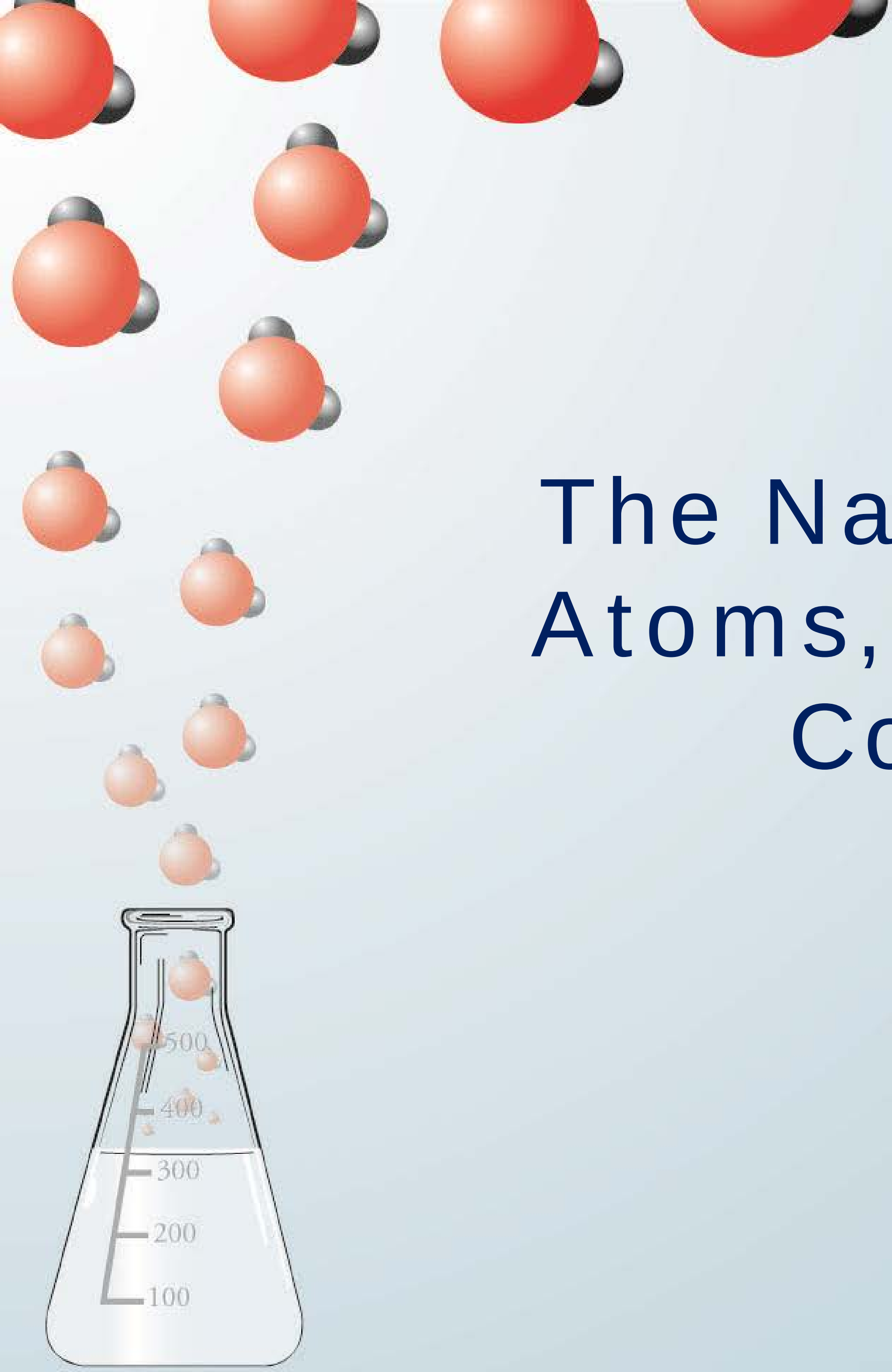


The Nature of Matter: Atoms, Elements, and Compounds

Scientific Models

- A ***model*** is a simplified approximation of reality.
- Scientific models are simplified but *useful* representations of something real.

Kinetic Molecular Theory

- All matter is composed of tiny particles.
- The particles are in constant motion.
- Increased temperature reflects increased motion of particles.
- Solids, liquids and gases differ in the freedom of motion of their particles and in how strongly the particles attract each other.

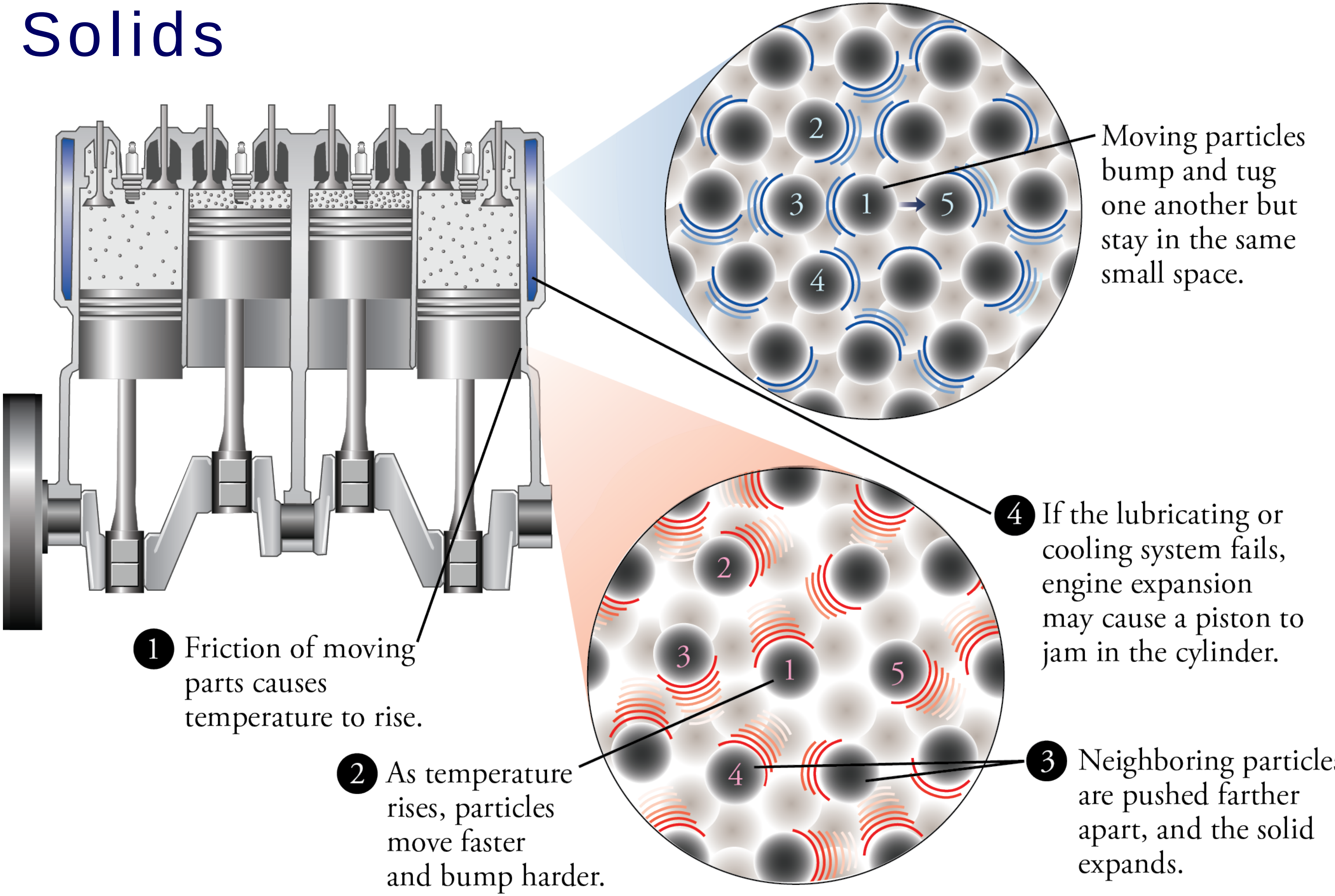
http://preparatorychemistry.com/KMT_flash.htm

http://preparatorychemistry.com/KMT_flash_audio.htm

Solid

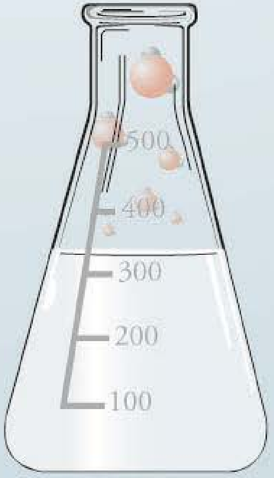
- Constant shape and volume
- The particles are constantly moving, colliding with other particles, and changing their direction and velocity.
- Each particle is trapped in a small cage whose walls are formed by other particles that are strongly attracted to each other.

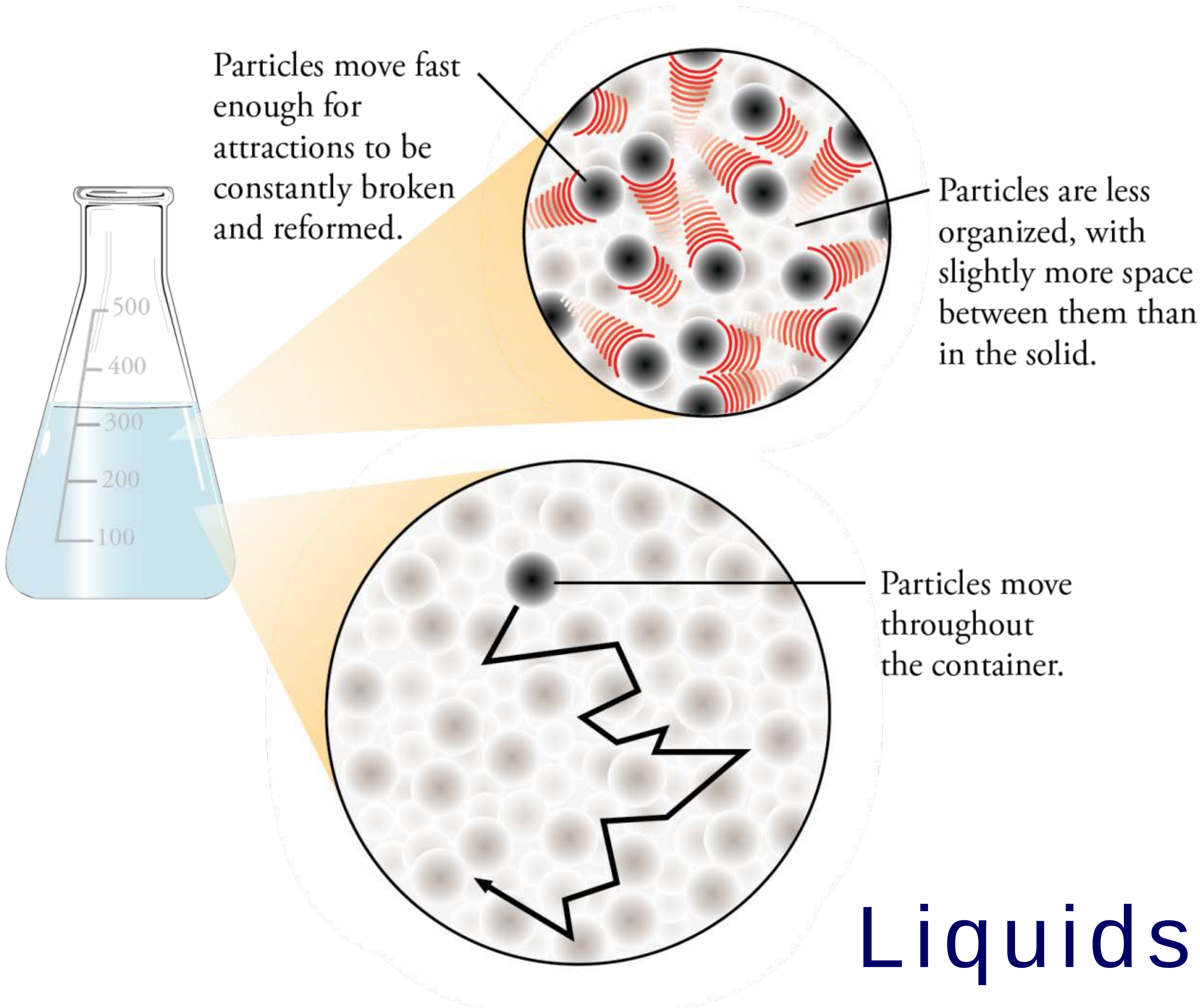
The Nature of Solids



Liquid

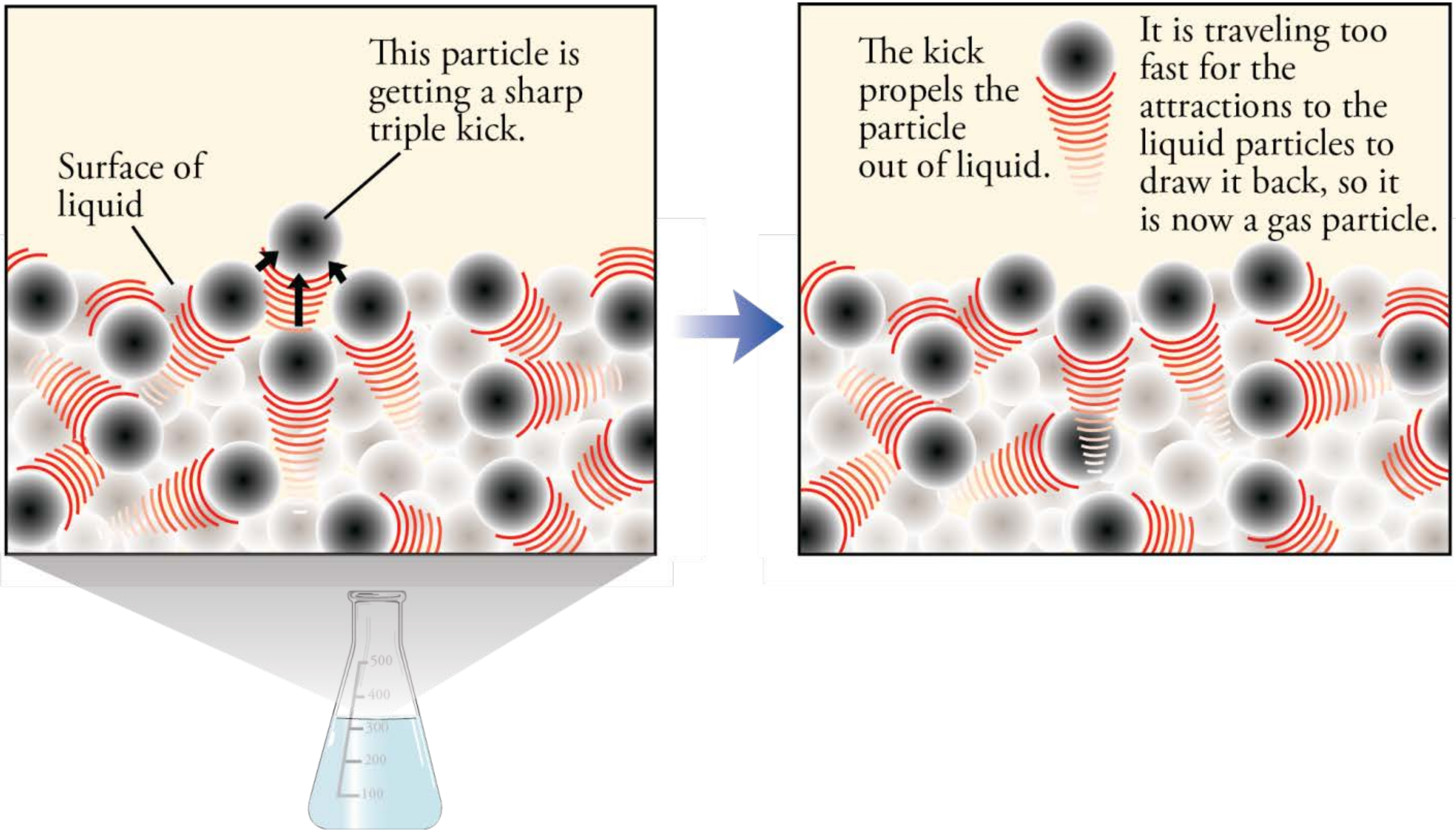
- Constant volume but variable shape
- The particles are moving fast enough to break the attractions between particles that form the walls of the cage that surround particles in the solid form.
- Thus each particle in a liquid is constantly moving from one part of the liquid to another.

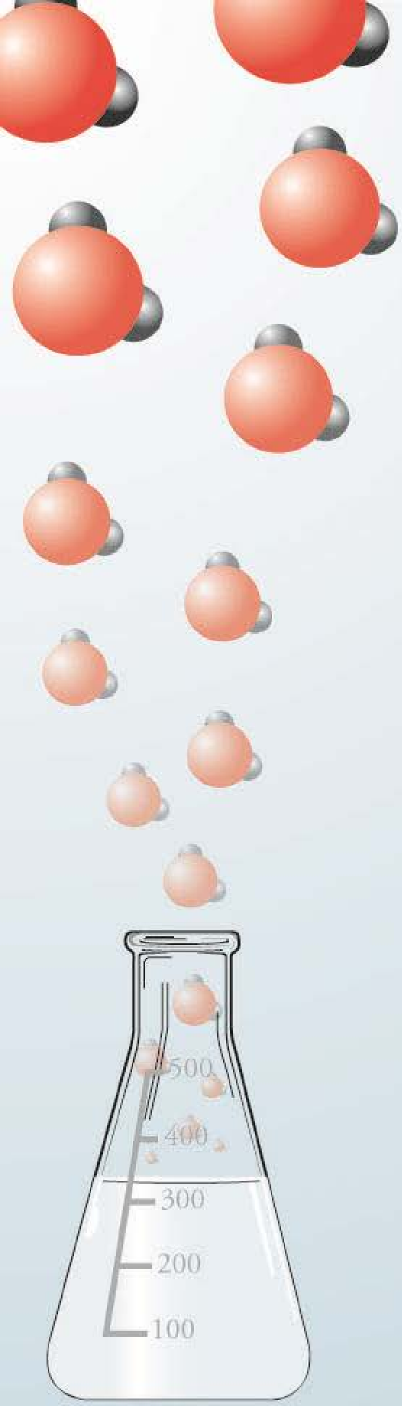



Particles move fast enough for attractions to be constantly broken and reformed.
Particles are less organized, with slightly more space between them than in the solid.
Particles move throughout the container.
500
400
300
200
100

Liquids

Evaporation

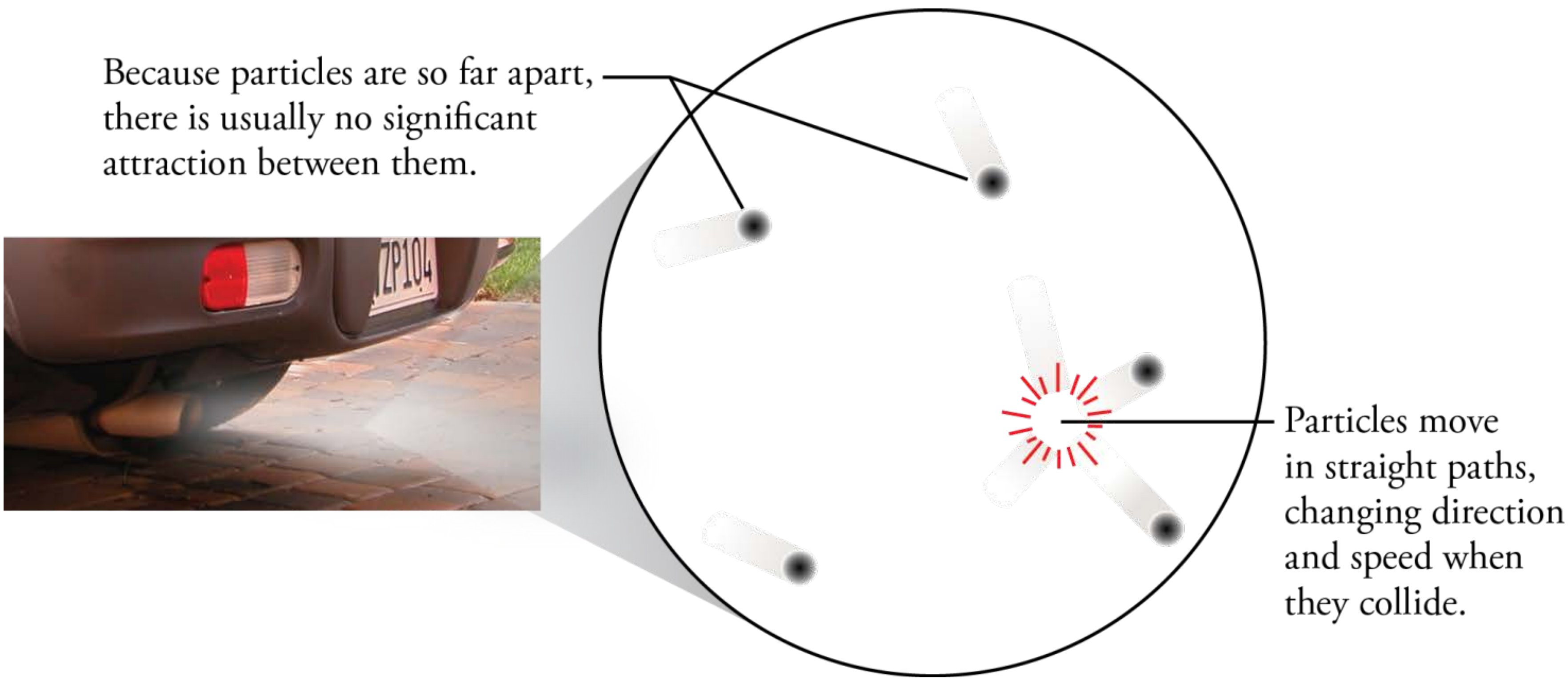




Gas

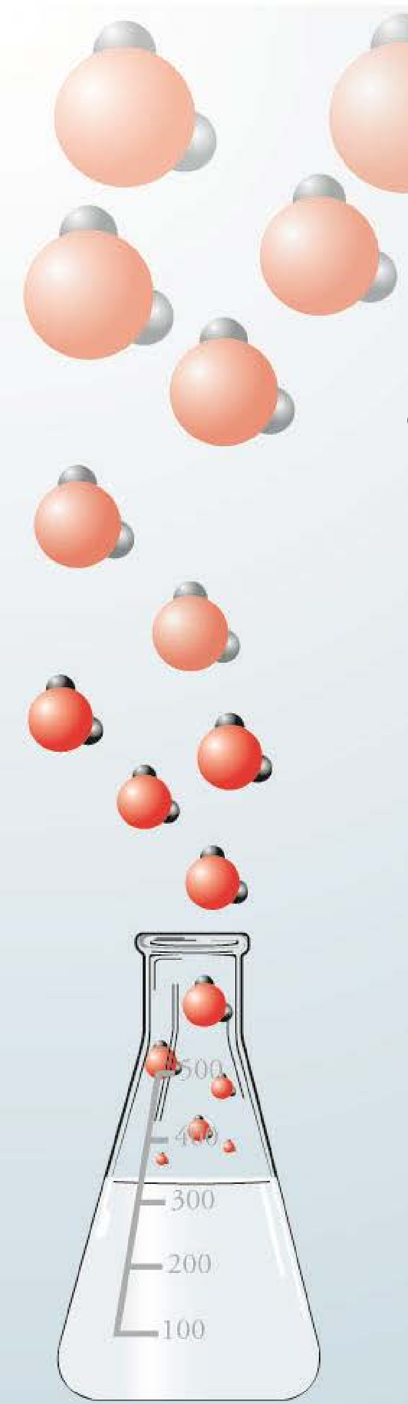
- Variable shape and volume
- Large average distances between particles
- Little attraction between particles
- Constant collisions between particles, leading to constant changes in direction and velocity

Gas


Because particles are so far apart, there is usually no significant attraction between them.
Particles move in straight paths, changing direction and speed when they collide.

