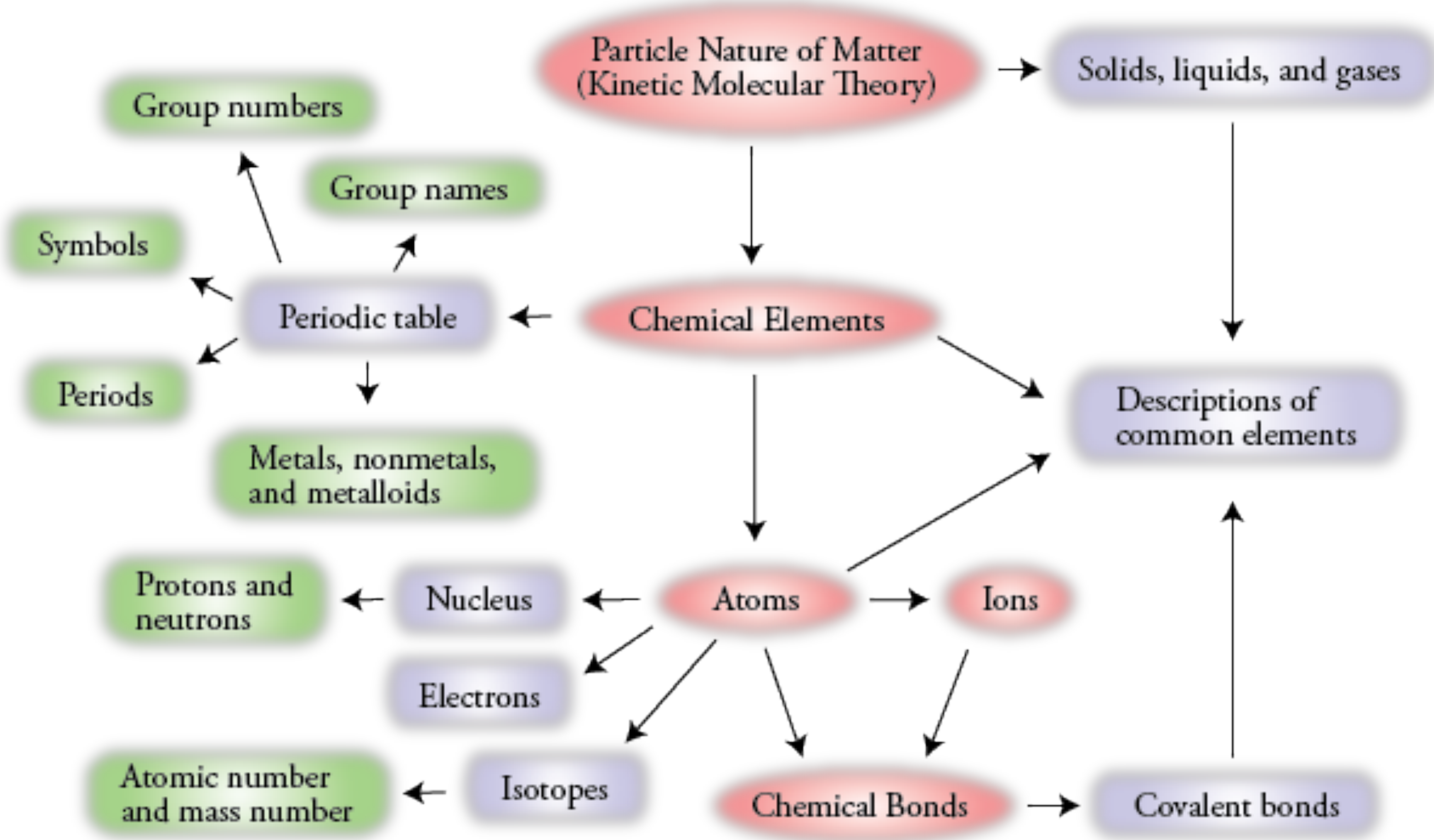
Chapter 2
The Structure of Matter and the Chemical Elements

An Introduction to Chemistry

By Mark Bishop

Chapter Map



Particle Nature of Matter (Kinetic Molecular Theory)
Solids, liquids, and gases
Group numbers
Group names
Symbols
Periodic table
Chemical Elements
Periods
Metals, nonmetals, and metalloids
Descriptions of common elements
Protons and neutrons
Nucleus
Atoms
Ions
Electrons
Atomic number and mass number
Isotopes
Chemical Bonds
Covalent bonds

Chemistry

The science that deals with the structure and behavior of matter

Scientific Models

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

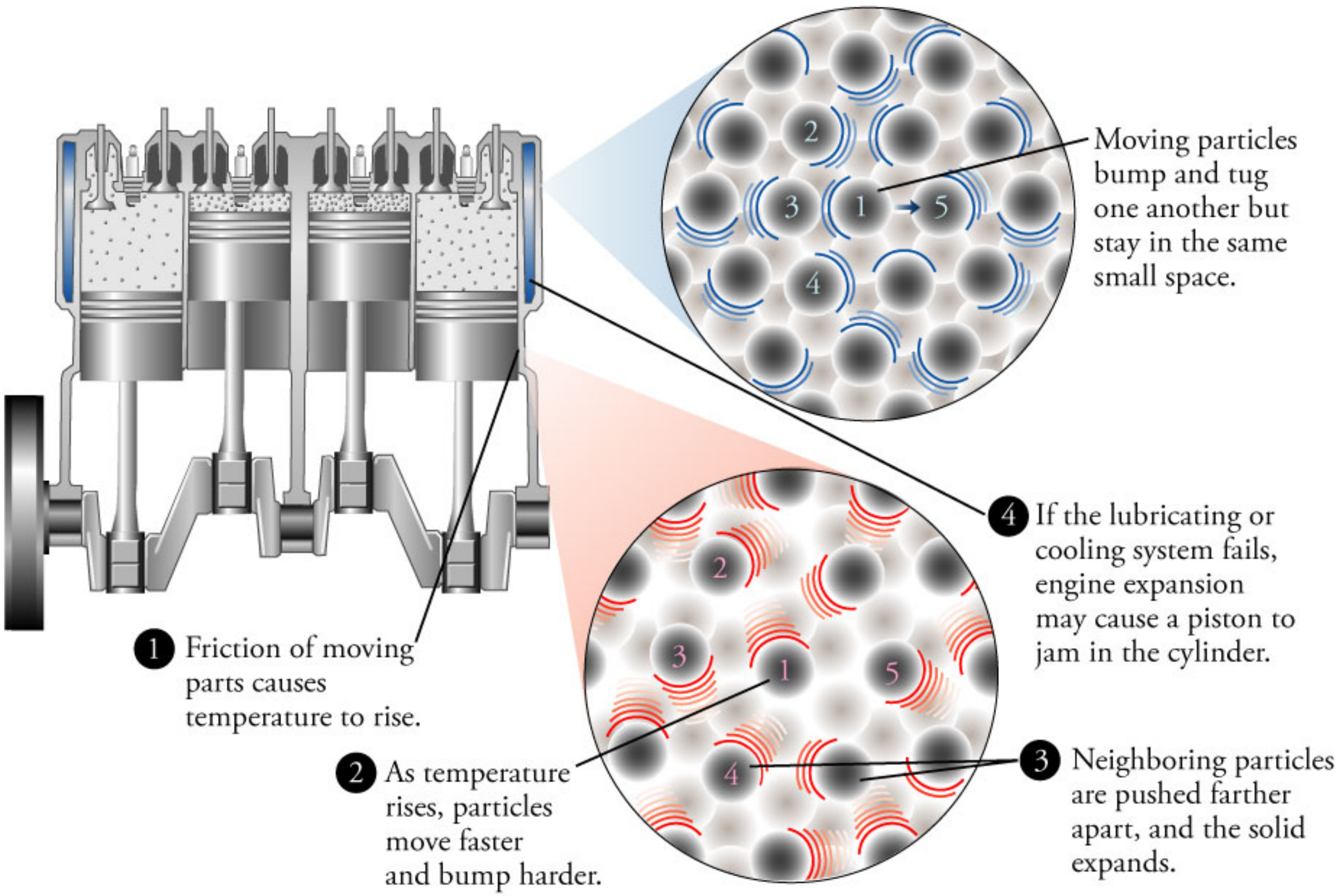
Kinetic Molecular Theory

- 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.

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.

