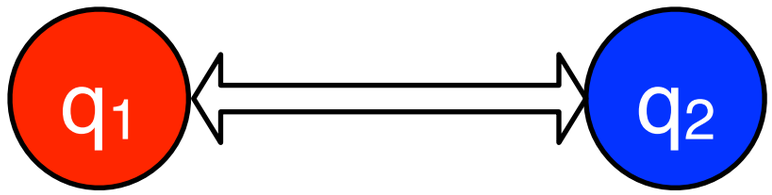
$$F = k \cdot \frac{q_1 \cdot q_2}{r^2}$$



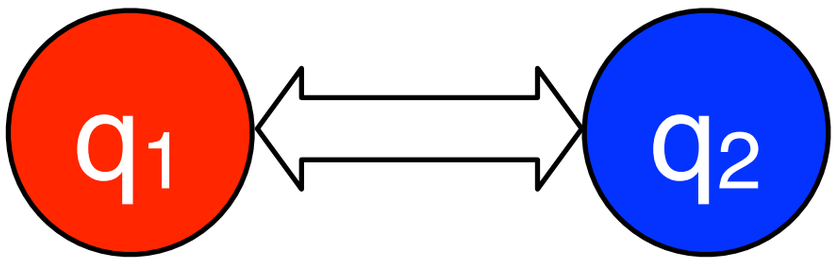
where F is force, k is a constant, q_1 and q_2 are the two charges and r is the distance between the charges

Electric Charge

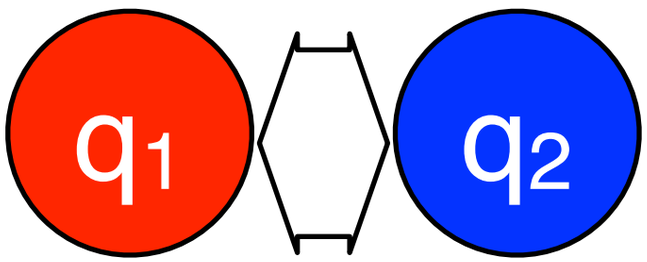
- **Coulomb's law** indicates that the force between the charges increases as q_1 and q_2 increase and as r decreases



Weak attraction



Strong attraction

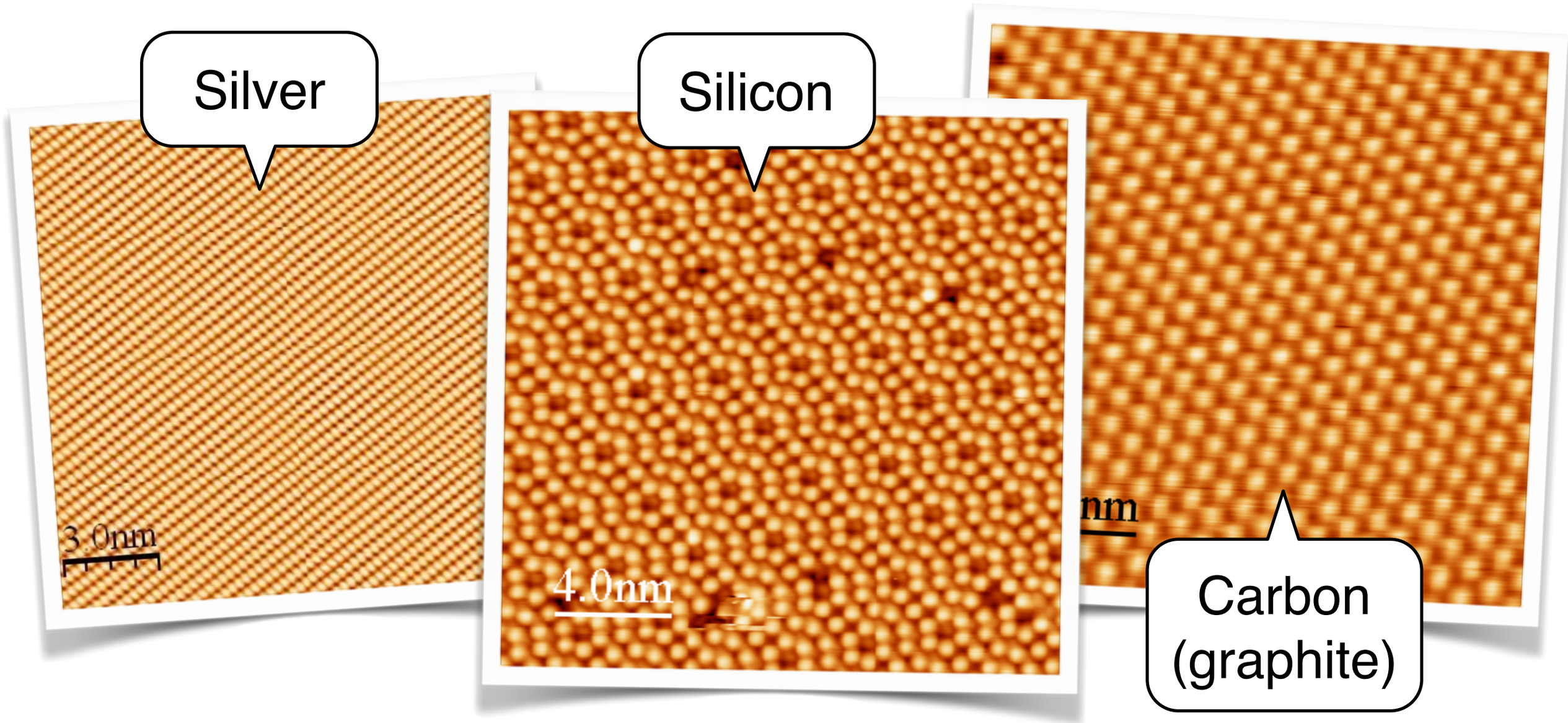


Strongest attraction

Charles-Augustin de Coulomb (1736-1806)

How Big Are Atoms?

- Atoms are the building blocks of the chemical elements



Atomic Structure

- Atoms are made of smaller building blocks called **subatomic particles**

1. The **electron** has a negative charge and very little mass
2. The **proton** has the same charge as the electron but is positive and has 1,800 times more mass than the electron
3. The **neutron** has no charge and nearly the same mass as the proton