Gas Model

- Gases are composed of tiny, widely-spaced particles.
  - For a typical gas, the average distance between particles is about ten times their diameter.



Gas Model (cont.)

- Because of the large distance between the particles, the volume occupied by the particles themselves is negligible (approximately zero).
  - For a typical gas at room temperature and pressure, the gas particles themselves occupy about 0.1% of the total volume. The other 99.9% of the total volume is empty space. This is very different than for a liquid for which about 70% of the volume is occupied by particles.

Gas Model (cont.)

- The particles have rapid and continuous motion.
  - For example, the average velocity of a helium atom, He, at room temperature is over 1000 m/s (or over 2000 mi/hr). The average velocity of the more massive nitrogen molecules, N_2, at room temperature is about 500 m/s.
  - Increased temperature means increased average velocity of the particles.

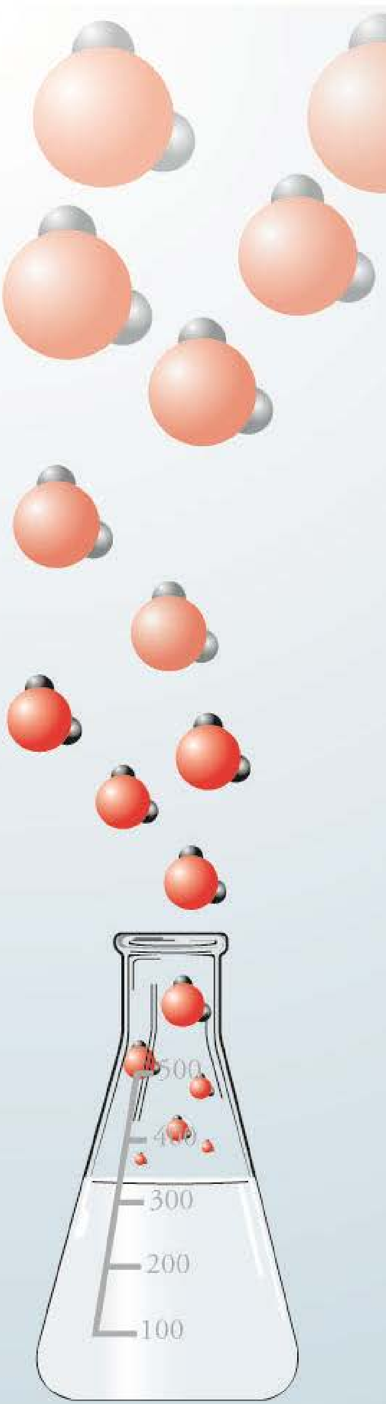
Gas Model (cont.)

- The particles are constantly colliding with the walls of the container and with each other.
  - Because of these collisions, the gas particles are constantly changing their direction of motion and their velocity. In a typical situation, a gas particle moves a very short distance between collisions. Oxygen, O_2, molecules at normal temperatures and pressures move an average of 10^{-7} m between collisions.

Gas Model (cont.)

- There is no net loss of energy in the collisions. A collision between two particles may lead to each particle changing its velocity and thus its energy, but the increase in energy by one particle is balanced by an equal decrease in energy by the other particle.

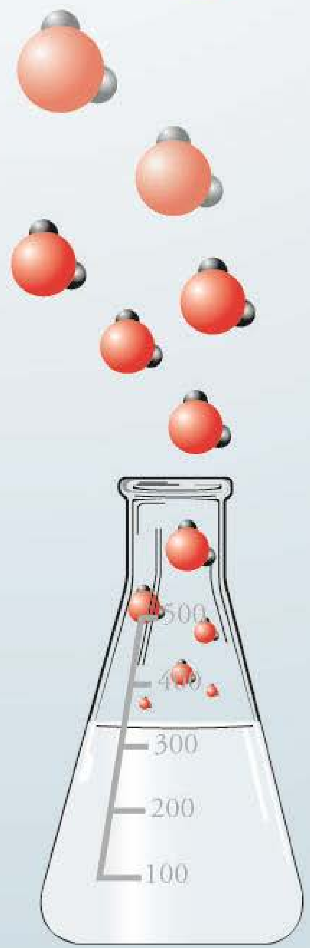
Ideal Gas



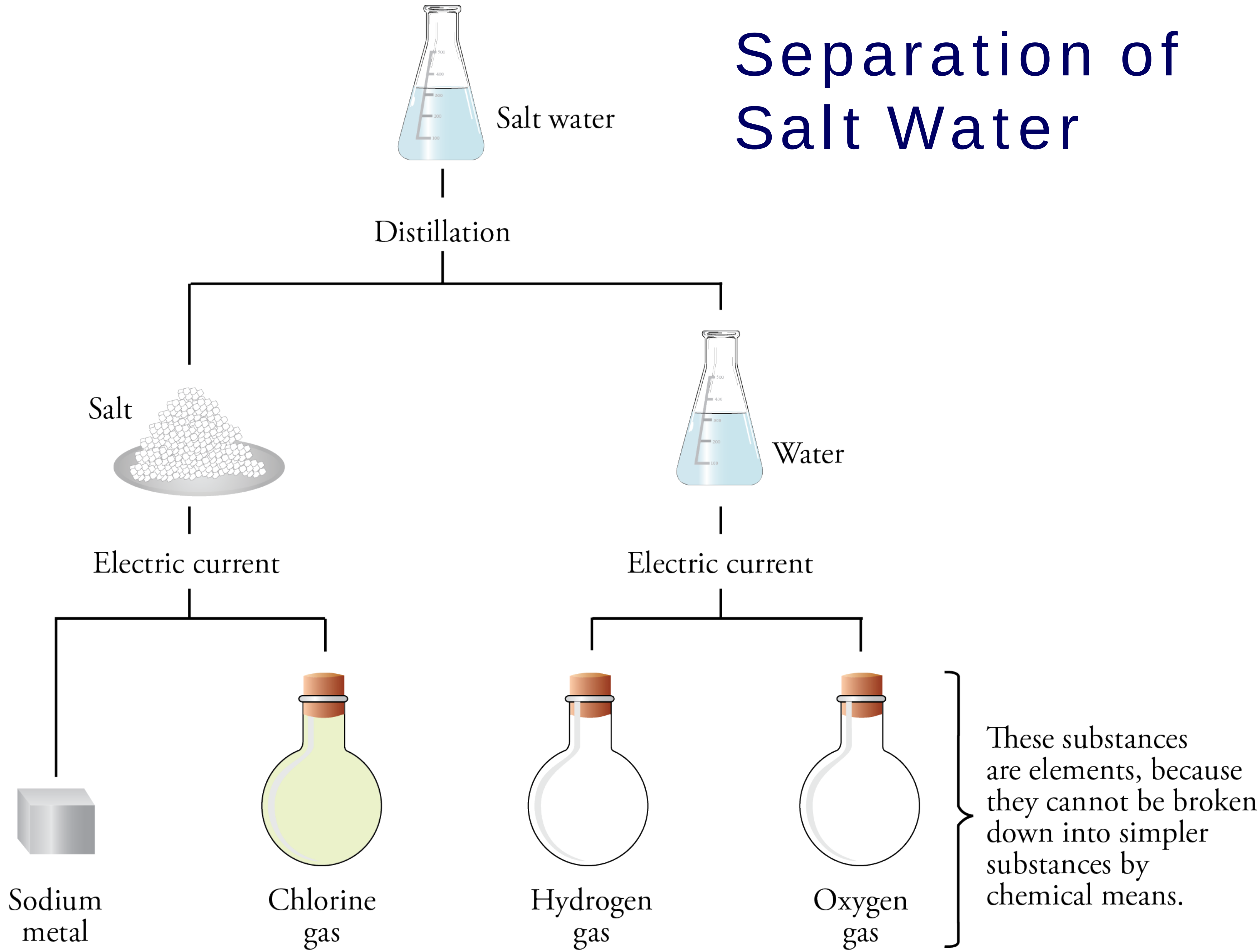
- The particles are assumed to be point-masses, that is, particles that have a mass but occupy no volume.
- There are no attractive or repulsive forces at all between the particles.

Gas Properties and their Units

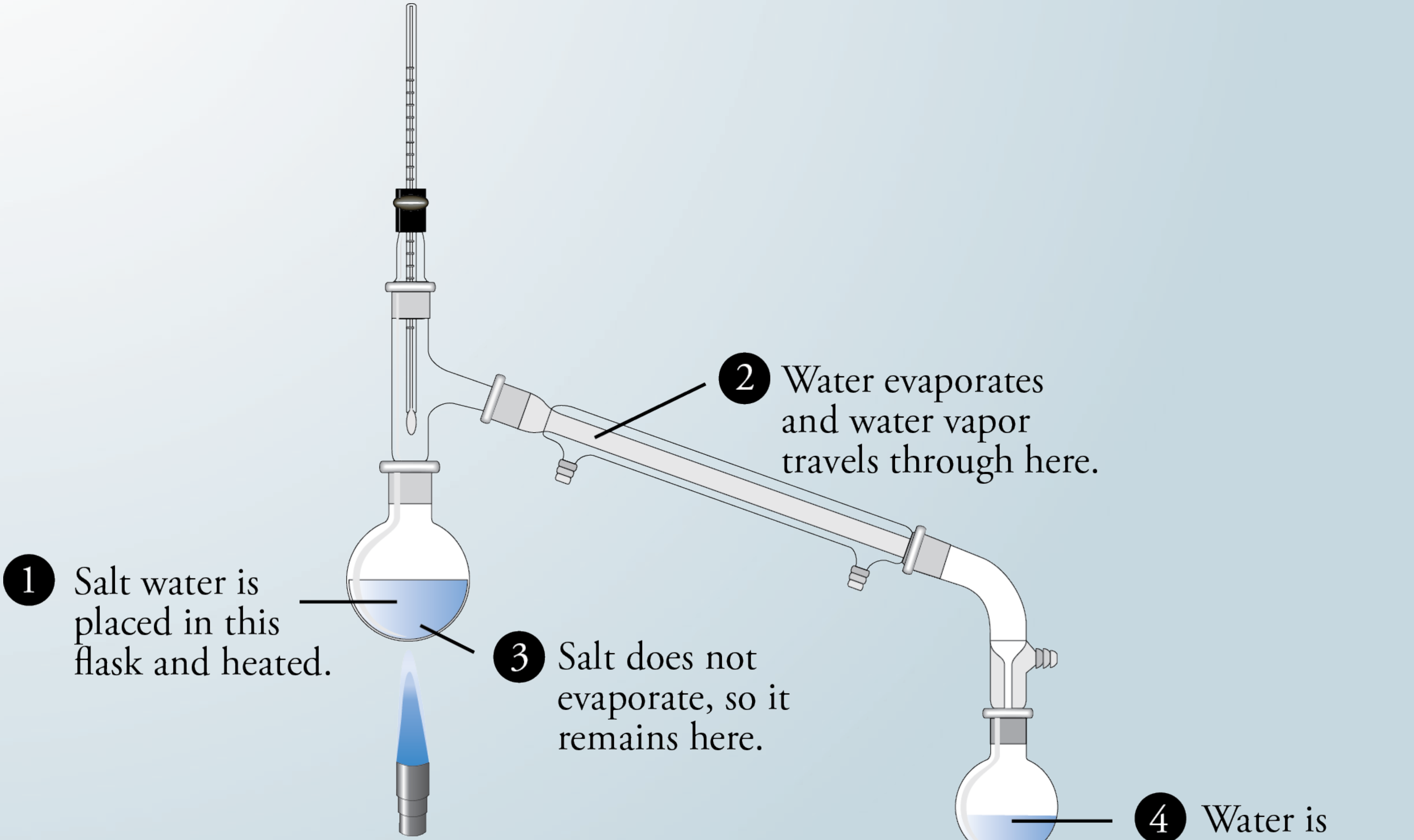
- Pressure (P) = Force/Area
  - units
    - 1 atm = 101.325 kPa = 760 mmHg = 760 torr = 14.7 lb/in^2 (psi)
    - 1 bar = 100 kPa = 0.9869 atm = 750.1 mmHg
- Volume (V)
  - unit usually liters (L)
- Temperature (T)
  - ? K = --- °C + 273.15
- Number of gas particles expressed in moles (n)



Separation of Salt Water



Distillation



114+ Known Elements

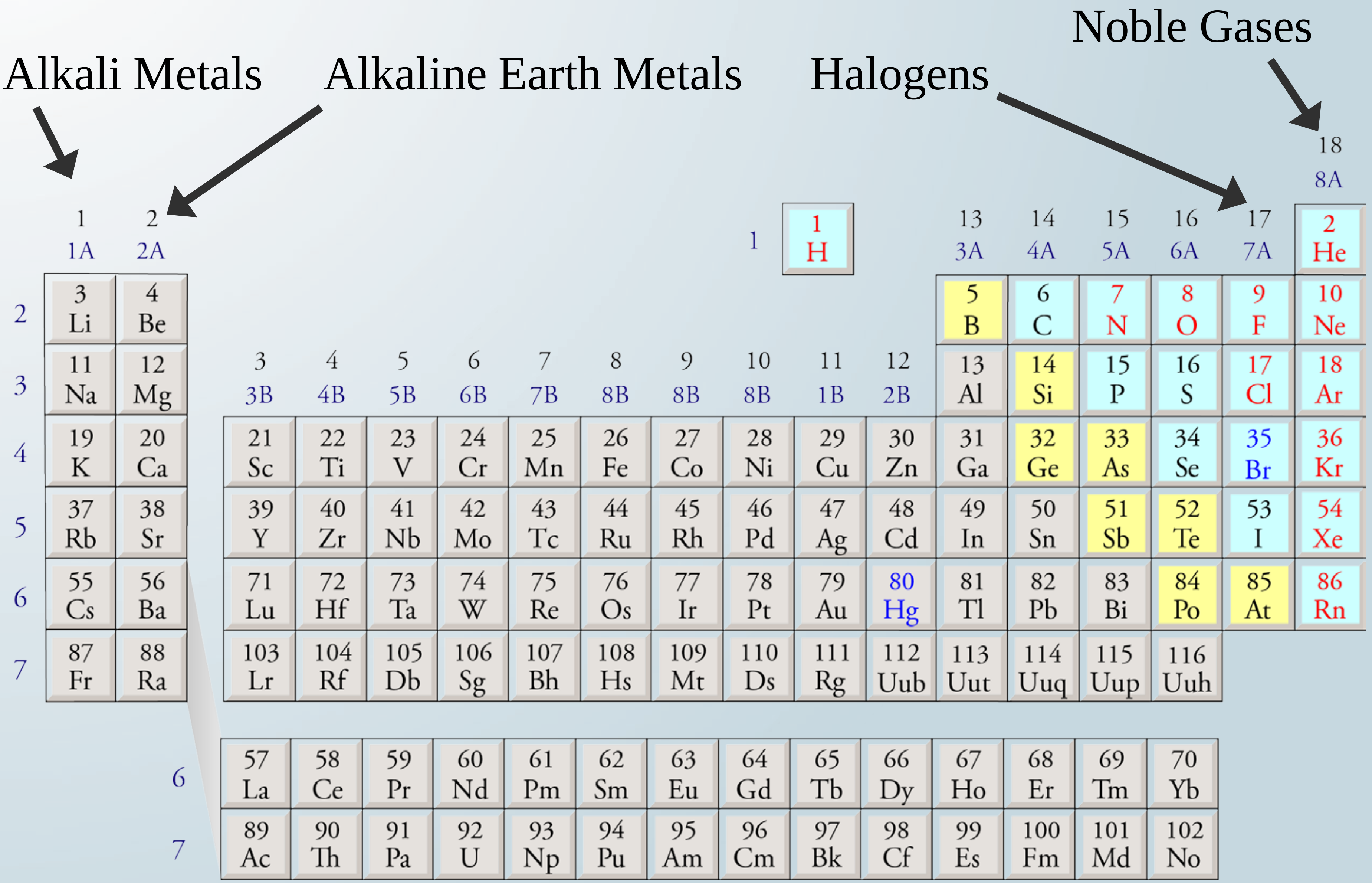
- 83 are stable and found in nature.
  - Many of these a very rare.
- 7 are found in nature but are radioactive.
- 24+ are not natural on the earth.
  - 2 or 3 of these might be found in stars.

Group Numbers on the Periodic Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											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	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
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh		

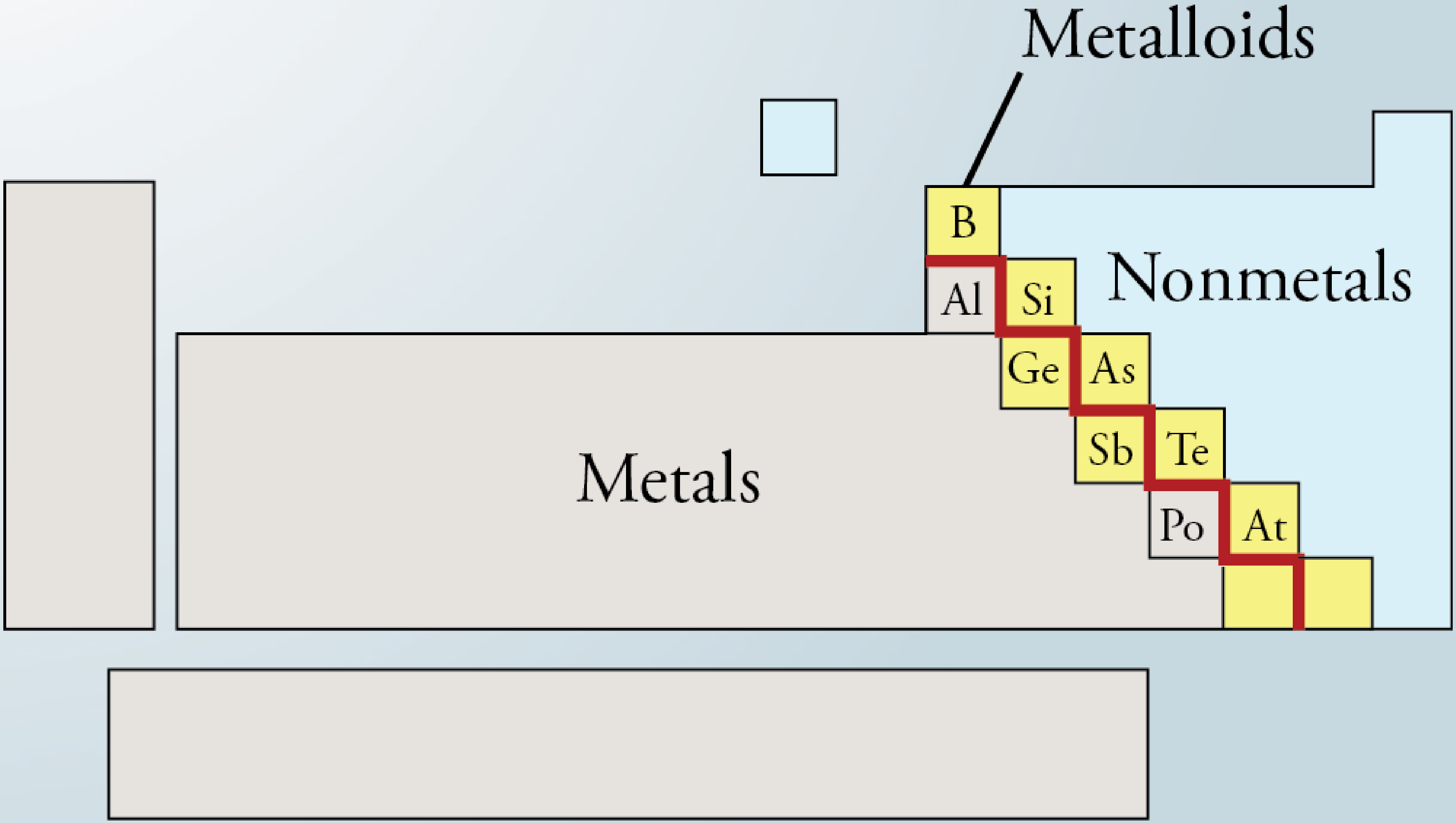
6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Group Names