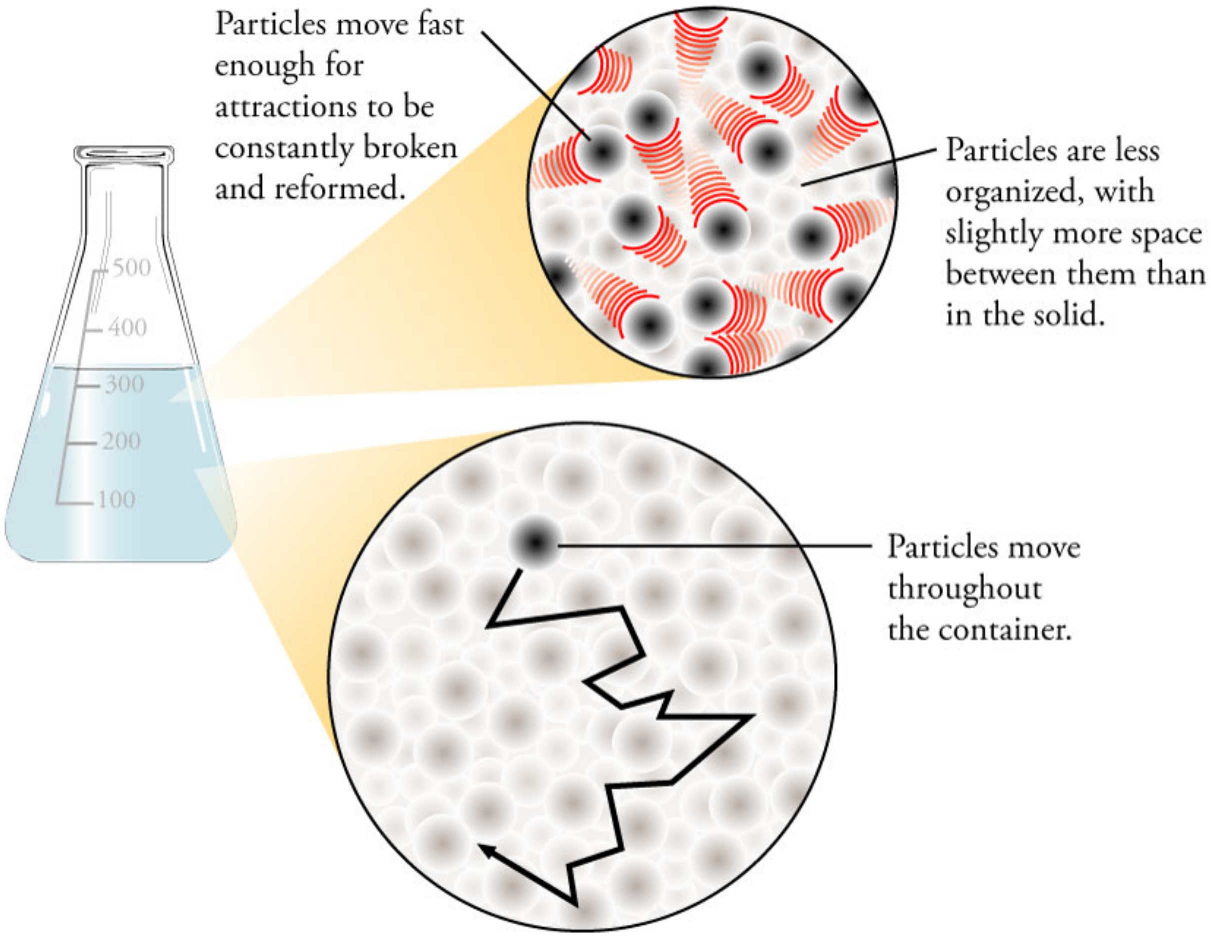
The Nature of Solids



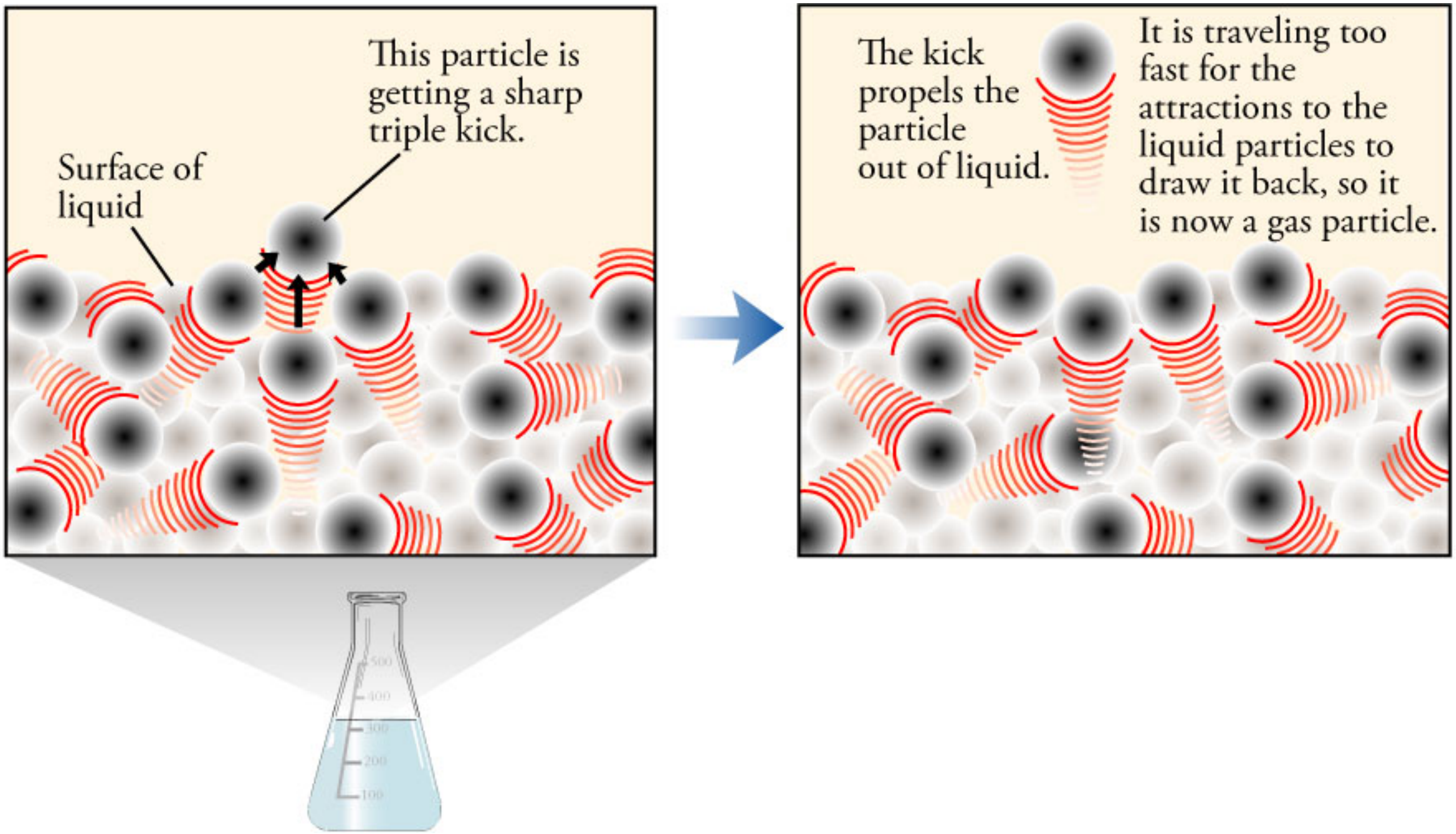
Liquid

- 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.

Liquids


500
400
300
200
100
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.

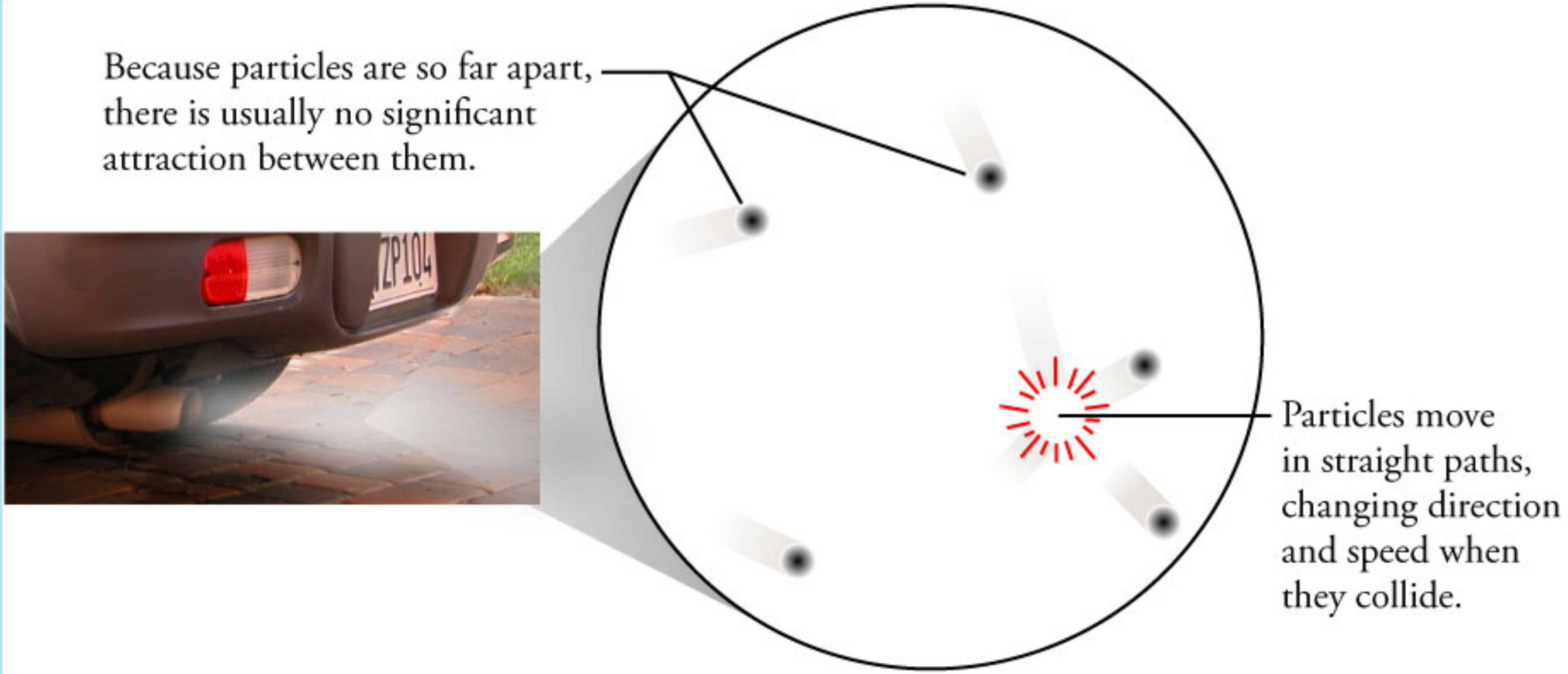
Evaporation



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

The Nature of Gases



Description of Solid

- Particles constantly moving.
- About 70% of volume occupied by particles…30% empty.
- Strong attractions keep particles trapped in cage.
- Constant collisions that lead to changes in direction and velocity.
- Constant volume and shape due to strong attractions and little freedom of motion.