- **All atoms are made of electrons and protons** and most contain **neutrons**

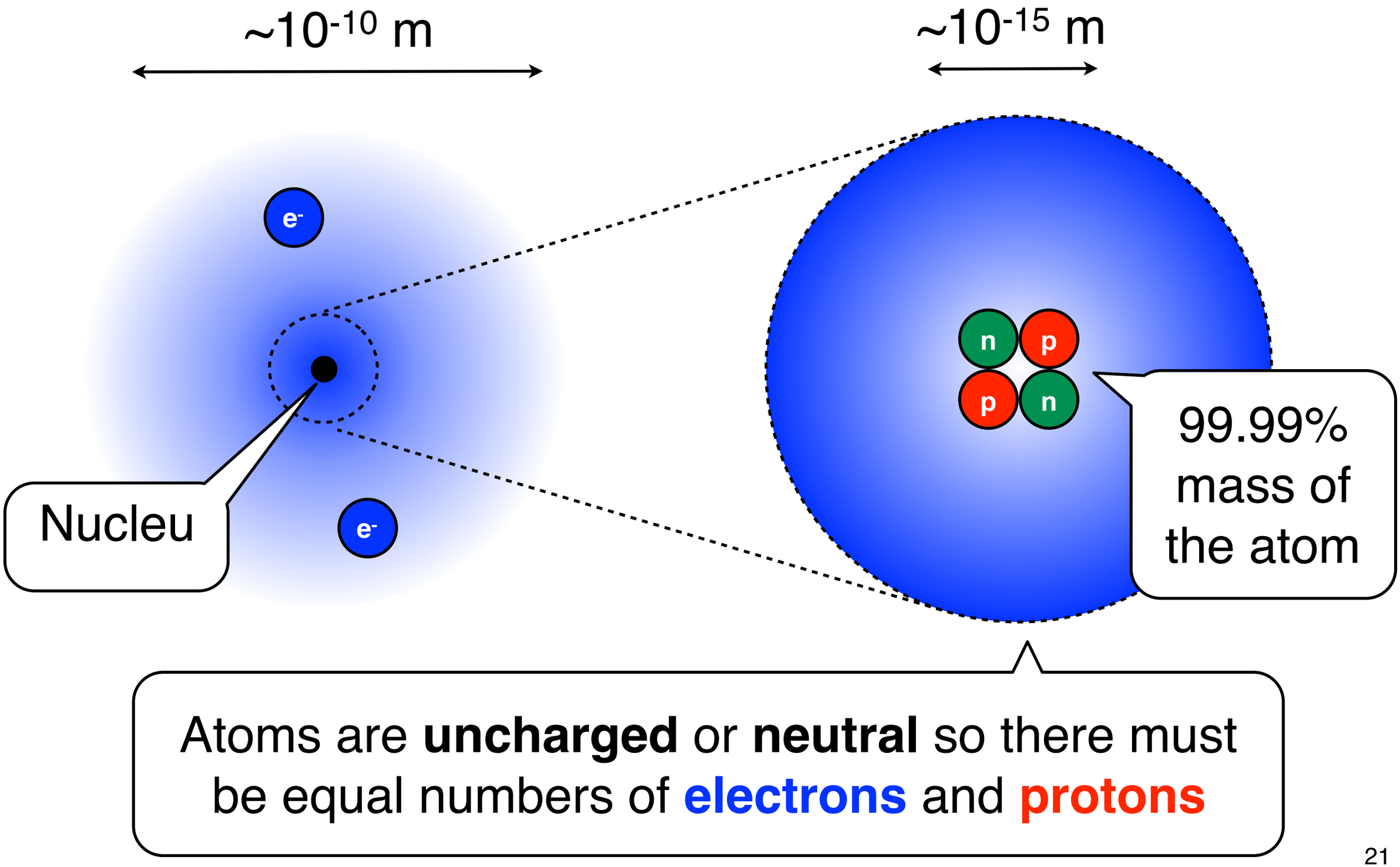
Subatomic Particles

The SI unit of charge is the coulomb (C)

Particle (symbol)	Location in atom	Relative electric charge	Mass (g)
Proton (p)	Inside the nucleus	+1	1.673×10^{-24}
Neutron (n)	Inside the nucleus	0	1.675×10^{-24}
Electron (e^-)	Outside the nucleus	-1	9.109×10^{-28}

The actual charge on the electron is -1.602×10^{-19} C

Atomic Structure



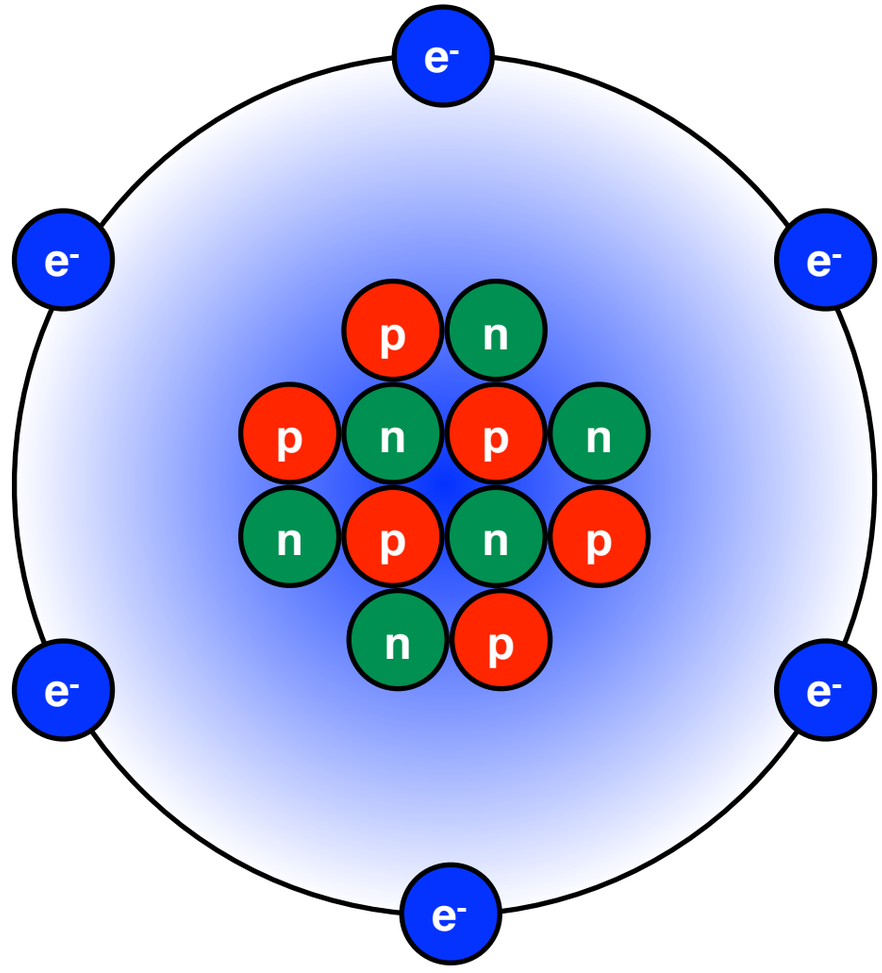
Atoms are **uncharged** or **neutral** so there must be equal numbers of **electrons** and **protons**

Atoms and Charges

- Protons and neutrons are held very tightly in the nucleus
  - They cannot be changed in a chemical reaction
- Electrons are held much more weakly
  - They are not drawn to the nucleus because they spin around the nucleus (simplified explanation)
- When charge flows, it is electrons that move
- When something charges up **positively** it is because electrons have been **removed**
- When something charges up **negatively** it is because electrons have been **added**

3.6 Chemical Elements and Atomic Number Z

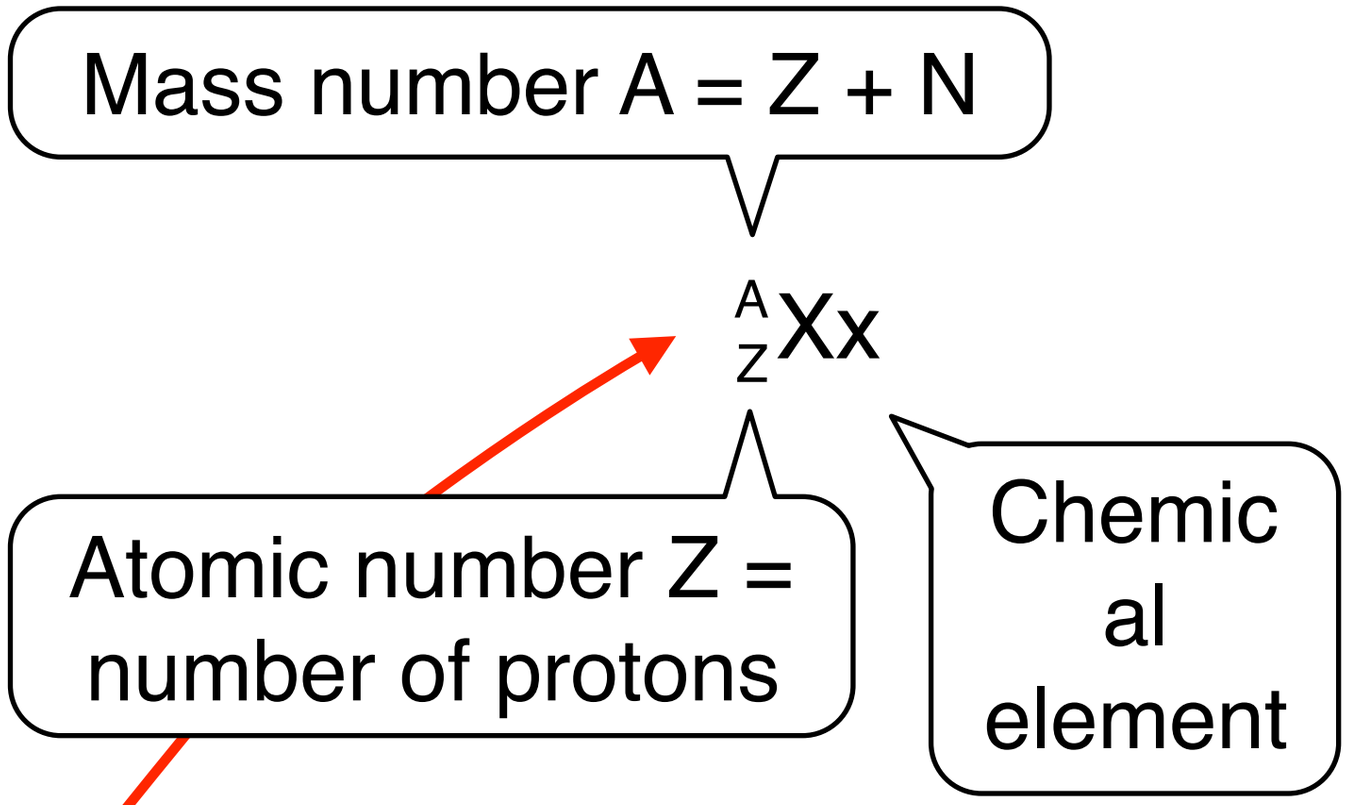
- Each element is different in terms of its number of subatomic particles
- The **atomic number Z** is the <u>number of protons</u> and it defines the chemical element
- Helium (Z = 2) has 2 protons
- Carbon (Z = 6) has 6 protons
- Gold (Z = 79) has 79



