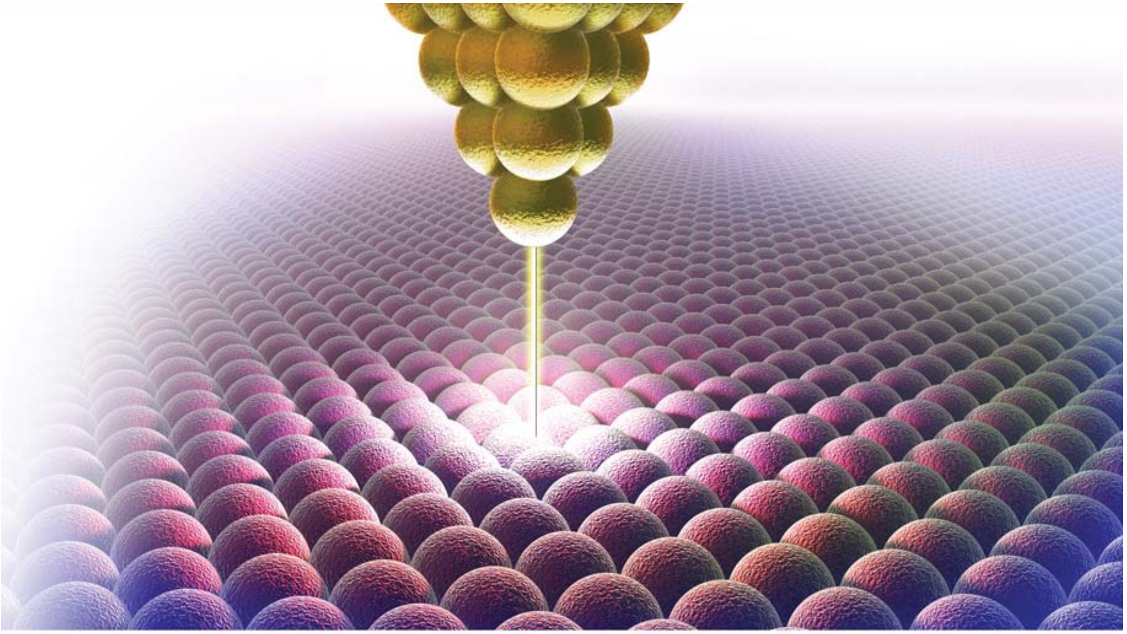
Chemistry: A Molecular Approach, 1st Ed.
Nivaldo Tro

Chapter 2 Atoms and Elements

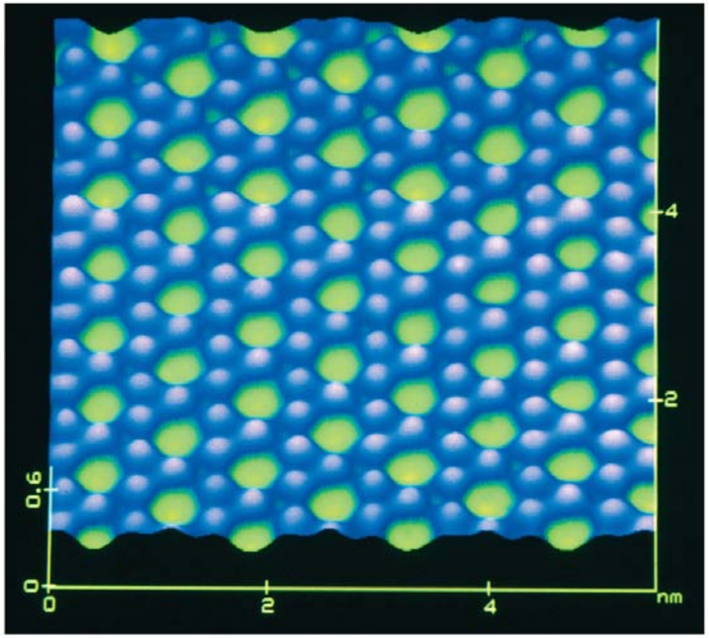


Roy Kennedy
Massachusetts Bay Community College
Wellesley Hills, MA

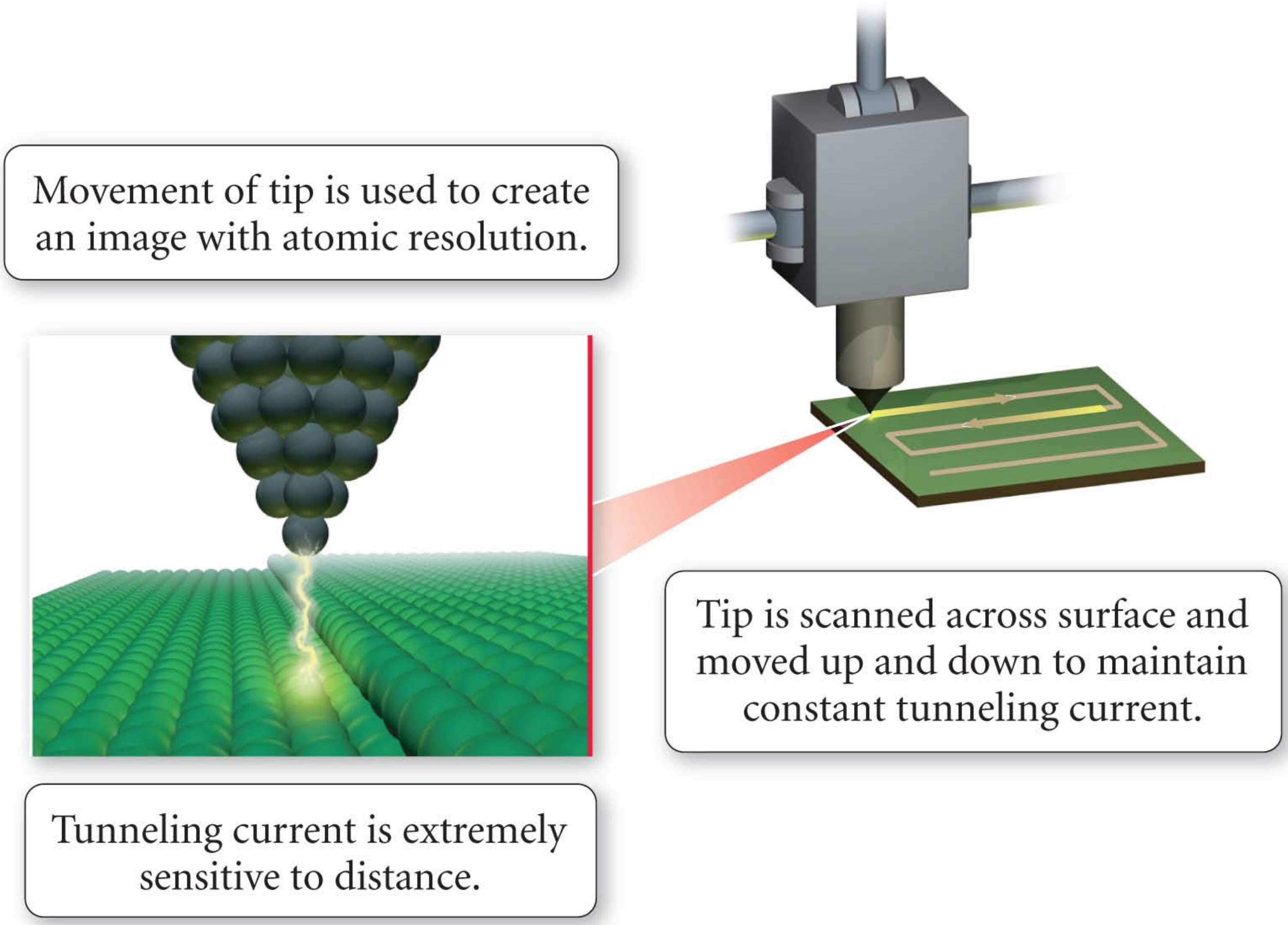
2008, Prentice Hall

Scanning Tunneling Microscope

- Gerd Bennig and Heinrich Rohrer found that as you pass a sharp metal tip over a flat metal surface, the amount of current that flowed varied with distance between the tip and the surface
- measuring this “tunneling” current allowed them to scan the surface on an atomic scale – essentially taking pictures of atoms on the surface

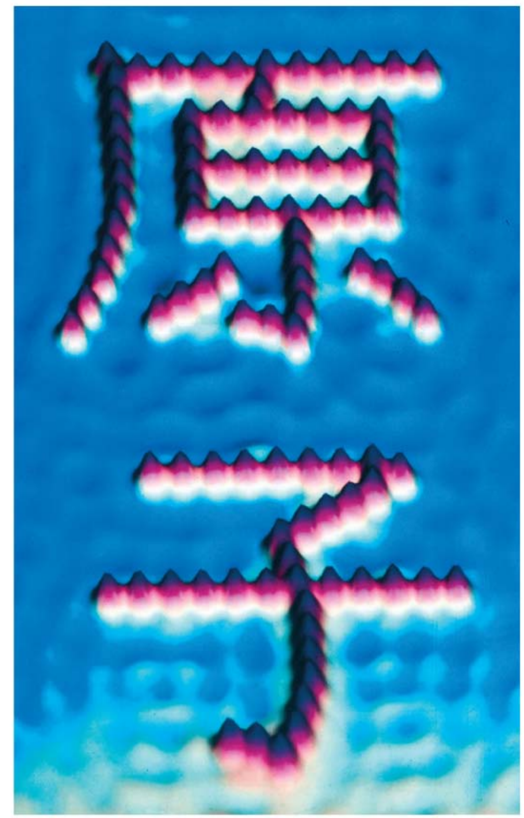


Operation of a STM



Scanning Tunneling Microscope

- later scientists found that not only can you see the atoms on the surface, but the instrument allows you to move individual atoms across the surface



Early Philosophy of Matter

- Some philosophers believed that matter had an ultimate, tiny, indivisible particle
  - ✓ Leucippus and Democritus
- Other philosophers believed that matter was infinitely divisible
  - ✓ Plato and Aristotle
- Since there was no experimental way of proving who was correct, the best debater was the person assumed correct, i.e., Aristotle

Scientific Revolution

- in the late 16th century, the scientific approach to understanding nature became established
- for the next 150+ years, observations about nature were made that could not easily be explained by the infinitely divisible matter concept

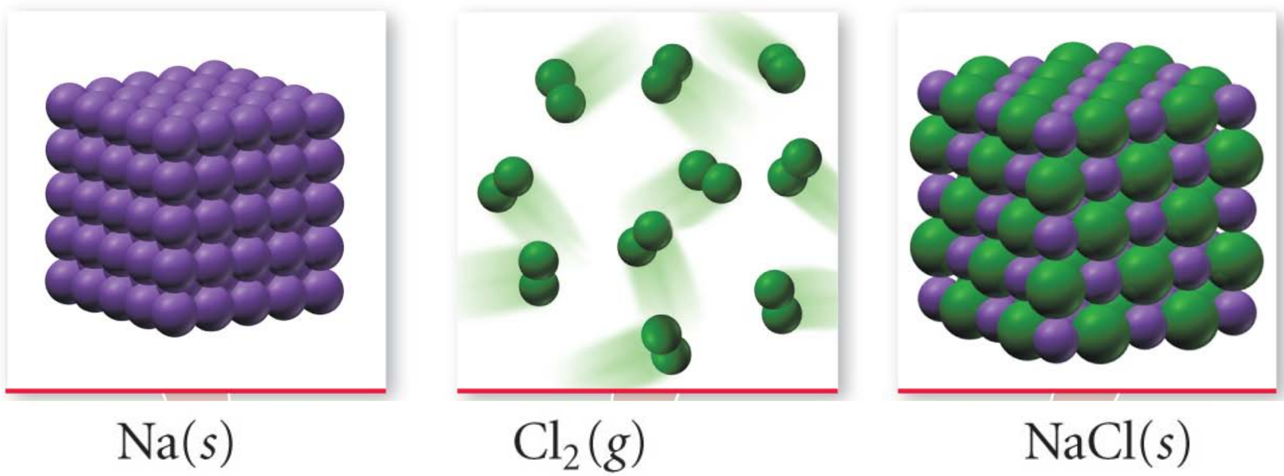
Law of Conservation of Mass

- in a chemical reaction, matter is neither created nor destroyed
- total mass of the materials you have before the reaction must equal the total mass of the materials you have at the end
  - ✓ total mass of reactants = total mass of products

Antoine Lavoisier
1743-1794

Reaction of Sodium with Chlorine to Make Sodium Chloride

- the mass of sodium and chlorine used is determined by the number of atoms that combine
- since only whole atoms combine and atoms are not changed or destroyed in the process, the mass of sodium chloride made must equal the total mass of sodium and chlorine atoms that combine together



$$7.7 \text{ g Na} \quad + \quad 11.9 \text{ g } Cl_2 \quad \rightarrow \quad 19.6 \text{ g NaCl}$$

Law of Definite Proportions

- All samples of a given compound, regardless of their source or how they were prepared, have the same proportions of their constituent elements

Joseph Proust
1754-1826

Proportions in Sodium Chloride

a 100.0 g sample of sodium chloride contains 39.3 g of sodium and 60.7 g of chlorine

$$\frac{\text{mass of Cl}}{\text{mass of Na}} = \frac{60.7\ \text{g}}{39.3\ \text{g}} = 1.54$$

a 200.0 g sample of sodium chloride contains 78.6 g of sodium and 121.4 g of chlorine

$$\frac{\text{mass of Cl}}{\text{mass of Na}} = \frac{121.4\ \text{g}}{78.6\ \text{g}} = 1.54$$

a 58.44 g sample of sodium chloride contains 22.99 g of sodium and 35.44 g of chlorine

$$\frac{\text{mass of Cl}}{\text{mass of Na}} = \frac{35.44\ \text{g}}{22.99\ \text{g}} = 1.541$$