Description of Liquid

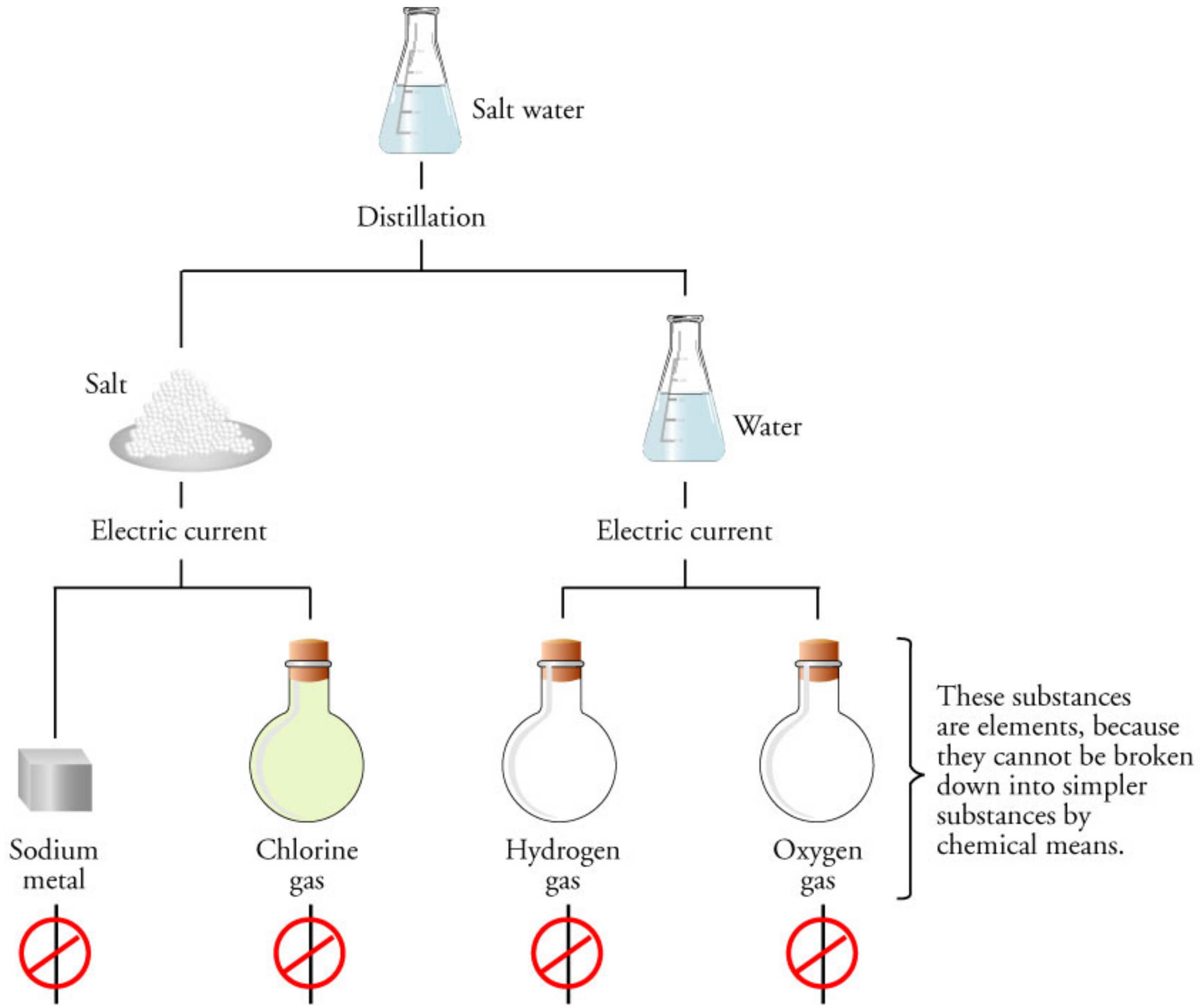
- Particles constantly moving.
- About 70% of volume occupied by particles…30% empty
- Attractions are strong but not strong enough to keep particles from moving throughout the liquid.
- Constant collisions that lead to changes in direction and velocity.
- Constant volume, due to significant attractions between the particles that keeps the particles at a constant average distance, but not constant shape, due to the freedom of motion.

Description of Gas

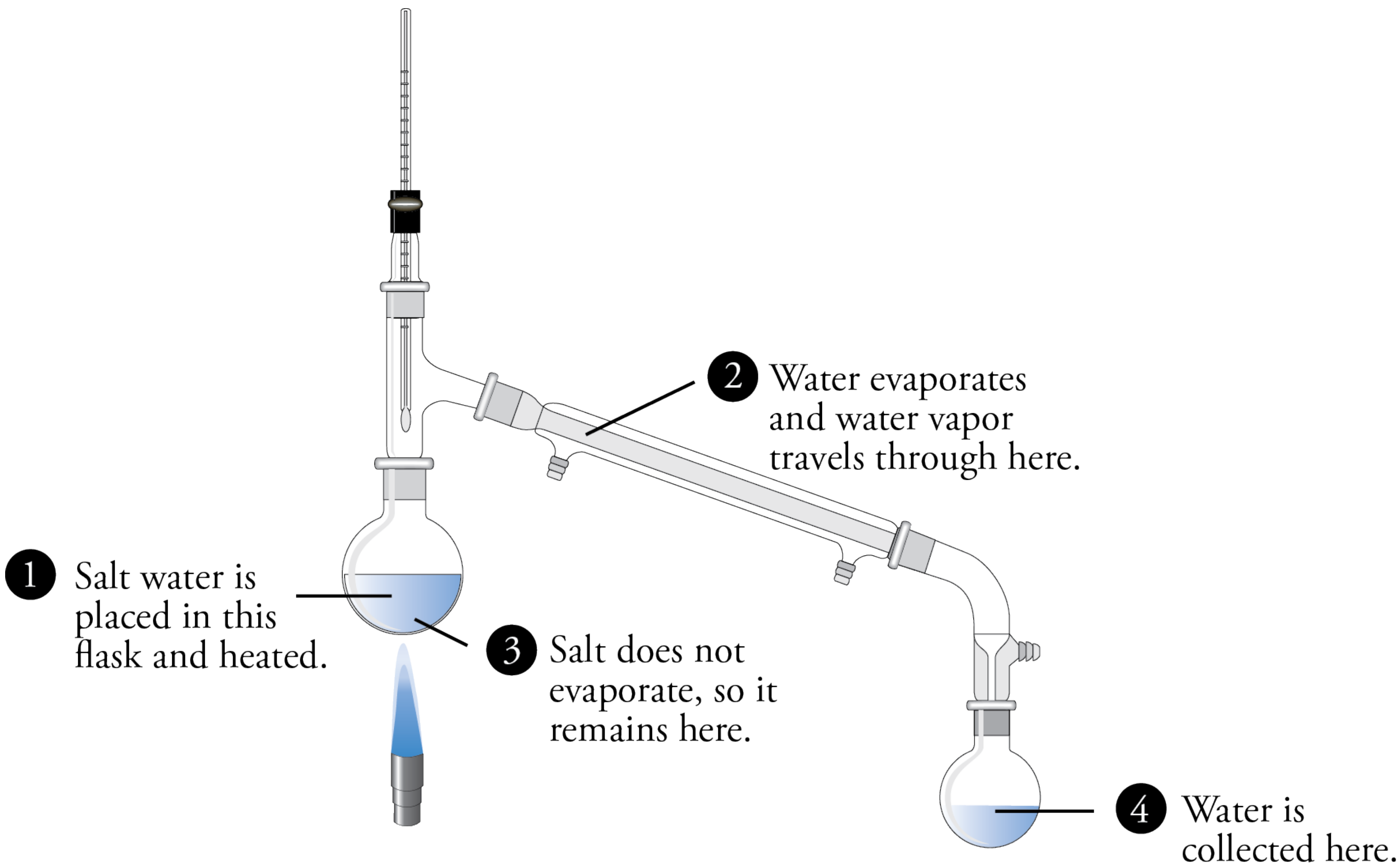
- Particles constantly moving in straight-line paths
- About 0.1% of volume occupied by particles…99.9% empty.
- Average distance between particles is about 10 times their diameter.
- No significant attractions or repulsions.
- Constant collisions that lead to changes in direction and velocity.
- Variable volume and shape, due to lack of attractions and a great freedom of motion.