Every carbon atom has 6 protons and 6 electrons

Mass Number A

- Some atoms of the same element have different numbers of neutrons (**isotopes**)
- The **mass number A** is the sum of the number of protons (Z) and neutrons (N)
- N = A - Z
- We use a



$^{12}_{6}C$ has 6 p, 6 e^-, 6 n

$^{1}_{1}H$ has 1 p, 1 e^-, 0 n

$^{197}_{79}Au$ has 79 p, 79 e^-, 118 n

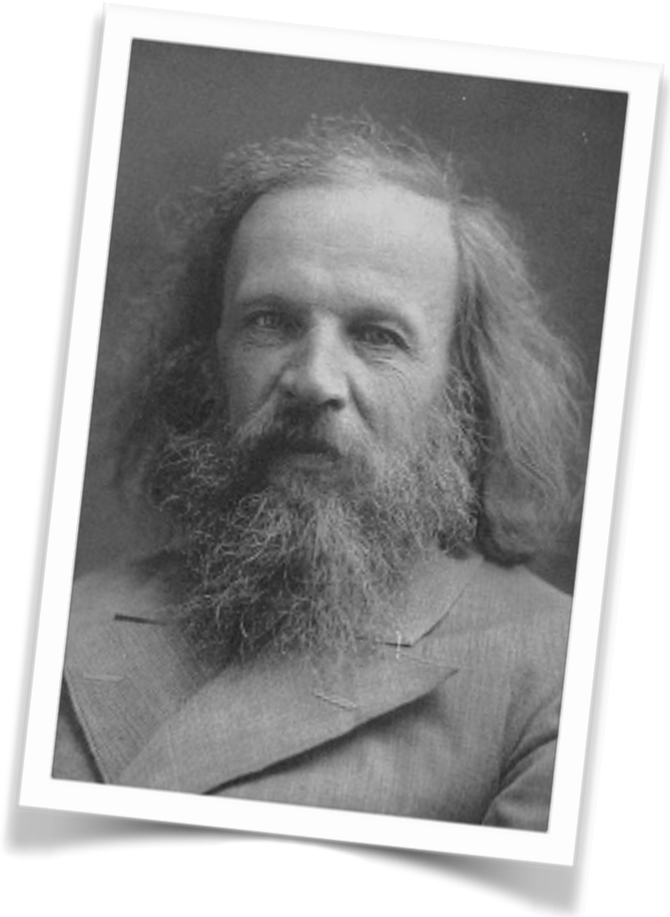
Test Yourself: Atomic Composition

Q Complete the following table:

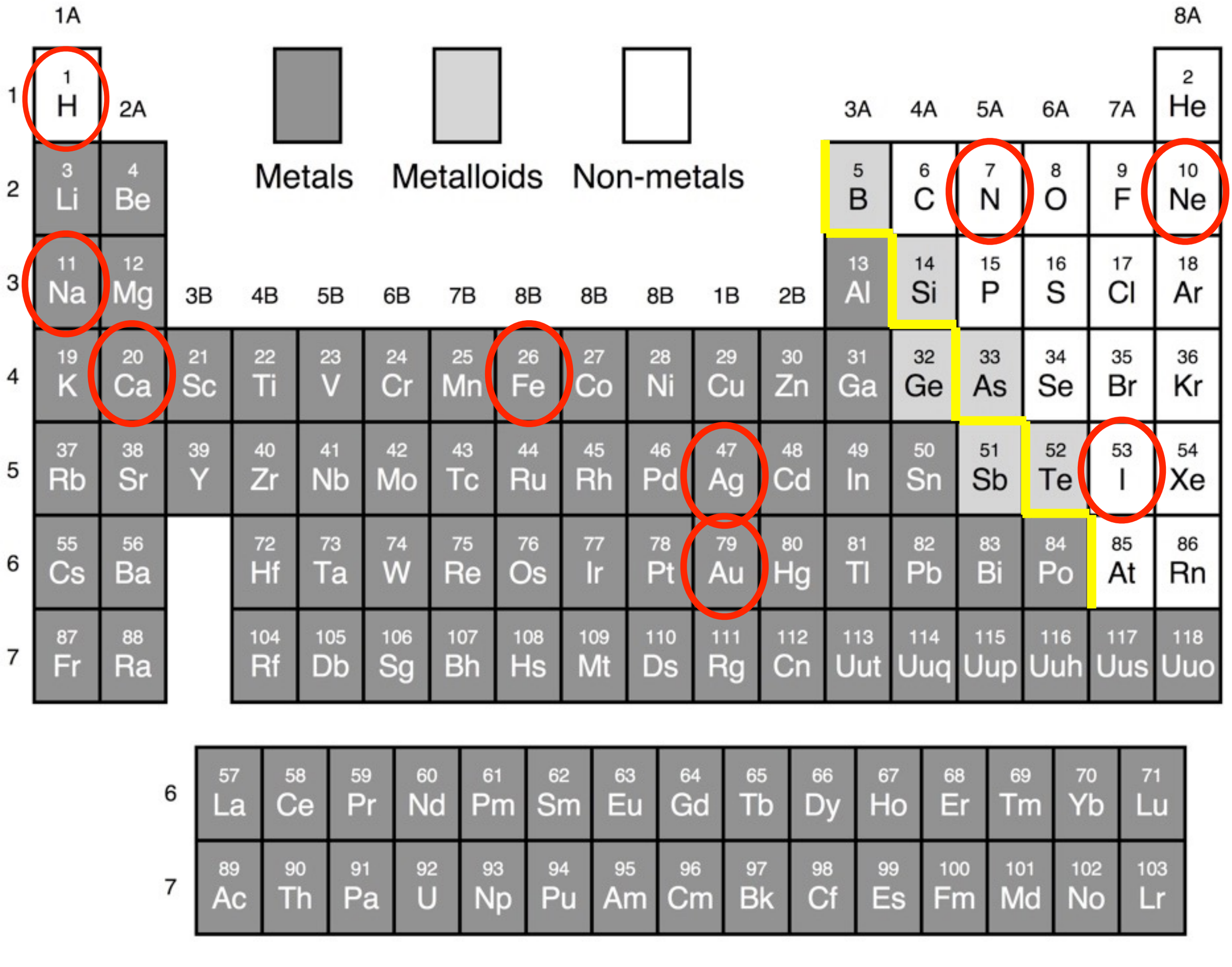
	Z	A	number of protons	number of electrons	number of neutrons
$^{16}_{8}O$	8	16	8	8	8
$^{23}_{11}Na$	11	23	11	11	12
$^{52}_{24}Cr$	24	52	24	24	28