Law of Multiple Proportions

- When two elements, (call them A and B), form two different compounds, the masses of B that combine with 1 g of A can be expressed as a ratio of small, whole numbers

John Dalton
1766-1844

Oxides of Carbon

- carbon combines with oxygen to form two different compounds, carbon monoxide and carbon dioxide
- carbon monoxide contains 1.33 g of oxygen for every 1.00 g of carbon
- carbon dioxide contains 2.67 g of oxygen for every 1.00 g of carbon
- since there are twice as many oxygen atoms per carbon atom in carbon dioxide than in carbon monoxide, the oxygen mass ratio should be 2

$$\frac{\text{mass of oxygen that combines with 1 g of carbon in carbon dioxide}}{\text{mass of oxygen that combines with 1 g of carbon in carbon monoxide}} = \frac{2.67\text{ g}}{1.33\text{ g}} = 2$$

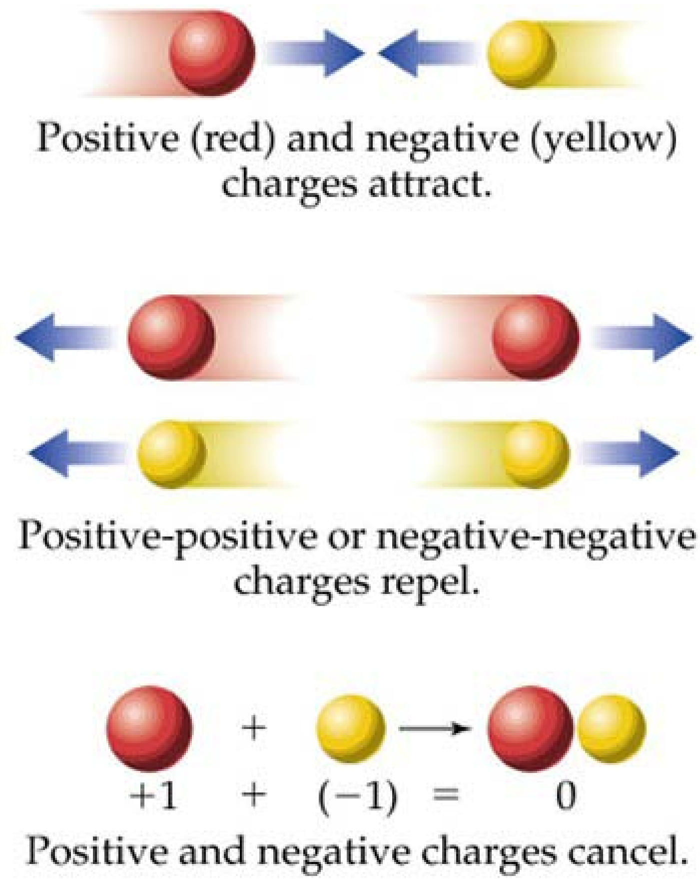
Dalton’s Atomic Theory

- Dalton proposed a theory of matter based on it having ultimate, indivisible particles to explain these laws

1) Each element is composed of tiny, indestructible particles called atoms
2) All atoms of a given element has the same mass and other properties that distinguish them from atoms of other elements
3) Atoms combine in simple, whole-number ratios to form molecules of compounds
4) In a chemical reaction, atoms of one element cannot change into atoms of another element
   - ✓ they simply rearrange the way they are attached

Some Notes on Charge

- Two kinds of charge called + and –
- Opposite charges attract
  - ✓ + attracted to –
- Like charges repel
  - ✓ + repels +
  - ✓ – repels –
- To be neutral, something must have no charge or equal amounts of opposite charges

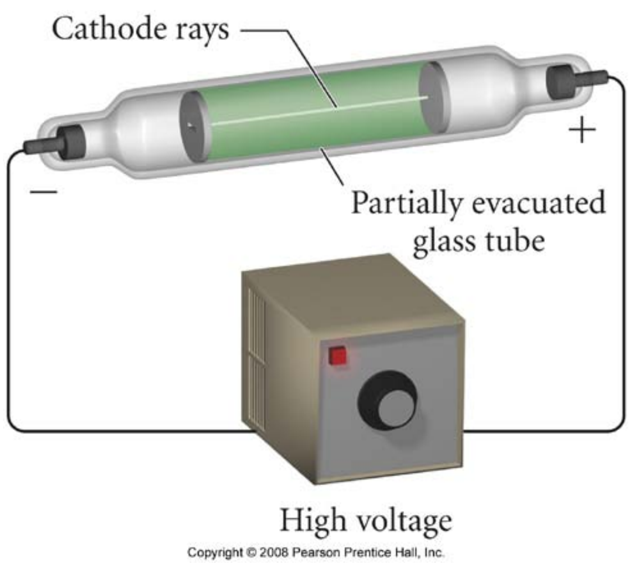


Cathode Ray Tubes

- glass tube containing metal electrodes from which almost all the air has been evacuated
- when connected to a high voltage power supply, a glowing area is seen emanating from the cathode

anode

cathode



J.J. Thomson

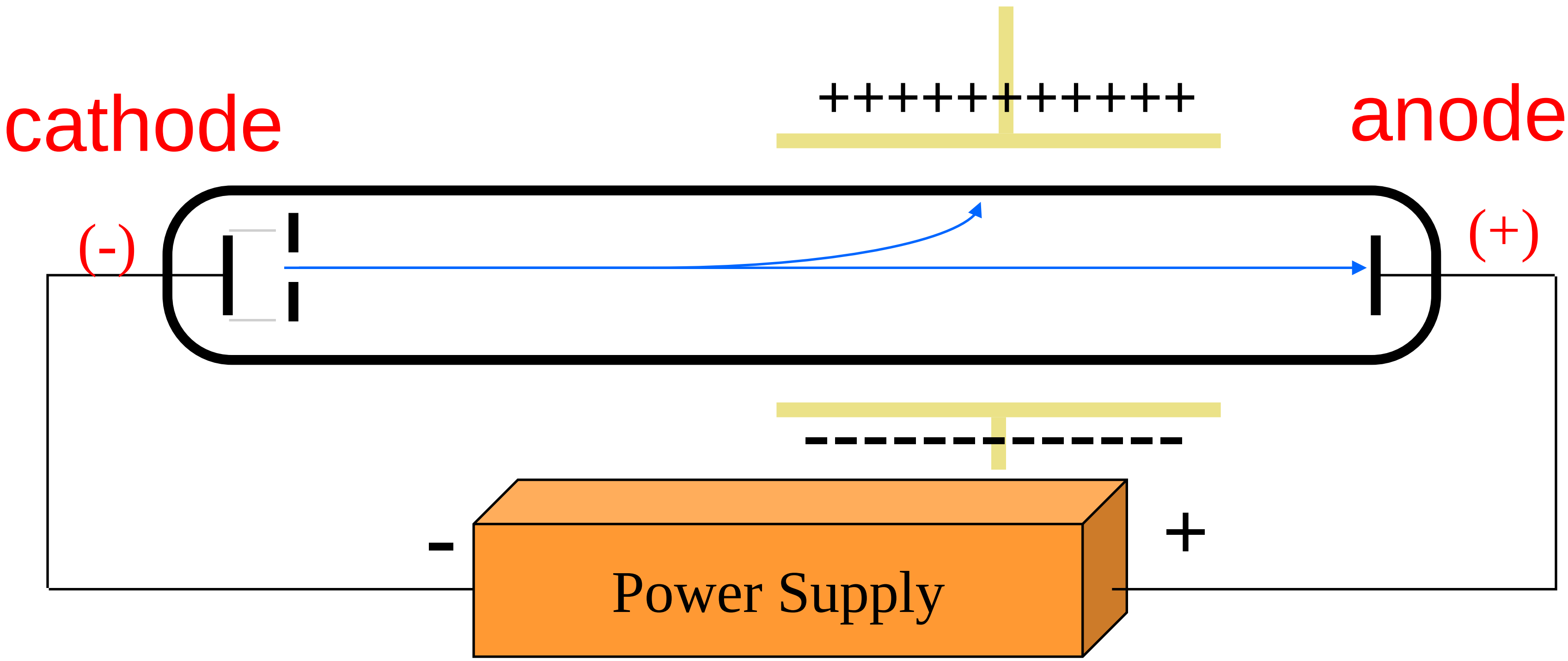
- believed that the cathode ray was composed of tiny particles with an electrical charge
- designed an experiment to demonstrate that there were particles by measuring the amount of force it takes to deflect their path a given amount
    - ✓ like measuring the amount of force it takes to make a car turn

Thomson's Experiment

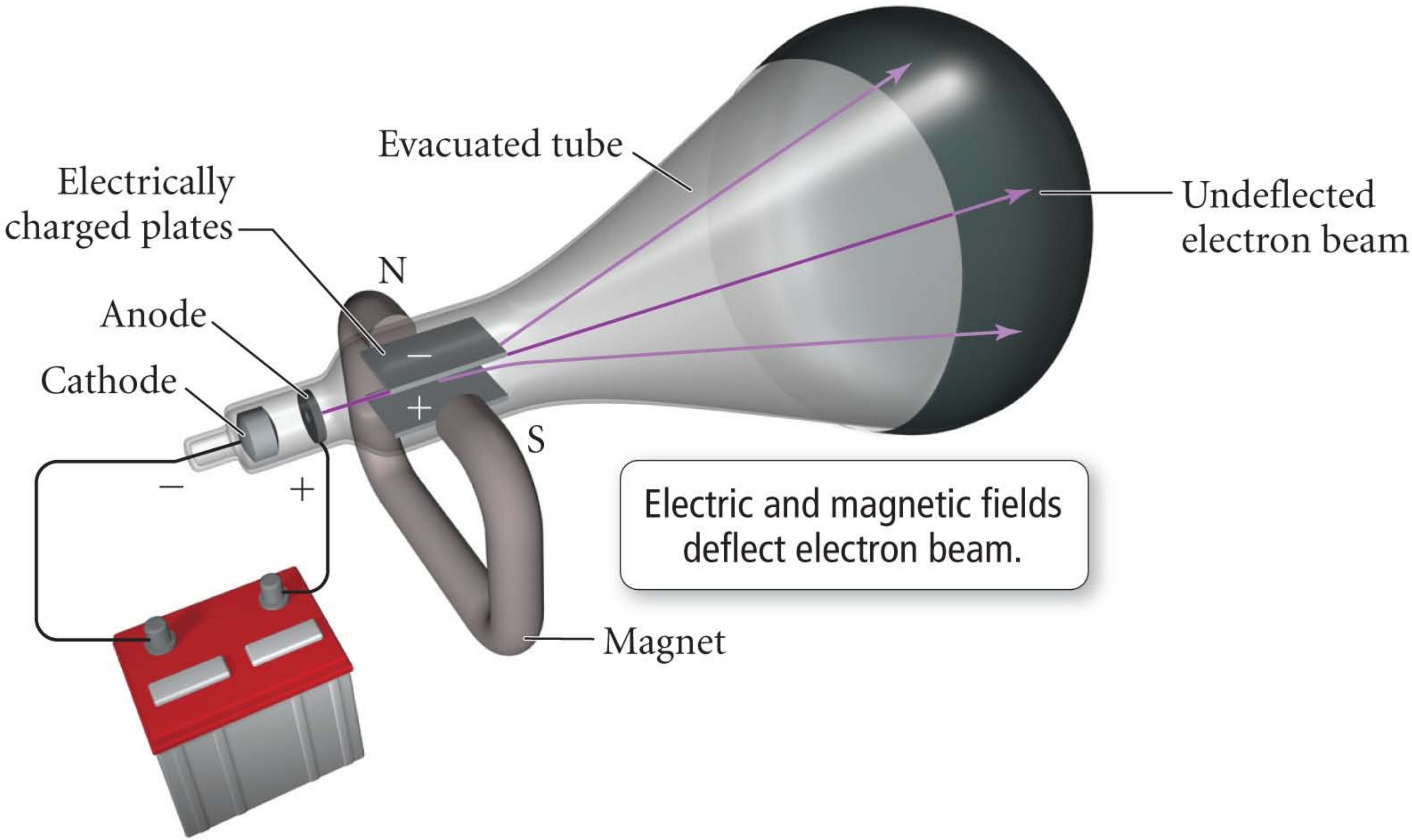
investigate the effect of placing an electric field around tube