Alkali Metals
Alkaline Earth Metals
Halogens
Noble Gases
1 1A
2 2A
3 3B
4 4B
5 5B
6 6B
7 7B
8 8B
9 8B
10 8B
11 1B
12 2B
13 3A
14 4A
15 5A
16 6A
17 7A
18 8A
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 Uub 113 Uut 114 Uuq 115 Uup 116 Uuh
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

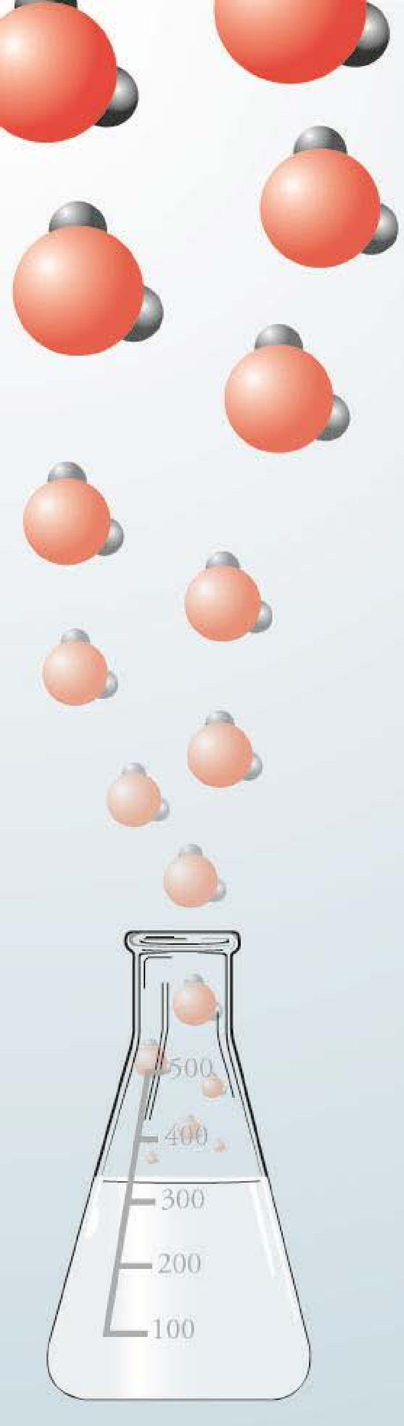
Metals, Nonmetals, and Metalloids

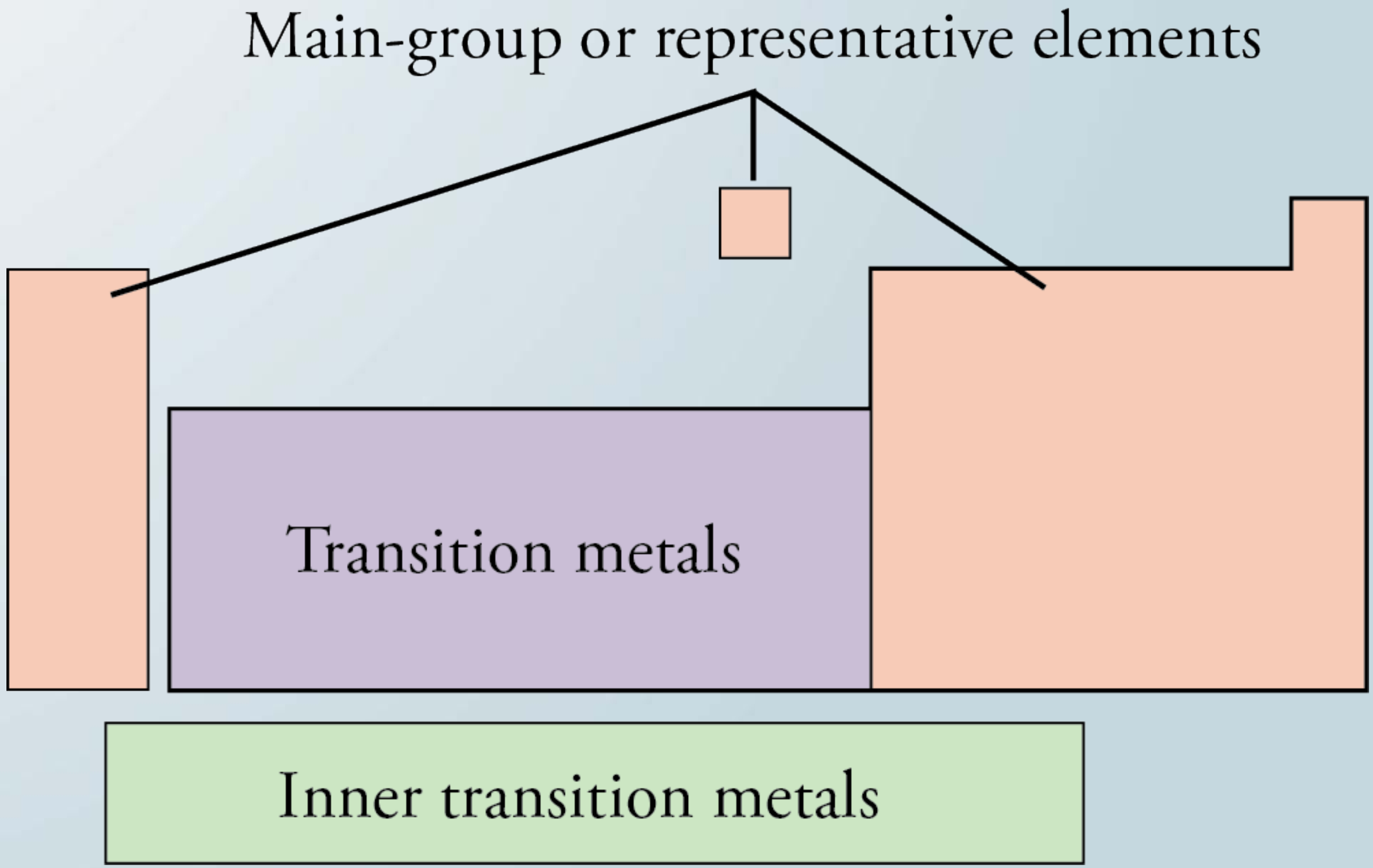


Characteristics of Metallic Elements

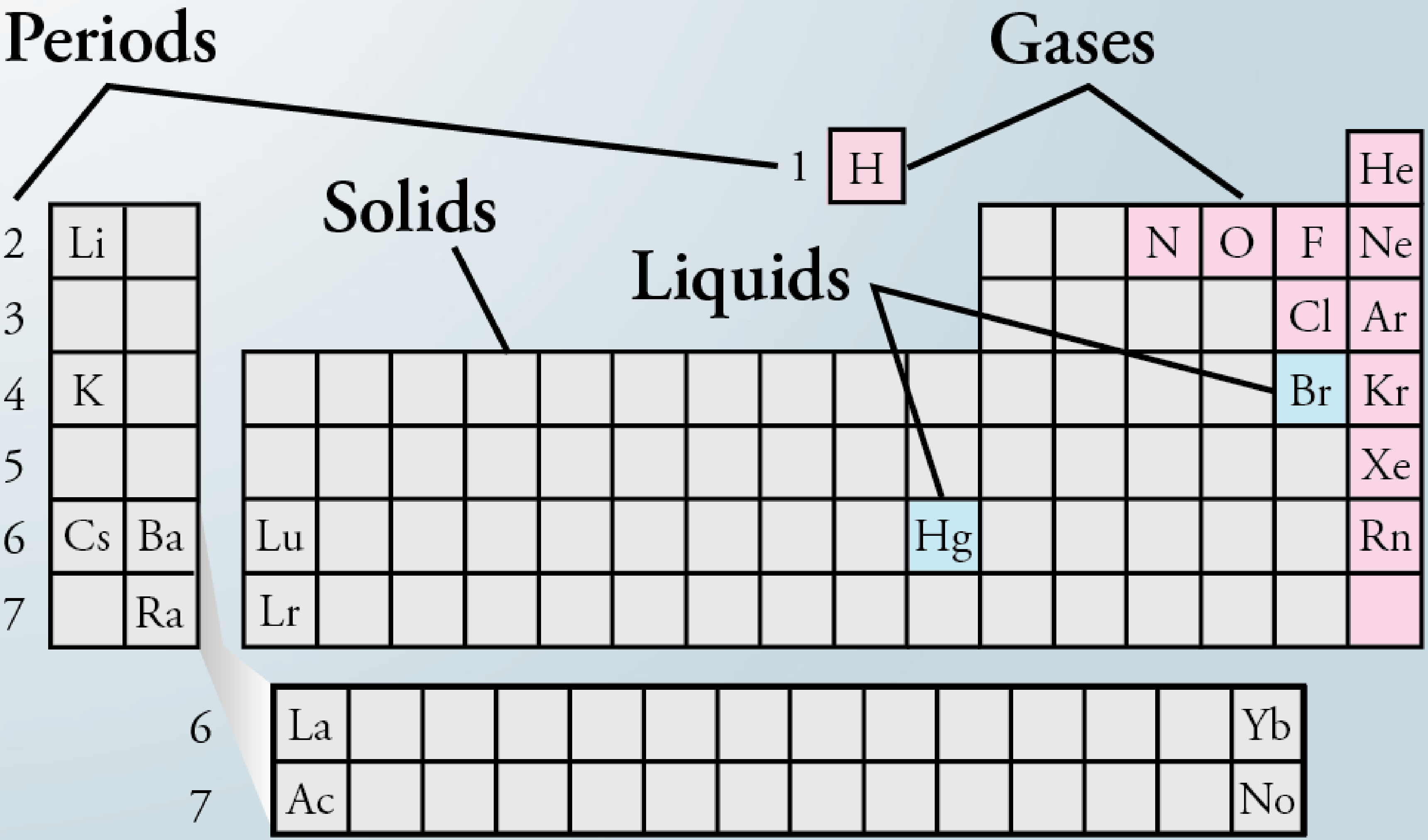
- Metals have a shiny metallic luster.
- Metals conduct heat well and conduct electric currents in the solid form.
- Metals are malleable.
  - For example, gold, Au, can be hammered into very thin sheets without breaking.

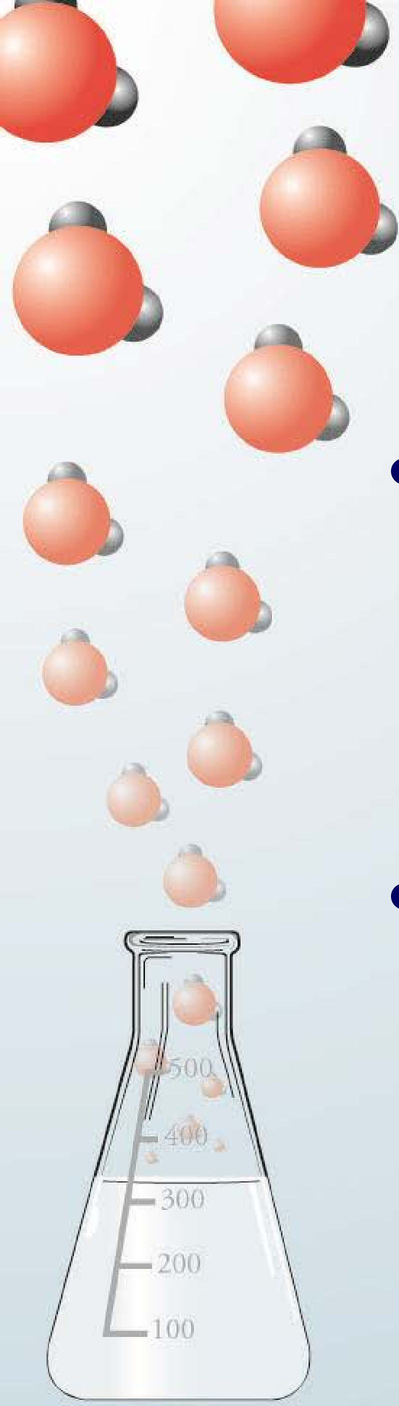
Classification of Elements





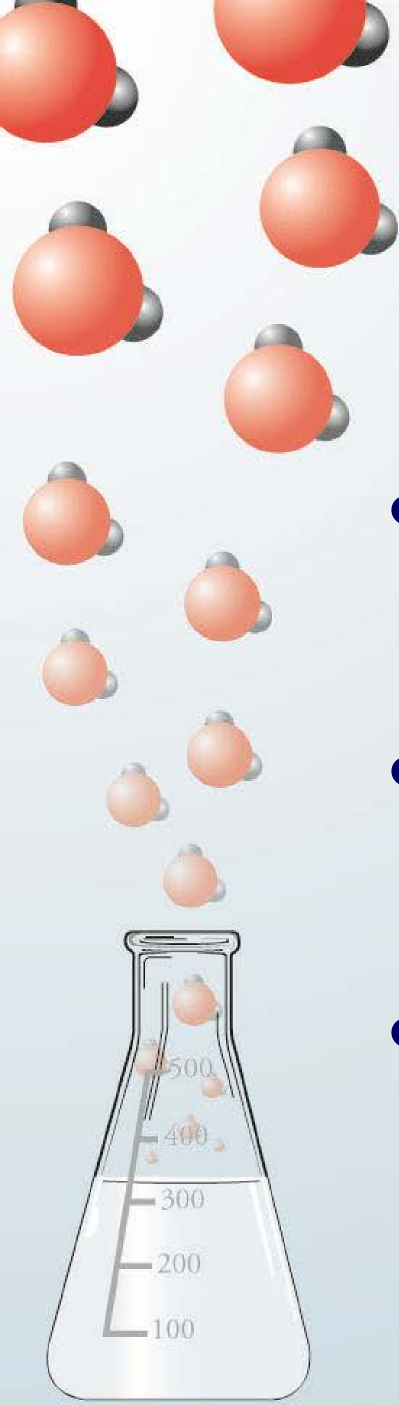
Solid, Liquid, and Gaseous Elements





Atoms

- Tiny…about 10^{-10} m
  - If the atoms in your body were 1 in. in diameter, you'd bump your head on the moon.
- Huge number of atoms in even a small sample of an element
  - 1/2 carat diamond has 5×10^{21} atoms…if lined up, would stretch to the sun.



Particles in the Atom

- Neutron (n)

  0 charge 1.00867 u in nucleus

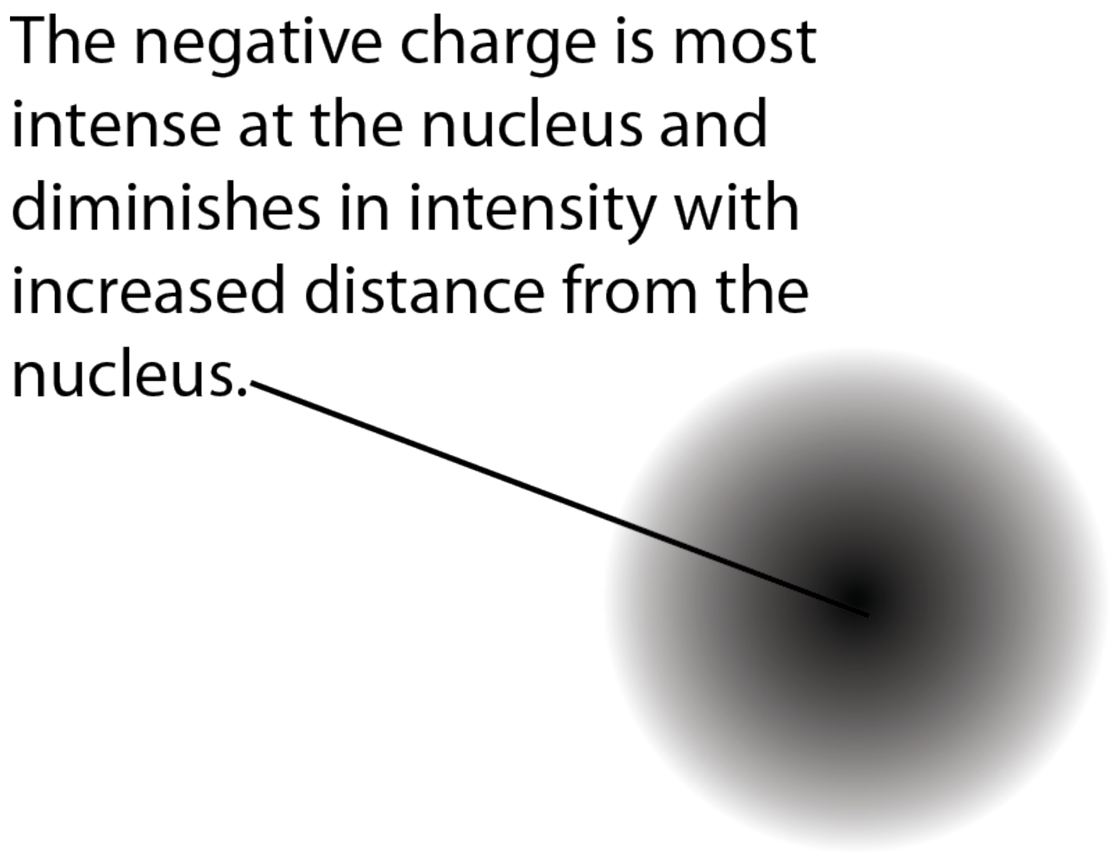
- Proton (p)

  +1 charge 1.00728 u in nucleus

- Electron (e^-)

  –1 charge 0.000549 u outside nucleus

Electron Cloud for Hydrogen Atom



http://preparatorychemistry.com/Hydrogen_1.html

The Electron

"If I seem unusually clear to you, you must have misunderstood what I said."

Alan Greenspan,

Former Head of the Federal Reserve Board

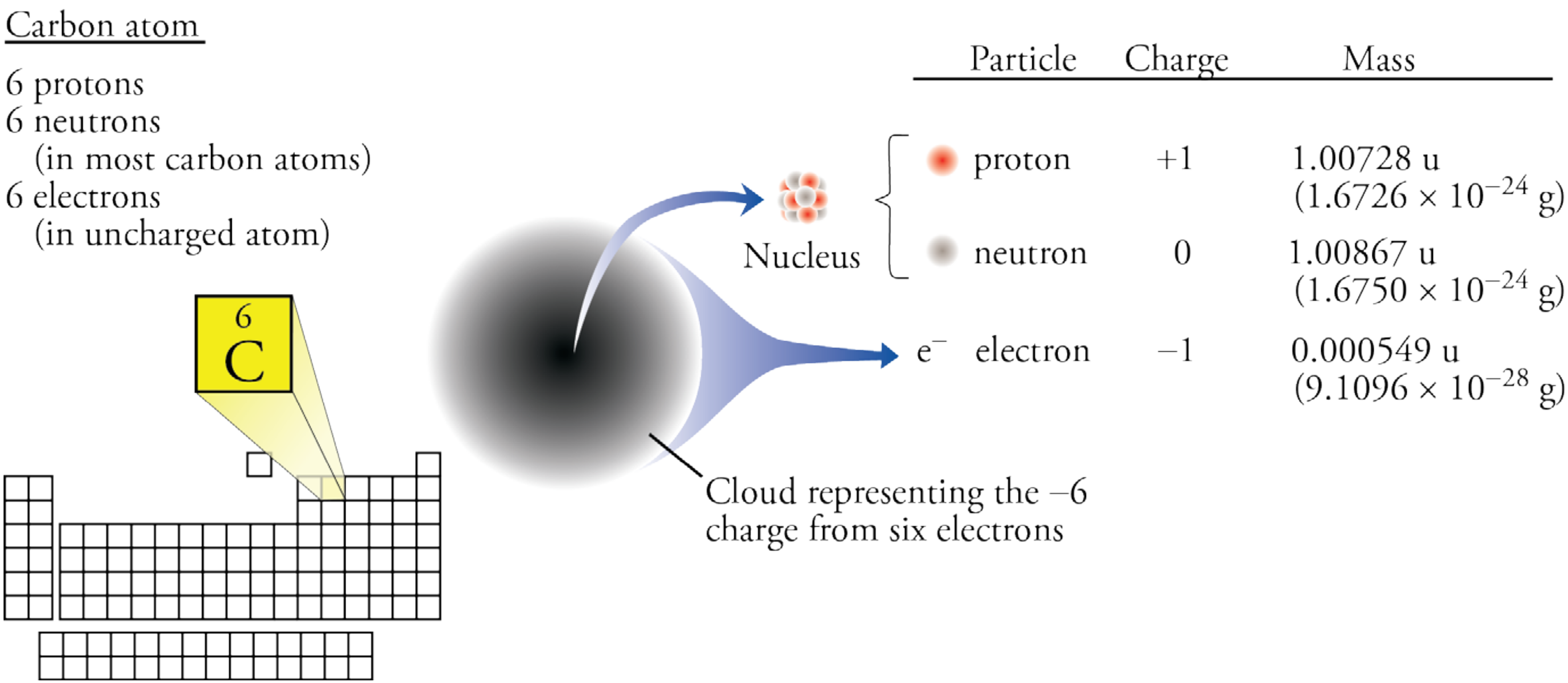
"It is probably as meaningless to discuss how much room an electron takes up as to discuss how much room a fear, an anxiety, or an uncertainty takes up."