https://preparatorychemistry.com/KMT_Canvas.html

Separation of Salt Water



Distillation



118 Known Elements

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

Group Numbers on the Periodic Table

	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	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

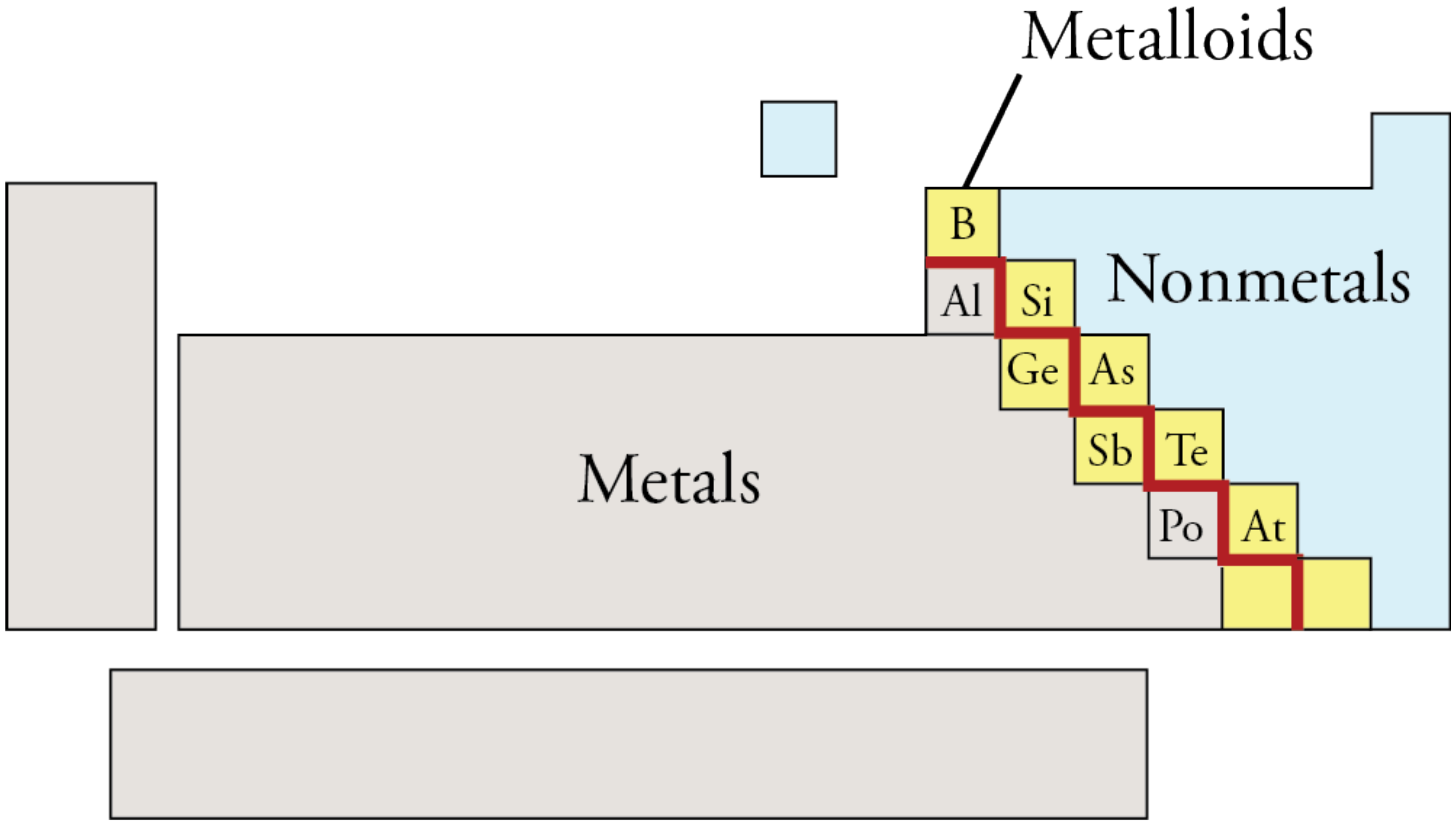
Halogens

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											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