(1) charged matter is attracted to an electric field

(2) light's path is not deflected by an electric field



Charge-to-Mass Ratio of the Electron



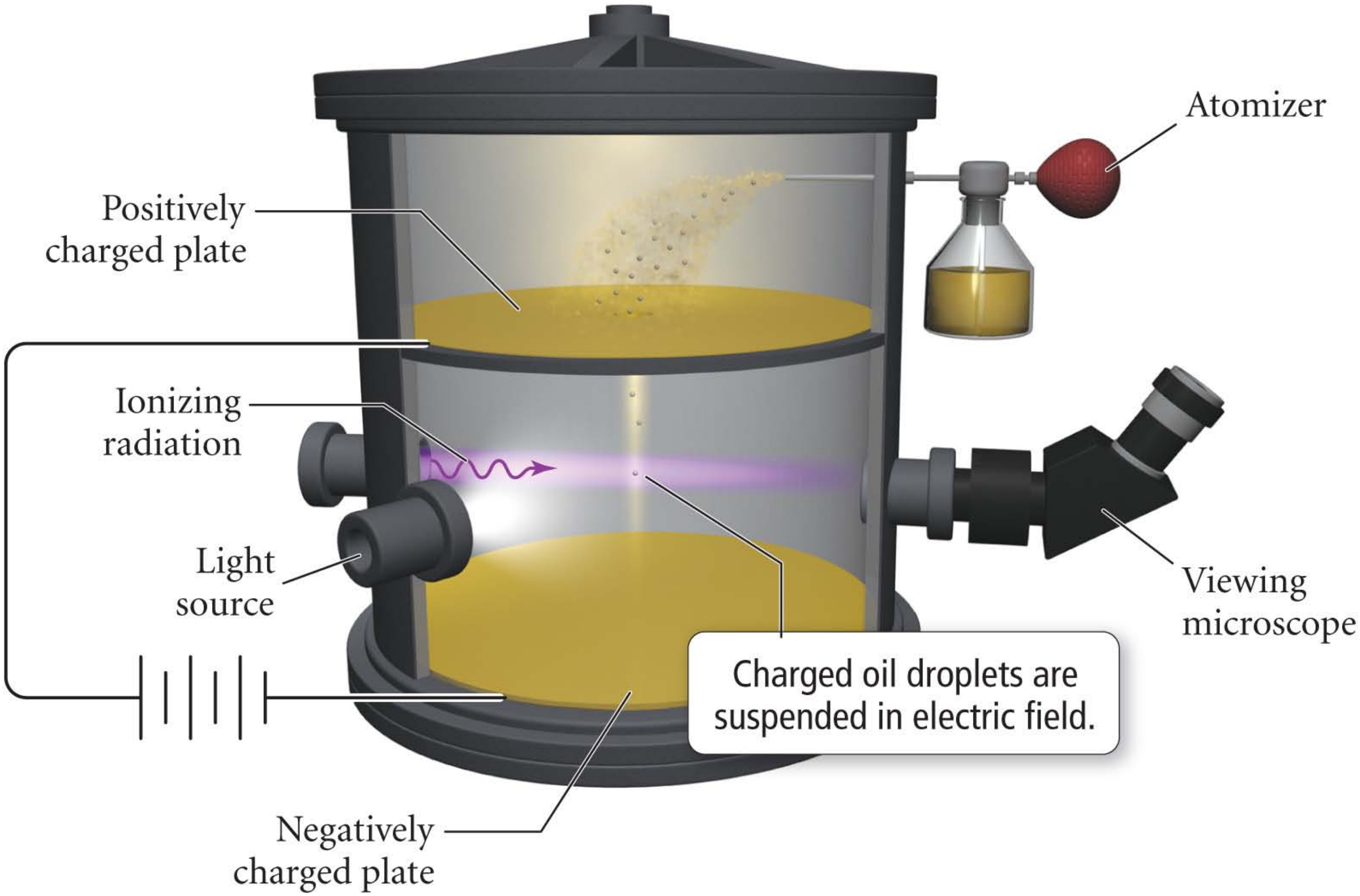
Thomson's Results

- the cathode rays are made of tiny particles
- these particles have a negative charge
  - ✓ because the beam always deflected toward the + plate
- the amount of deflection was related to two factors, the charge and mass of the particles
- every material tested contained these same particles
- the charge/mass of these particles was -1.76×10^8 C/g
  - ✓ the charge/mass of the hydrogen ion is $+9.58 \times 10^4$ C/g

Thomson's Conclusions

- if the particle has the same amount of charge as a hydrogen ion, then it must have a mass almost 2000x smaller than hydrogen atoms!
  - ✓ later experiments by Millikan showed that the particle did have the same amount of charge as the hydrogen ion
- the only way for this to be true is if these particles were pieces of atoms
  - ✓ apparently, the atom is not unbreakable
- Thomson believed that these particles were therefore the ultimate building blocks of matter
- these cathode ray particles became known as **electrons**

Millikan's Oil Drop Experiment



Electrons

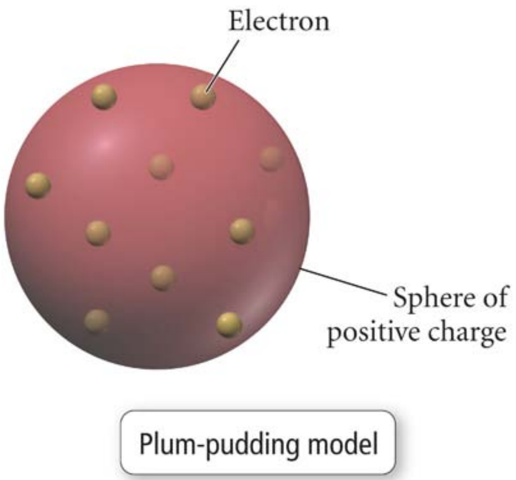
- electrons are particles found in all atoms
- cathode rays are streams of electrons
- the electron has a charge of -1.60 x 10^{19} C
- the electron has a mass of 9.1 x 10^{-28} g

A New Theory of the Atom

- since the atom is no longer indivisible, Thomson must propose a new model of the atom to replace the first statement in Dalton's Atomic Theory
  - ✓rest of Dalton's theory still valid at this point
- Thomson proposes that instead of being a hard, marble-like unbreakable sphere, the way Dalton described it, that it actually had an inner structure

Thomson's Plum Pudding Atom

- the structure of the atom contains many negatively charged electrons
- these electrons are held in the atom by their attraction for a positively charged electric field within the atom
  - ✓ there had to be a source of positive charge because the atom is neutral
  - ✓ Thomson assumed there were no positively charged pieces because none showed up in the cathode ray experiment



Predictions of the Plum Pudding Atom

- the mass of the atom is due to the mass of the electrons within it
  - ✓ electrons are the only particles in Plum Pudding atoms
- the atom is mostly empty space
  - ✓ cannot have a bunch of negatively charged particles near each other as they would repel

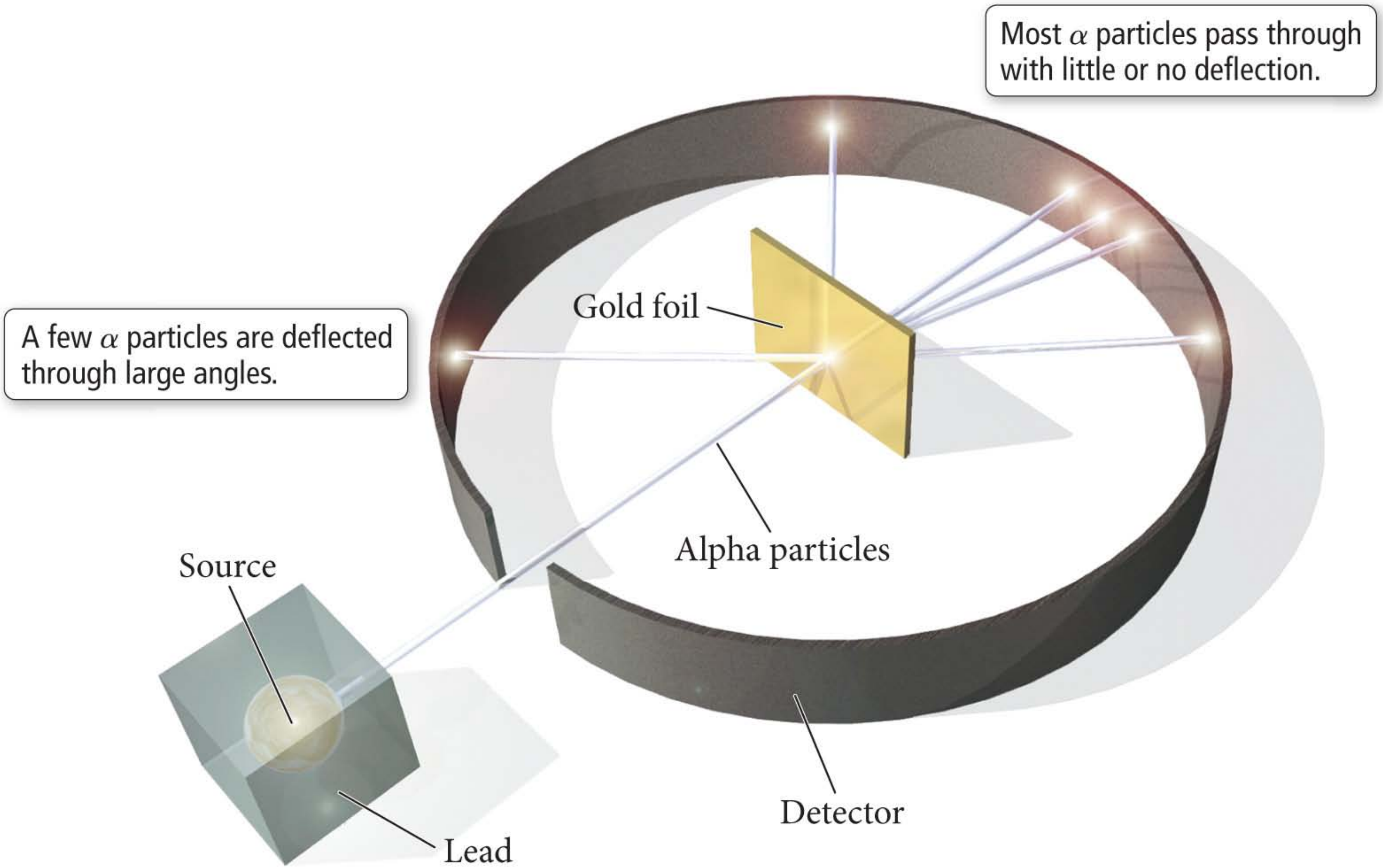
Radioactivity

- in the late 1800s, Henri Becquerel and Marie Curie discovered that certain elements would constantly emit small, energetic particles and rays
- these energetic particles could penetrate matter
- Ernest Rutherford discovered that there were three different kinds of emissions
  - ✓ alpha, α, particles with a mass 4x H atom and + charge
  - ✓ beta, β, particles with a mass ~1/2000th H atom and – charge
  - ✓ gamma, γ, rays that are energy rays, not particles

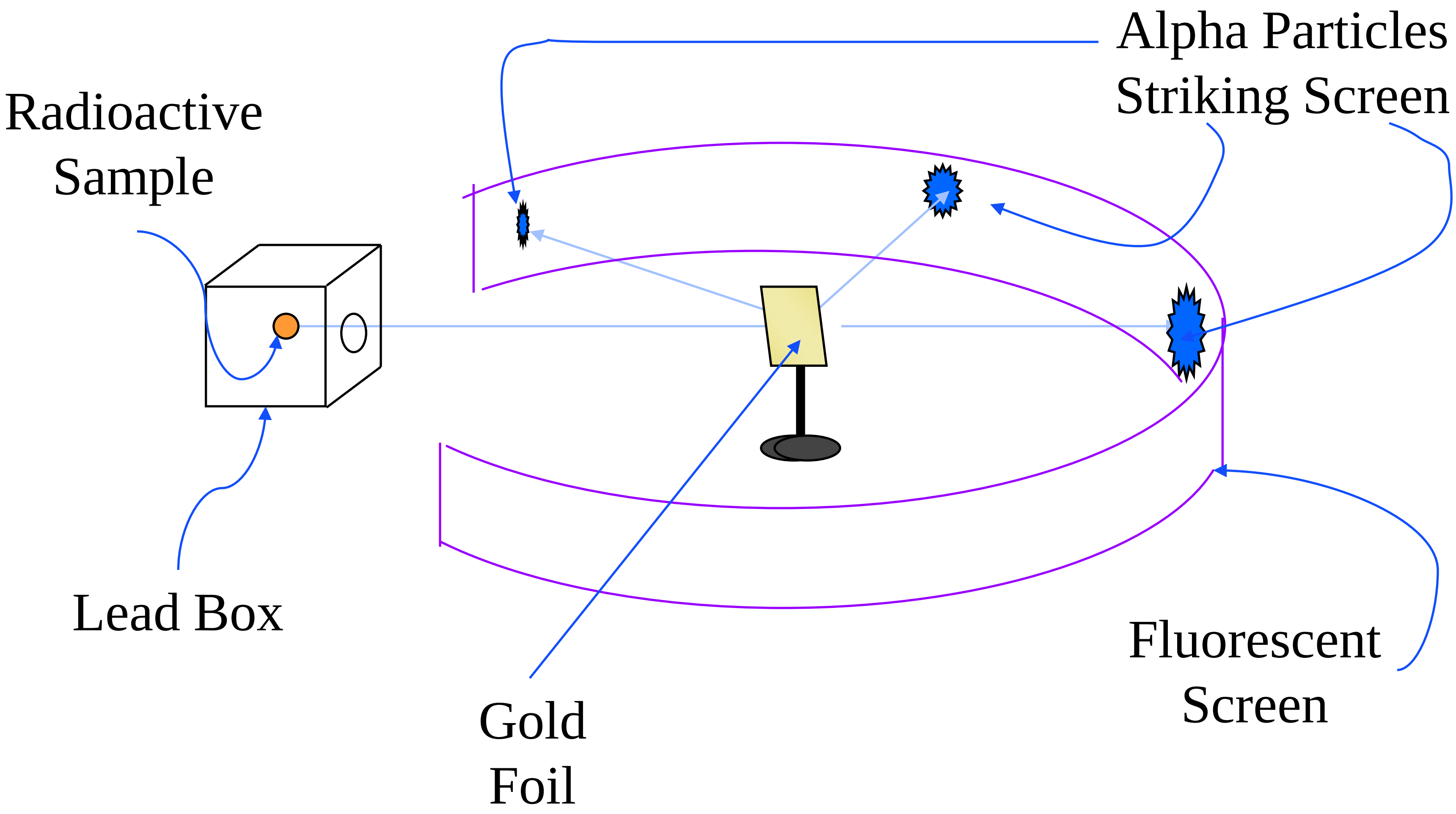
Rutherford's Experiment

- How can you prove something is empty?
- put something through it
  - ✓use large target atoms
    - ➢use very thin sheets of target so do not absorb "bullet"
  - ✓use very small particle as bullet with very high energy
    - ➢but not so small that electrons will affect it
- bullet = alpha particles, target atoms = gold foil
  - ✓ α particles have a mass of 4 amu & charge of +2 c.u.
  - ✓ gold has a mass of 197 amu & is very malleable

