Chapter 2a
Atoms, Molecules, and Ions

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Atomic Theory Until 19th Century

John Dalton (1766-1844)

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

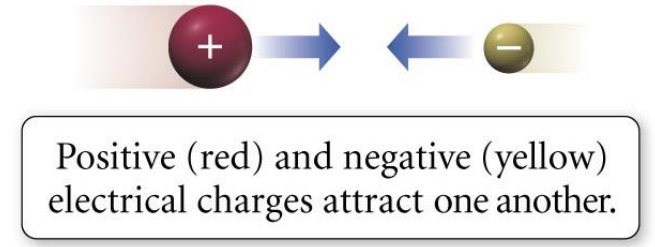
1. Each element is composed of tiny, indestructible particles called atoms
2. All atoms of a given element have the same mass and other properties that distinguish them from atoms of other elements
3. Atoms combine in simple, whole-number ratios to form molecules of compounds
4. In a chemical reaction,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

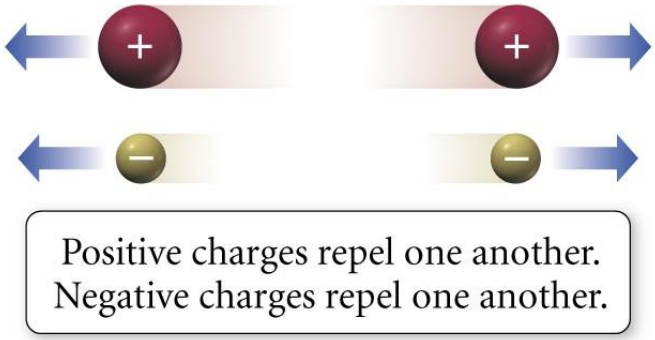
Since the End of 19th Century Discovery of Subatomic Particles

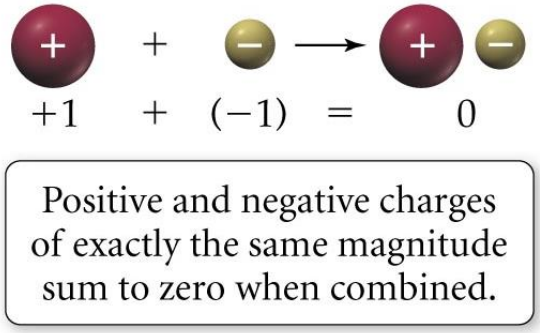
- Electron (-1)
- Nucleus
  - Proton (+1)
  - Neutron (0)