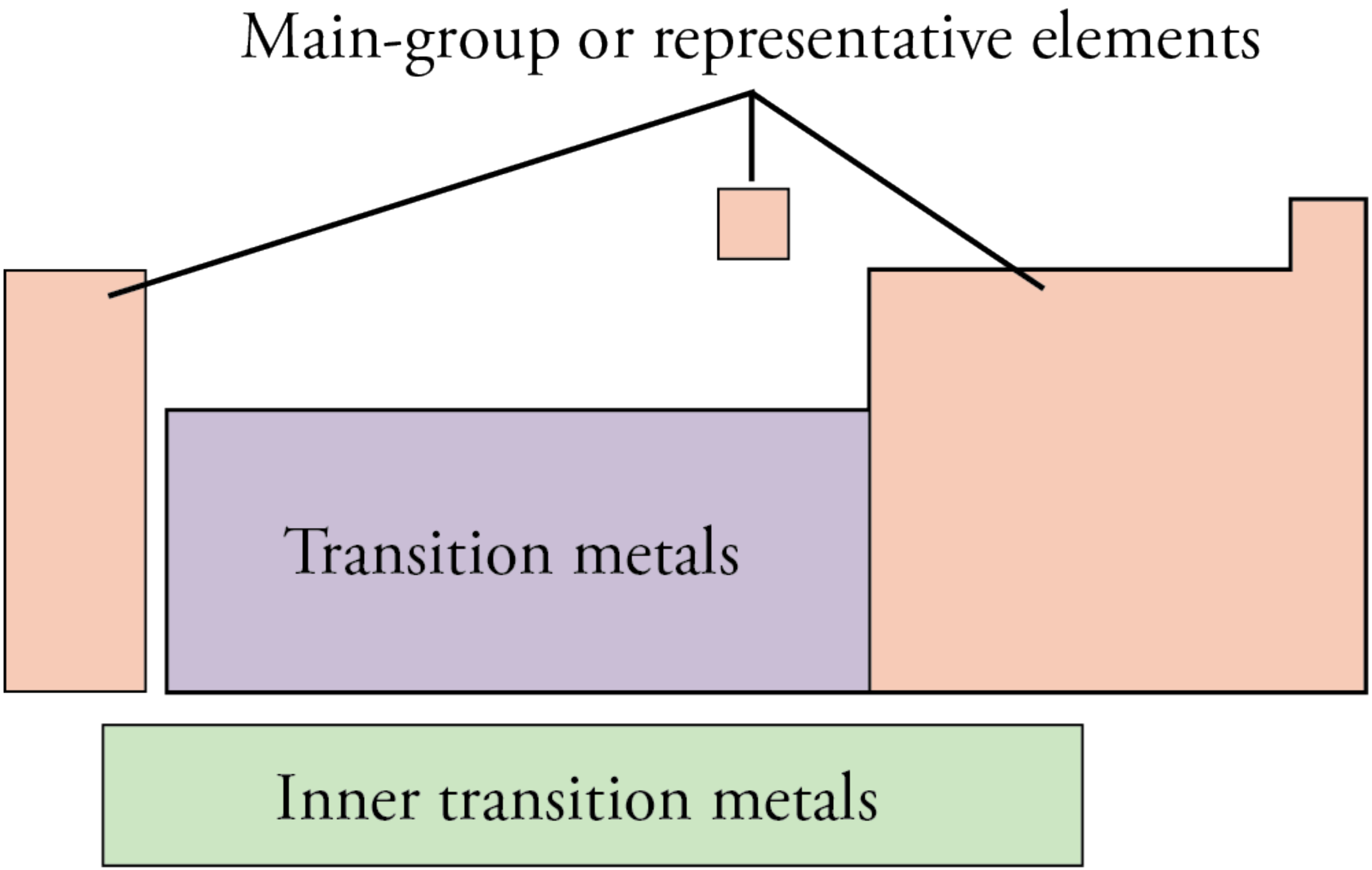
Metals, Nonmetals, and Metalloids



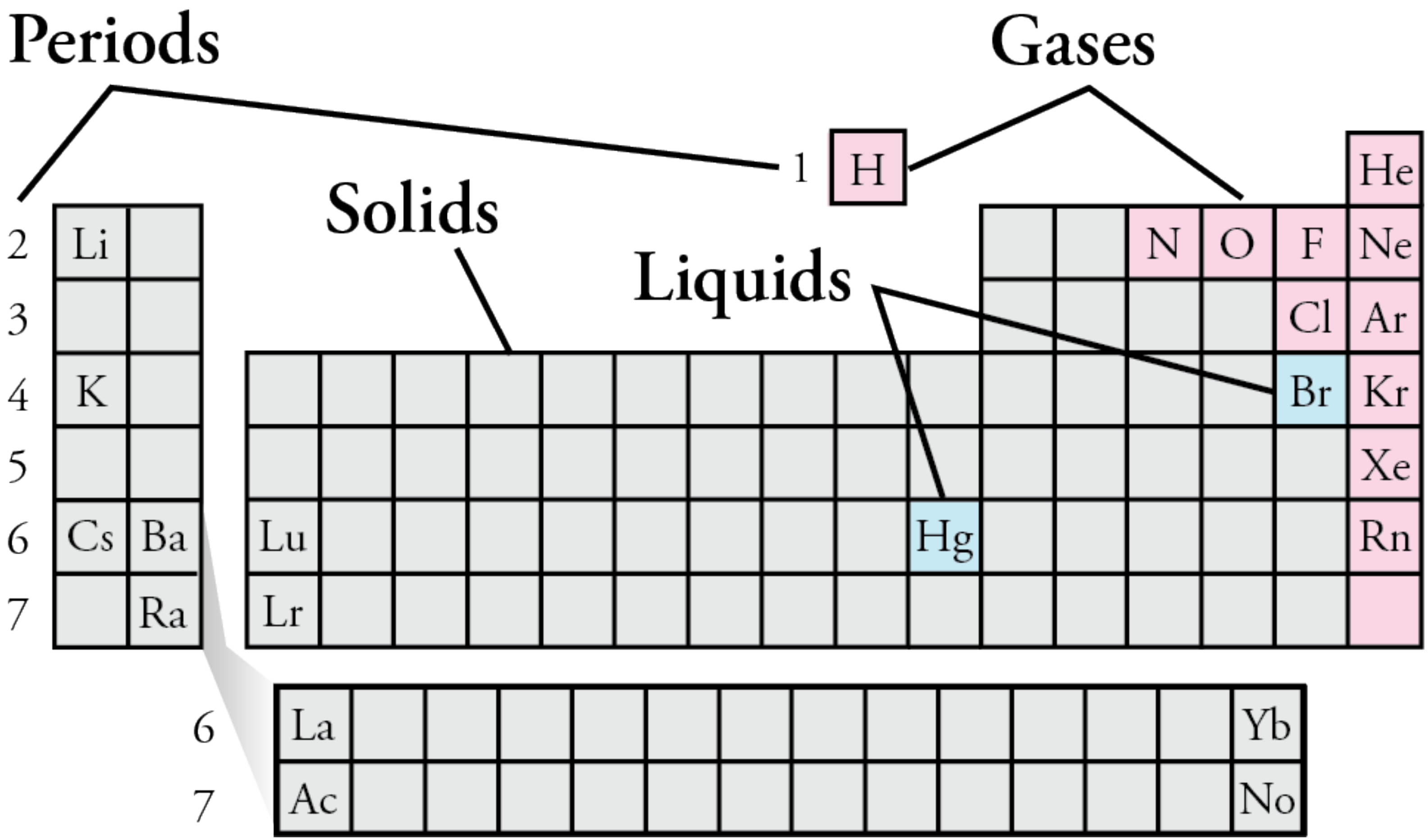
Characteristics of Metallic Elements

- 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

The Electron

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

Alan Greenspan,

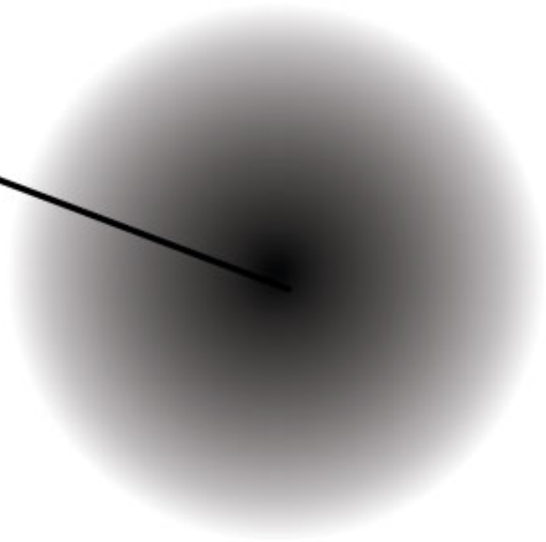
Head of the Federal Reserve Board

"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)

Electron Cloud for Hydrogen Atom

The negative charge is most intense at the nucleus and diminishes in intensity with increased distance from the nucleus.



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Helium Atom

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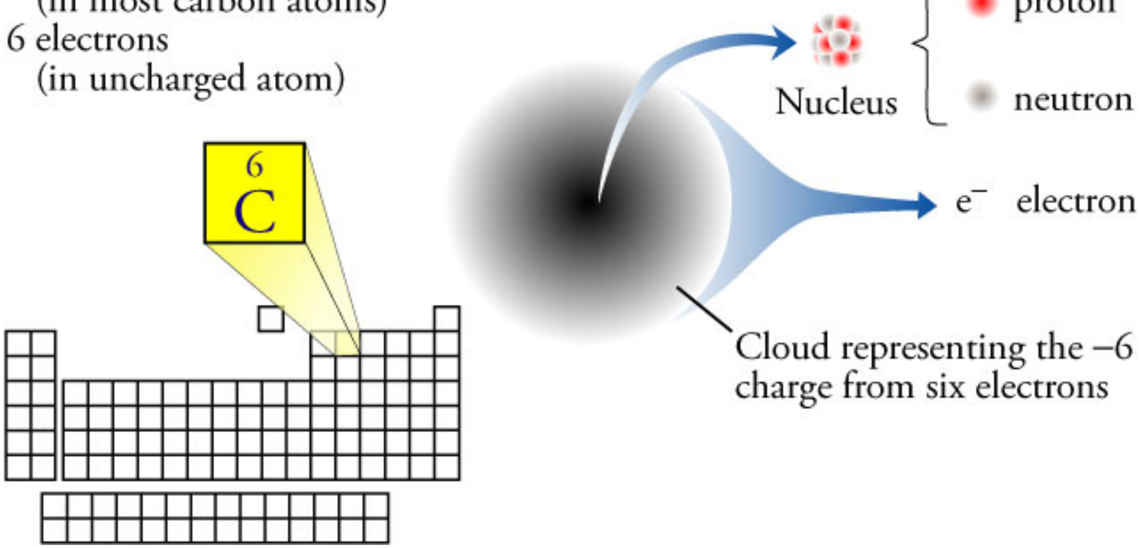
Carbon Atom

Carbon atom

6 protons
6 neutrons
(in most carbon atoms)
6 electrons
(in uncharged atom)

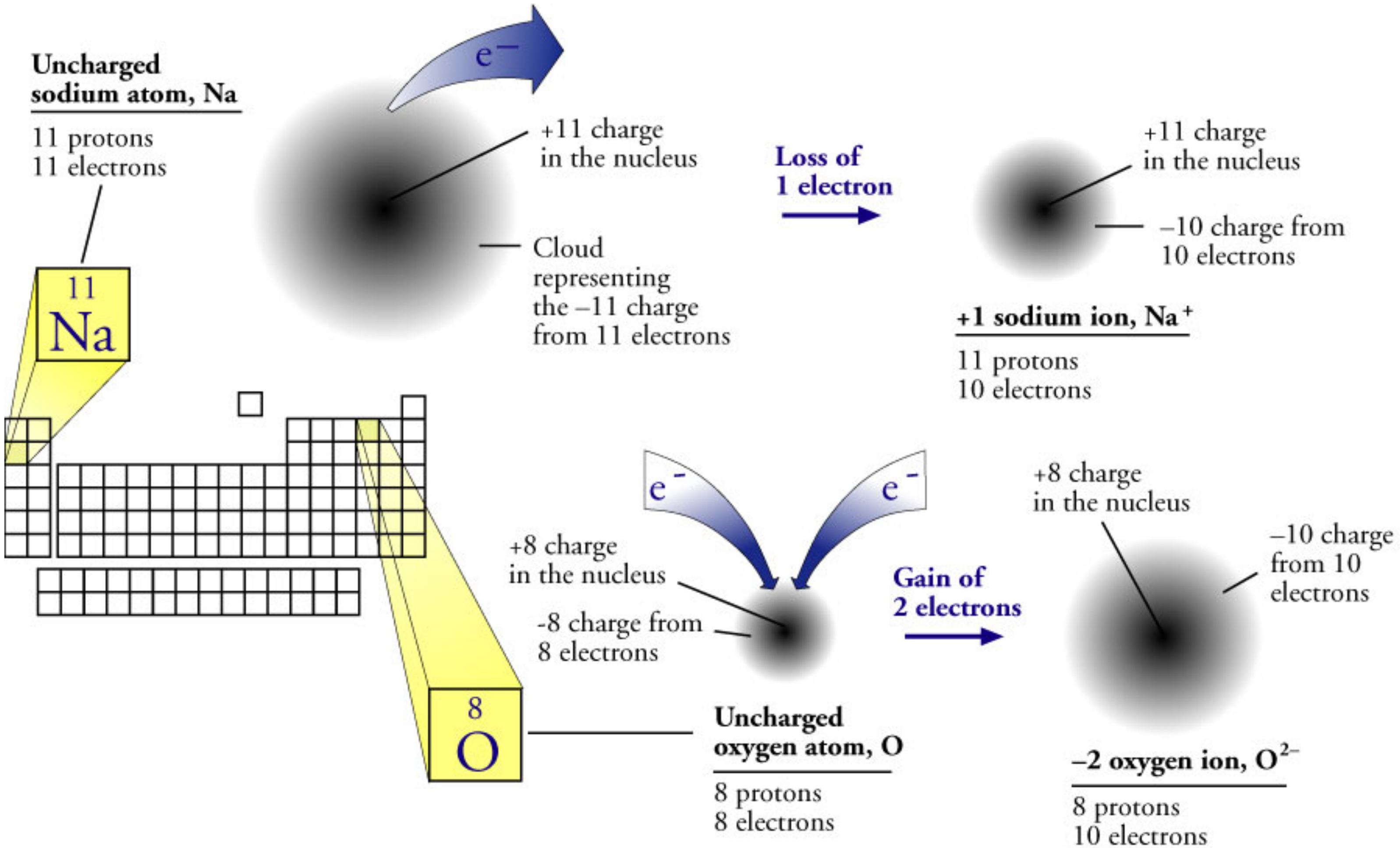


Particle	Charge	Mass
proton	+1	1.00728 u (1.6726×10^{-24} g)
neutron	0	1.00867 u (1.6750×10^{-24} g)
e^- electron	−1	0.000549 u (9.1096×10^{-28} g)

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***.