Rutherford's Gold Foil Experiment



Rutherford’s Experiment

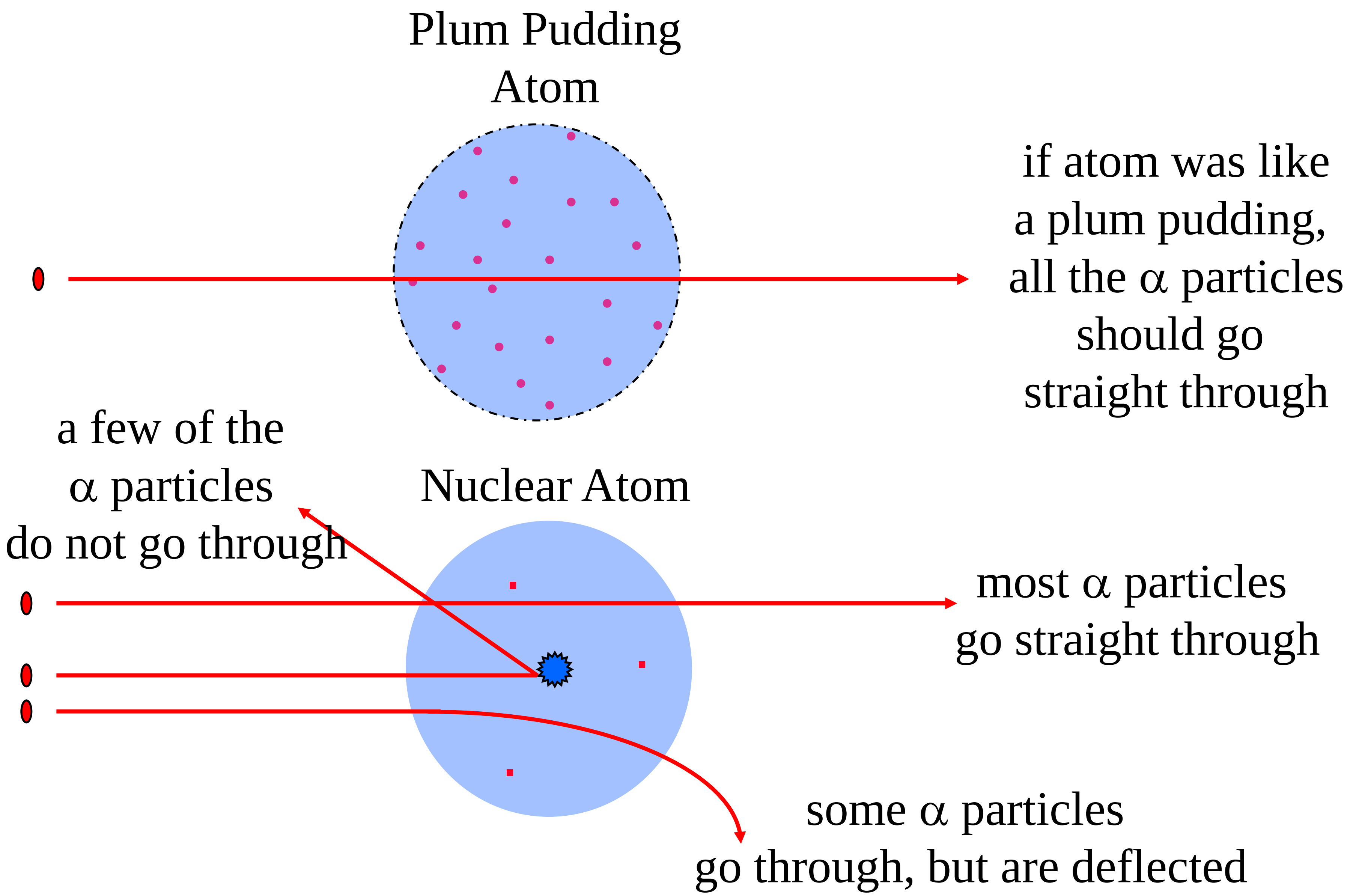


Rutherford's Results

- Over 98% of the α particles went straight through
- About 2% of the α particles went through but were deflected by large angles
- About 0.01% of the α particles bounced off the gold foil
  - ✓ "...as if you fired a 15" cannon shell at a piece of tissue paper and it came back and hit you."

Rutherford's Conclusions

- Atom mostly empty space
  - ✓because almost all the particles went straight through
- Atom contains a dense particle that was small in volume compared to the atom but large in mass
  - ✓because of the few particles that bounced back
- This dense particle was positively charged
  - ✓because of the large deflections of some of the particles

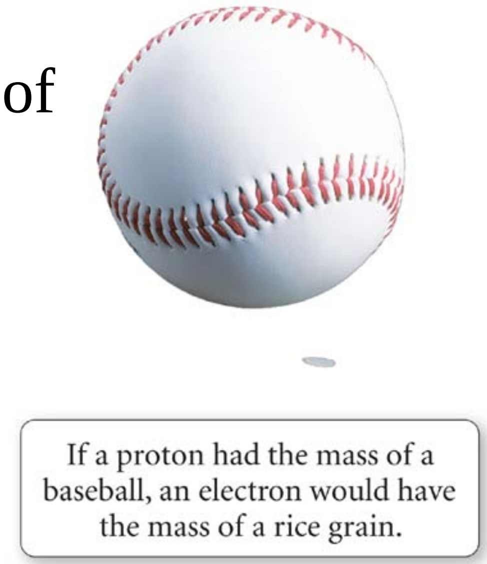

Plum Pudding
Atom
if atom was like
a plum pudding,
all the α particles
should go
straight through
a few of the
α particles
do not go through
Nuclear Atom
most α particles
go straight through
some α particles
go through, but are deflected

Rutherford's Interpretation – the Nuclear Model

1) The atom contains a tiny dense center called the **nucleus**
   - ✓ the amount of space taken by the nucleus is only about 1/10 trillionth the volume of the atom
2) The nucleus has essentially the entire mass of the atom
   - ✓ the electrons weigh so little they give practically no mass to the atom
3) The nucleus is positively charged
   - ✓ the amount of positive charge balances the negative charge of the electrons
4) The electrons are dispersed in the empty space of the atom surrounding the nucleus

Structure of the Atom

- Rutherford proposed that the nucleus had a particle that had the **same amount of charge as an electron** but opposite sign
  - ✓ based on measurements of the nuclear charge of the elements
- these particles are called **protons**
  - ✓ charge = +1.60 x 10^{19} C
  - ✓ mass = 1.67262 x 10^{-24} g
- since protons and electrons have the same amount of charge, for the ***atom to be neutral there must be equal numbers of protons and electrons***



Relative Mass and Charge

- it is sometimes easier to compare things to each other rather than to an outside standard
- when you do this, the scale of comparison is called a **relative** scale
- we generally talk about the size of charge on atoms by comparing it to the amount of charge on an electron, which we call -1 charge units
  - ✓ proton has a charge of +1cu
  - ✓ protons and electrons have equal amounts of charge, but opposite signs
- we generally talk about the mass of atoms by comparing it to $1/12^{th}$ the mass of a carbon atom with 6 protons and 6 neutrons, which we call 1 atomic mass unit
  - ✓ protons have a mass of 1amu
  - ✓ electrons have a mass of 0.00055 amu, which is generally too small to be relevant

Some Problems

- How could beryllium have 4 protons stuck together in the nucleus?
  - ✓ shouldn't they repel each other?
- If a beryllium atom has 4 protons, then it should weigh 4 amu; but it actually weighs 9.01 amu! Where is the extra mass coming from?
  - ✓ each proton weighs 1 amu
  - ✓ remember, the electron's mass is only about 0.00055 amu and Be has only 4 electrons – it can't account for the extra 5 amu of mass

There Must Be Something Else There!

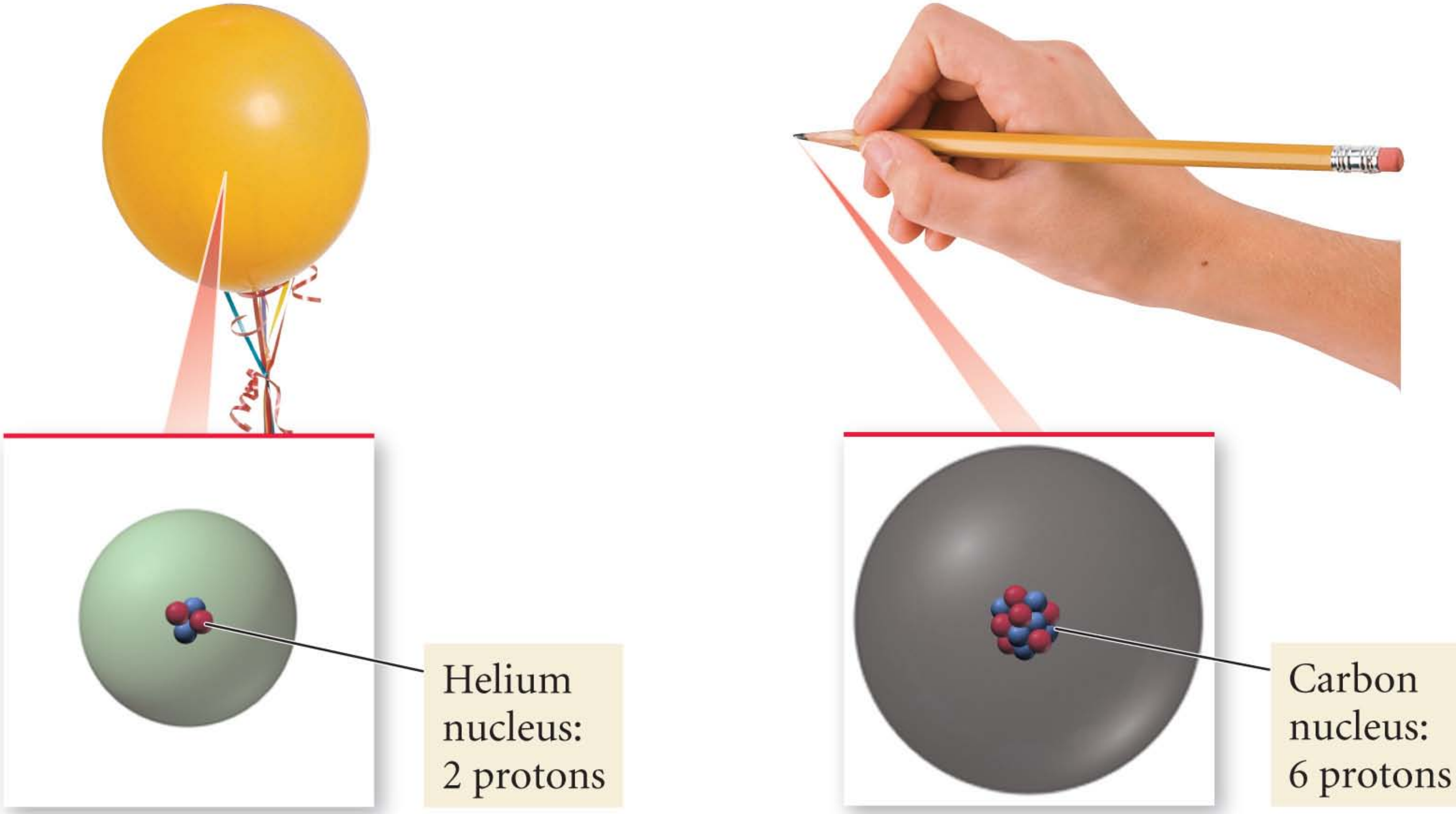
- to answer these questions, Rutherford proposed that there was another particle in the nucleus – it is called a **neutron**
- neutrons have no charge and a mass of 1 amu
  - ✓mass = 1.67493 x 10^{-24} g
    - ➢slightly heavier than a proton
  - ✓no charge

Subatomic Particle	Mass g	Mass amu	Location in atom	Charge	Symbol
Proton	1.67262 x 10^{-24}	1.00727	nucleus	+1	p, p^+, H^+
Electron	0.00091 x 10^{-24}	0.00055	empty space	-1	e, e^-
Neutron	1.67493 x 10^{-24}	1.00866	nucleus	0	n, n^0

Elements

- each element has a unique number of protons in its nucleus
- the number of protons in the nucleus of an atom is called the **atomic number**
  - ✓ the elements are arranged on the Periodic Table in order of their atomic numbers
- each element has a unique name and symbol
  - ✓ symbol either one or two letters
    - ➢ one capital letter or one capital letter + one lowercase

The Number of Protons Defines the Element



The Periodic Table of Elements

Key: 4 / **Be** / beryllium — Atomic number (Z); Chemical symbol; Name

1 **H** hydrogen																	2 **He** helium
3 **Li** lithium	4 **Be** beryllium											5 **B** boron	6 **C** carbon	7 **N** nitrogen	8 **O** oxygen	9 **F** fluorine	10 **Ne** neon
11 **Na** sodium	12 **Mg** magnesium											13 **Al** aluminum	14 **Si** silicon	15 **P** phosphorus	16 **S** sulfur	17 **Cl** chlorine	18 **Ar** argon
19 **K** potassium	20 **Ca** calcium	21 **Sc** scandium	22 **Ti** titanium	23 **V** vanadium	24 **Cr** chromium	25 **Mn** manganese	26 **Fe** iron	27 **Co** cobalt	28 **Ni** nickel	29 **Cu** copper	30 **Zn** zinc	31 **Ga** gallium	32 **Ge** germanium	33 **As** arsenic	34 **Se** selenium	35 **Br** bromine	36 **Kr** krypton
37 **Rb** rubidium	38 **Sr** strontium	39 **Y** yttrium	40 **Zr** zirconium	41 **Nb** niobium	42 **Mo** molybdenum	43 **Tc** technetium	44 **Ru** ruthenium	45 **Rh** rhodium	46 **Pd** palladium	47 **Ag** silver	48 **Cd** cadmium	49 **In** indium	50 **Sn** tin	51 **Sb** antimony	52 **Te** tellurium	53 **I** iodine	54 **Xe** xenon
55 **Cs** cesium	56 **Ba** barium	57 **La** lathanum	72 **Hf** hafnium	73 **Ta** tantalum	74 **W** tungsten	75 **Re** rhenium	76 **Os** osmium	77 **Ir** iridium	78 **Pt** platinum	79 **Au** gold	80 **Hg** mercury	81 **Tl** thallium	82 **Pb** lead	83 **Bi** bismuth	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
87 **Fr** francium	88 **Ra** radium	89 **Ac** actinium	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **		114 **		116 **		
				58 **Ce** cerium	59 **Pr** praseodymium	60 **Nd** neodymium	61 **Pm** promethium	62 **Sm** samarium	63 **Eu** europium	64 **Gd** gadolinium	65 **Tb** terbium	66 **Dy** dysprosium	67 **Ho** holmium	68 **Er** erbium	69 **Tm** thulium	70 **Yb** ytterbium	71 **Lu** lutetium
				90 **Th** thorium	91 **Pa** protactinium	92 **U** uranium	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