Sir James Hopwood Jeans,
English mathematician, physicist and astronomer (1877-1946)

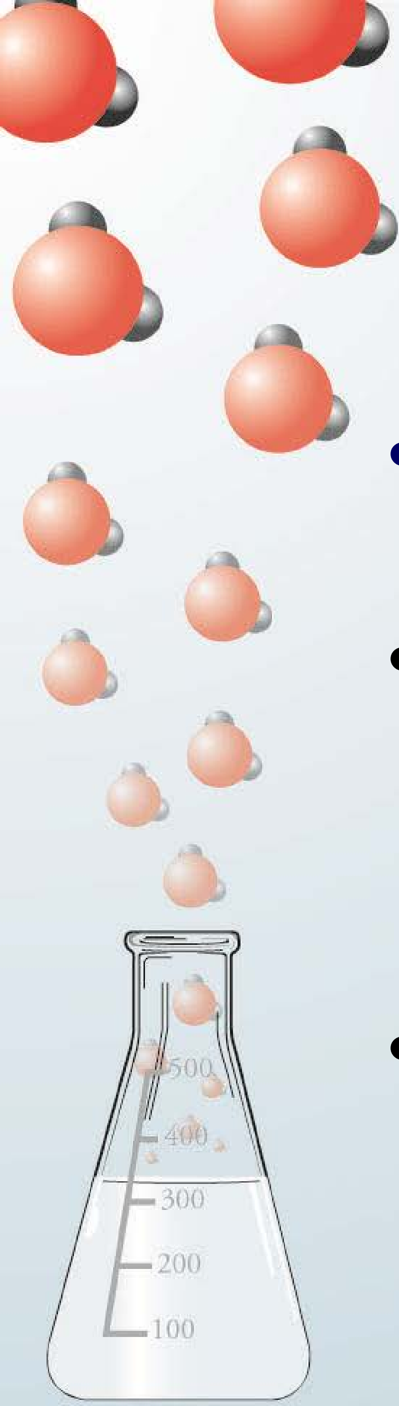
Helium Atom

http://preparatorychemistry.com/helium_atom.html

Carbon Atom



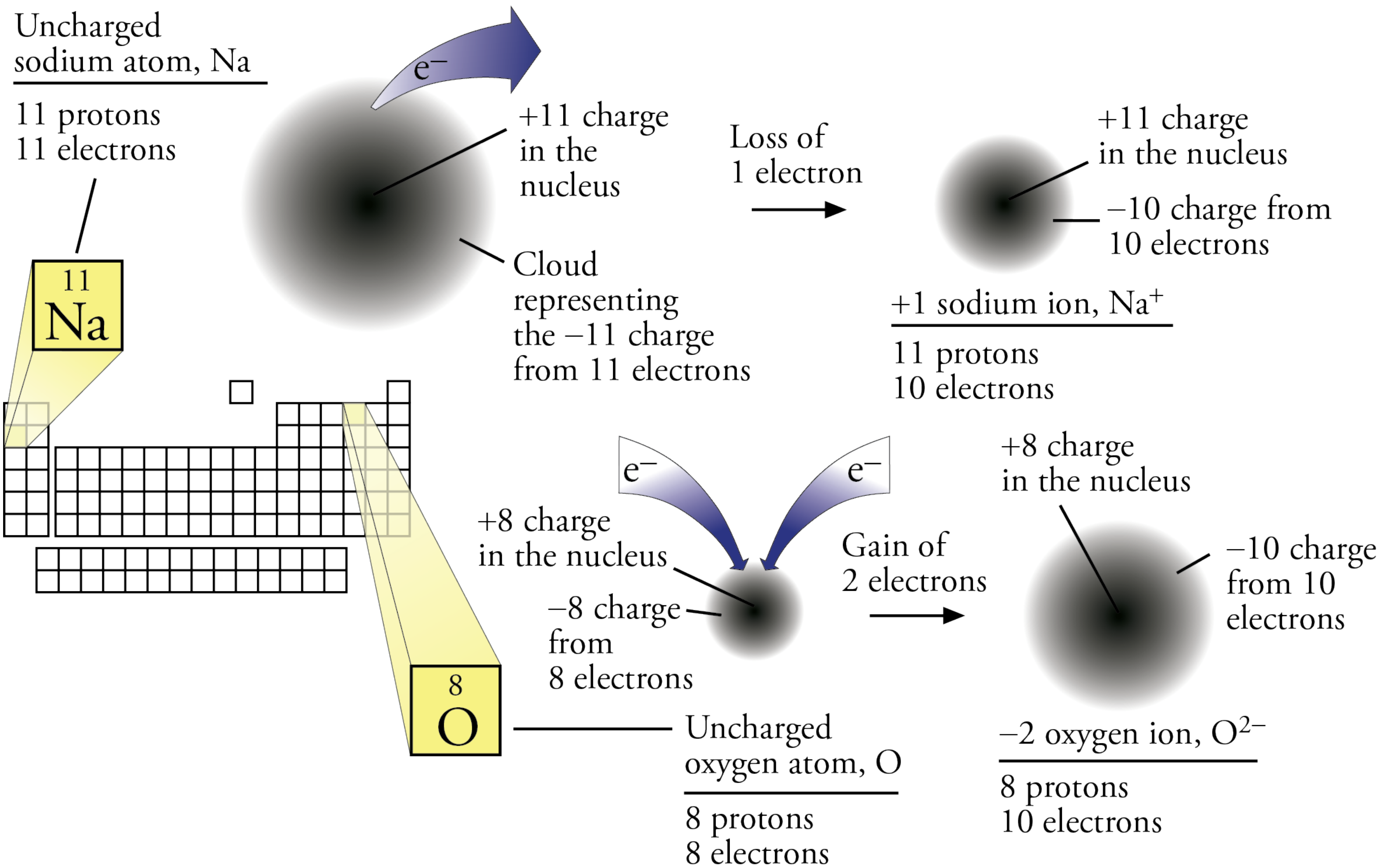
Carbon atom
6 protons
6 neutrons
(in most carbon atoms)
6 electrons
(in uncharged atom)
6
C
Nucleus
Particle
Charge
Mass
proton
+1
1.00728 u
(1.6726 × 10^−24 g)
neutron
0
1.00867 u
(1.6750 × 10^−24 g)
e^−
electron
−1
0.000549 u
(9.1096 × 10^−28 g)
Cloud representing the −6
charge from six electrons

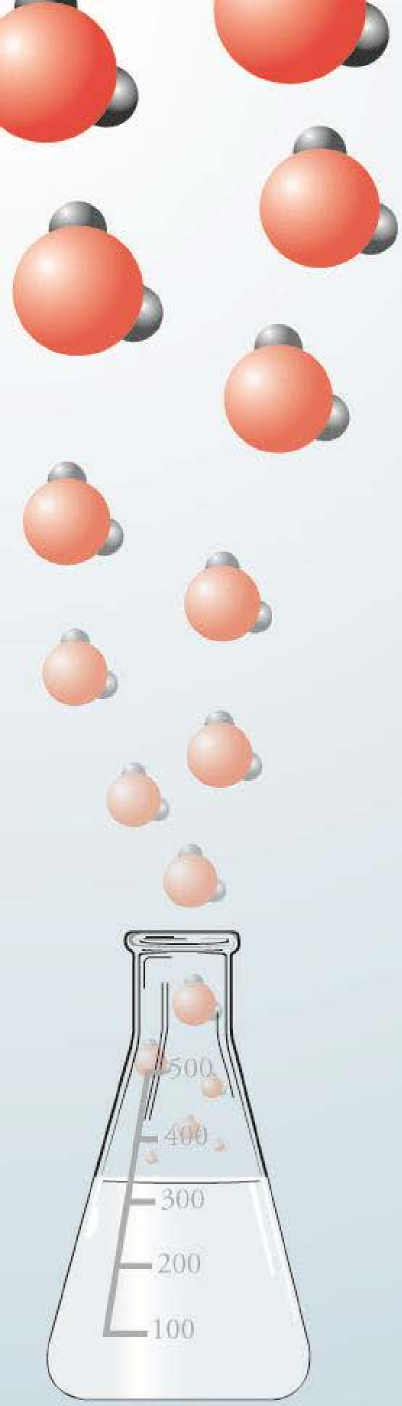


Ions

- ***Ions*** are charged particles due to a loss or gain of electrons.
- When particles lose one or more electrons, leaving them with a positive overall charge, they become ***cations***.
- When particles gain one or more electrons, leaving them with a negative overall charge, they become ***anions***.

Example Ions

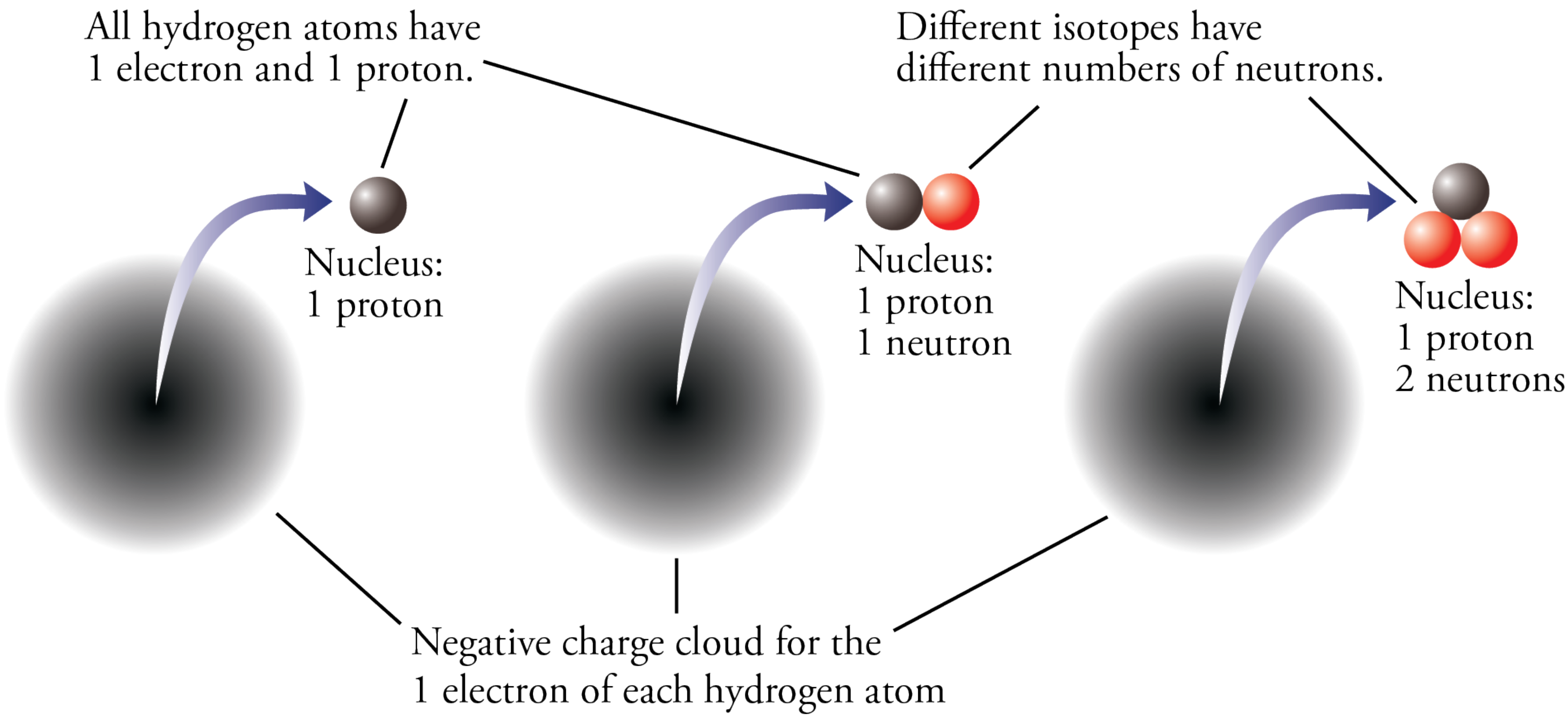




Isotopes

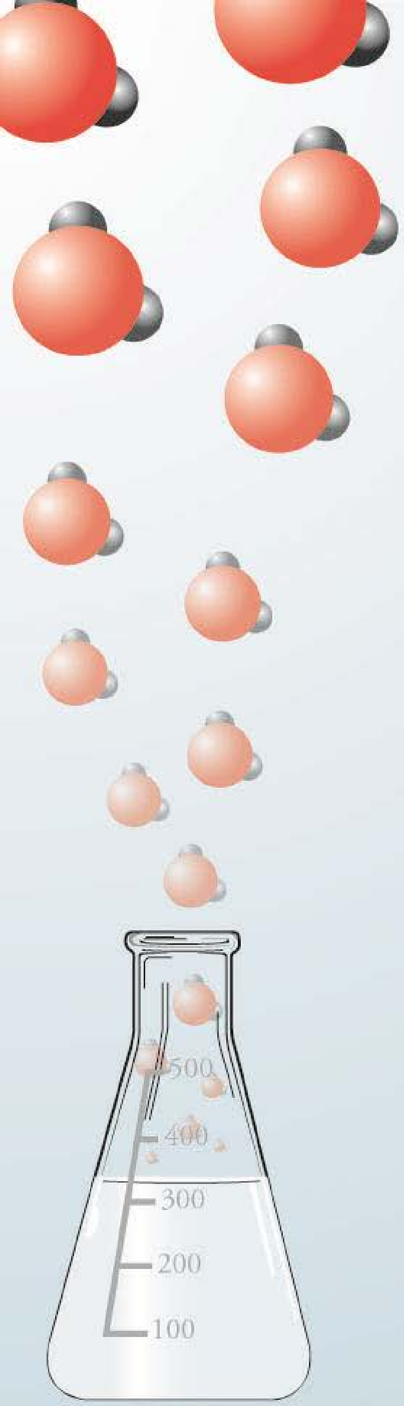
- ***Isotopes*** are atoms with the same atomic number but different mass numbers.
- ***Isotopes*** are atoms with the same number of protons and electrons in the uncharged atom but different numbers of neutrons.
- ***Isotopes*** are atoms of the same element with different masses.

Isotopes of Hydrogen



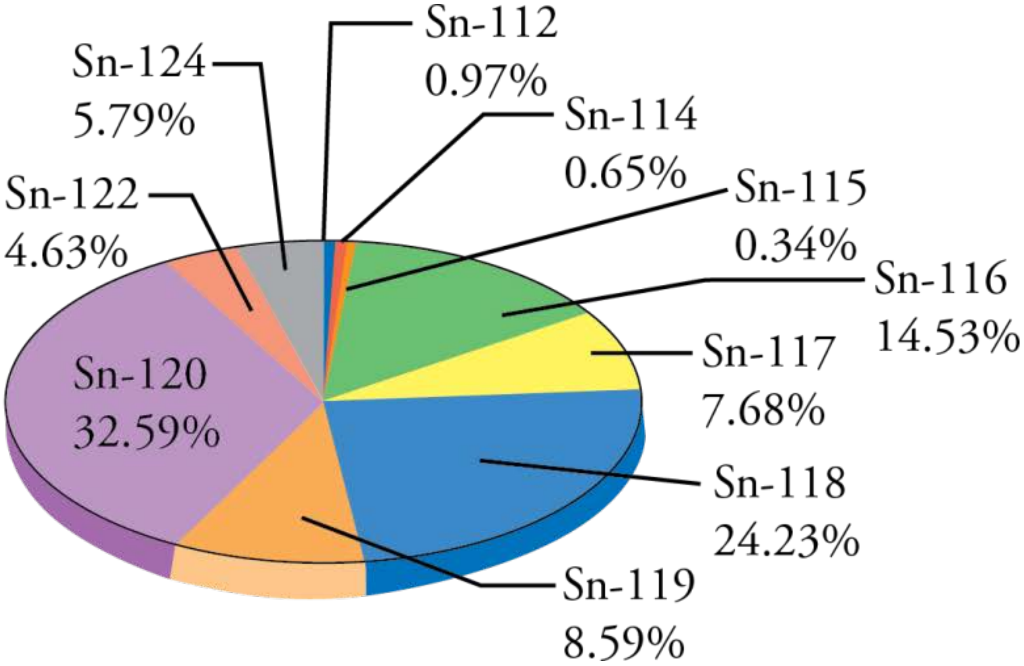
http://preparatorychemistry.com/Hydrogen_1.html
http://preparatorychemistry.com/Hydrogen_2.html
http://preparatorychemistry.com/Hydrogen_3.html

Effect on Chemical Changes

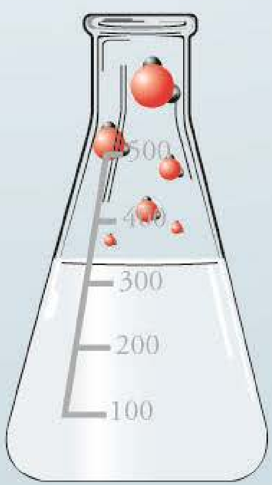


- Electrons
  - Can be gained, lost, or shared…actively participate in chemical changes
  - Affect other atoms through their -1 charge
- Protons
  - Affect other atoms through their +1 charge
  - Determine the number of electrons in uncharged atoms
- Neutrons
  - No charge…no effect outside the atom and no direct effect on the number of electrons.

Tin has ten natural isotopes.

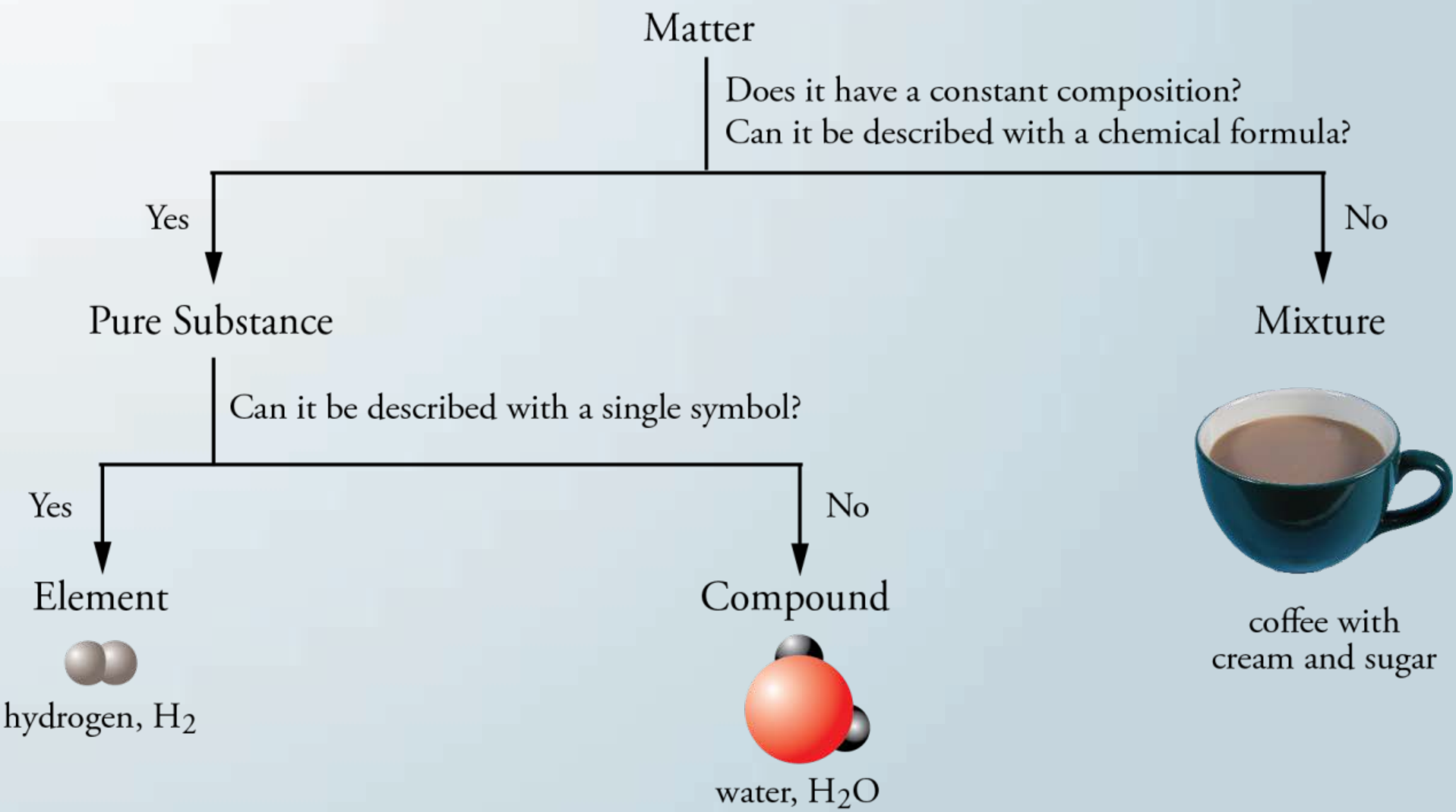


Elements, Compounds, and Mixtures

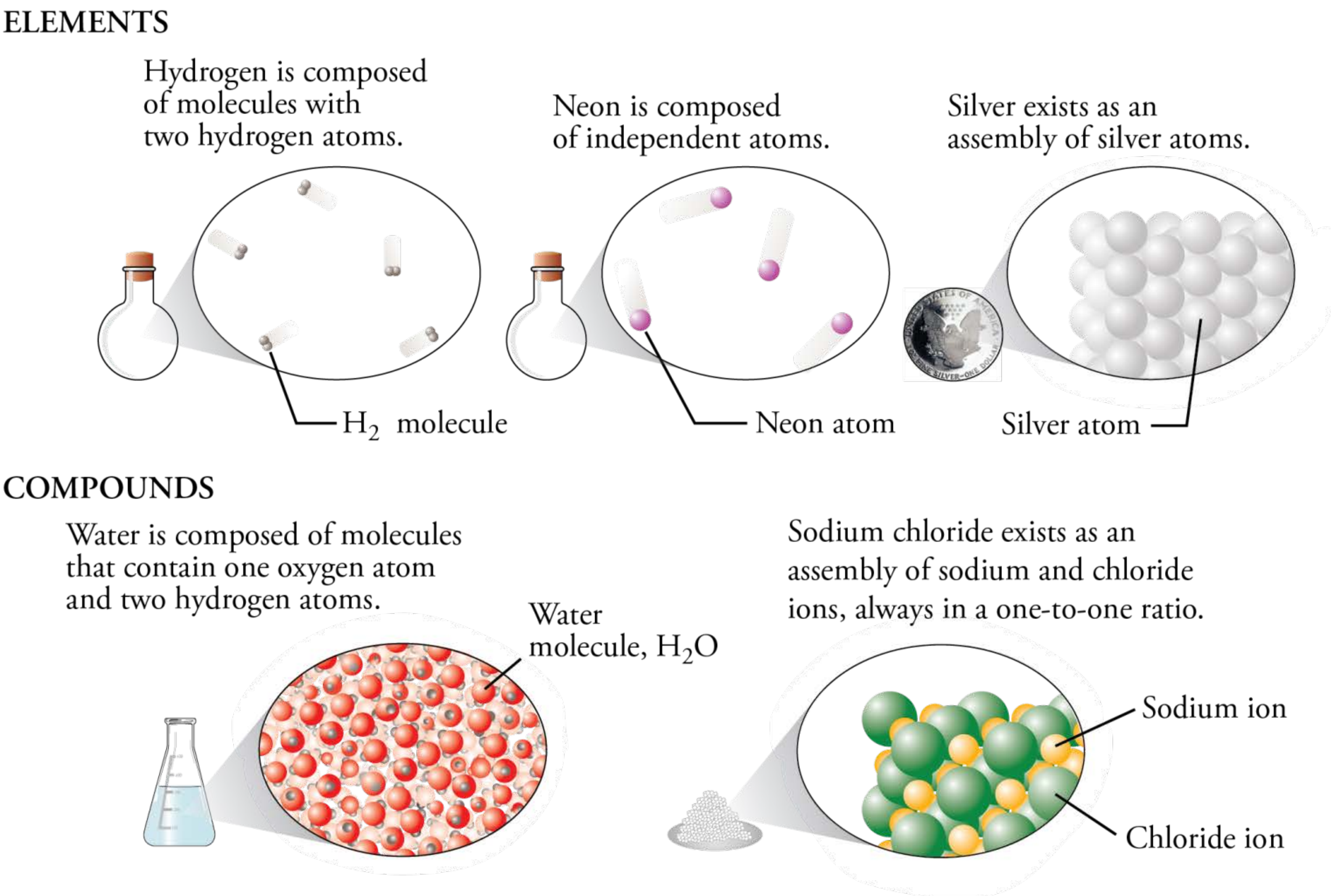


- **Element:** A substance that cannot be chemically converted into simpler substances; a substance in which all of the atoms have the same number of protons and therefore the same chemical characteristics.
- **Compound:** A substance that contains two or more elements, the atoms of these elements always combining in the same whole-number ratio.
- **Mixture:** A sample of matter that contains two or more pure substances (elements and compounds) and has variable composition.