The Periodic Table

- In 1869 **Dmitri Mendeleev** proposed arranging the chemical elements into a table
- The elements are ordered by increasing atomic number
  - Hydrogen (Z = 1) is top left; ununoctium (Z = 118) is bottom right
  - He organized it so elements with similar properties are grouped
  - He left gaps for elements not discovered in 1869
- The table is called the **periodic table**



Dmitri Mendeleev
(1834-1907)


1A
8A
2A
3A
4A
5A
6A
7A
Metals
Metalloids
Non-metals
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
3B
4B
5B
6B
7B
8B
8B
8B
1B
2B
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
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
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113 Uut
114 Uuq
115 Uup
116 Uuh
117 Uus
118 Uuo
6
7
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
71 Lu
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
103 Lr

The Periodic Table

- **Metals** (like copper) are shiny, good conductors of heat and electricity, dense and malleable
  - All are solids except mercury (Hg)
- **Non-metals** (like oxygen) do not conduct heat or electricity and have low melting temperatures and densities
  - Many are gases
- **Metalloids** (like silicon) exist in different forms, one of which is like a metal and one of which is like a non-metal
  - Many are used to make semiconductors

Organization of The Periodic Table

Main group
(A) elements

Main group
(A) elements

Transition
(B) elements

	1A												3A	4A	5A	6A	7A	8A
1	1 H	2A																2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	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
5	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
6	55 Cs	56 Ba		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
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

6	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	71 Lu
7	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	103 Lr

Organization of The Periodic Table

Group

Period

	1A												3A	4A	5A	6A	7A	8A
1	1 H	2A																2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	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
5	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
6	55 Cs	56 Ba		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
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

6	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	71 Lu
7	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	103 Lr

Organization of The Periodic Table

- Elements in the same group tend to have similar chemical properties
- Some groups have special names

Group	Name
1A (except H)	Alkali metals
2A	Alkaline earth metals
7A	Halogens
8A	Noble gases

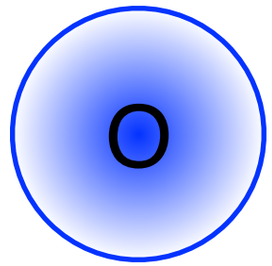
Organization of The Periodic Table

- For most elements, the atom is the smallest unit
- For some elements, a pair of joined atoms is the smallest unit

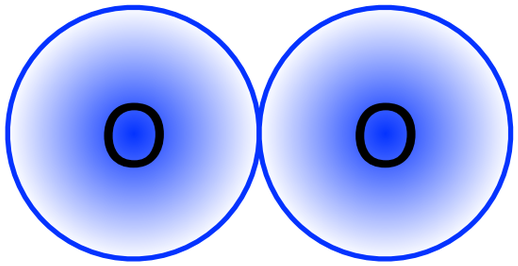
H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2

  - The subscript ($_2$) indicates the atoms are joined

- These elements are <u>always</u> found in nature as **diatomic molecules** and should be written as such
- A **molecule** is **two or more atoms joined together**



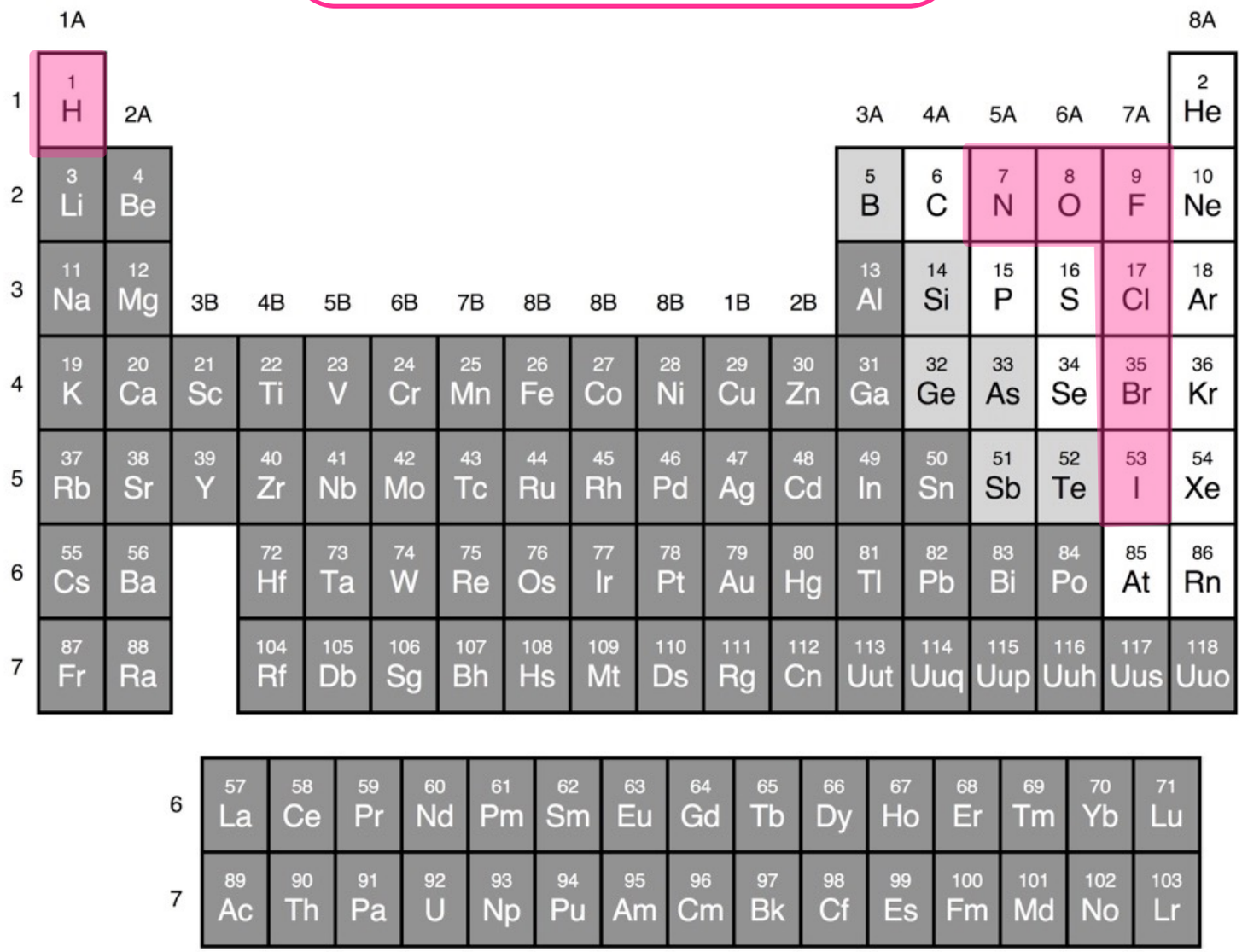
An oxygen atom O



An oxygen molecule O_2

Organization of The Periodic Table

The 7 **diatomic molecules**



3.7 Gaining and Losing Electrons

- Atoms may gain or lose whole electrons to form **ions**
- Atoms that lose electrons become **positively** charged and are called **cations; they tend to be metals**
- Sodium atoms may lose an electron to become a

$$Na\,(11\,p, 11\,e^-) \rightarrow Na^+\,(11\,p, 10\,e^-) + e^-$$

$$Ca\,(20\,p, 20\,e^-) \rightarrow Ca^{2+}\,(20\,p, 18\,e^-) + 2\,e^-$$

Calcium **atom**

Calcium **ion**

Ignore uncharged neutrons!