Structure of the Nucleus

- Soddy discovered that the same element could have atoms with different masses, which he called **isotopes**
  - ✓ there are 2 isotopes of chlorine found in nature, one that has a mass of about 35 amu and another that weighs about 37 amu
- The observed mass is a weighted average of the weights of all the naturally occurring atoms
  - ✓ the percentage of an element that is 1 isotope is called the isotope's **natural abundance**
  - ✓ the atomic mass of chlorine is 35.45 amu

Isotopes

- all isotopes of an element are chemically identical
  - ✓undergo the exact same chemical reactions
- all isotopes of an element have the same number of protons
- isotopes of an element have different masses
- isotopes of an element have different numbers of neutrons
- isotopes are identified by their **mass numbers**
  - ✓protons + neutrons

Isotopes

- Atomic Number
  - ✓ Number of protons
  - ✓ Z
- Mass Number
  - ✓ Protons + Neutrons
  - ✓ Whole number
  - ✓ A
- Abundance = relative amount found in a sample

Neon

Symbol	Number of Protons	Number of Neutrons	A, Mass Number	Percent Natural Abundance
Ne-20 or $^{20}_{10}$Ne	10	10	20	90.48%
Ne-21 or $^{21}_{10}$Ne	10	11	21	0.27%
Ne-22 or $^{22}_{10}$Ne	10	12	22	9.25%

Example 2.3b How many protons, electrons, and neutrons are in an atom of ${}^{52}_{24}Cr$?

Given:	${}^{52}_{24}Cr$ therefore A = 52, Z = 24
Find:	# p^+, # e^-, # n^0
Concept Plan:	symbol → atomic number → # p^+ → # e^- symbol → atomic & mass numbers → # n^0
Relationships:	in neutral atom, # p^+ = # e^- mass number = # p^+ + # n^0
Solution:	Z = 24 = # p^+ # e^- = # p^+ = 24 A = Z + # n^0 52 = 24 + # n^0 28 = # n^0
Check:	for most stable isotopes, n^0 > p^+

Reacting Atoms

- when elements undergo chemical reactions, the reacting elements do not turn into other elements
  - ✓ Statement 4 of Dalton's Atomic Theory
- this requires that all the atoms present when you start the reaction will still be there after the reaction
- since the number of protons determines the kind of element, the number of protons in the atom does not change in a chemical reaction
- however, many reactions involve transferring electrons from one atom to another

Charged Atoms

- when atoms gain or lose electrons, they acquire a charge
- charged particles are called **ions**
- when atoms gain electrons, they become negatively charged ions, called **anions**
- when atoms lose electrons, they become positively charged ions, called **cations**
- ions behave much differently than the neutral atom
  - ✓ e.g., The metal sodium, made of neutral Na atoms, is highly reactive and quite unstable. However, the sodium cations, Na^+, found in table salt are very nonreactive and stable
- since materials like table salt are neutral, there must be equal amounts of charge from cations and anions in them

Atomic Structures of Ions

- Nonmetals form anions
- For each negative charge, the ion has 1 more electron than the neutral atom
  - ✓ F = 9 p^+ and 9 e^-, F^- = 9 p^+ and 10 e^-
  - ✓ P = 15 p^+ and 15 e^-, P^{3-} = 15 p^+ and 18 e^-
- Anions are named by changing the ending of the name to ***-ide***

fluorine	$F + 1e^- \rightarrow F^-$	fluoride ion
oxygen	$O + 2e^- \rightarrow O^{2-}$	oxide ion

Atomic Structures of Ions

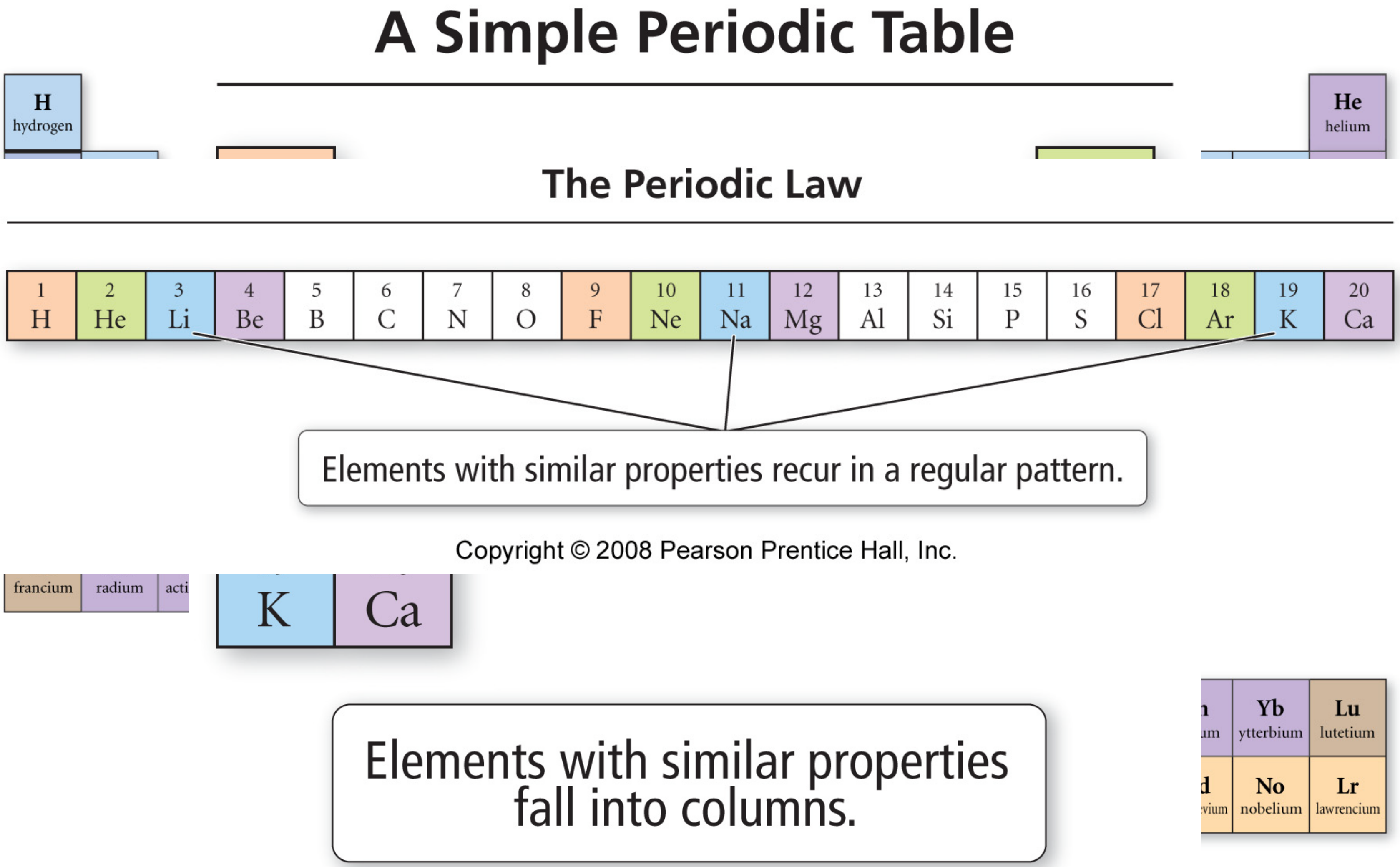
- Metals form cations
- For each positive charge, the ion has 1 less electron than the neutral atom
  - ✓ Na atom = 11 p^+ and 11 e^-, Na^+ ion = 11 p^+ and 10 e^-
  - ✓ Ca atom = 20 p^+ and 20 e^-, Ca^{2+} ion = 20 p^+ and 18 e^-
- Cations are named the same as the metal

sodium	$Na \rightarrow Na^+ + 1e^-$	sodium ion
calcium	$Ca \rightarrow Ca^{2+} + 2e^-$	calcium ion

Mendeleev

- order elements by atomic mass
- saw a repeating pattern of properties
- **Periodic Law** – When the elements are arranged in order of increasing atomic mass, certain sets of properties recur periodically
- put elements with similar properties in the same column
- used pattern to predict properties of undiscovered elements
- where atomic mass order did not fit other properties, he re-ordered by other properties
  - ✓ Te & I

Periodic Pattern



Periodic Pattern

nm H_2O a/b **H** 1 H_2						
m Li_2O **Li** b 7 LiH	m/nm BeO **Be** a/b 9 BeH_2	nm B_2O_3 **B** a 11 $(BH_3)_n$	nm CO_2 **C** a 12 CH_4	nm N_2O_5 **N** a 14 NH_3	nm O_2 **O** 16 H_2O	nm **F** 19 HF
m Na_2O **Na** b 23 NaH	m MgO **Mg** b 24 MgH_2	m Al_2O_3 **Al** a/b 27 (AlH_3)	nm/m SiO_2 **Si** a 28 SiH_4	nm P_4O_{10} **P** a 31 PH_3	nm SO_3 **S** a 32 H_2S	nm Cl_2O_7 **Cl** a 35.5 HCl

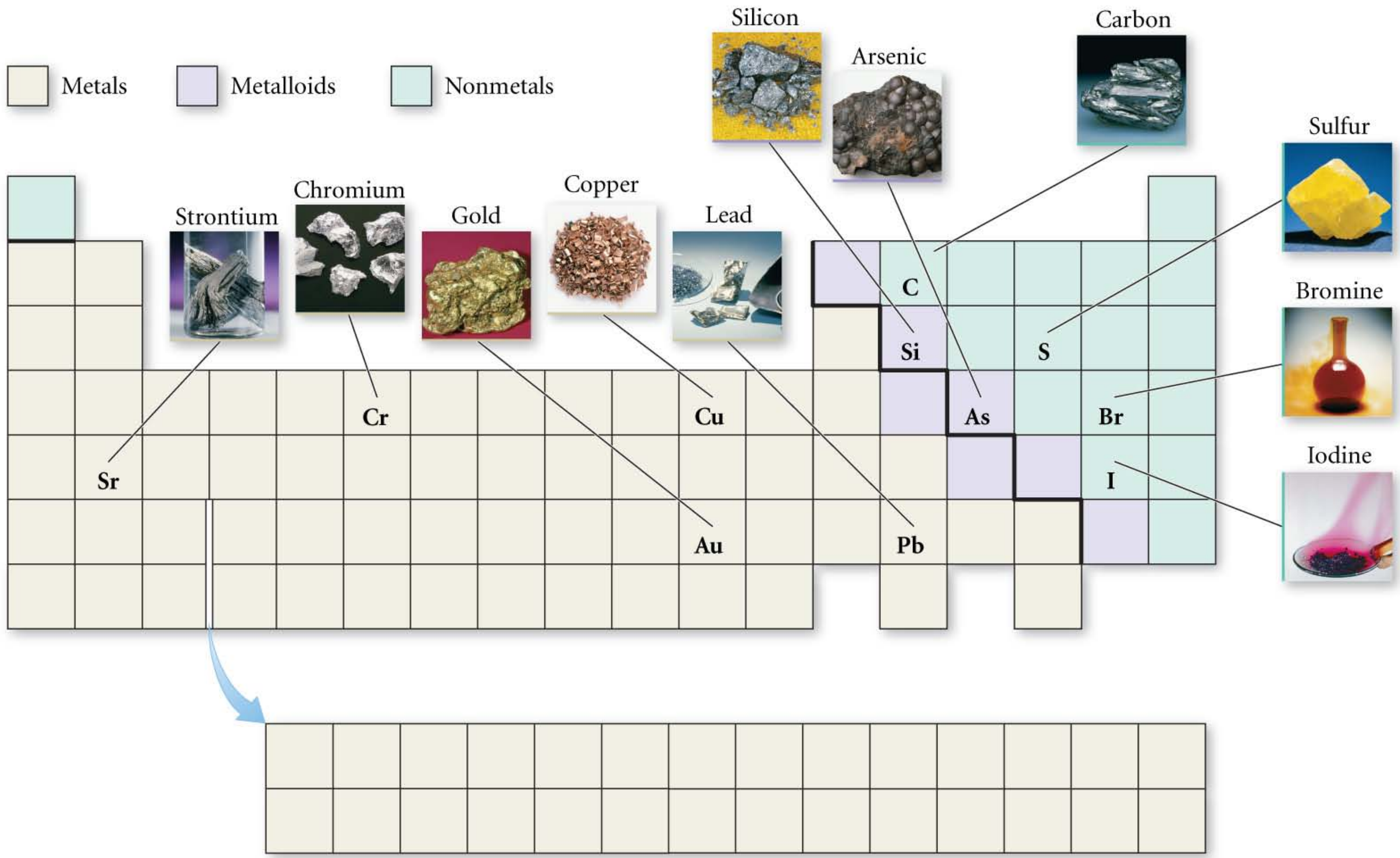
m = metal, nm = nonmetal, m/nm = metalloid

a = acidic oxide, b = basic oxide, a/b = amphoteric oxide

Mendeleev's Predictions for Ekasilicon (Germanium)