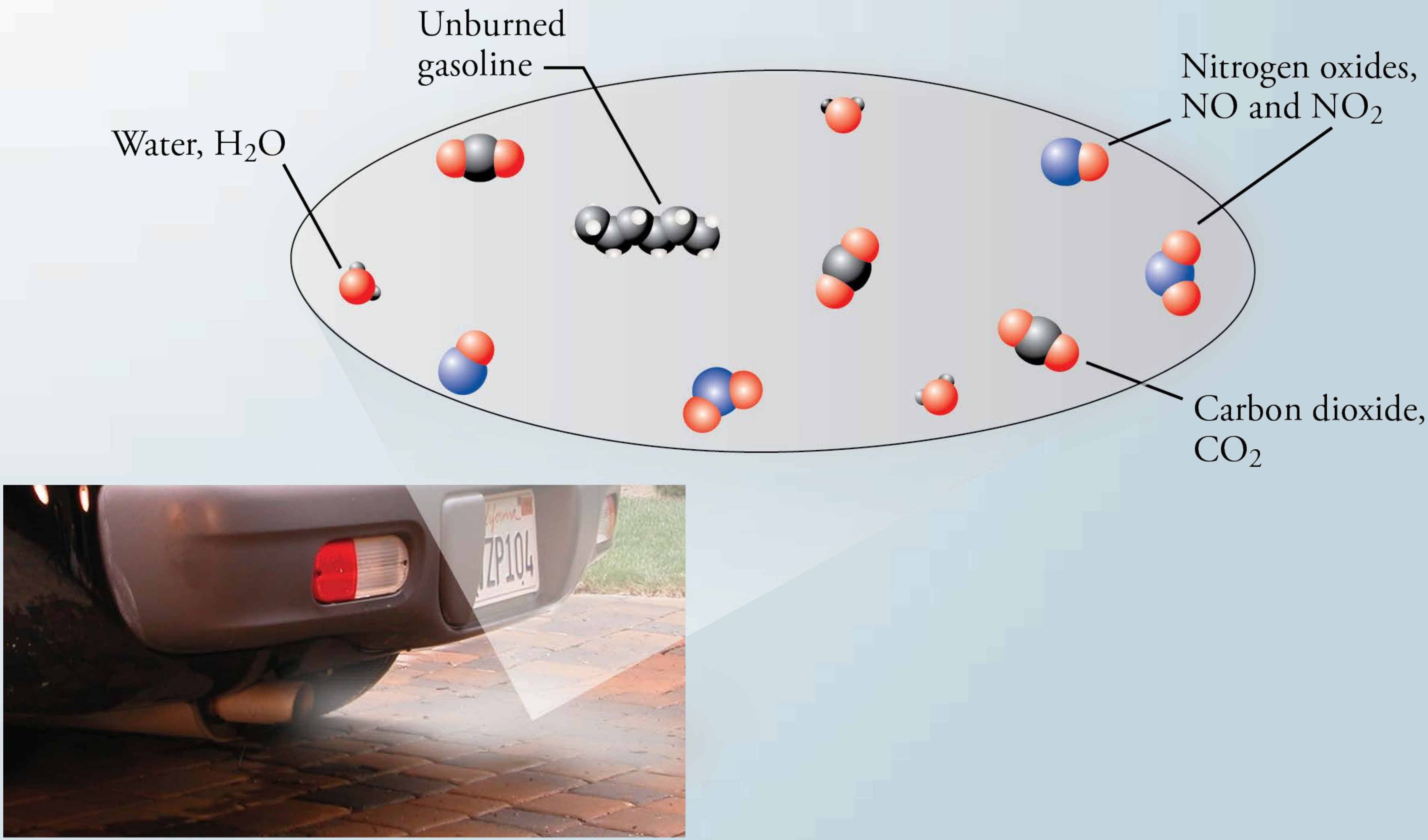
Classification of Matter



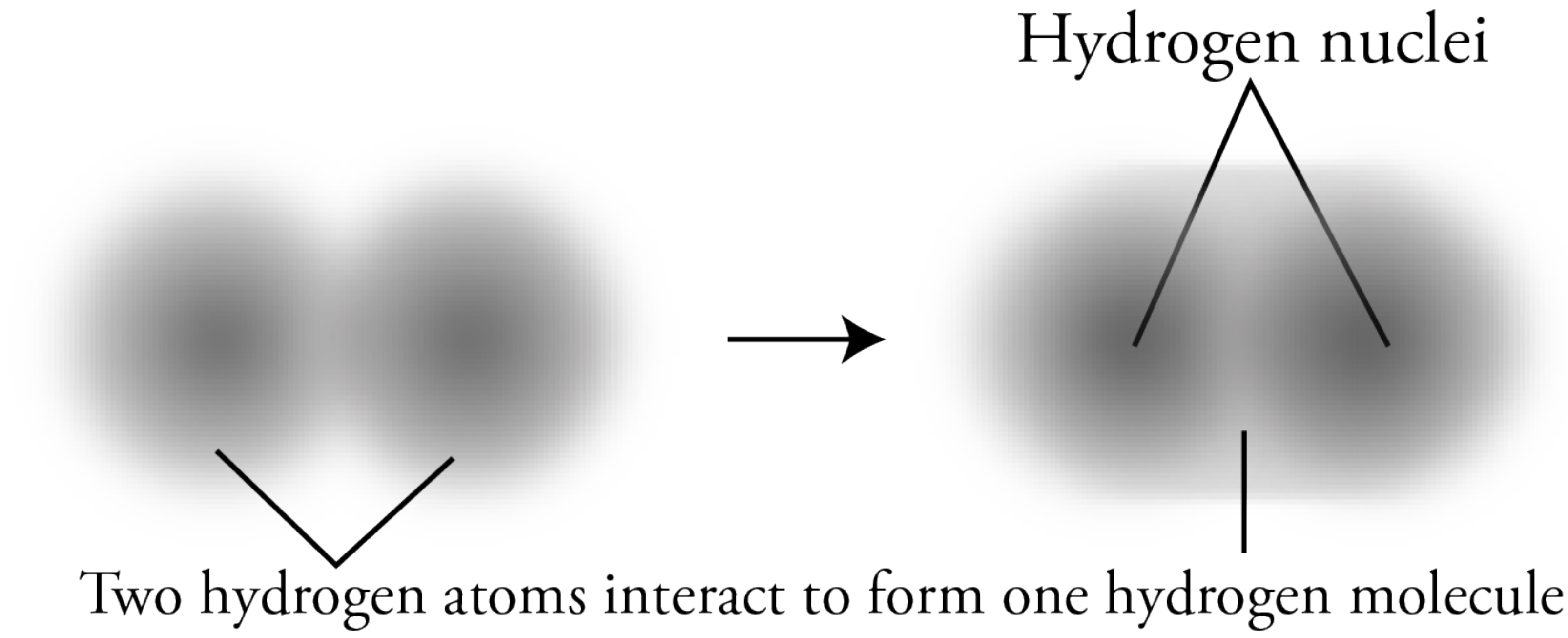
Elements and Compounds



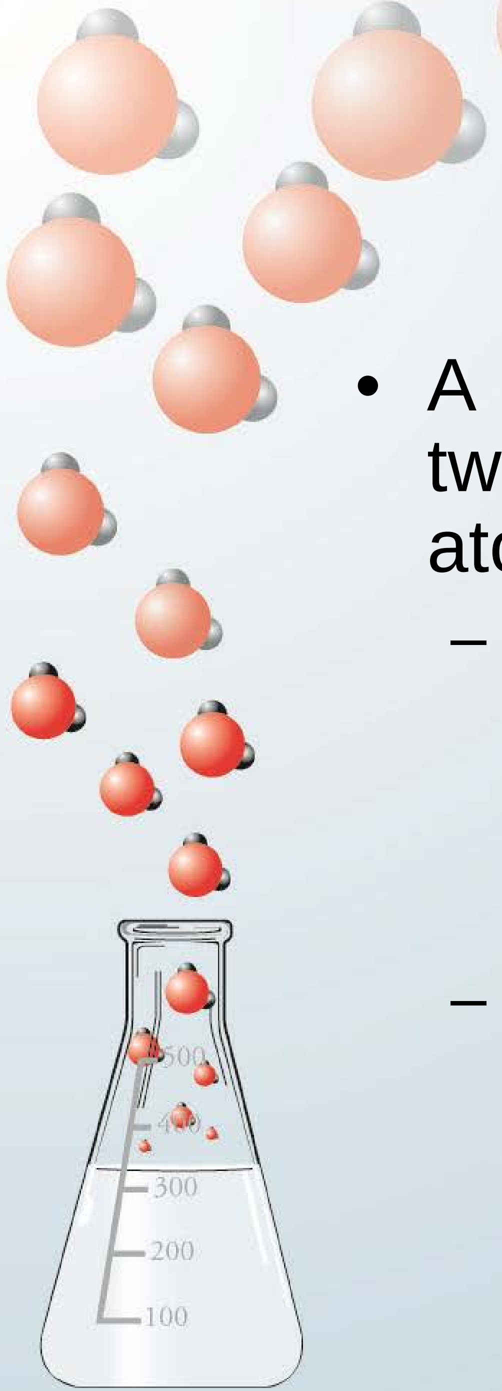
Exhaust – a Mixture



Covalent Bond Formation

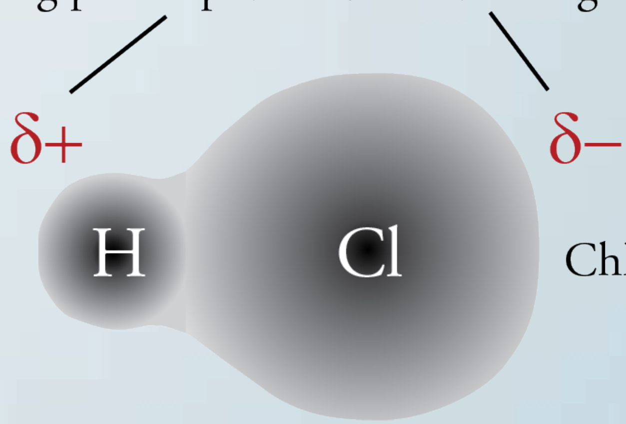


Covalent Bond



- A link between atoms due to the sharing of two electrons. This bond forms between atoms of two nonmetallic elements.
  - If the electrons are shared equally, there is a even distribution of the negative charge for the electrons in the bond, so there is no partial charges on the atoms. The bond is called a ***nonpolar covalent bond***.
  - If one atom in the bond attracts electrons more than the other atom, the electron negative charge shifts to that atom giving it a partial negative charge. The other atom loses negative charge giving it a partial positive charge. The bond is called a ***polar covalent bond***.

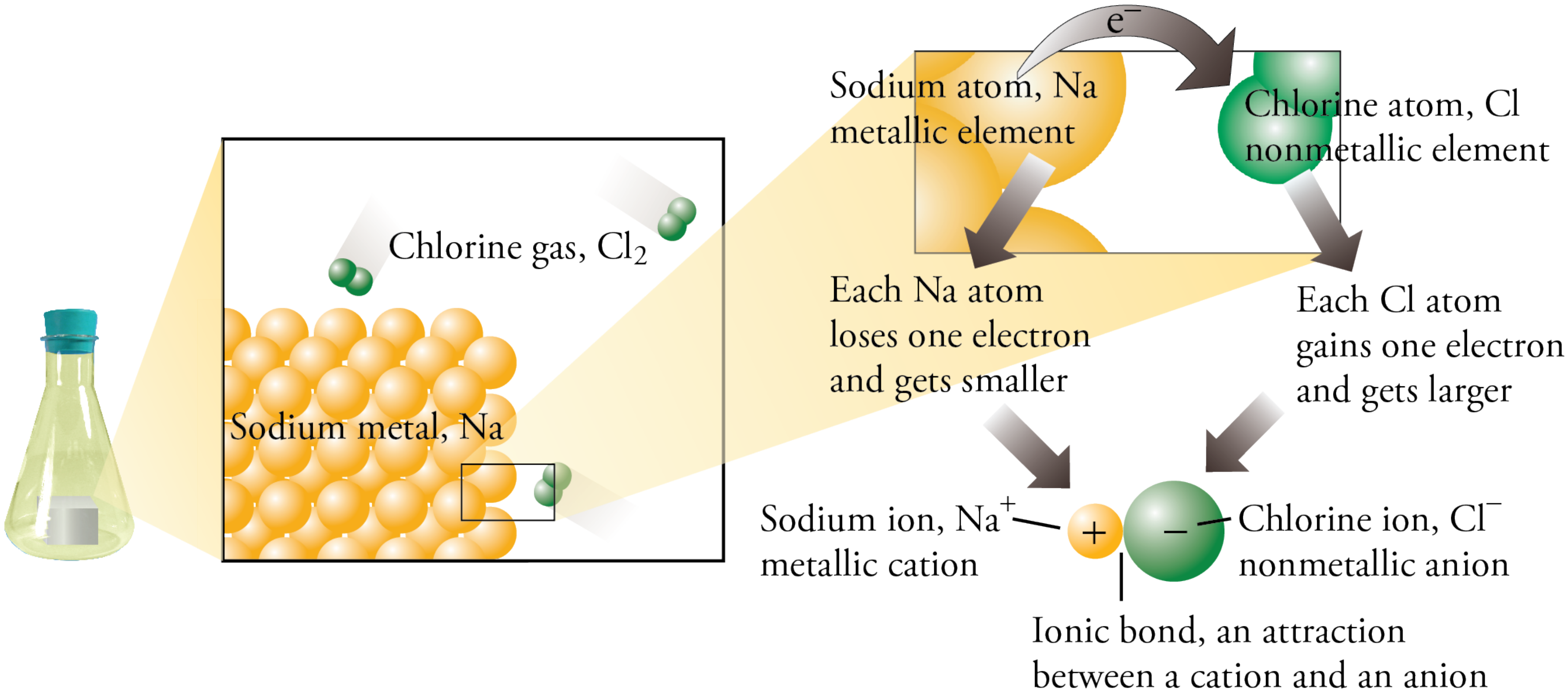
Polar Covalent Bond



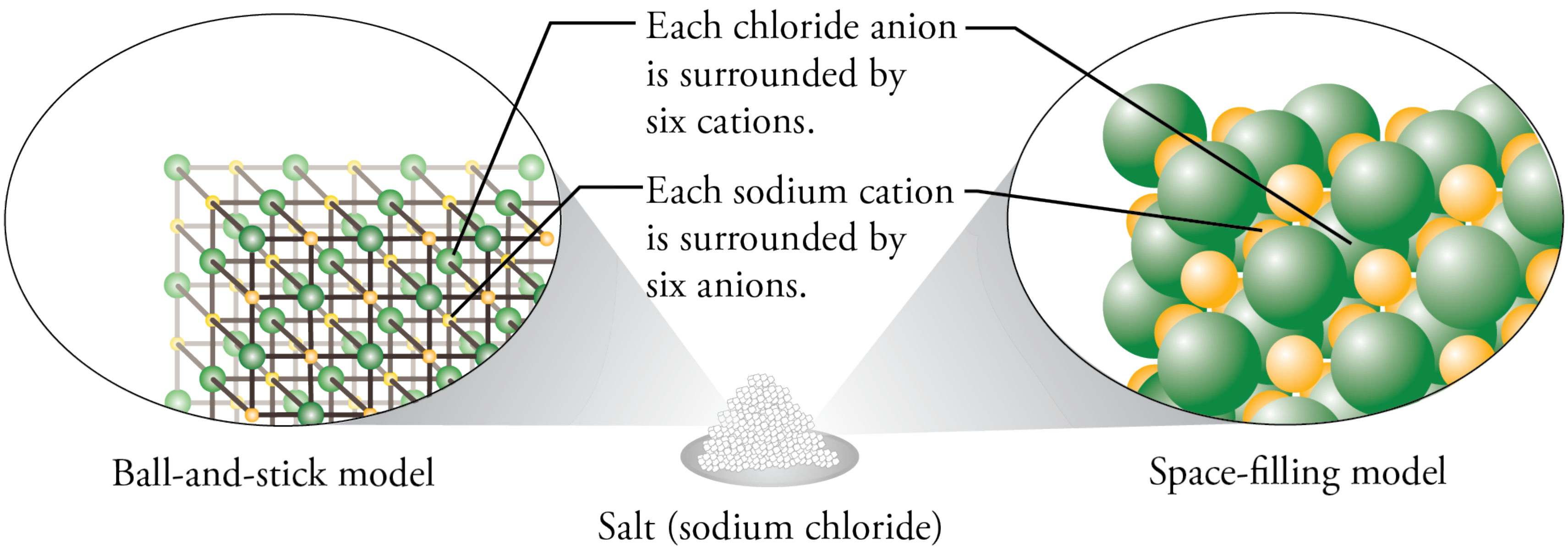
Ionic Bond

- The attraction between cation and anion.
- Atoms of nonmetallic elements often attract electrons so much more strongly than atoms of metallic elements that one or more electrons are transferred from the metallic atom (forming a positively charged particle or ***cation***), to the nonmetallic atom (forming a negatively charged particle or ***anion***).
- For example, an uncharged chlorine atom can pull one electron from an uncharged sodium atom, yielding Cl^- and Na^+.