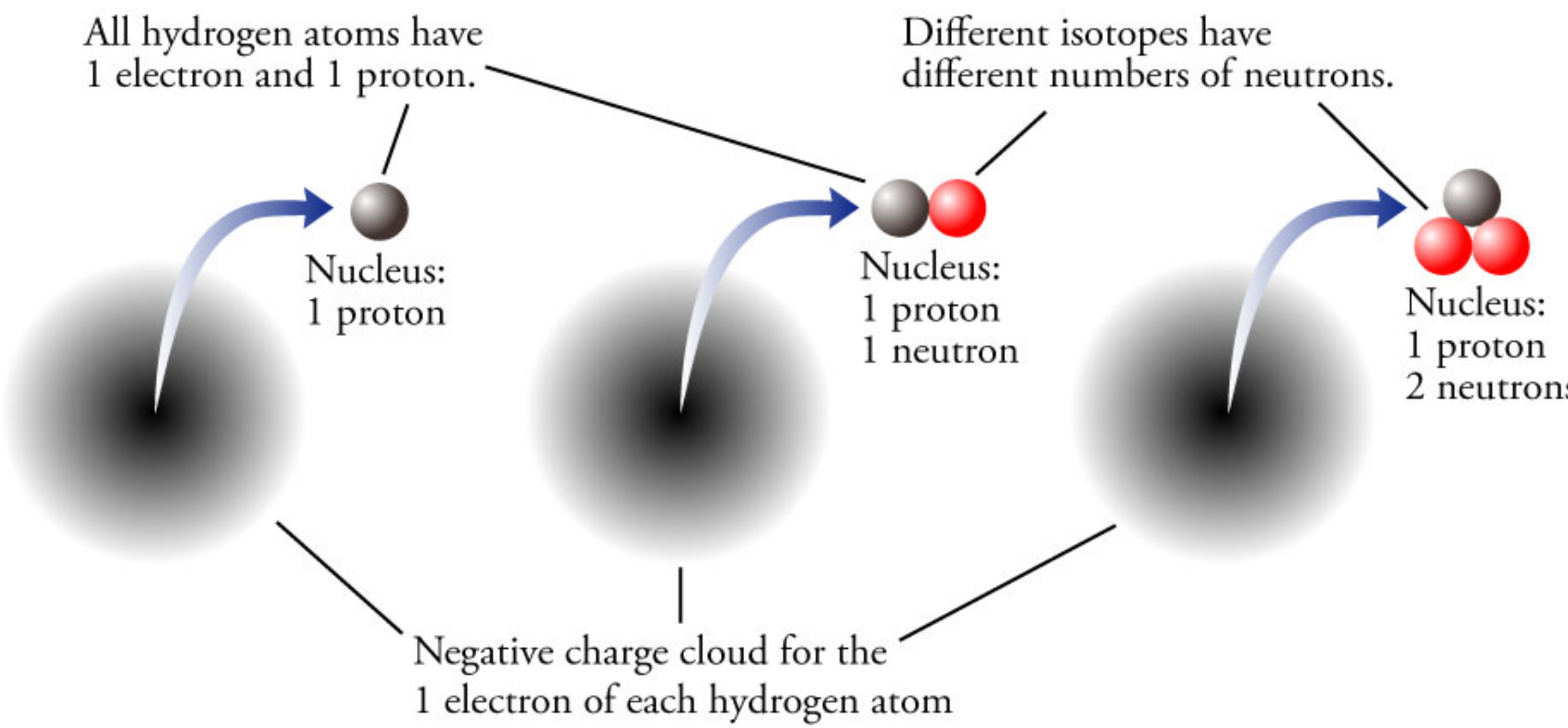
Example Ions



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



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Possible Discovery of Elements 113 and 115

- Dubna, Russia
- Dubna's Joint Institute for Nuclear Research and Lawrence Livermore National Laboratory
- Bombarded a target enriched in americium, ^{243}Am, with calcium atoms, ^{48}Ca.
- From analysis of decay products, they concluded that four atoms of element 115 were created.

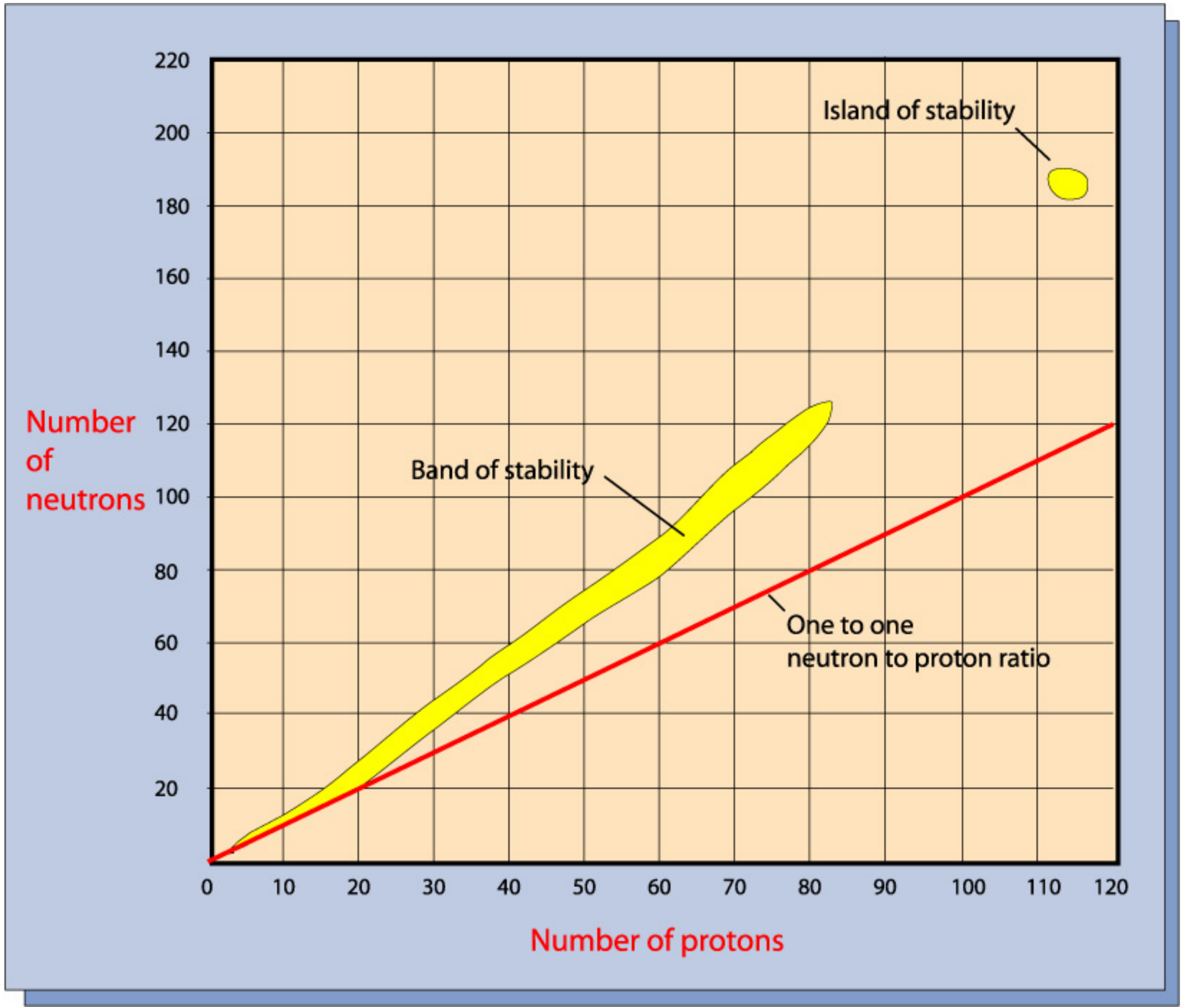
Elements 113 and 115

- Created $^{288}115$, which lasted about 100 milliseconds…a very long time for this large an isotope.
- $^{288}115$ emitted an α-particle, ^{4}He, to form $^{284}113$.
- The results need to be confirmed.

Why try to make elements that last such a short time?

- To support theories of the nature of matter.
  - The standard model of the nature of matter predicts that elements with roughly 184 neutrons and 114 protons would be fairly stable. (See next slide.)
  - $^{288}115$, which lasted a relatively long time, has 115 protons and 173 neutrons.