Gaining and Losing Electrons

- Atoms that gain electrons become **negatively** charged and are called **anions; they tend to be non-metals**
- Chlorine atoms may gain an electron to become a

$$Cl\,(17\,p, 17\,e^-) + e^- \rightarrow Cl^-\,(17\,p, 18\,e^-)$$

$$S\,(16\,p, 16\,e^-) + 2\,e^- \rightarrow S^{2-}\,(16\,p, 18\,e^-)$$

Sulfur **atom**

Sulfide **ion**

- Try these:

Q How many electrons are there in N^{3-}? (10)

Q How many electrons are there in Be^{2+}? (2)

Naming Ions

- What are the rules for naming anions and cations?
- All **monatomic cations** are named the same as the element plus "ion"

  Na^+ is the sodium ion

  Mg^{2+} is the magnesium ion

monatomic means one atom
diatomic means two atoms

- All **monatomic anions** are named with the first part of the element name with the suffix "-ide" plus "ion"

  Cl^- (chlorine + -ide + ion) is the chloride ion

  O^{2-} (oxygen + -ide + ion) is the oxide ion

  N^{3-} (nitrogen + -ide + ion) is the nitride ion

Common Stems of Element Names

- Many element **stems** can be guessed by dropping the last syllable of the element name
- Hydrogen = **hydr**
- Carbon = **carb**
- Oxygen = **ox**
- Fluorine = **fluor**
- Silicon = **silic**
- Phosphorus = **phosph**
- Sulfur = **sulf**
- Chlorine = **chlor**

Usually drop a vowel or “y” if it is followed by another vowel

Test Yourself: Monatomic Ion Names

Q Name the following monatomic ions:

Ion	Anion or cation?	Name
H^+	Cation	Hydrogen ion
Ca^{2+}	Cation	Calcium ion
P^{3-}	Anion	Phosphide ion
F^-	Anion	Fluoride ion
Li^+	Cation	Lithium ion
S^{2-}	Anion	Sulfide ion

Predicting the Charges on Monatomic Ions

- How can we predict the charges on monatomic ions?
- The **A group metals** tend to **lose electrons to form cations with a charge equal to the group number**

  The potassium ion comes from potassium (K) which is in group 1A so it is written K^+

- The **non-metals** tend to **gain electrons to form anions with a charge equal to the group number minus 8**

  The bromine ion comes from bromine (Br) which is in group 7A (7 - 8 = -1) so it is written Br^-

- An important exception is H^+

Test Yourself: Monatomic Ion Charges

Q Write the symbols for the following monatomic ions:

Name	Anion or cation?	Group?	Charge?	Symbol
Barium ion	Cation	2A	+2	Ba^{2+}
Lithium ion	Cation	1A	+1	Li^{+}
Hydrogen ion	Cation	1A	+1	H^{+}
Iodide ion	Anion	7A	-1	I^{-}
Sulfide ion	Anion	6A	-2	S^{2-}

Transition Ion Charges

- Unfortunately, the previous guides don't apply for determining charge for B group elements
  - They are all metals so all tend to form cations
- Many exist in several forms

  Fe^{2+} and Fe^{3+}
- They are named using Roman numerals

  Fe^{2+} is known as the iron (II) ion

  Fe^{3+} is known as the iron (III) ion

- Try these:

Q Name Ti^{2+}, Ti^{3+} and Ti^{4+}

Name	Symbol
Silver	Ag^{+}

Name	Symbol
Zinc	Zn^{2+}
Cadmium	Cd^{2+}
Nickel	Ni^{2+}
Manganese	Mn^{2+}
Tin	Sn^{2+}
Lead	Pb^{2+}

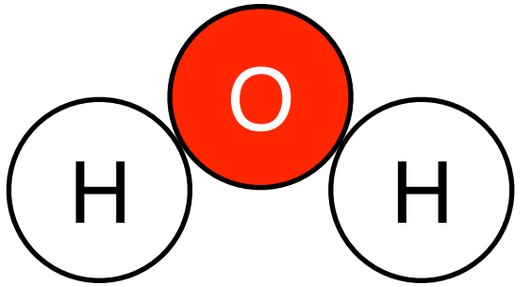
Name	Symbol
Copper (I)	Cu^{+}
Copper (II)	Cu^{2+}
Mercury (I)	Hg_2^{2+}
Mercury (II)	Hg^{2+}
Iron (II)	Fe^{2+}
Iron (III)	Fe^{3+}
Cobalt (II)	Co^{2+}
Cobalt (III)	Co^{3+}
Chromium (II)	Cr^{2+}
Chromium (III)	Cr^{3+}

3.8 Chemical Compounds

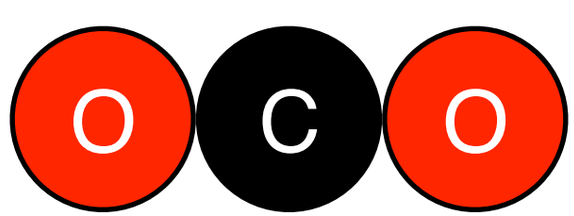
- A **compound** is two or more different elements joined together
  - They are formed by chemical reactions
  - They are pure substances so they have a fixed composition
- The **law of constant composition** states **all samples of a specific compound contain the same proportions of their constituent elements**
- This means a shorthand can be written for compounds
- The shorthand is called the **chemical formula** and it indicates the constituents and their proportions
- The compound has different properties than its

Chemical Formulas

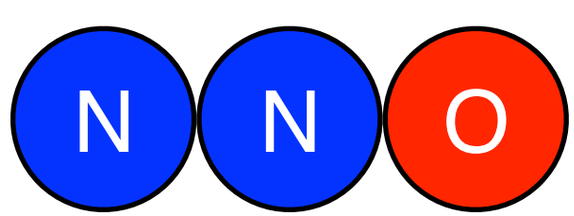
- The chemical formula for carbon dioxide is CO_2
- The constituents are carbon (C) and oxygen (O) only
- The subscript ($_2$) indicates the compound contains exactly 2 atoms of O and 1 atom of C



H_2O
Water



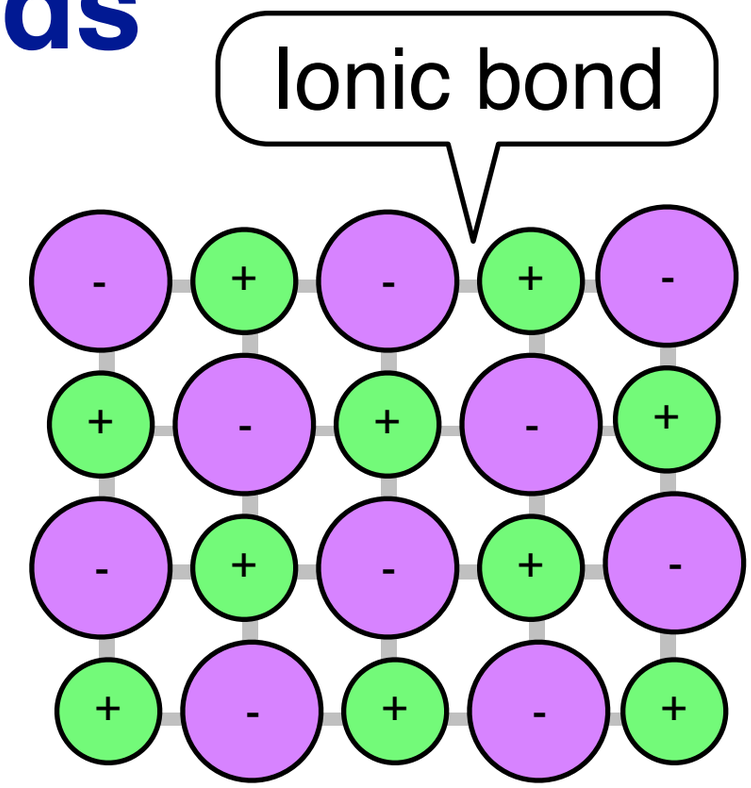
CO_2
Carbon dioxide



N_2O
Nitrous oxide

The chemical formula does not show the way that the atoms are joined!