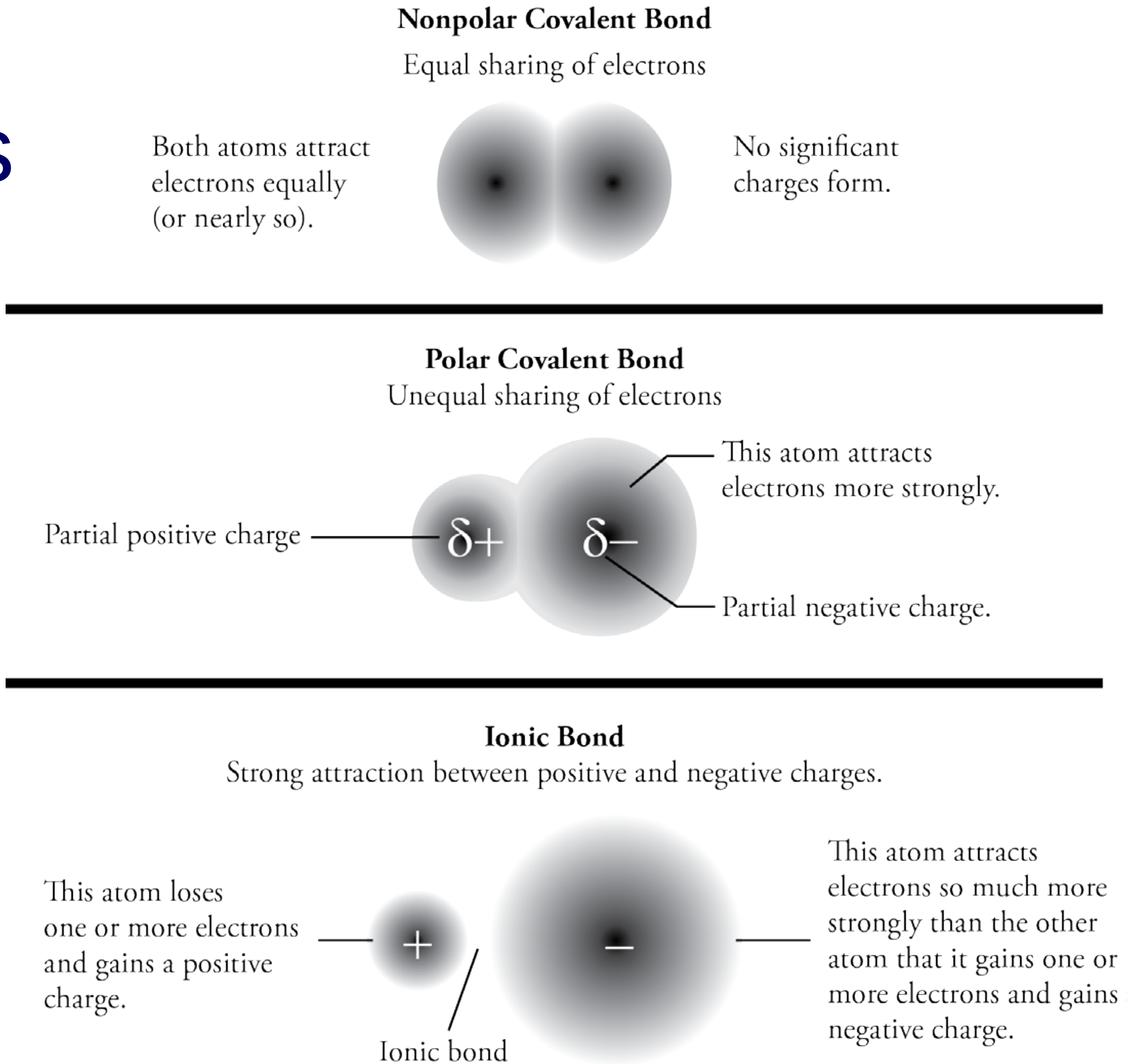
Ionic Bond Formation



Sodium Chloride, NaCl, Structure

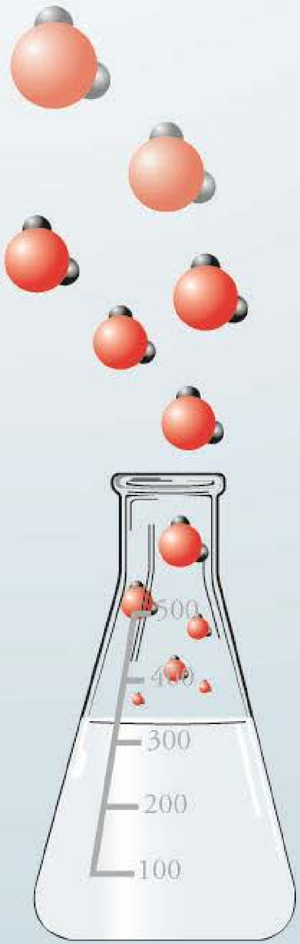


Bond Types



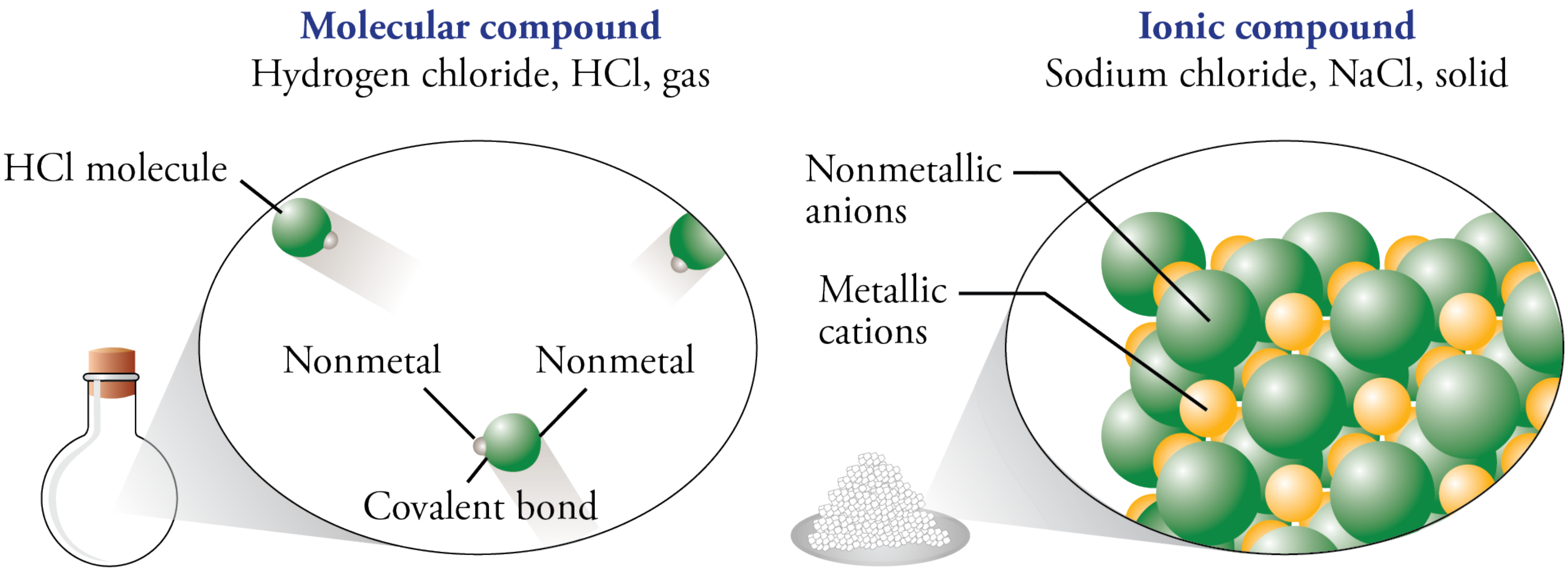
Nonpolar Covalent Bond
Equal sharing of electrons
Both atoms attract electrons equally (or nearly so).
No significant charges form.
Polar Covalent Bond
Unequal sharing of electrons
Partial positive charge
δ+
δ−
This atom attracts electrons more strongly.
Partial negative charge.
Ionic Bond
Strong attraction between positive and negative charges.
This atom loses one or more electrons and gains a positive charge.
+
−
Ionic bond
This atom attracts electrons so much more strongly than the other atom that it gains one or more electrons and gains a negative charge.

Types of Compounds



- All nonmetallic atoms usually leads to all covalent bonds, which from molecules. These compounds are called ***molecular compounds***.
- Metal-nonmetal combinations usually lead to ionic bonds and ***ionic compounds***.

Classification of Compounds



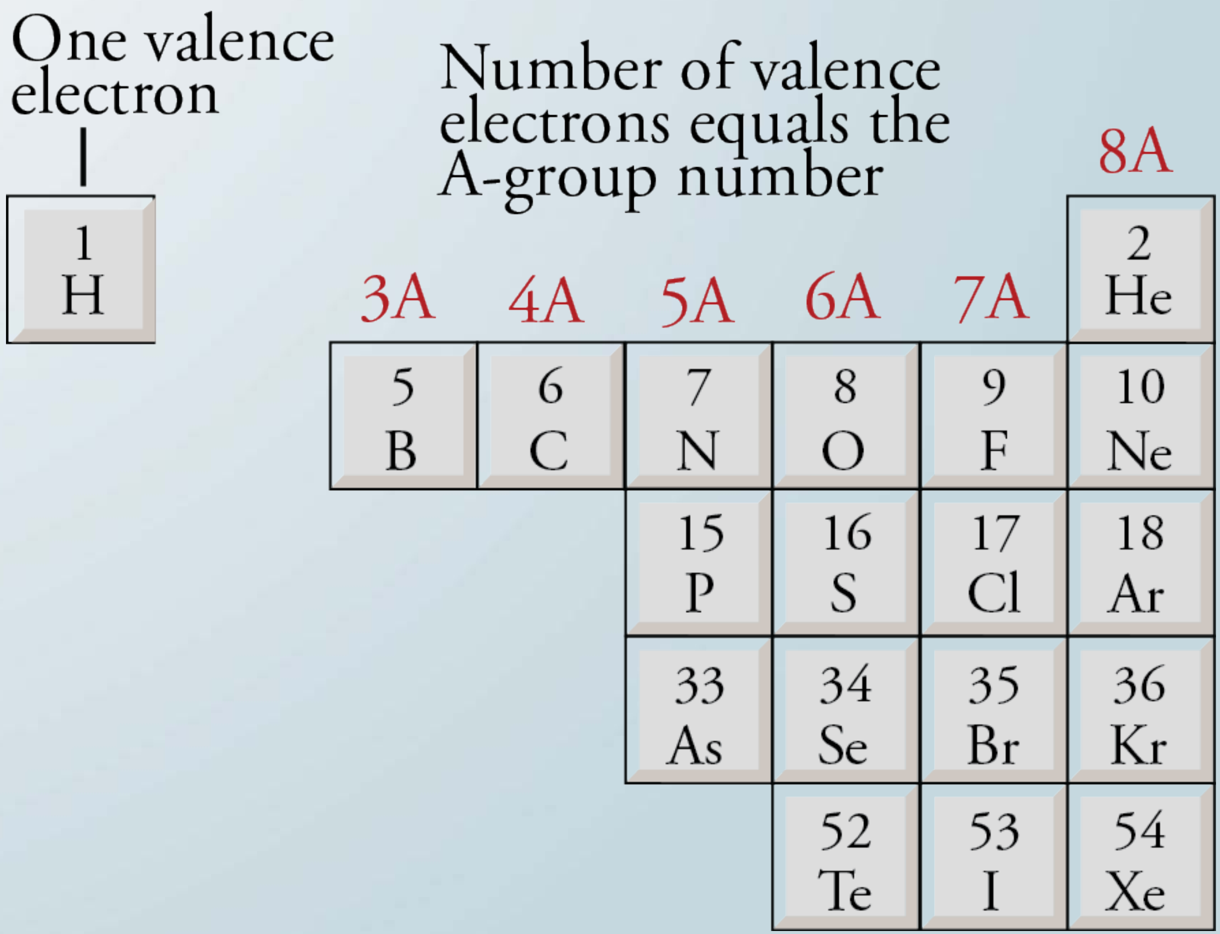
Summary

- **Nonmetal-nonmetal** combinations (e.g. HCl)
  - Covalent bonds
  - Molecules
  - Molecular Compound
- **Metal-nonmetal** combinations (e.g. NaCl)
  - Probably ionic bonds
  - Alternating cations and anions in crystal structure
  - Ionic compound

Valence Electrons

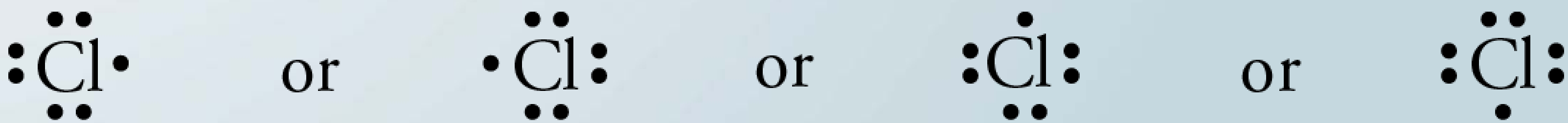
- The valence electrons for each atom are the most important electrons in the formation of chemical bonds.
- The number of valence electrons for the atoms of each element is equal to the element's A-group number on the periodic table.
- Covalent bonds often form to pair unpaired electrons and give the atoms of the elements other than hydrogen and boron eight valence electrons (an octet of valence electrons).

Valence Electrons and A-Group Numbers



Electron-Dot Symbols and Lewis Structures

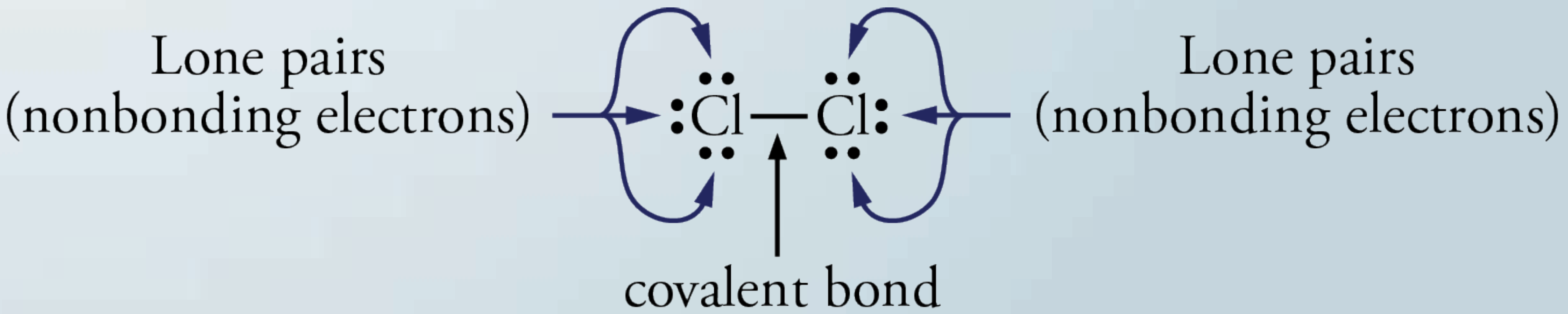
- **Electron-dot symbols** show valence electrons.



- Nonbonding pairs of valence electrons are called ***lone pairs***.

Lewis Structures

- ***Lewis structures*** represent molecules using element symbols, lines for bonds, and dots for lone pairs.



Most Common Bonding Patterns for Nonmetals

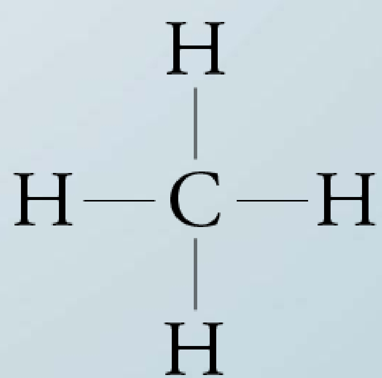
Element	# Bonds	# lone pairs
H	1	0
C	4	0
N, P	3	1
O, S, Se	2	2
F, Cl, Br, I	1	3

Drawing Lewis Structures

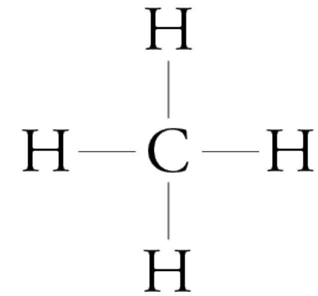
- Many Lewis structures can be drawn by attempting to give each atom in a molecule its most common bonding pattern.

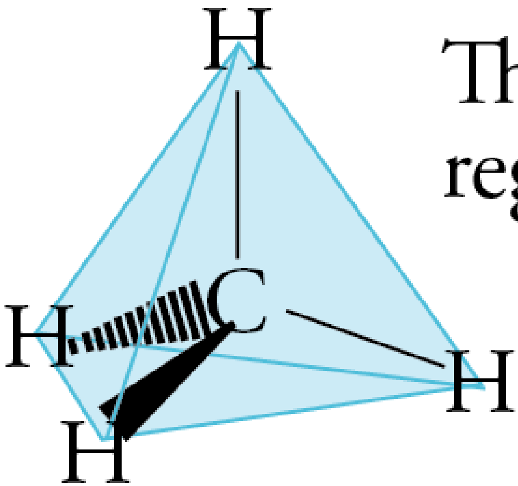
Lewis Structure for Methane, CH_4

- Carbon atoms usually have 4 bonds and no lone pairs.
- Hydrogen atoms have 1 bond and no lone pairs.

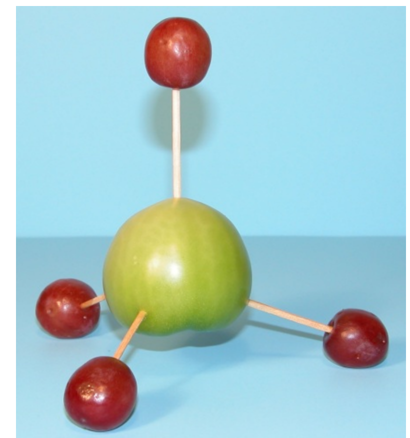


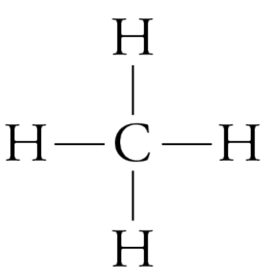
Methane, CH_4



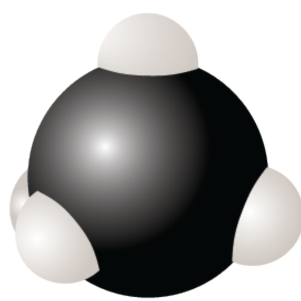


The shaded shape is a regular tetrahedron.

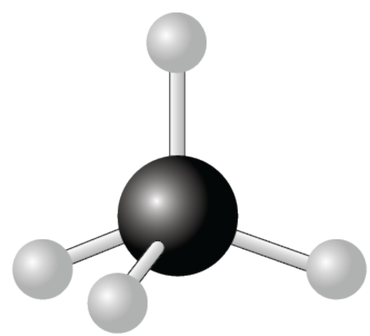




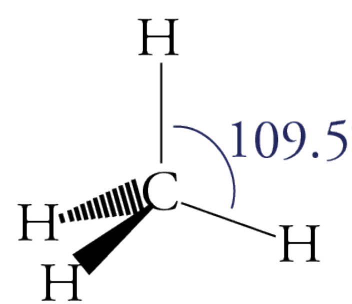
Lewis structure



Space-filling model



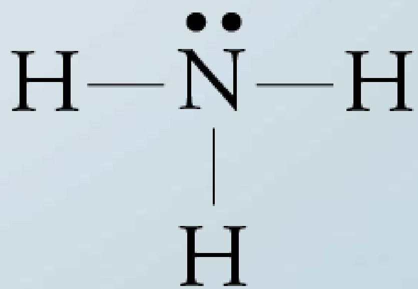
Ball-and-stick model



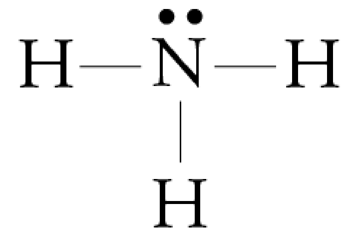
Geometric Sketch

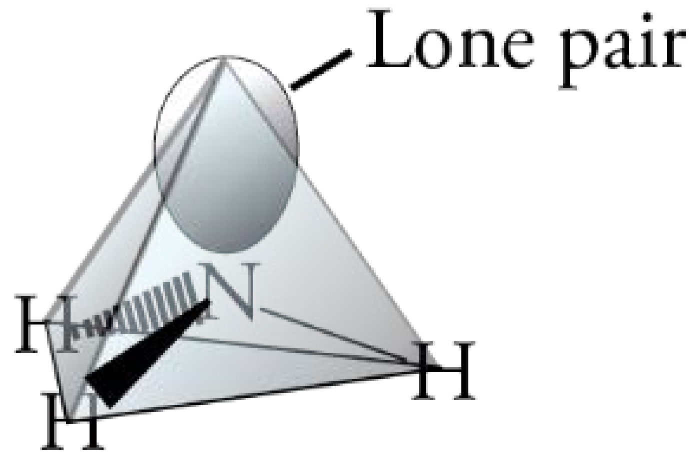
Lewis Structure for Ammonia, NH_3

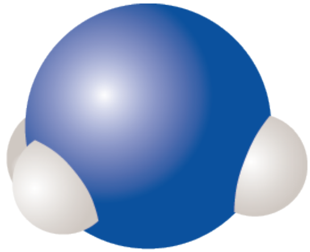
- Nitrogen atoms usually have 3 bonds and 1 lone pair.
- Hydrogen atoms have 1 bond and no lone pairs.



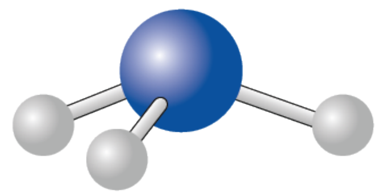
Ammonia, NH_3



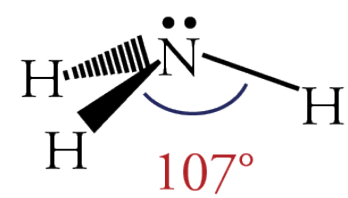




Space-filling model



Ball-and-stick model

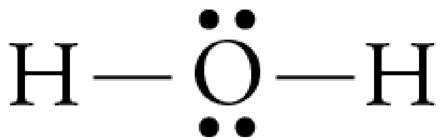


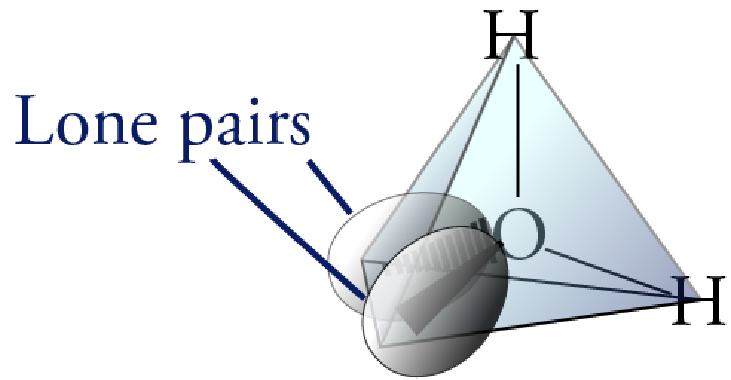
Geometric sketch

Lewis Structure for Water, H_2O

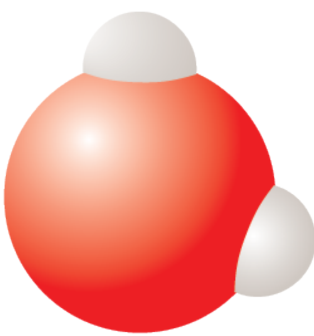
- Oxygen atoms usually have 2 bonds and 2 lone pairs.
- Hydrogen atoms have 1 bond and no lone pairs.