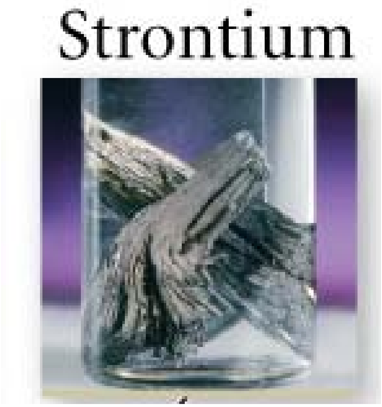
Property	***Silicon's Props***	***Tin's Props***	***Predicted Value***	***Measured Value***
Atomic Mass	28	118	72	72.6
Color	Grey	White metal	Grey	Grey-White
Density	2.32	7.28	5.5	5.4
Reaction w/ Acid & Base	Resists Acid, Reacts Base	Reacts Acid, Resists Base	Resists Both	Resists Both
Oxide	SiO_2	SnO_2	Eks_1O_2	GeO_2

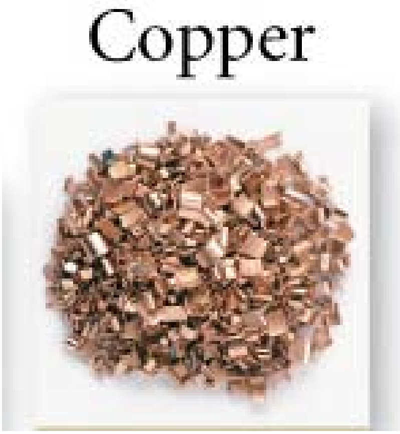
Major Divisions of the Periodic Table



Metals

- solids at room temperature, except Hg
- reflective surface
  - ✓ shiny
- conduct heat
- conduct electricity
- malleable
  - ✓ can be shaped
- ductile
  - ✓ drawn or pulled into wires
- lose electrons and form cations in reactions
- about 75% of the elements are metals
- lower left on the table



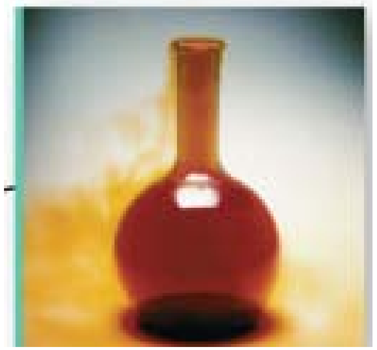


Nonmetals

- found in all 3 states
- poor conductors of heat
- poor conductors of electricity
- solids are brittle
- gain electrons in reactions to become anions
- upper right on the table
  - ✓except H

Sulfur, S(*s*)

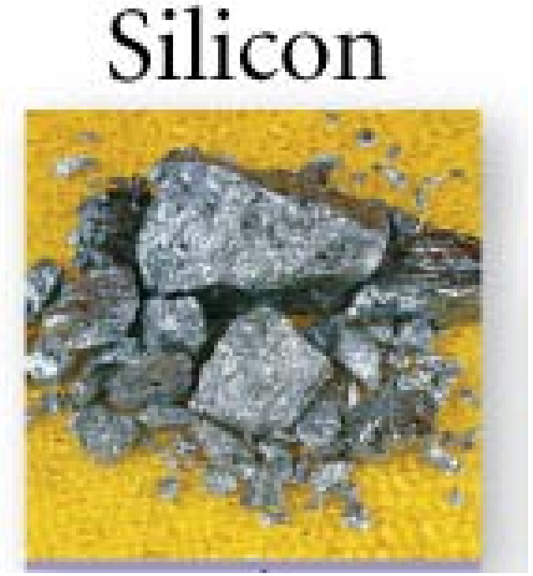
Bromine, $Br_2(l)$



Chlorine, $Cl_2(l)$

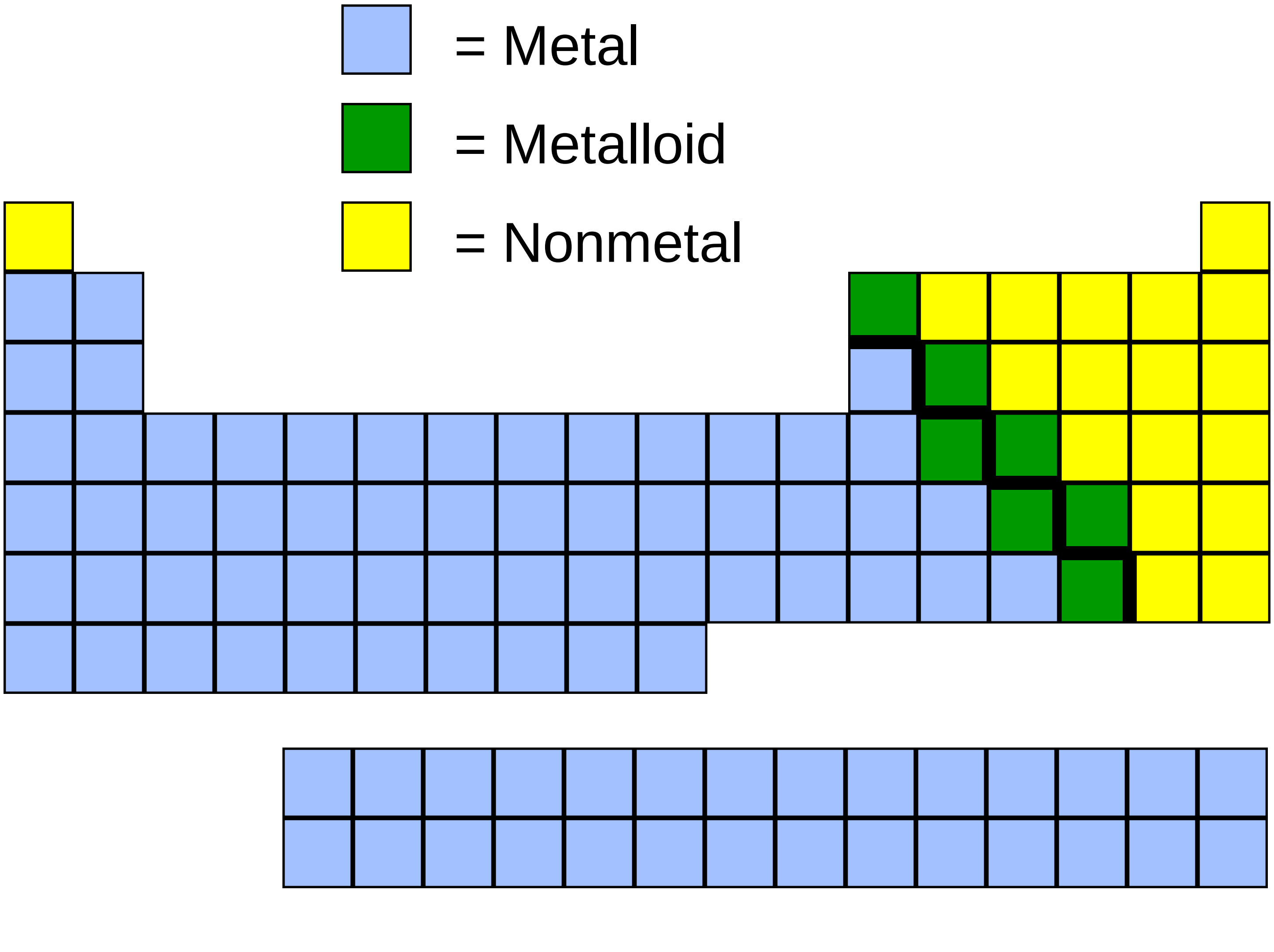
Metalloids

- show some properties of metals and some of nonmetals
- also known as semiconductors



Properties of Silicon
shiny
conducts electricity
does not conduct heat well
brittle

Patterns in Metallic Character



The Modern Periodic Table

- Elements with similar chemical and physical properties are in the same column
- columns are called **Groups** or **Families**
  - ✓designated by a number and letter at top
- rows are called **Periods**
- each period shows the pattern of properties repeated in the next period

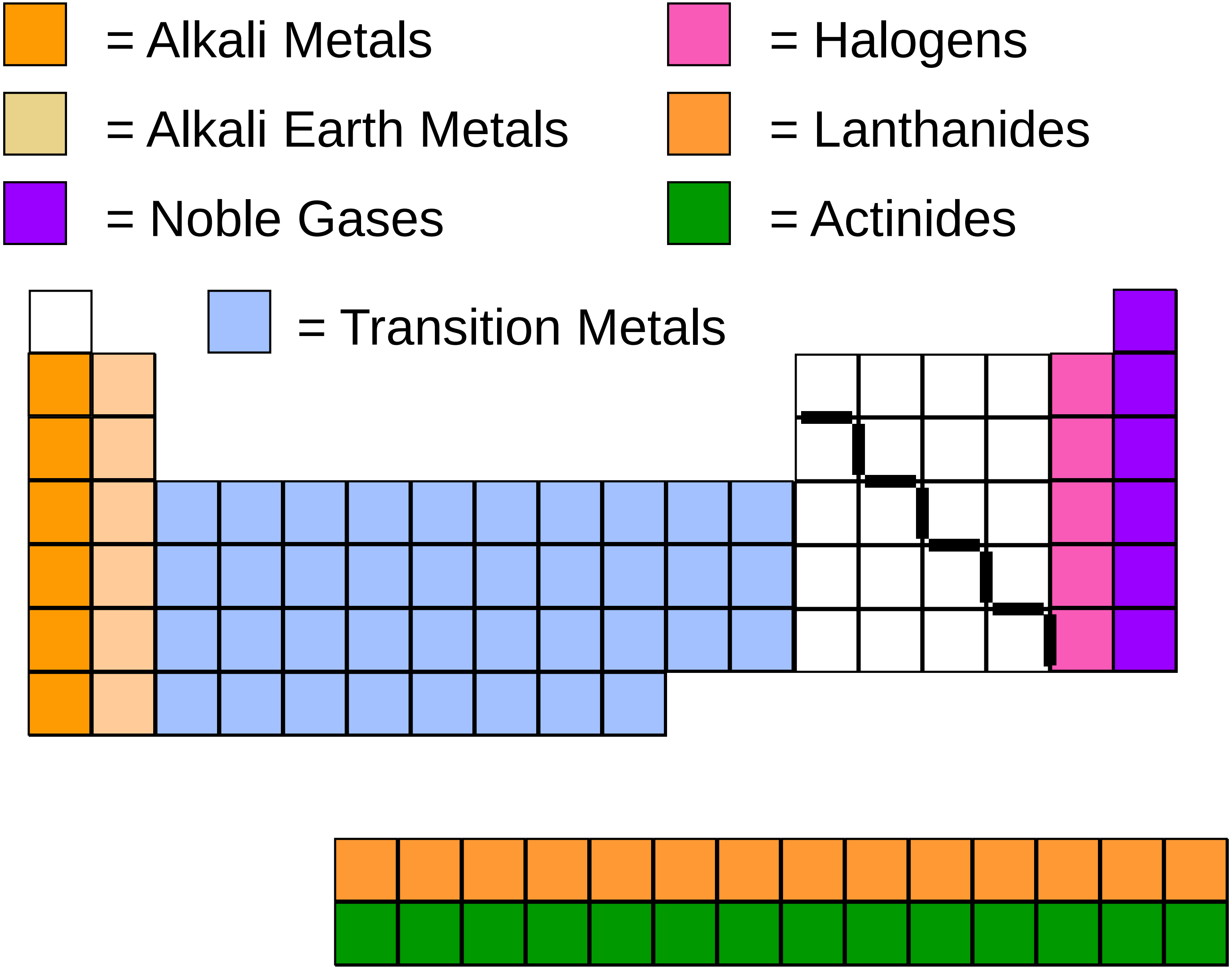
The Modern Periodic Table

- Main Group = Representative Elements = “A” groups
- Transition Elements = “B” groups
  - ✓all metals
- Bottom Rows = Inner Transition Elements = Rare Earth Elements
  - ✓metals
  - ✓really belong in Period 6 & 7

Main-group elements | Transition elements | Main-group elements

Group number

Periods	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	57 La	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	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112		114		116		


= Alkali Metals
= Alkali Earth Metals
= Noble Gases
= Halogens
= Lanthanides
= Actinides
= Transition Metals