Chemical Compounds



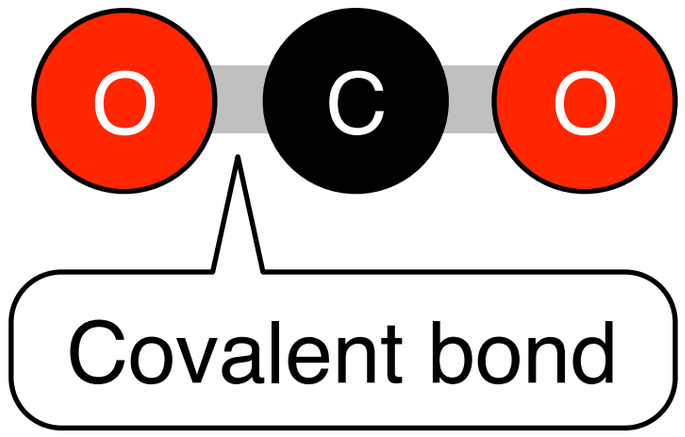
- Chemical compounds come in two basic types:

1. **Ionic compounds** are 3-D arrangements of cations and anions held together by electrostatic forces

   The forces are known as **ionic bonds**

2. **Molecular compounds** are separate molecules formed when two non-metals are joined by **covalent bonds**

   The covalent bond is an electrostatic attraction between two nuclei and a cloud of electrons between them



Ionic Compounds

- Ionic compounds are formed by a metal and a non-metal
  - Usually the cation is formed by the metal and the anion formed by the non-metal
- Ionic compounds are uncharged
  - The **positive charges** and **negative charges**

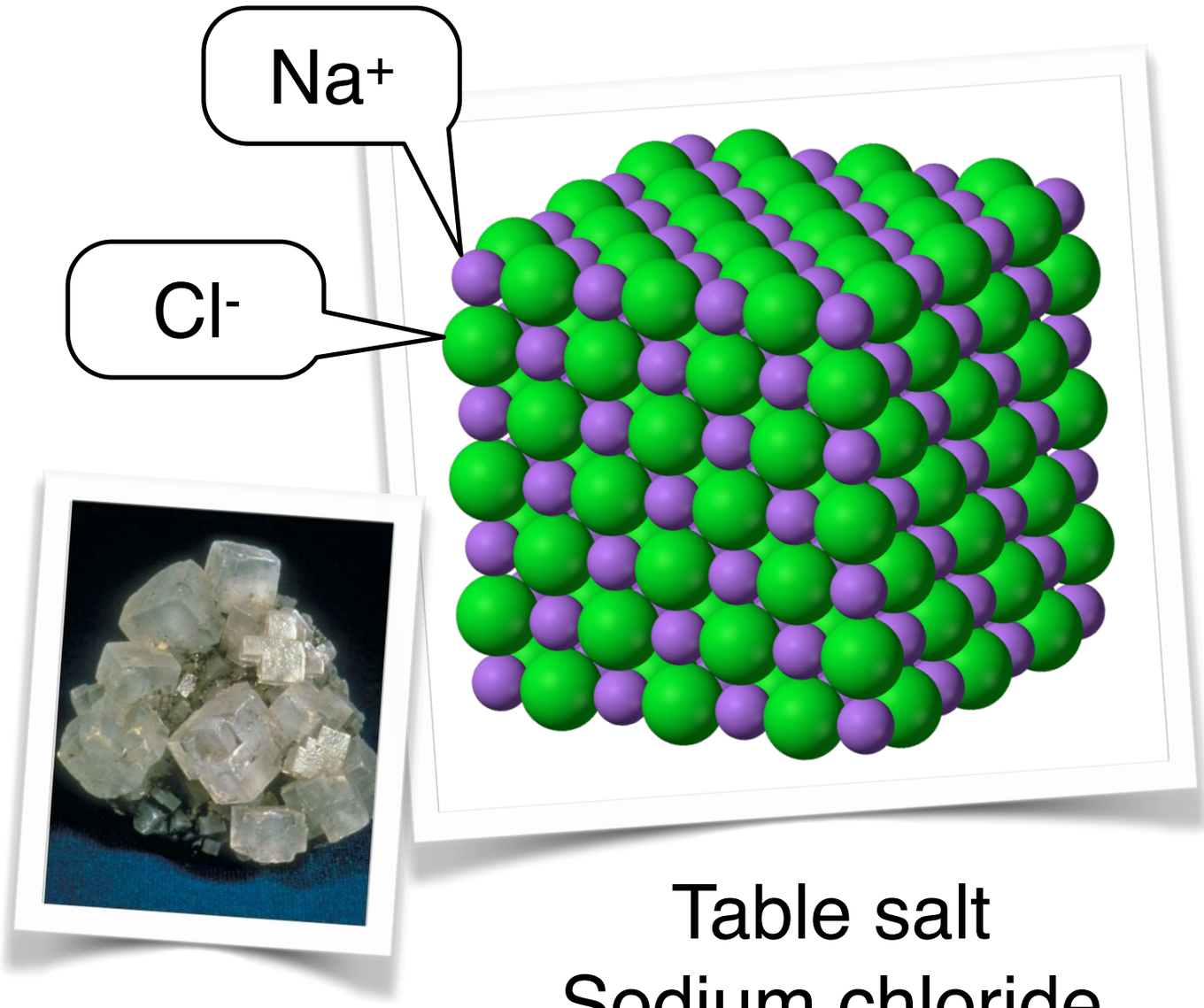


Table salt
Sodium chloride
NaCl

Ionic Compounds and Formula Units

- Since there may be a large number of ions in a sample, we use **formula unit,** the simplest integer ratio of the constituents of an ionic compound
- An ionic compound is named "cation anion"

  NaCl is sodium chloride

  MgF_2 is magnesium fluoride

  Ca_3P_2 is calcium phosphide

  PbS is lead sulfide

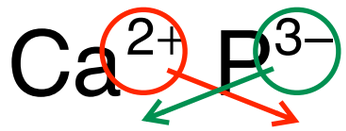
Galena
Lead sulfide

Most minerals are are ionic compounds

Ionic Compounds and Formula Units

- How is the formula unit determined?
- The general formula unit is **$\text{cation}_x\text{anion}_y$**
- x and y are chosen so that the compound is uncharged

Q What is the formula unit of the compound formed from the reaction of calcium and phosphorus?



A The formula unit is Ca_3P_2

Test Yourself: Formula Units

Q Write the formula units for following compounds:

Name	Cation?	Anion?	Formula unit
Lithium fluoride	Li^{+}	F^{-}	LiF
Magnesium oxide	Mg^{2+}	O^{2-}	MgO
Calcium bromide	Ca^{2+}	Br^{-}	$CaBr_2$
Sodium sulfide	Na^{+}	S^{2-}	Na_2S
Aluminum oxide	Al^{3+}	O^{2-}	Al_2O_3

Polyatomic Ions

- There are many instances of polyatomic ions in chemistry
- A **polyatomic ion** is a charged group of atoms
  - NH_4^+ is the **ammonium ion**
  - CO_3^{2-} is the **carbonate ion**
  - PO_4^{3-} is the **phosphate ion**
- The procedure for naming is the same as before
  - "Cation anion"

Q What is the name for the ionic compound formed from the sodium and carbonate ions?

A Sodium carbonate

Name	Symbol
Ammonium	NH_4^+

Name	Symbol
Hydroxide	OH^-
Nitrite	NO_2^-
Nitrate	NO_3^-
Acetate	$C_2H_3O_2^-$
Cyanide	CN^-
Hypochlorite	ClO^-

Name	Symbol
Chlorite	ClO_2^-
Chlorate	ClO_3^-
Perchlorate	ClO_4^-
Hydrogen carbonate	HCO_3^-
Hydrogen sulfite	HSO_3^-
Hydrogen sulfate	HSO_4^-
Permanganate	MnO_4^-

Memorize these!