Water, H_2O

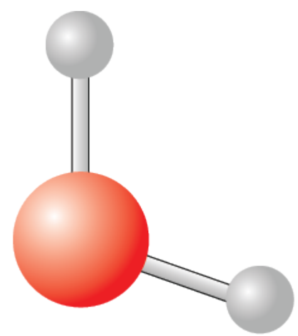




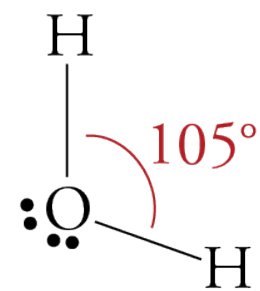
Electron group geometry (tetrahedral)



Space-filling model



Ball-and-stick model

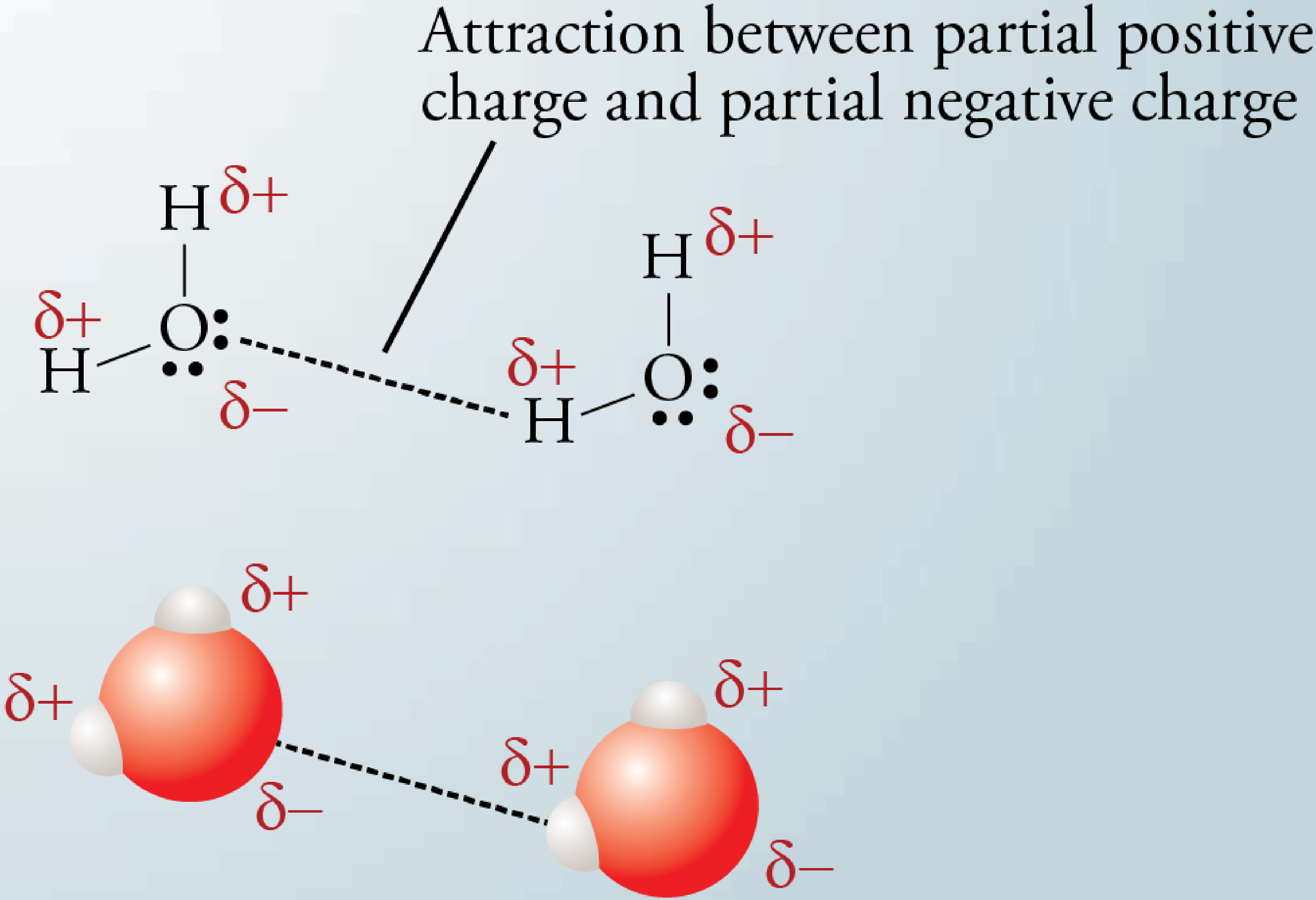


Geometric Sketch

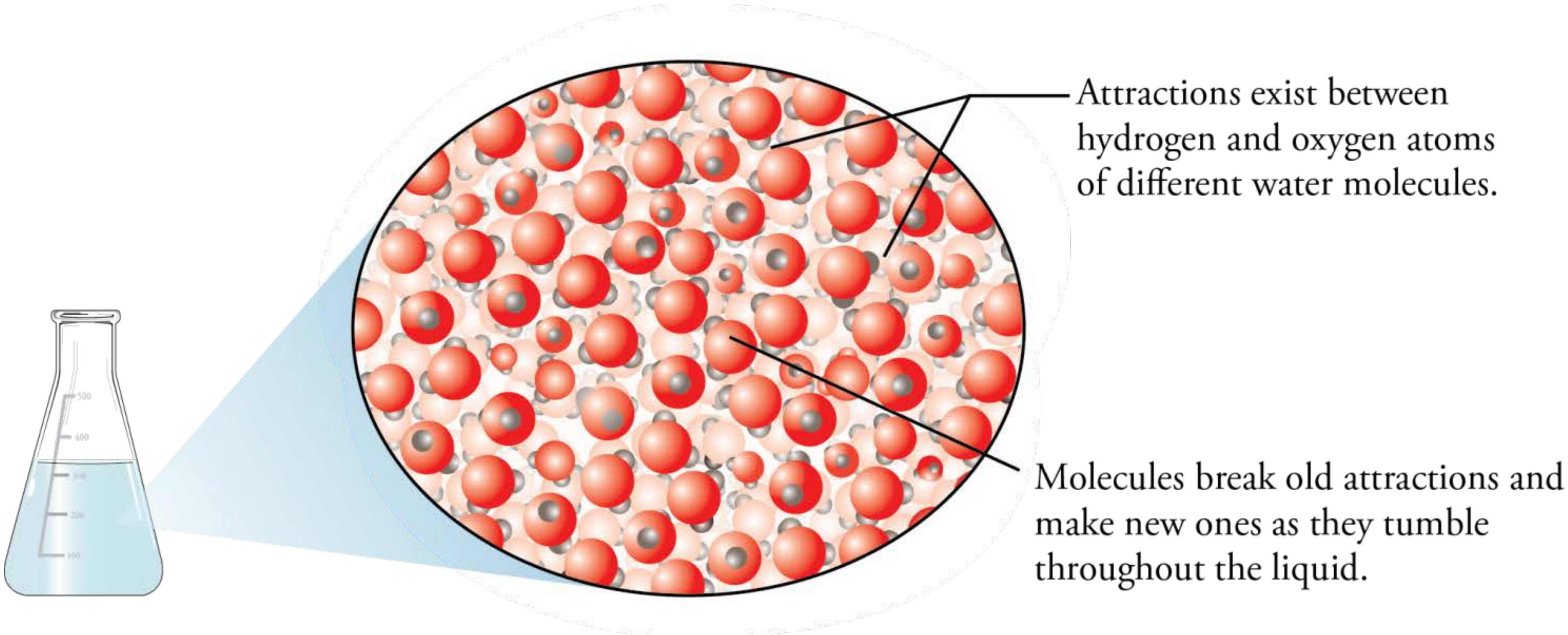
Unique Properties of Water, H_2O

- Solid less dense than liquid (maximum density at 4 °C).
- Relatively high melting point (0 °C) and boiling point (100 °C)
- High specific heat (4.184 kJ/kg°C)
- High heat of vaporization (2258 kJ/kg)

Water Attractions



Liquid Water



http://preparatorychemistry.com/water_flash.htm

The Making of an Anion

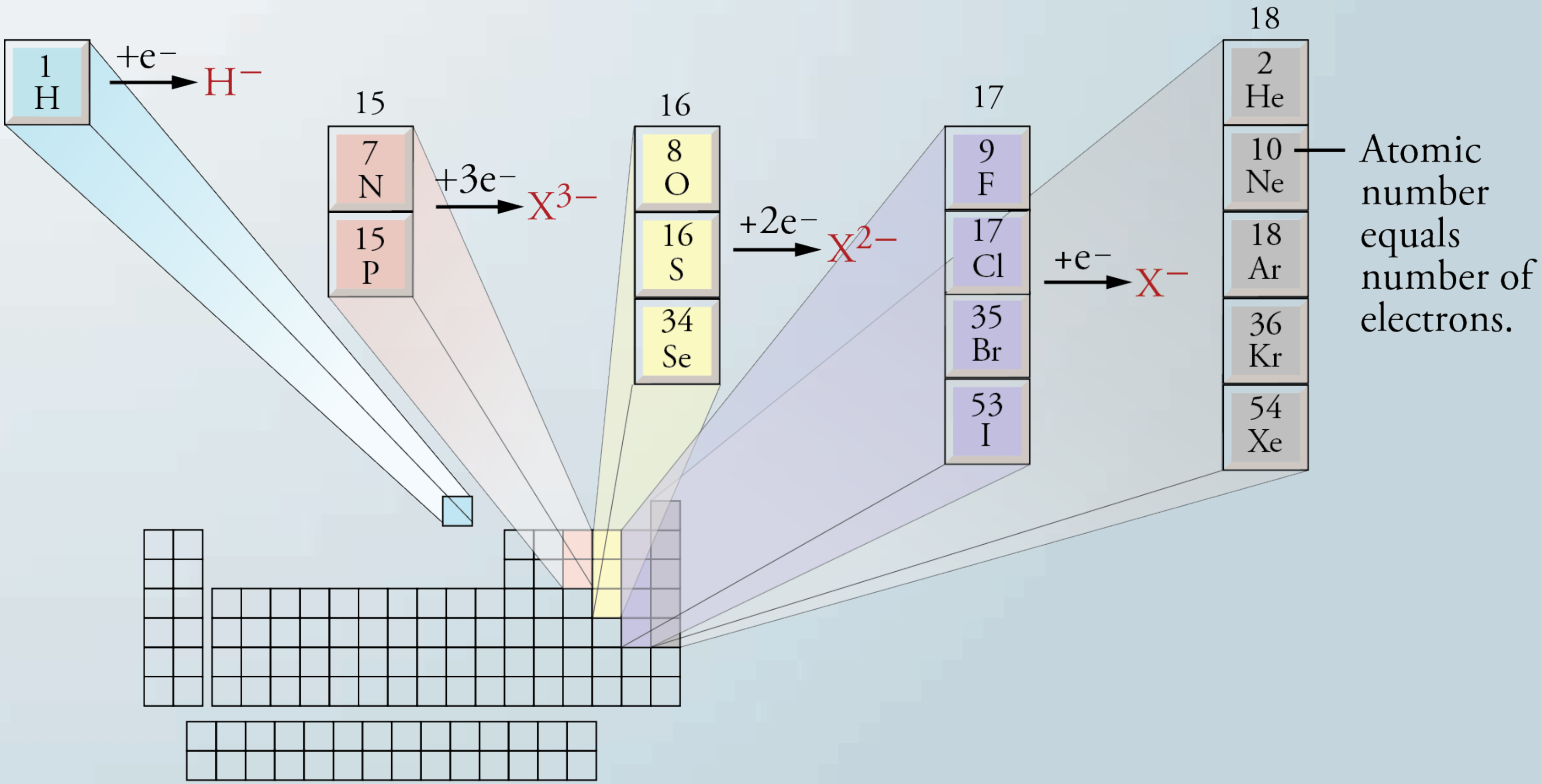
When a hydrogen atom gains one electron,

or when an atom in group 15 gains three electrons,

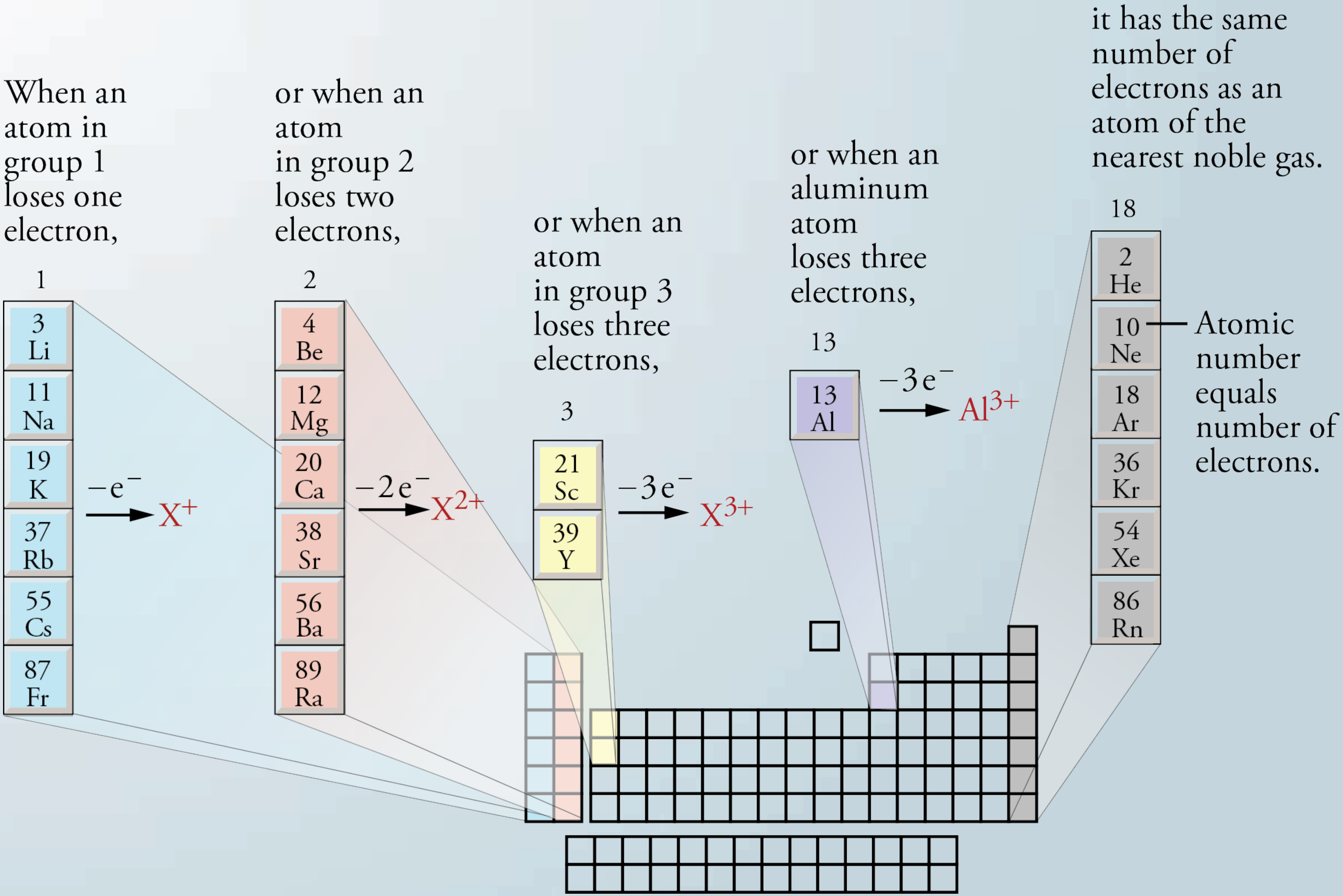
or when an atom in group 16 gains two electrons,

or when an atom in group 17 gains one electron,

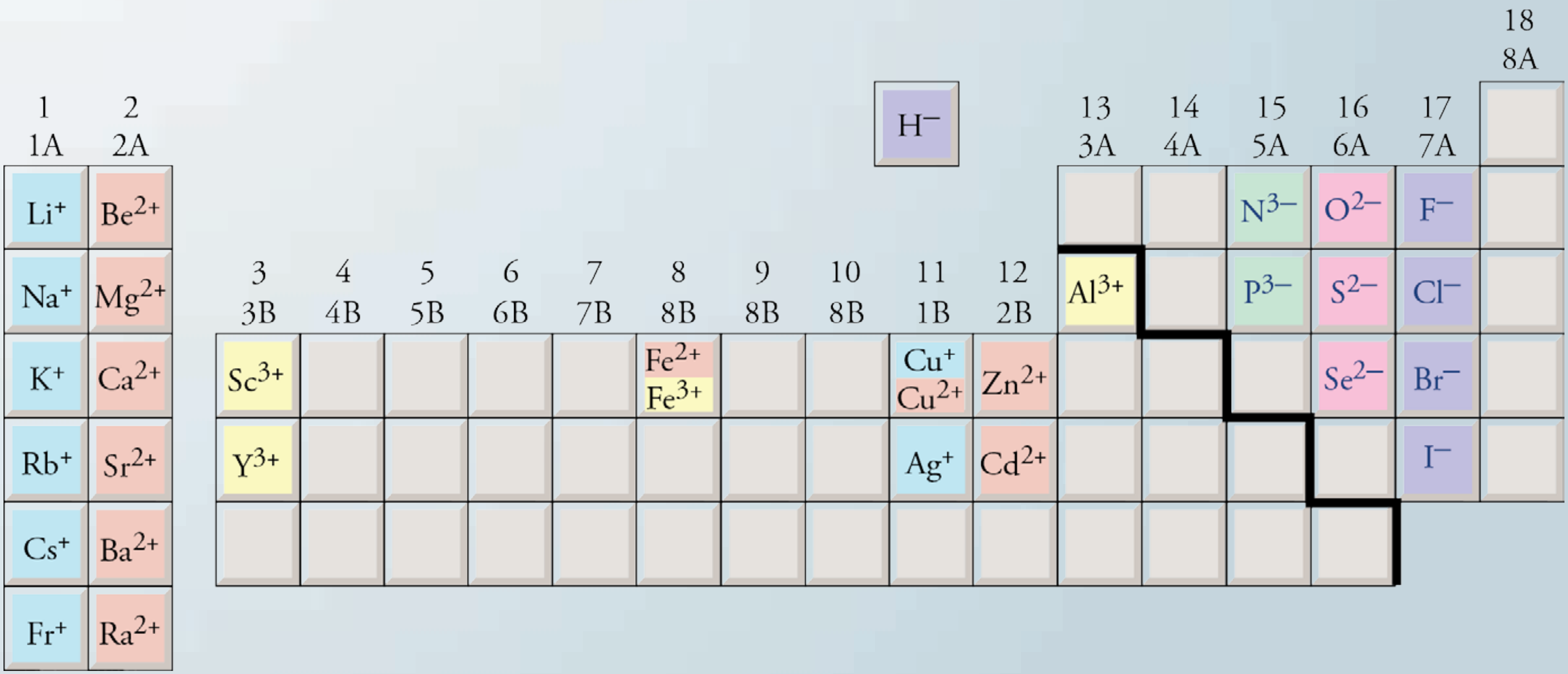
it has the same number of electrons as an atom of the nearest noble gas.



The Making of a Cation



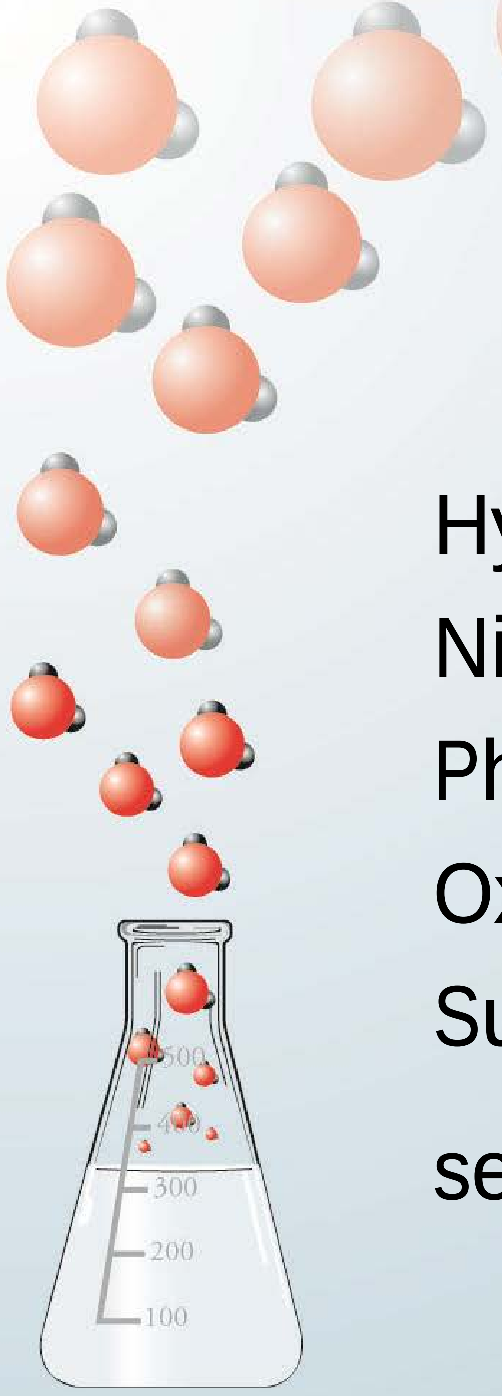
Monatomic Ions



Monatomic Ion Names

- Monatomic Cations
  - (name of metal)
    - Groups 1, 2, and 3 metals
    - Al^{3+}, Zn^{2+}, Cd^{2+}, Ag^{+}
  - (name of metal)(Roman numeral)
    - All metallic cations not mentioned above
- Monatomic Anions
  - (root of nonmetal name)ide