Band of Stability



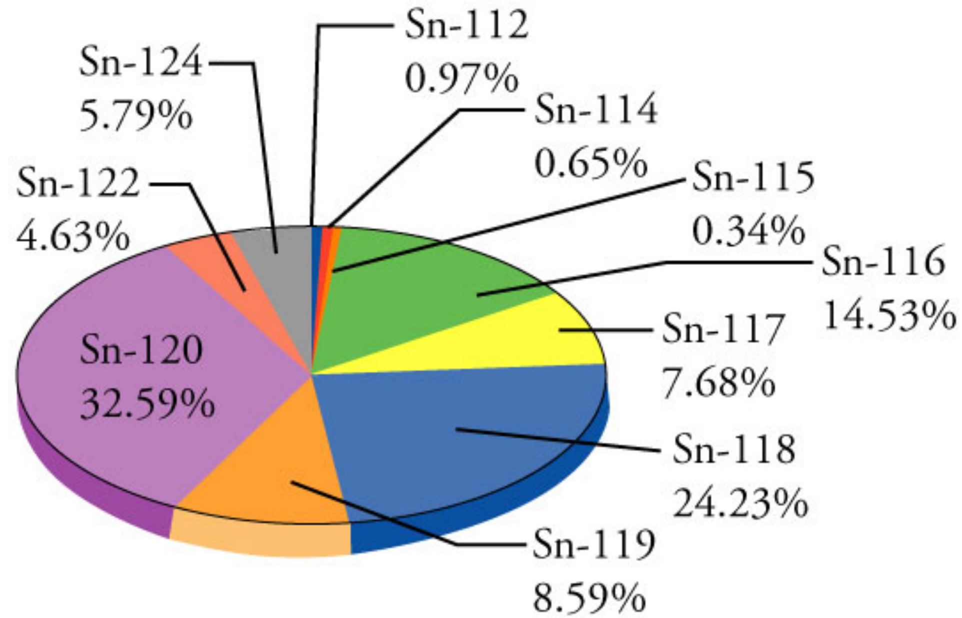
Why try to make elements that last such a short time? (cont.)

- The technology developed to make new elements is also being used for medical purposes.
  - Heavy-ion therapy as a treatment for inoperable cancers
    - Beams of carbon atoms shot at tumor.
    - Heavier particle beam is less likely to scatter.
    - Releases most of energy at end of path so easier to focus.

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.



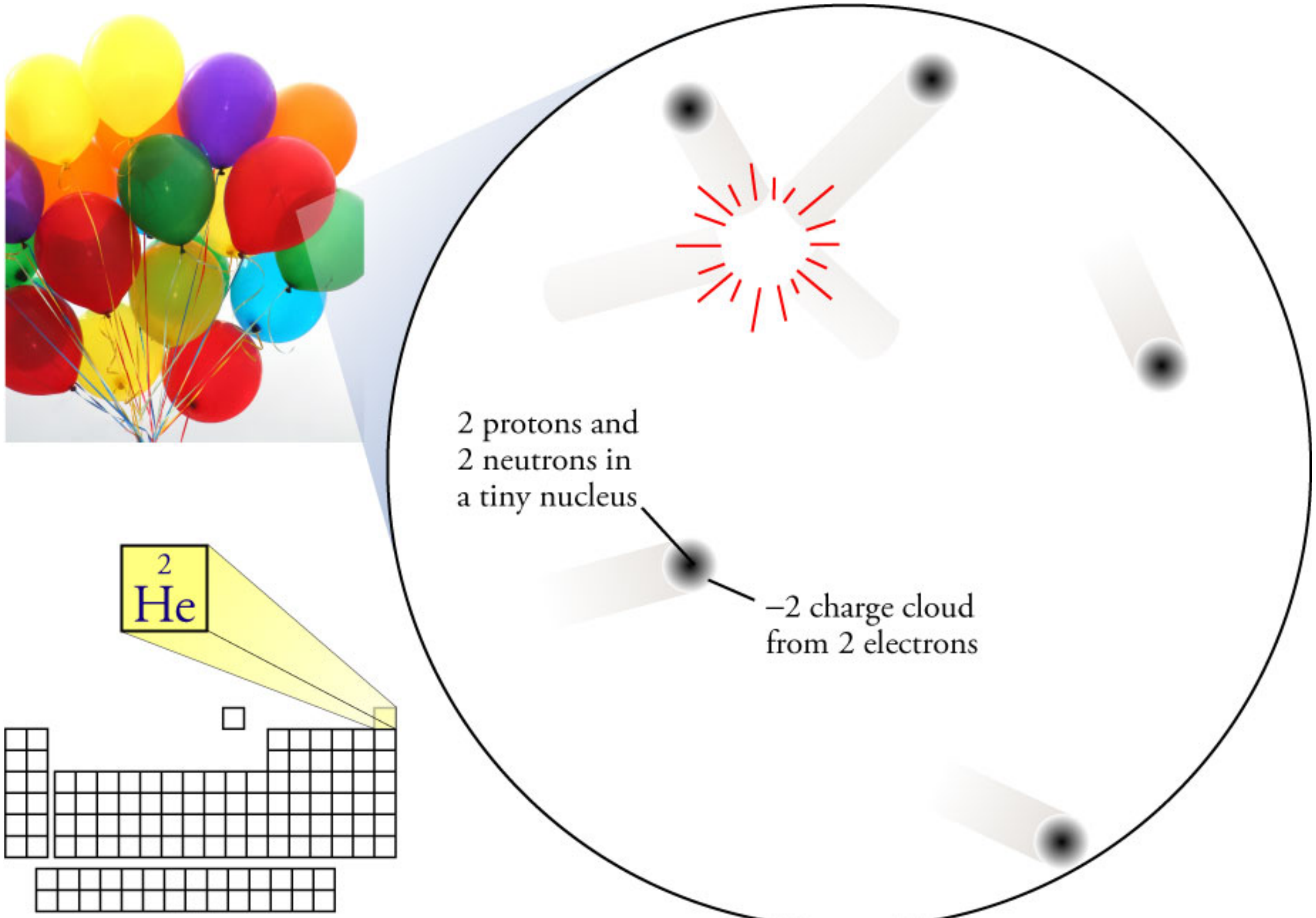
To Describe Structure of Elements

- What particles?
  - Noble gases – atoms
  - Other nonmetals - molecules
    - Diatomic elements – H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2
    - S_8, Se_8, P_4
    - C(diamond) huge molecules
  - Metallic elements – cations in a sea of electrons

To Describe Structure of Elements (2)

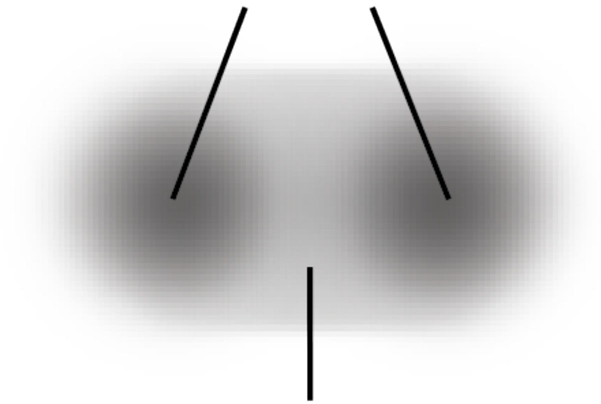
- Solid, liquid, or gas?
  - Gases - H_2, N_2, O_2, F_2, Cl_2, He, Ne, Ar, Kr, and Xe
  - Liquids – Br_2 and Hg
  - Solids – the rest
- Standard description of (1) solid, (2) liquid, (3) gas, or (4) metal.

Helium Gas, He

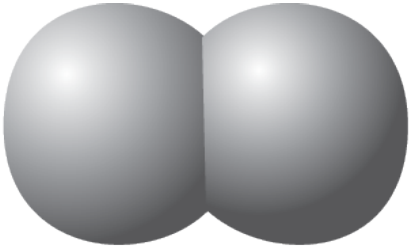


Hydrogen, H_2, Molecule

Hydrogen nuclei

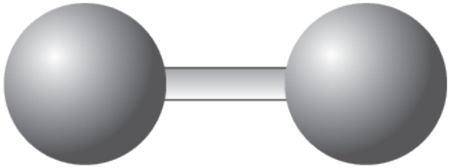


The two electrons generate a charge cloud surrounding both nuclei.