Name	Symbol
Oxide*	O^{2-}
Peroxide	O_2^{2-}
Sulfide*	S^{2-}
Sulfite	SO_3^{2-}
Sulfate	SO_4^{2-}
Carbonate	CO_3^{2-}
Oxalate	$C_2O_4^{2-}$
Silicate	SiO_3^{2-}
Chromate	CrO_4^{2-}
Dichromate	$Cr_2O_7^{2-}$

Name	Symbol
Thiosulfate	$S_2O_3^{2-}$
Hydrogen phosphate	HPO_4^{2-}

Name	Symbol
Phosphide*	P^{3-}
Phosphate	PO_4^{3-}

* Not polyatomic ions

Memorize these!

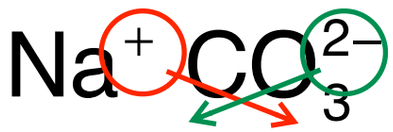
Polyatomic Ions and Formula Units

- The procedure for finding the formula unit is the same as before except the **polyatomic ion is enclosed in parentheses if more than one is needed**

Sodium carbonate
Na_2CO_3

Q What is the formula unit for sodium carbonate?

A The two ions are Na^+ and CO_3^{2-}

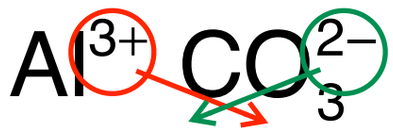


A Na_2CO_3

Polyatomic Ions and Formula Units

Q What is the formula unit for aluminum carbonate?

A The two ions are Al^{3+} and CO_3^{2-}



A $Al_2CO_{3\ 3}$?

But this is confusing so the correct answer makes use of parentheses - $Al_2(CO_3)_3$

Q How many atoms of each kind are there in one formula unit of $Al_2(CO_3)_3$

A 2 Al atoms, 3 C atoms and 9 O atoms

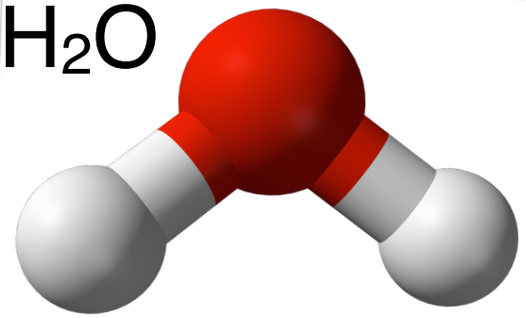
3.10 Molecular Compounds

- **Molecular compounds** are molecules composed of <u>two or more different atoms</u> joined by covalent bonds
- Molecular compounds are composed of <u>non-metal atoms</u>
- The chemical formula indicates how many atoms of each element are present (not the simplest ratio)
  - CH_4 - 1 carbon atom and 4 hydrogen atoms
  - N_2H_4 - 2 nitrogen atoms and 4 hydrogen atoms
  - C_4H_{10} - 4 carbon atoms and 10 hydrogen atoms

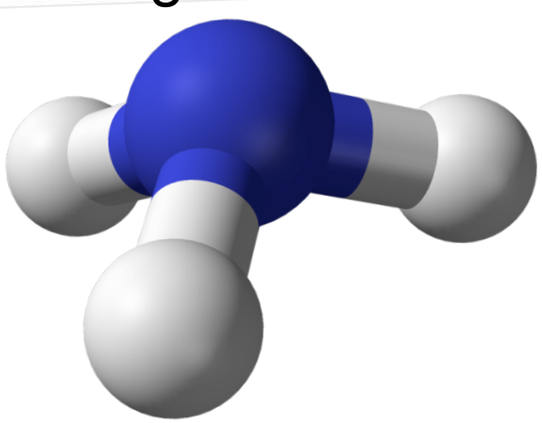
Visualizing Molecular Compounds

- To help visualize molecular compounds, chemists use either **ball-and-stick** or **space-filling** models

H_2O



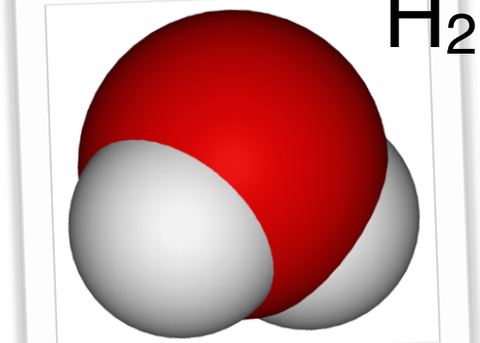
NH_3



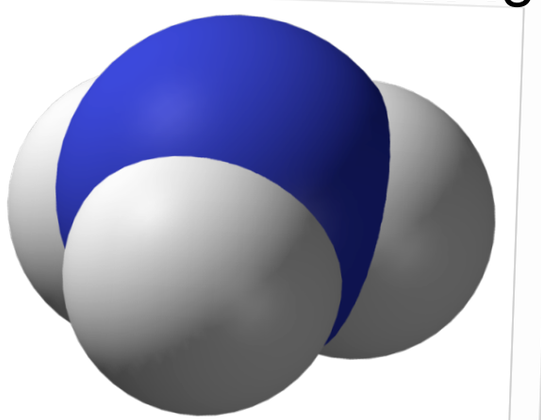
Ball-and-stick is simpler, best for showing connectivity of molecule