Monatomic Anions



Hydride H^{-}

Nitride N^{3-}

Phosphide P^{3-}

Oxide O^{2-}

Sulfide S^{2-}

selenide Se^{2-}

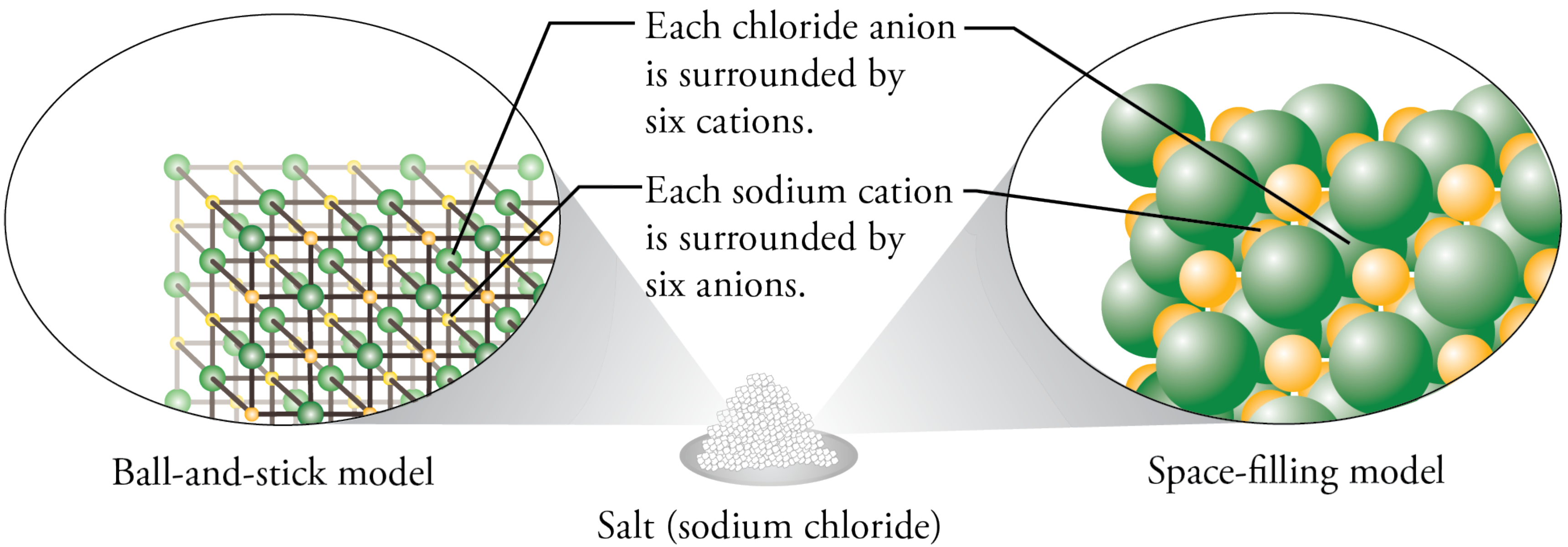
fluoride F^{-}

chloride Cl^{-}

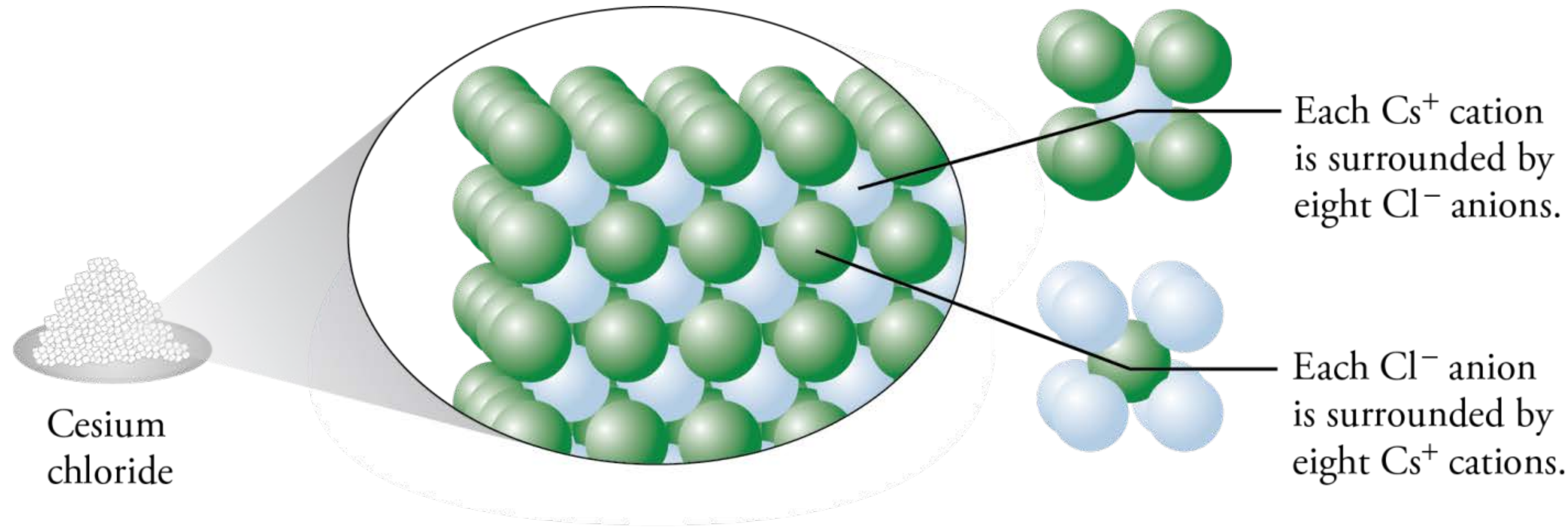
bromide Br^{-}

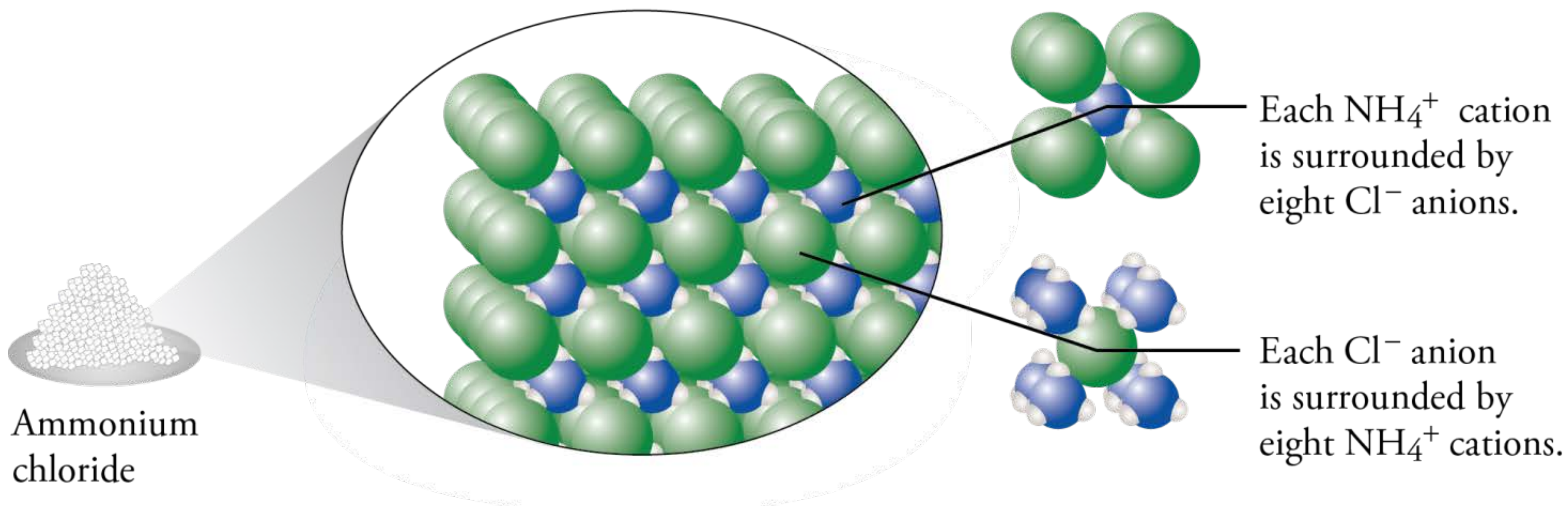
iodide I^{-}

Sodium Chloride, NaCl, Structure



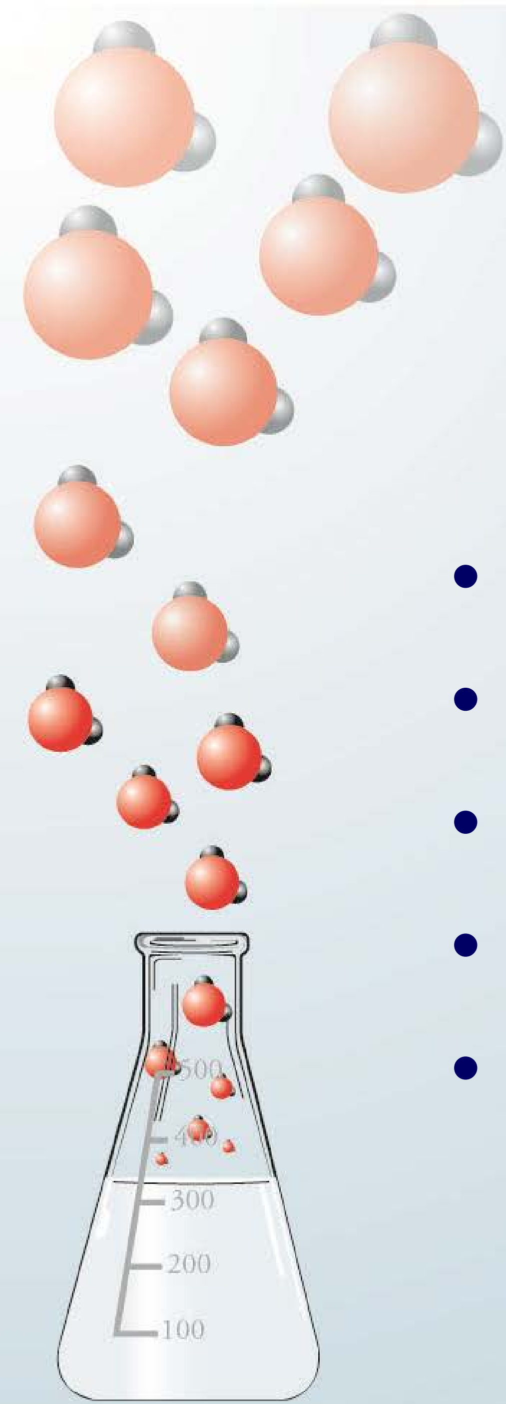
CsCl and NH_4Cl structure





Polyatomic Ions

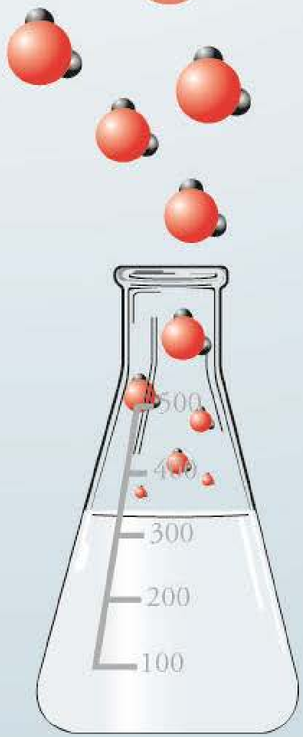
Ion	Name	Ion	Name
NH_4^+	ammonium	NO_3^-	nitrate
OH^-	hydroxide	SO_4^{2-}	sulfate
CO_3^{2-}	carbonate	$C_2H_3O_2^-$	acetate
PO_4^{3-}	phosphate		



Polyatomic Ions with Hydrogen

- HCO_3^- hydrogen carbonate
- HSO_4^- hydrogen sulfate
- HS^- hydrogen sulfide
- HPO_4^{2-} hydrogen phosphate
- $H_2PO_4^-$ dihydrogen phosphate

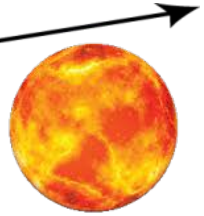
Mole



- A ***mole*** (mol) is an amount of substance that contains the same number of particles as there are atoms in 12 g of carbon-12.
- To four significant figures, there are 6.022×10^{23} atoms in 12 g of carbon-12.
- Thus a mole of natural carbon is the amount of carbon that contains 6.022×10^{23} carbon atoms.
- The number 6.022×10^{23} is often called ***Avogadro's number***.

Avogadro’s Number

If the extremely tiny atoms in just 12 grams of carbon are arranged in the line, the line would extend over 500 times the distance between earth and the sun.



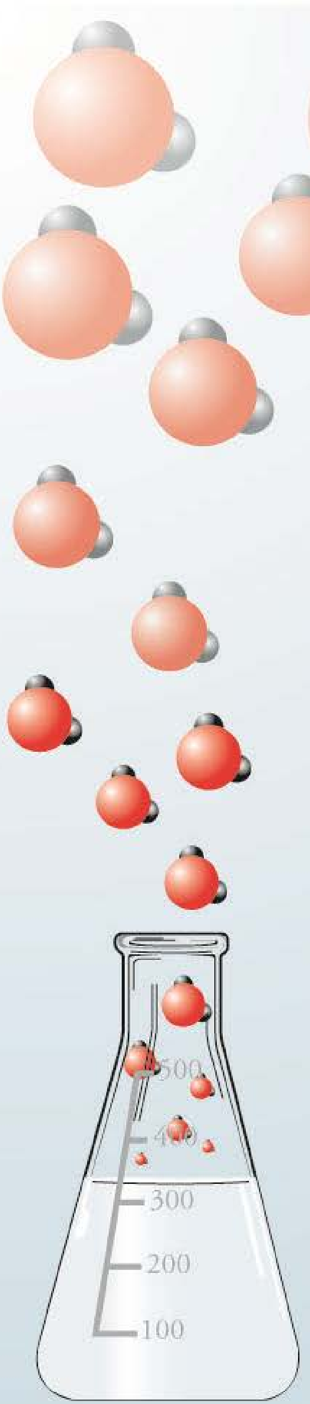
Molar Mass For Elements

- Atomic Mass from the Periodic Table

$$\left(\frac{\text{(atomic mass) g element}}{\text{1mol element}}\right)$$

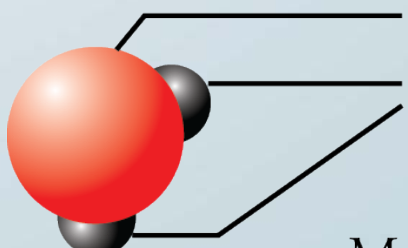
Molar Mass Calculation for Carbon

$$? \text{ mol C} = 0.55 \cancel{\text{carat}}\ \cancel{\text{C}} \left(\frac{1\ \cancel{\text{g}}}{5\ \cancel{\text{carat}}}\right)\left(\frac{1\ \text{mol C}}{12.011\ \cancel{\text{g}}\ \cancel{\text{C}}}\right) = \mathbf{9.2 \times 10^{-3}\ mol\ C}$$

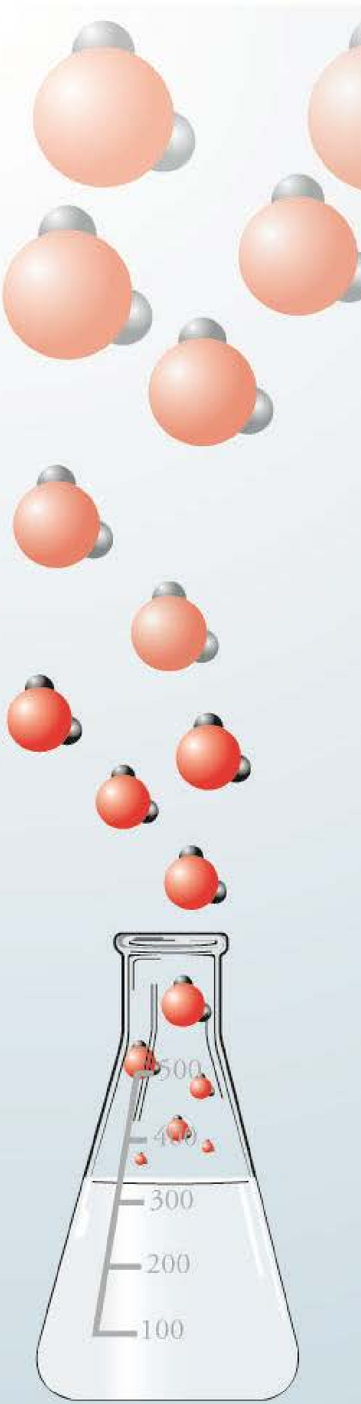


Molecular Mass

- Whole = sum of parts
- mass of a molecule = sum of the masses of the atoms in the molecule
- **molecular mass** = the sum of the atomic masses of the atoms in the molecule



Molar mass O:	15.9994 g/mol
Molar mass H:	1.00794 g/mol
	1.00794 g/mol
Molar mass H_2O:	18.0153 g/mol

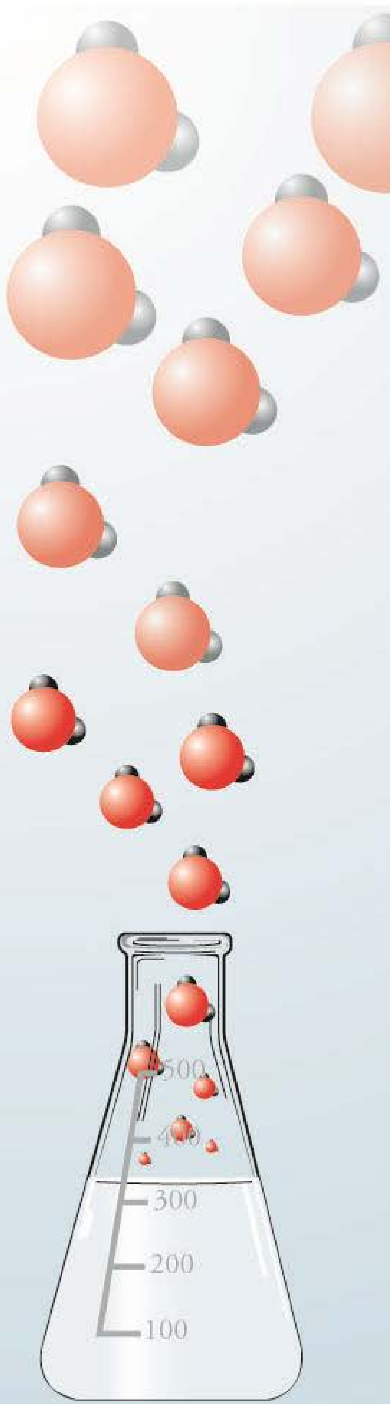


Molar Mass For Molecular Compounds

- ***Molecular Mass*** = Sum of the atomic masses of atoms in one molecule

$$\left(\frac{(\text{molecular mass})\,\text{g molecular compound}}{1\,\text{mol molecular compound}}\right)$$

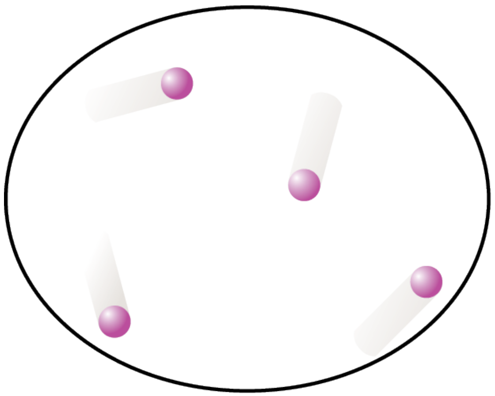
Formula Units



- A ***formula unit*** of a substance is the group represented by the substance’s chemical formula, that is, a group containing the kinds and numbers of atoms or ions listed in the chemical formula.
- Formula unit is a general term that can be used in reference to elements, molecular compounds, or ionic compounds.

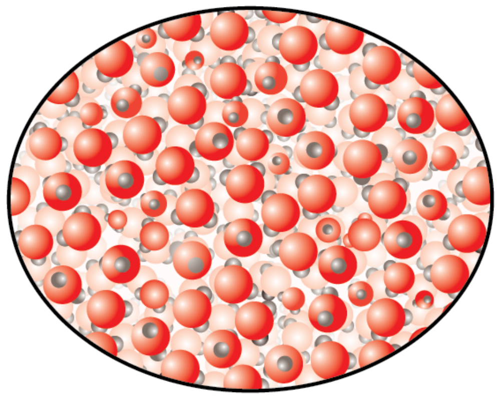
Formula Unit Examples

neon gas
(element)



A formula unit of neon contains one Ne atom.

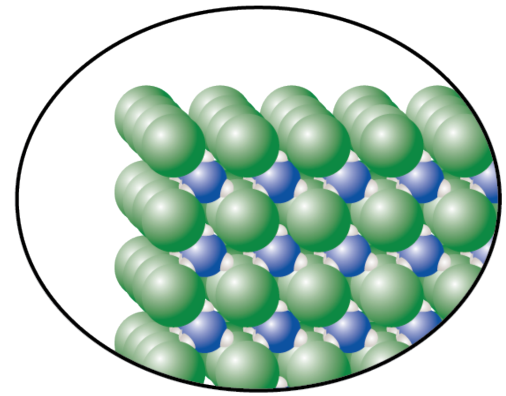
liquid water
(molecular compound)



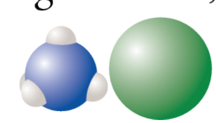
Liquid water is composed of discrete H_2O molecules.

A formula unit of water contains one oxygen atom and two hydrogen atoms.

ammonium chloride
(ionic compound)

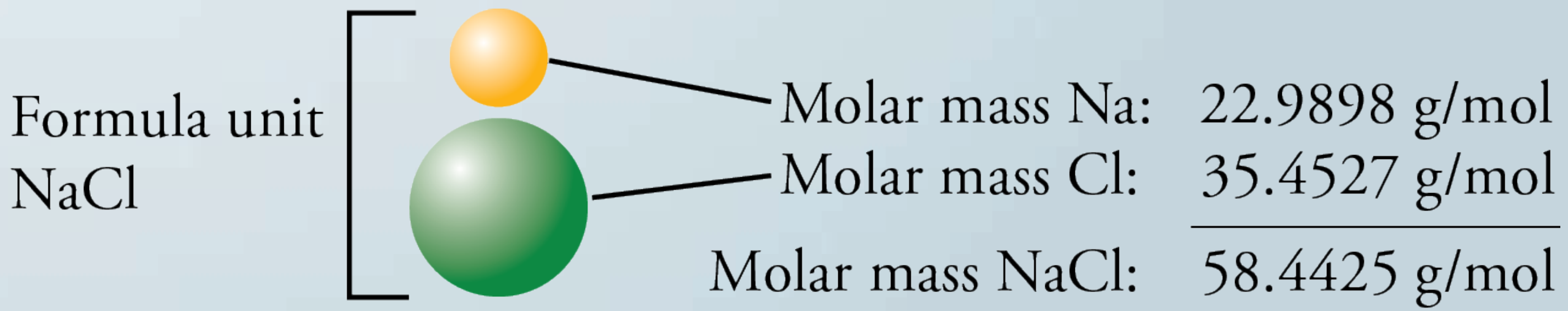


There are no separate ammonium chloride, NH_4Cl, molecules. Each ion is equally attracted to eight others.
A formula unit of ammonium chloride contains one ammonium ion, NH_4^+, and one chloride ion, Cl^-, (or one nitrogen atom, four hydrogen atoms, and one chloride ion).



Formula Mass for Ionic Compounds

- Whole = sum of parts
- Mass of a formula unit = sum of the masses of the atoms in the formula unit
- ***Formula mass*** = the sum of the atomic masses of the atoms in the formula



Molar Mass For Ionic Compounds

- ***Formula Mass*** = Sum of the atomic masses of the atoms in a formula unit

$$\left(\frac{\text{(formula mass) g ionic compound}}{\text{1 mol ionic compound}}\right)$$