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

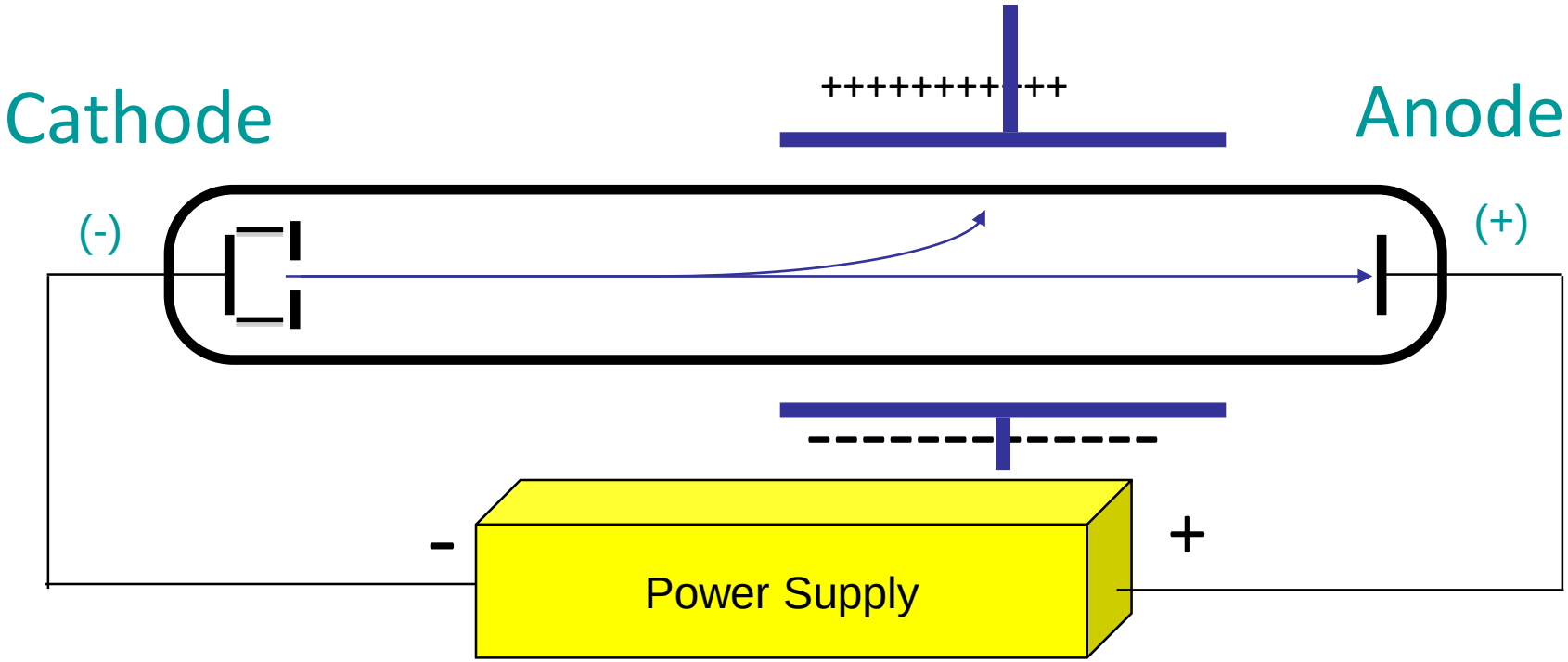






Thomson's Cathode Ray Experiment (1897)

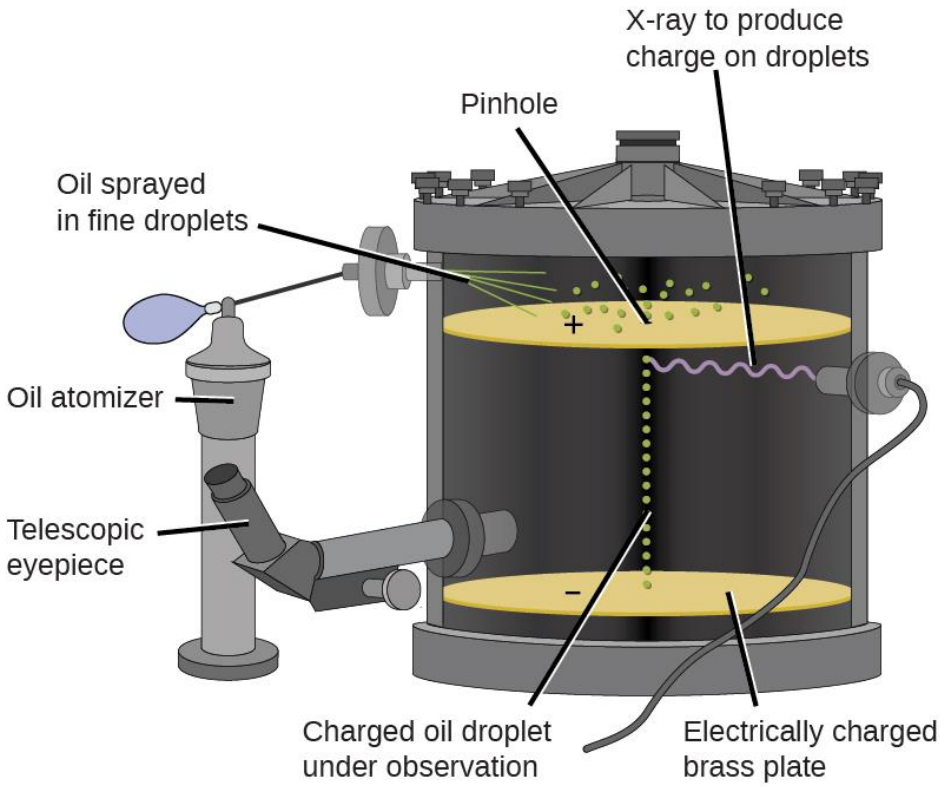
1. Charged matter coming out of cathode is attracted to an electric field to positively charged plate
2. Light's path is not deflected by an electric field



Thomson's Results: Electrons

- The cathode rays are made of tiny particles
- These particles have a negative charge
  - because the beam always deflected toward the + plate
- Every material tested contained these same particles
- The charge:mass ratio of these particles was -1.76×10^{8} C/g
- These cathode ray particles became known as **electrons**

Milikan's Experiment (1906)



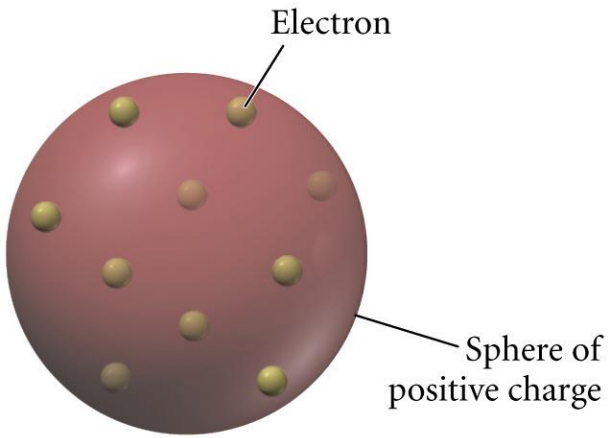
Oil drop	Charge in coulombs (C)
A	4.8×10^{-19} C
B	3.2×10^{-19} C
C	6.4×10^{-19} C
D	1.6×10^{-19} C
E	4.8×10^{-19} C