Important Groups - Hydrogen

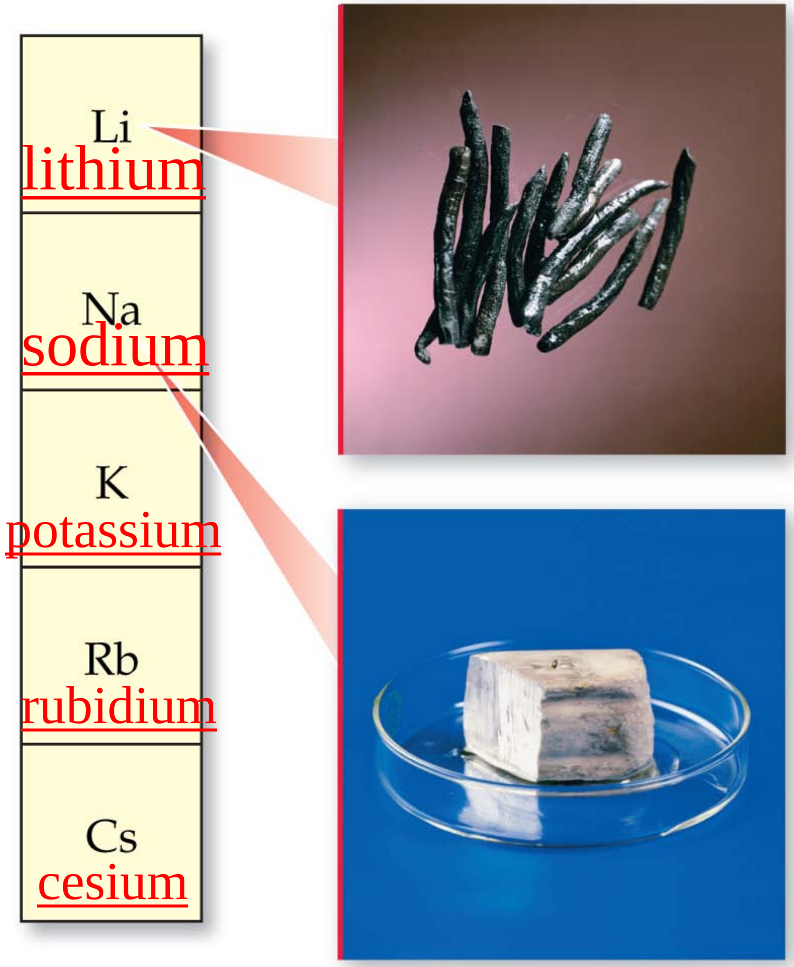
- nonmetal
- colorless, diatomic gas
  - ✓ very low melting point and density
- reacts with nonmetals to form molecular compounds
  - ✓ HCl is acidic gas
  - ✓ H_2O is a liquid
- reacts with metals to form hydrides
  - ✓ metal hydrides react with water to form H_2
- HX dissolves in water to form acids

Important Groups - Alkali Metals

- Group IA = Alkali Metals
- hydrogen usually placed here, though it doesn't belong
- soft, low melting points, low density
- flame tests → Li = red, Na = yellow, K = violet
- very reactive, never find uncombined in nature
- tend to form water-soluble compounds, therefore crystallized from seawater then molten salt electrolyzed
  - ➢colorless solutions
- react with water to form basic (alkaline) solutions and H_2

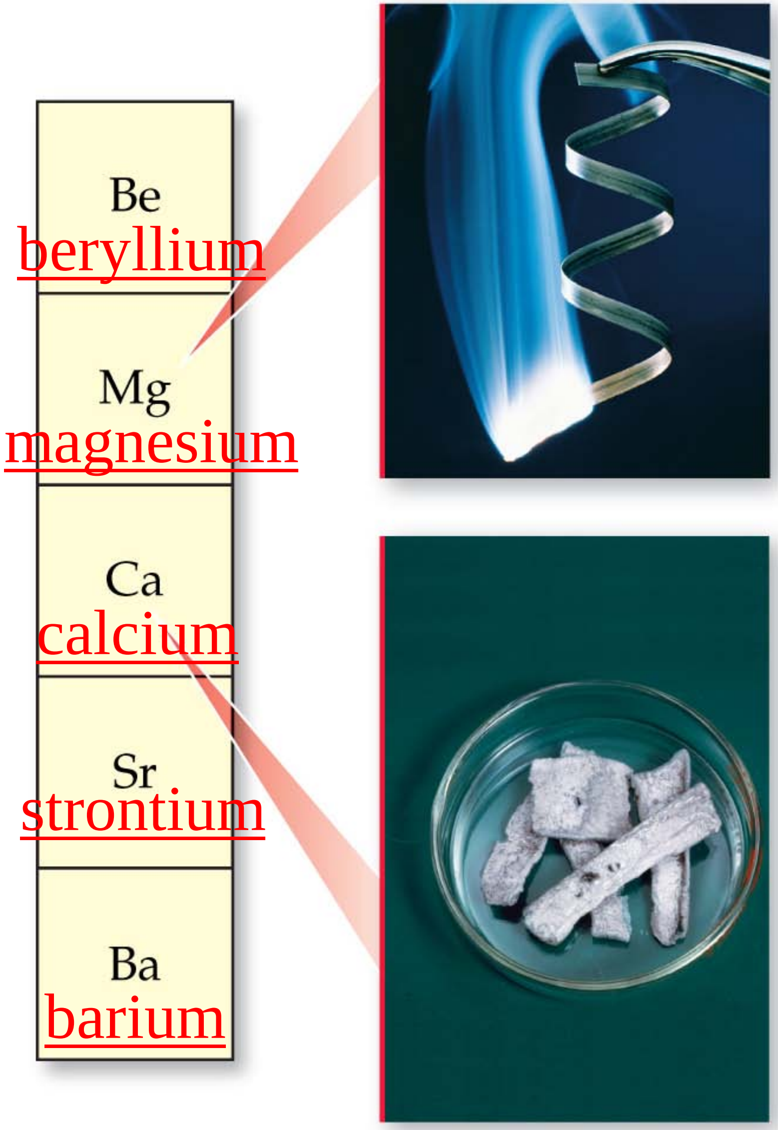
$$2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2$$

  - ➢releases a lot of heat



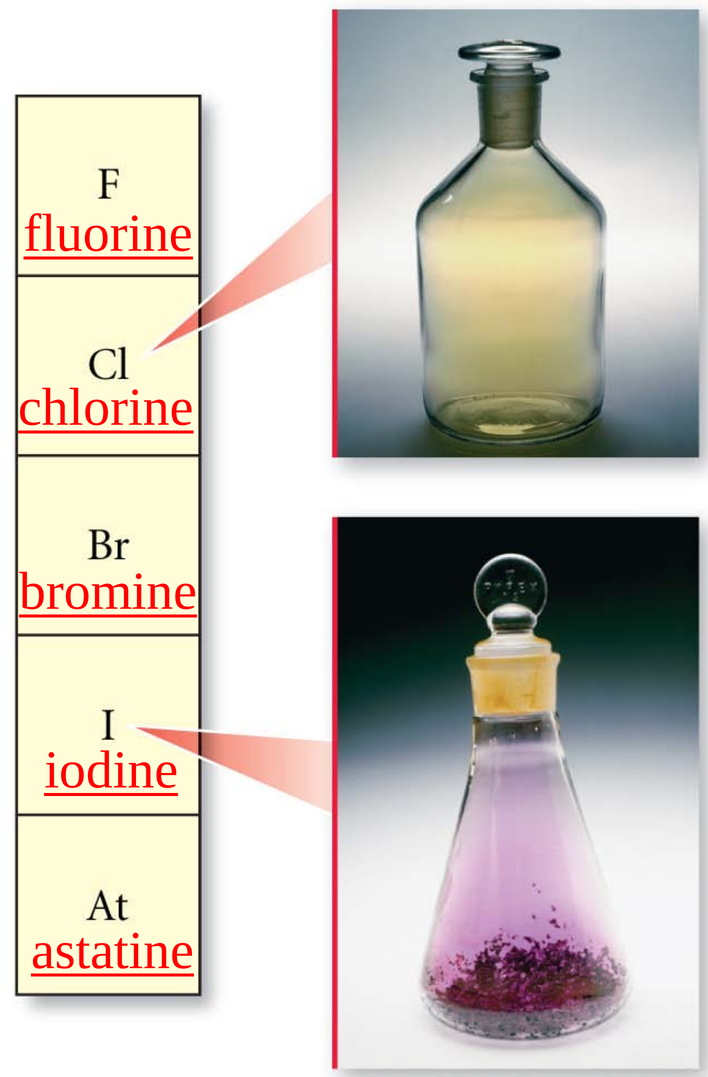
Important Groups - Alkali Earth Metals

- Group IIA = Alkali Earth Metals
- harder, higher melting, and denser than alkali metals
  - ✓ Mg alloys used as structural materials
- flame tests → Ca = red, Sr = red, Ba = yellow-green
- reactive, but less than corresponding alkali metal
- form stable, insoluble oxides from which they are normally extracted
- oxides are basic = alkaline earth
- reactivity with water to form H_2 → Be = none; Mg = steam; Ca, Sr, Ba = cold water



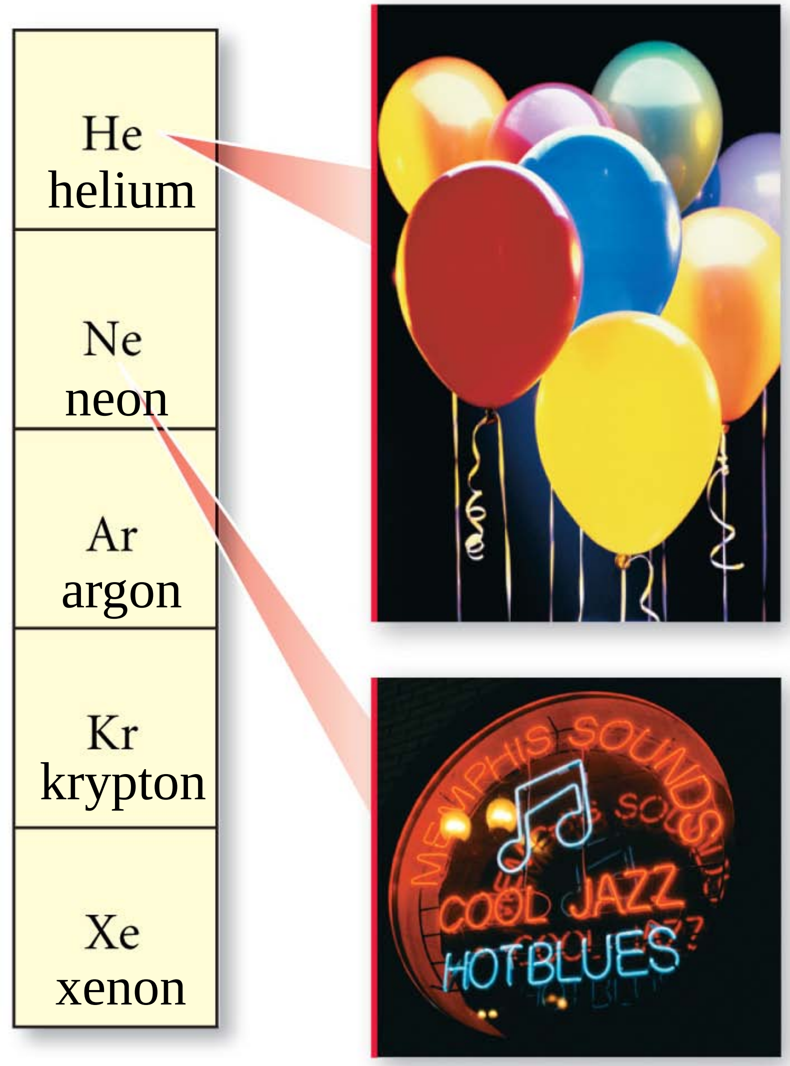
Important Groups - Halogens

- Group VIIA = Halogens
- nonmetals
- F_2 and Cl_2 gases; Br_2 liquid; I_2 solid
- all diatomic
- very reactive
- Cl_2, Br_2 react slowly with water
  - $Br_2 + H_2O \rightarrow HBr + HOBr$
- react with metals to form ionic compounds
- HX all acids
  - ✓ HF weak < HCl < HBr < HI



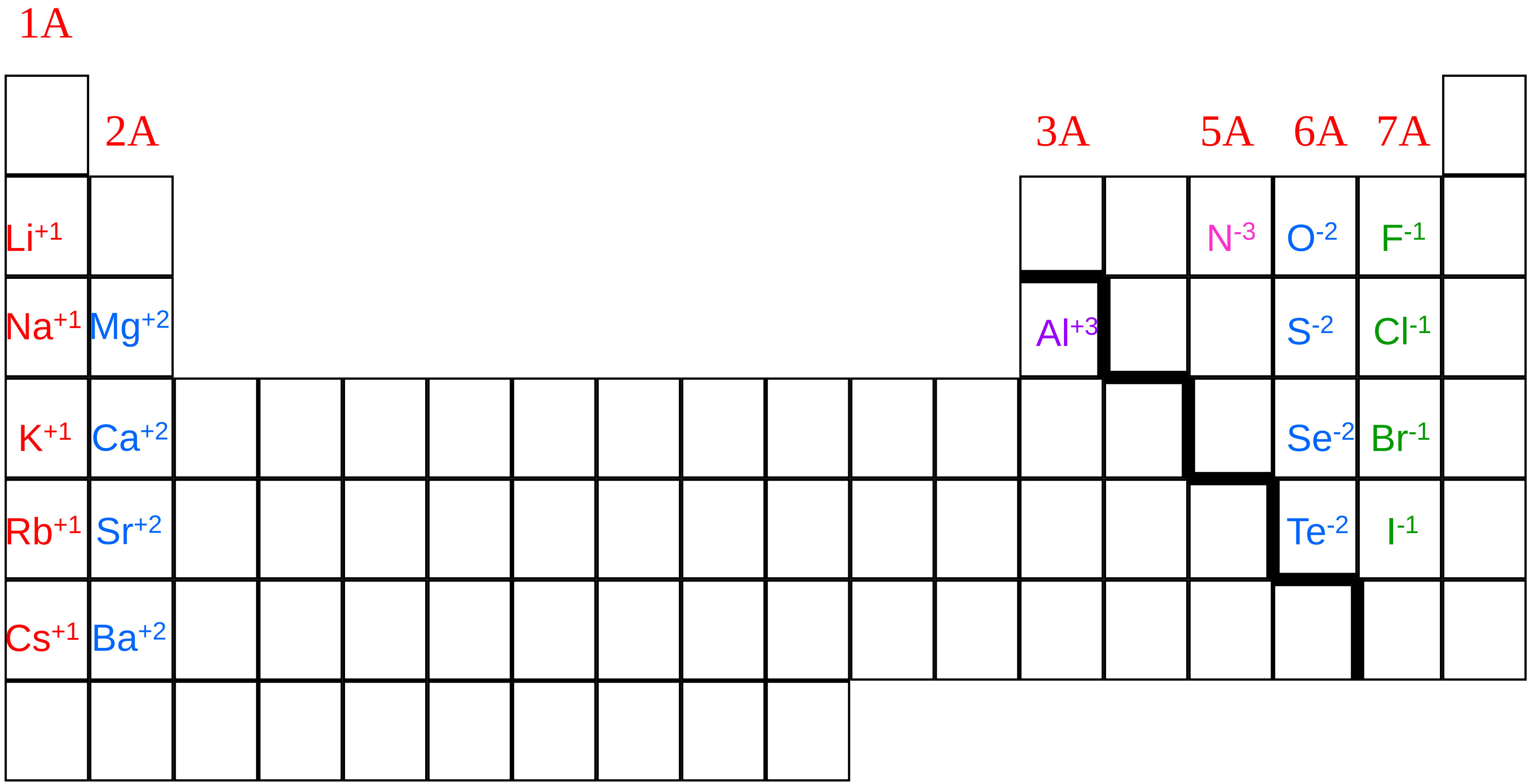
Important Groups - Noble Gases

- Group VIIIA = Noble Gases
- all gases at room temperature
  - ✓ very low melting and boiling points
- very unreactive, practically inert
- very hard to remove electron from or give an electron to