Space-filling model

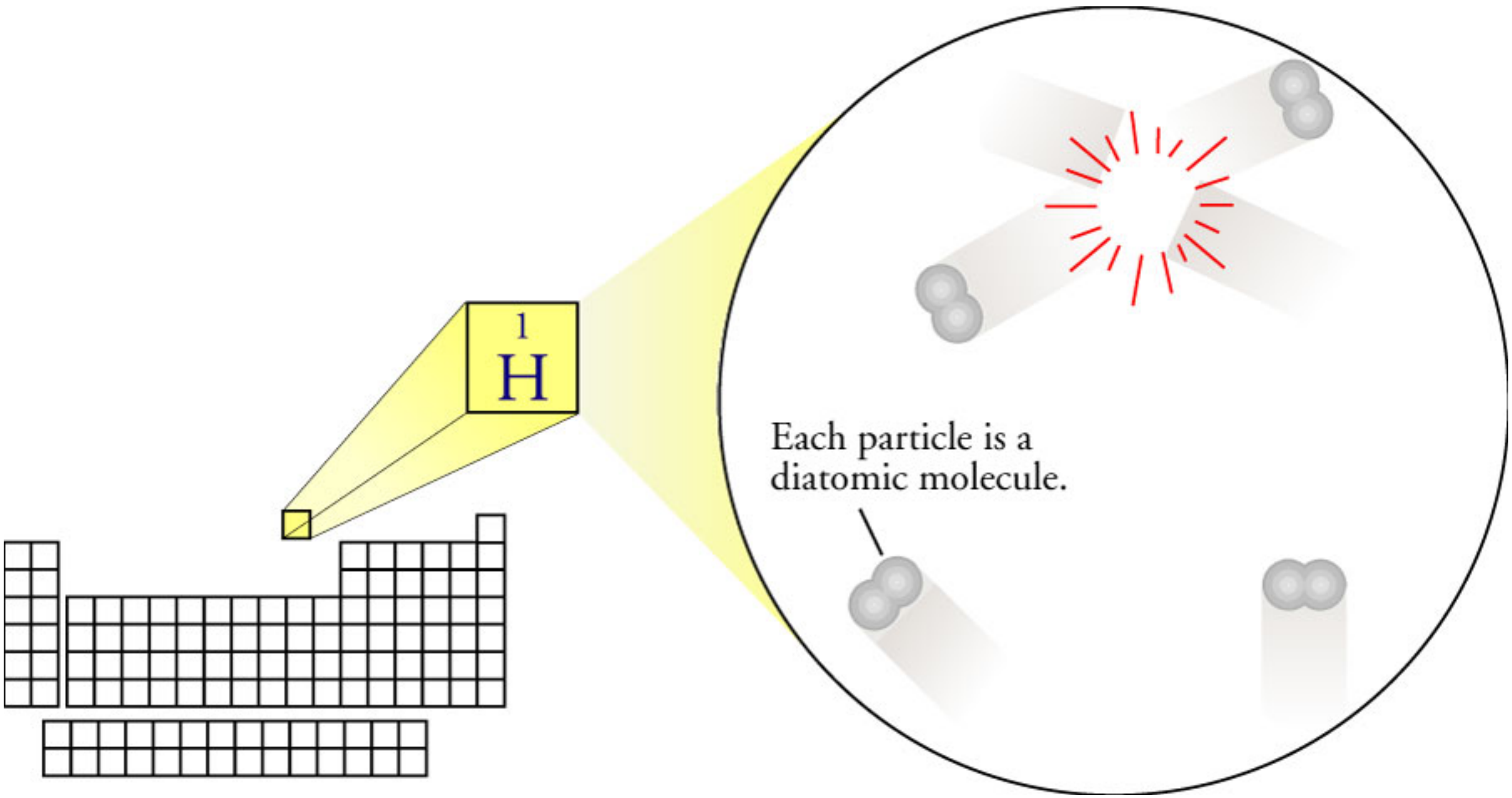
Emphasizes individual atoms



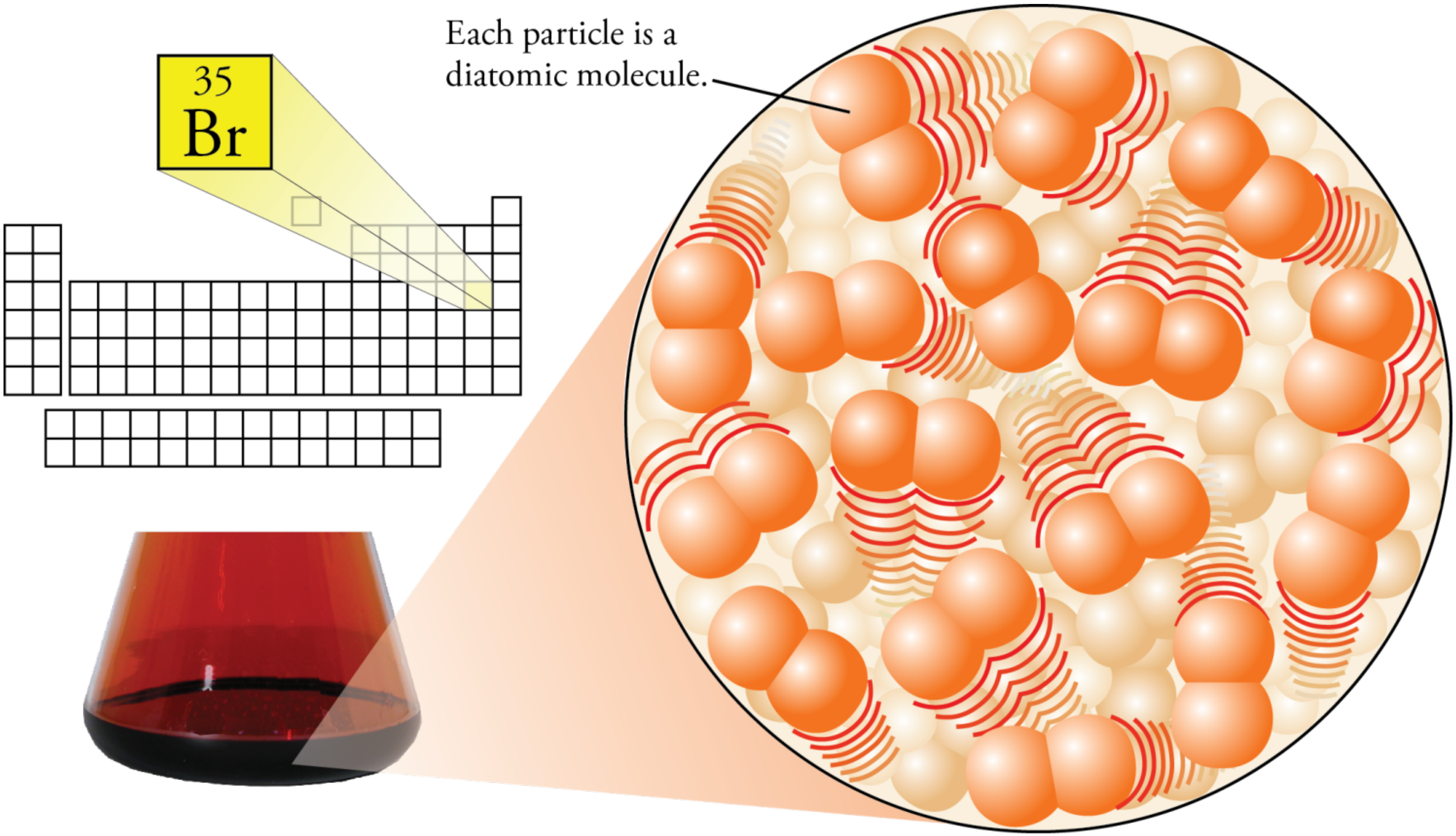
Ball-and-stick model

Emphasizes bond

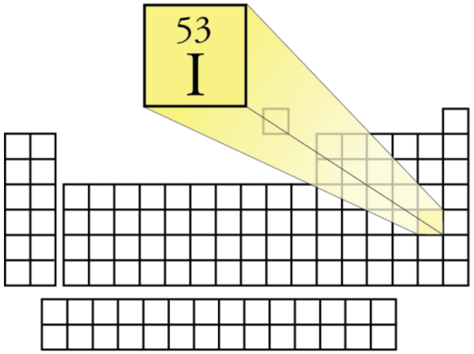
Hydrogen Gas, H_2

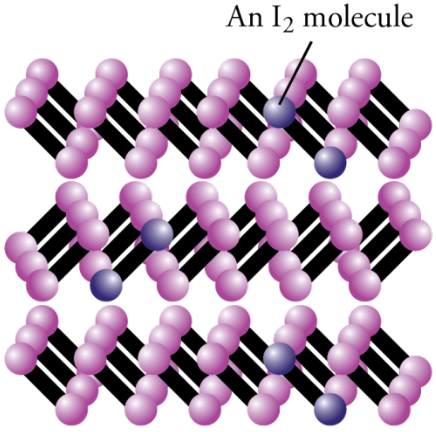


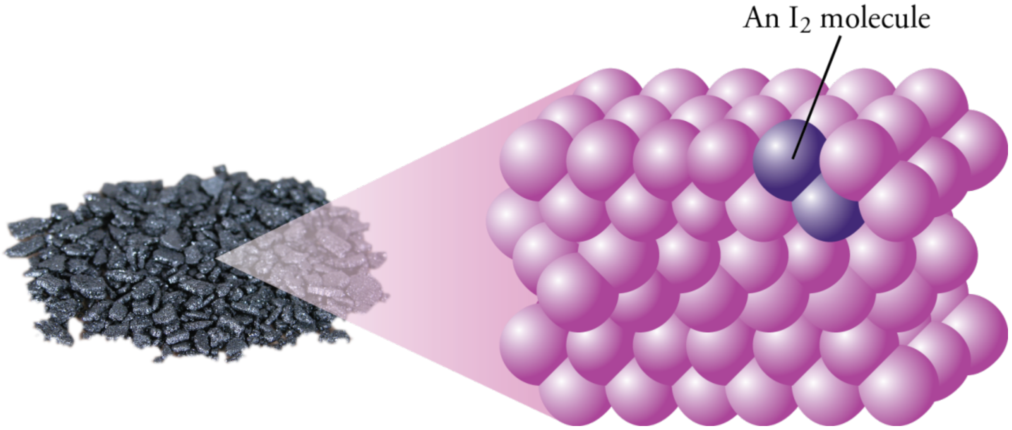
Bromine Liquid, Br_2



Iodine Solid







https://preparatorychemistry.com/element_properties_Canvas.html

Typical Metallic Solid and Its "Sea of Electrons"