Space-filling is best for showing true size and shape of molecule

H_2O

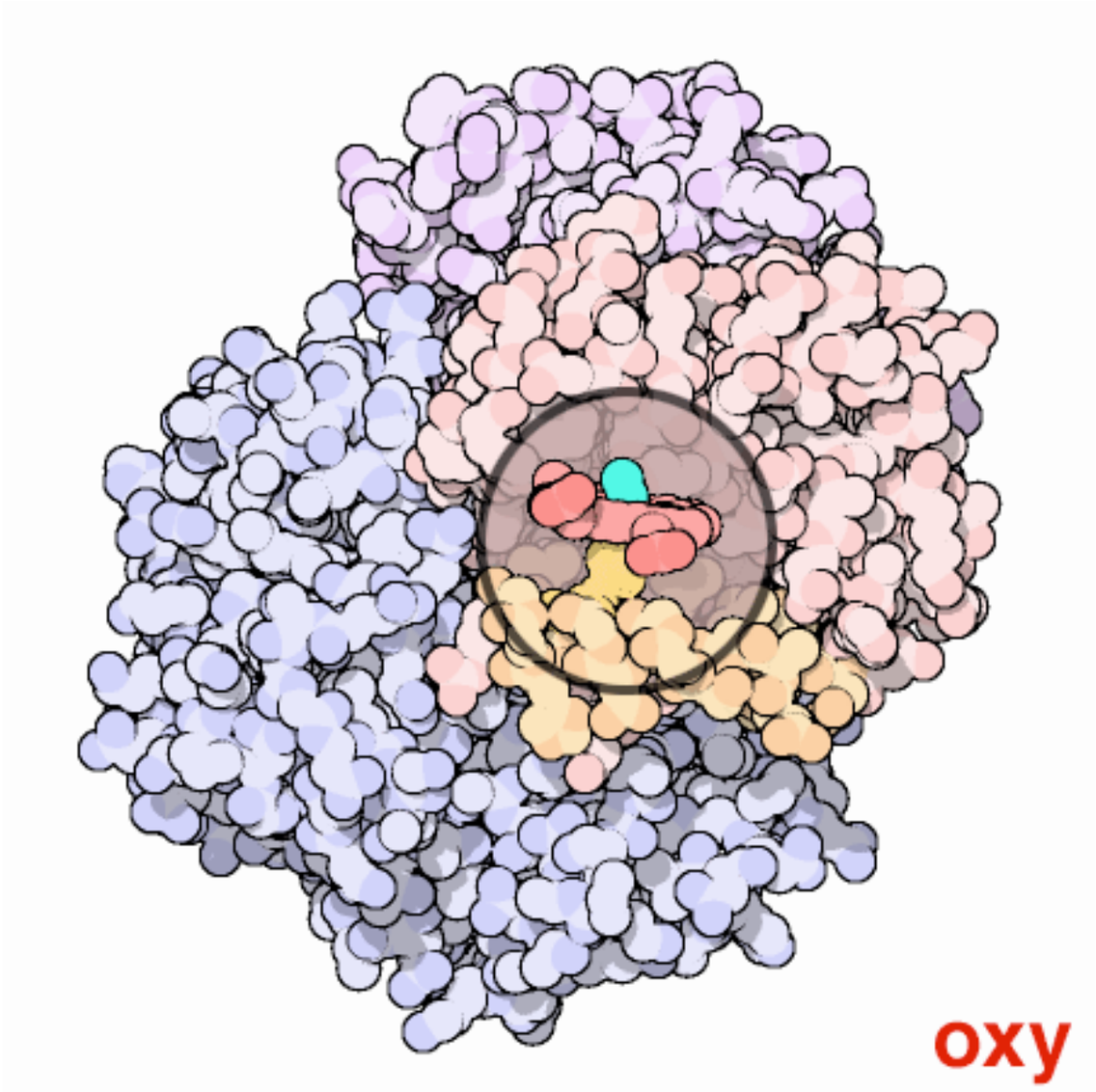


NH_3



Visualizing Molecular Compounds

- Models help chemists understand how even complex molecules work
- Hemoglobin is the molecule that picks up and transports oxygen (O_2) around the blood
- Its chemical formula is $C_{738}H_{1166}N_{812}O_{203}S_2Fe$!



Properties of Ionic Compounds and Molecular Compounds

Ionic Compounds	Molecular Compounds
Metal and non-metal with ionic bonding	Different non-metals with covalent bonding
3-D packing of cations and anions	Discrete molecules
Chemical formula (formula unit) indicates simplest ratio of atoms	Chemical formula indicates exact number of atoms
Usually hard solids	Small molecules may be gases or liquids, large molecules are solids
Do not conduct electricity except when dissolved in water	Do not conduct electricity even when dissolved in water (except acids)
Examples: NaCl, TiO_2, NaOH	Examples: H_2O, CO_2, CH_4, HCl

Naming Molecular Compounds

- **Binary** (two different atom) **molecular** compounds have the basic chemical formula $\mathbf{A_xB_y}$
  - Unlike ionic compounds, there are no charges to guide how to choose values for x and y
- We have to rely on the name to tell us x and y

1. Number prefix for A element
2. A element name
3. Number prefix for B element
4. Stem of B element name
5. -ide suffix

Naming Binary Molecular Compounds

- The number prefix is given by a Latin or Greek word
- To make the name more readable:

1. Drop <u>mono</u> for the first element
2. Drop <u>all prefixes</u> if the first element is H
3. Drop the last <u>o</u> or <u>a</u> of the prefix prior to a vowel

Prefix	Number
Mono	1
Di	2
Tri	3
Tetra	4
Penta	5
Hexa	6
Hepta	7
Octa	8
Nona	9
Deca	10

Memorize these prefixes

Naming Binary Molecular Compounds

Q Name the compound SF_6

A Following the 5 steps:

1. There is 1 A atom = **mono**
2. The A atom name = **sulfur**
3. There are 6 B atoms = **hexa**
4. The B atom name is fluorine and stem is **fluor**
5. Add **-ide**

   Monosulfur hexafluoride = **Sulfur hexafluoride**

Naming Binary Molecular Compounds

Q Name the compound N_2O_4

A Following the 5 steps:

1. There are 2 A atoms = **di**
2. The A atom name = **nitrogen**
3. There are 4 B atoms = **tetra**
4. The B atom name is oxygen and stem is **ox**
5. Add **-ide**

   Dinitrogen tetraoxide = **Dinitrogen tetroxide**

Test Yourself: Molecular Compounds

Q Name the following binary compounds:

Chemical Formula	Name
NO_2	Nitrogen dioxide
N_2O	Dinitrogen monoxide
CS_2	Carbon disulfide
PCl_5	Phosphorus pentachloride
N_2H_4	Dinitrogen tetrahydride
P_2O_5	Diphosphorus pentoxide

Binary Acids

- **Binary acids** are molecular compounds with the general formula **$H_xA(aq)$**
  - A is a non-metal
  - (aq) means **aqueous** (dissolved in water)
- **Acids produce $H^+(aq)$** when dissolved

Hydrochloric acid (HCl) is the primary stomach acid

Also known as muriatic acid

Naming Binary Acids

- Binary acids are named in 4 steps:

1. Hydro- prefix
2. Stem of non-metal A element
3. -ic suffix
4. Acid

Q Name the acid HF

1. Prefix = **Hydro-**
2. Stem = **Fluor**
3. Suffix = **-ic**
4. **Acid**

A Hydrofluoric acid

Test Yourself: Binary Acids

Q Name the following binary acids:

Chemical Formula	Name
HI	Hydroiodic acid
HBr	Hydrobromic acid
H_2S	Hydrosulfuric acid (not hydrosulfic acid)

Oxoacids

- **Oxoacids** are molecular compounds with the general formula $\mathbf{H_xAO_y(aq)}$
  - A is a non-metal
  - At least one H atom and one O atom
- How are they named?

Carbonic acid (H_2CO_3) is present in all carbonated beverages

Naming Oxoacids

- Oxoacids are named **according to the anion** formed when the H^+ ions leave
- HNO_3 loses H^+ to form NO_3^-
- The **nitrate** polyatomic anion is formed
- The acid is named in 4 steps:

1. The stem of the non-metal AO_y anion
2. If the anion ends in -ate, replace with -ic
3. If the anion end in -ite, replace with -ous
4. Acid

I **ate** something and now I feel **ic**k!

Naming Oxoacids

Q What is the name of the acid HNO_3?

1. The anion formed is NO_3^- (**nitr<u>ate</u>**)
2. The stem is **nitr**
3. **-ate** changes to **-ic**
4. Add the word **acid**

A The acid is **nitric acid**

Q What is the name of the acid HNO_2?

1. The anion formed is NO_2^- (**nitr<u>ite</u>**)
2. The stem is **nitr**
3. **-ite** changes to **-ous**
4. Add the word **acid**

A The acid is **nitrous acid**

Naming Summary

- You <u>must</u> identify whether a substance is ionic or molecular before trying to name it

1. Ionic compounds contain a metal and non-metal
   - Named **cation anion**
   - Chemical formula is determined by charges
2. Molecular compounds contain only non-metals
   - Binary compounds are named **number prefix** + **first element name** + **number prefix** + **second element stem** + **-ide**
   - Binary acids are named **hydro-** + **stem of non-metal** + **-ic** + **acid**
   - Oxoacids are **anion name** (**ate** to **ic**, **ite** to **ous**) + **acid**

Test Yourself: Naming Compounds

Q Name the following compounds:

Chemical Formula	Type?	Name
MgO	Ionic	Magnesium oxide
H_2SO_3	Oxoacid	Sulfurous acid
HCl	Binary acid	Hydrochloric acid
P_2Cl_6	Molecular	Diphosphorus hexachloride
Fe_2O_3	Ionic	Iron (III) oxide
$HClO_4$	Oxoacid	Perchloric acid

Review: Learning Objectives

- Classify materials as pure substances or mixtures (Section 3.1, 3.3; Exercises 1-5, 20, 21)
- Distinguish between chemical and physical change (Section 3.2; Exercises 6, 7, 17)
- Describe the subatomic composition of atoms & ions (Section 3.5, 3.6, 3.7; Exercises 8-11)
- Identify fundamental properties of elements (Section 3.5; Exercises 8-11)
- Distinguish between ionic and molecular compounds (Section 3.8, 3.9, 3.10; Exercises 12, 14, 18, 19, 23)
- Write chemical formulas and names for compounds (Section 3.9, 3.10; Exercises 13, 15, 16, 24, 25)