Ion Charge and the Periodic Table

- the charge on an ion can often be determined from an element's position on the Periodic Table
- metals are always positively charged ions, nonmetals are negatively charged ions
- for many main group metals, the charge = the group number
- for nonmetals, the charge = the group number - 8


1A
2A
3A
5A
6A
7A
Li+1
N-3
O-2
F-1
Na+1
Mg+2
Al+3
S-2
Cl-1
K+1
Ca+2
Se-2
Br-1
Rb+1
Sr+2
Te-2
I-1
Cs+1
Ba+2

Atomic Mass

17
Cl
35.45
chlorine

- we previously learned that not all atoms of an element have the same mass
  - ✓ isotopes
- we generally use the average mass of all an element’s atoms found in a sample in calculations
  - ✓ however the average must take into account the abundance of each isotope in the sample
- we call the average mass the **atomic mass**

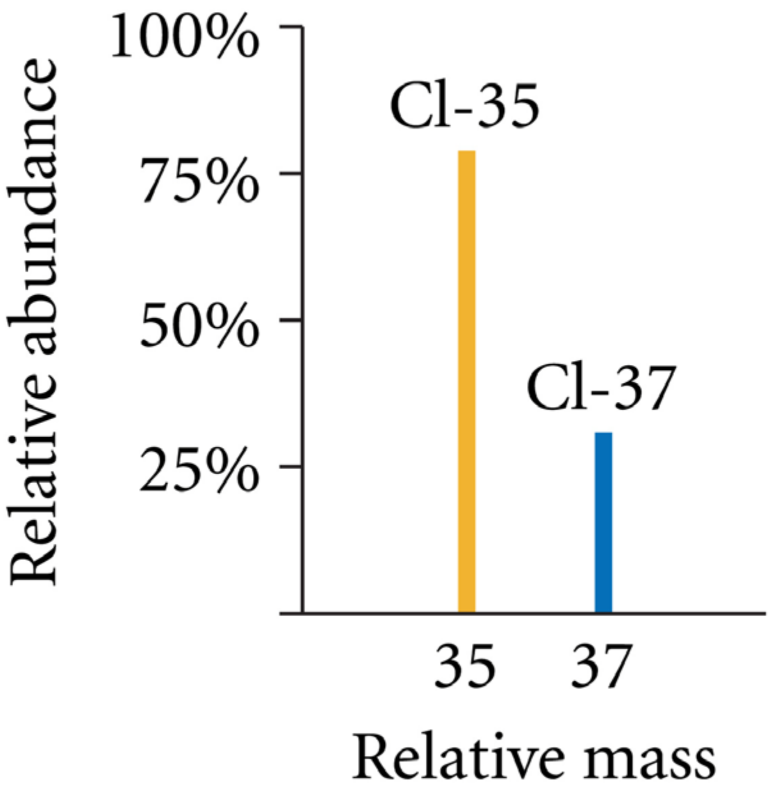
$$\text{Atomic Mass} = \sum \left(\text{fractional abundance of isotope}\right)_n \times \left(\text{mass of isotope}\right)_n$$

Mass Spectrometry

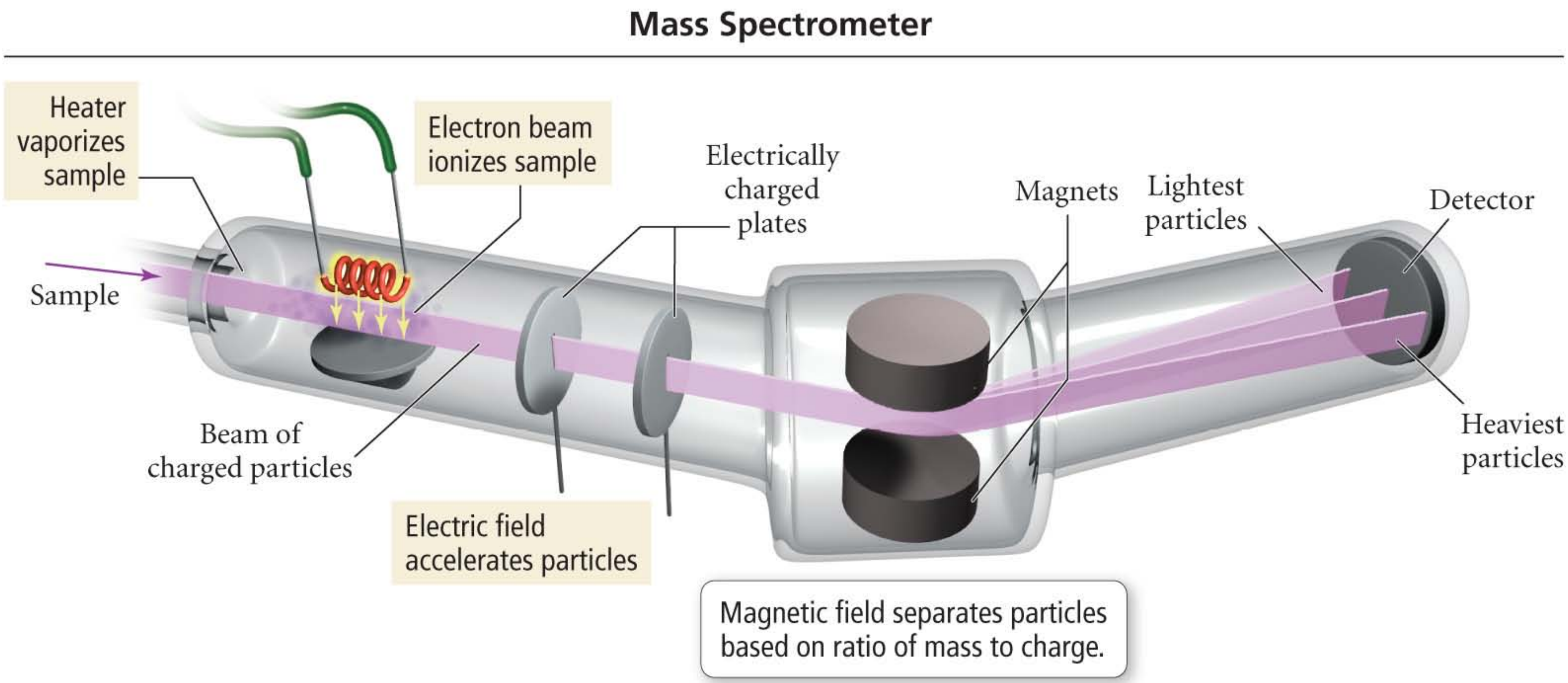
- masses and abundances of isotopes are measured with a **mass spectrometer**
- atoms or molecules are ionized, then accelerated down a tube
  - ✓ some molecules into fragments are broken during the ionization process
  - ✓ these fragments can be used to help determine the structure of the molecule
- their path is bent by a magnetic field, separating them by mass
  - ✓ similar to Thomson's Cathode Ray Experiment

Mass Spectrum

- a mass spectrum is a graph that gives the relative mass and relative abundance of each particle
- relative mass of the particle is plotted in the *x*-axis
- relative abundance of the particle is plotted in the *y*-axis



Mass Spectrometer

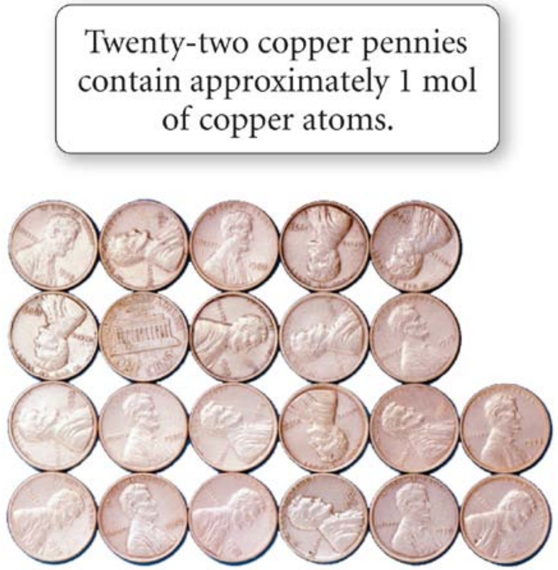


Example 2.5 If copper is 69.17% Cu-63 with a mass of 62.9396 amu and the rest Cu-65 with a mass of 64.9278 amu, find copper's atomic mass

Given:	Cu-63 = 69.17%, 62.9396 amu Cu-65 = 100-69.17%, 64.9278 amu
Find:	atomic mass, amu
Concept Plan:	isotope masses, isotope fractions → avg. atomic mass
Relationships:	$\text{Atomic Mass} = \sum (\text{fractional abundance of isotope})_n \times (\text{mass of isotope})_n$
Solution:	$\text{Atomic Mass} = (0.6917)(62.9396\ \text{amu}) + (0.3083)(64.9278\ \text{amu})$ $\text{Atomic Mass} = 63.5525 = 63.55\ \text{amu}$
Check:	the average is between the two masses, closer to the major isotope

Counting Atoms by Moles

- If we can find the mass of a particular number of atoms, we can use this information to convert the mass of an element sample into the number of atoms in the sample.
- The number of atoms we will use is 6.022×10^{23} and we call this a **mole**
  - ✓ 1 mole = 6.022×10^{23} things
    - ➢ Like 1 dozen = 12 things



Chemical Packages - Moles

- mole = number of particles equal to the number of atoms in 12 g of C-12
  - ✓ 1 atom of C-12 weighs exactly 12 amu
  - ✓ 1 mole of C-12 weighs exactly 12 g
- The number of particles in 1 mole is called **Avogadro's Number = 6.0221421 x 10^{23}**
  - ✓ 1 mole of C atoms weighs 12.01 g and has 6.022 x 10^{23} atoms
    - ➢ the average mass of a C atom is 12.01 amu

Example 2.6 Calculate the number of atoms in 2.45 mol of copper

Given: **Find:**	2.45 mol Cu atoms Cu
Concept Plan: **Relationships:**	mol Cu → atoms Cu $\frac{6.022\times10^{23}\text{ atoms}}{1\text{ mol}}$ 1 mol = 6.022 x 10^{23} atoms
Solution:	$2.45\text{ mol Cu}\times\frac{6.022\times10^{23}\text{ atoms}}{1\text{ mol}}$ $=1.48\times10^{24}\text{ atoms Cu}$
Check:	since atoms are small, the large number of atoms makes sense

Relationship Between Moles and Mass

- The mass of one mole of atoms is called the **molar mass**
- The molar mass of an element, in grams, is numerically equal to the element's atomic mass, in amu
- The lighter the atom, the less a mole weighs
- The lighter the atom, the more atoms there are in 1 g

Mole and Mass Relationships

Substance	***Weight of 1 atom***	***Pieces in 1 mole***	***Weight of 1 mole***
hydrogen	1.008 amu	6.022×10^{23} atoms	1.008 g
carbon	12.01 amu	6.022×10^{23} atoms	12.01 g
oxygen	16.00 amu	6.022×10^{23} atoms	16.00 g
sulfur	32.06 amu	6.022×10^{23} atoms	32.06 g
calcium	40.08 amu	6.022×10^{23} atoms	40.08 g
chlorine	35.45 amu	6.022×10^{23} atoms	35.45 g
copper	63.55 amu	6.022×10^{23} atoms	63.55 g

1 mole
sulfur
32.06 g

1 mole
carbon
12.01 g

Example 2.7 Calculate the moles of carbon in 0.0265 g of pencil lead

Given: **Find:**	0.0265 g C mol C
Concept Plan: **Relationships:**	g C → mol C $\frac{1\,\text{mol}}{12.01\,\text{g}}$ 1 mol C = 12.01 g
Solution:	$0.0265\,\text{g C} \times \frac{1\,\text{mol}}{12.01\,\text{g}}$ $= 2.21 \times 10^{-3}\,\text{mol C}$
Check:	since the given amount is much less than 1 mol C, the number makes sense

Example 2.8 How many copper atoms are in a penny weighing 3.10 g?

Given: **Find:**	3.10 g Cu atoms Cu
Concept Plan:	g Cu → mol Cu → atoms Cu $\frac{1\,\text{mol}}{63.55\,\text{g}}$ $\frac{6.022\times10^{23}\ \text{atoms}}{1\,\text{mol}}$
Relationships:	1 mol Cu = 63.55 g, 1 mol = 6.022 x 10^{23}
Solution:	$3.10\,\text{g Cu}\times\frac{1\,\text{mol Cu}}{63.55\,\text{g Cu}}\times\frac{6.022\times10^{23}\ \text{atoms}}{1\,\text{mol}}$ $=2.94\times10^{22}\ \text{atoms Cu}$
Check:	since the given amount is much less than 1 mol Cu, the number makes sense