- Millikan's experiment measured the charge of individual elecron. (-1.6×10^{-19})

Subatomic particle: Electrons

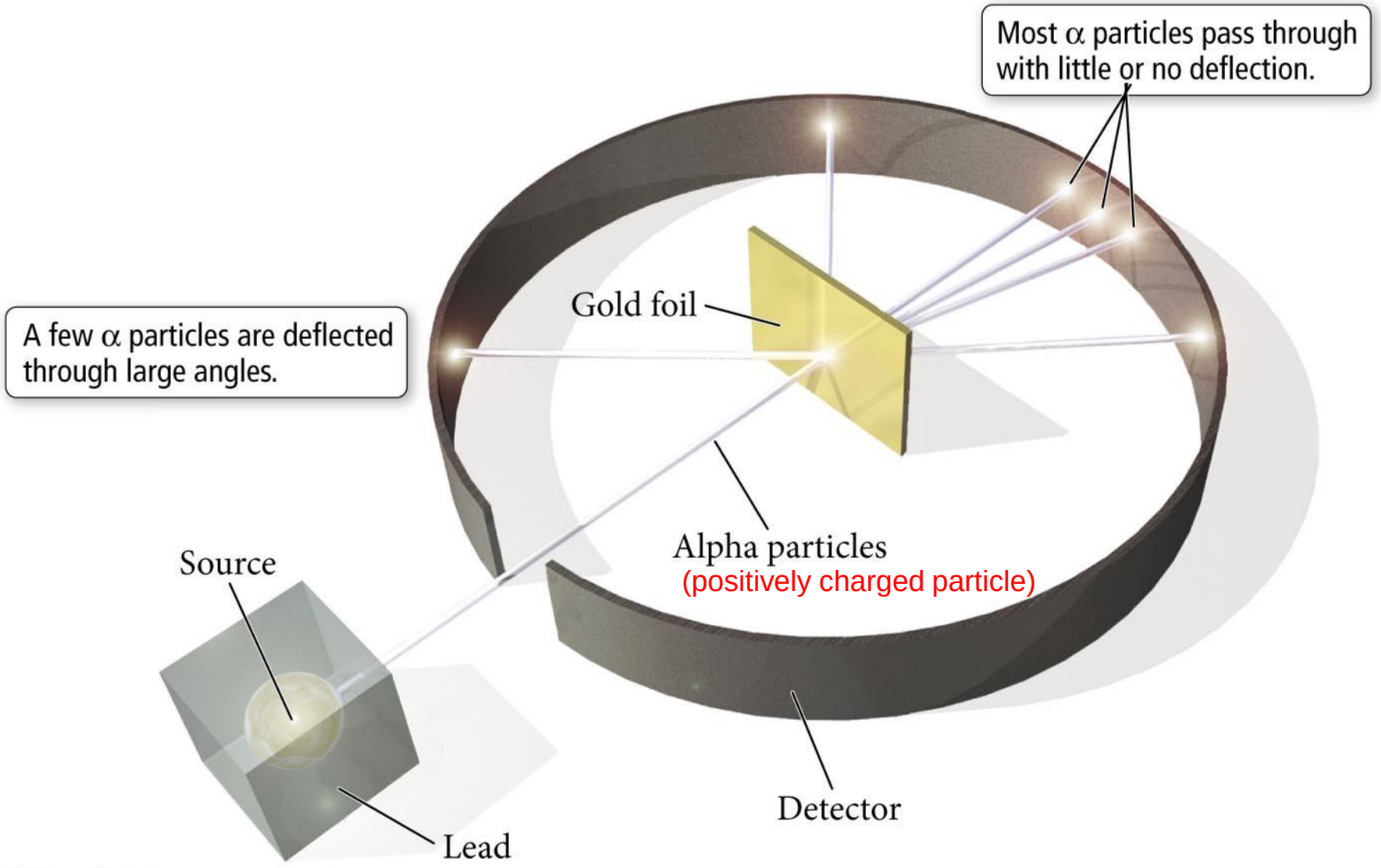
- **Electrons** are tiny, negatively charged particles found in all atoms
- The electron has a charge of -1.60×10^{19} C (-1 charge)
- The electron has a mass of 9.1×10^{-28} g

- 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



Plum-pudding model

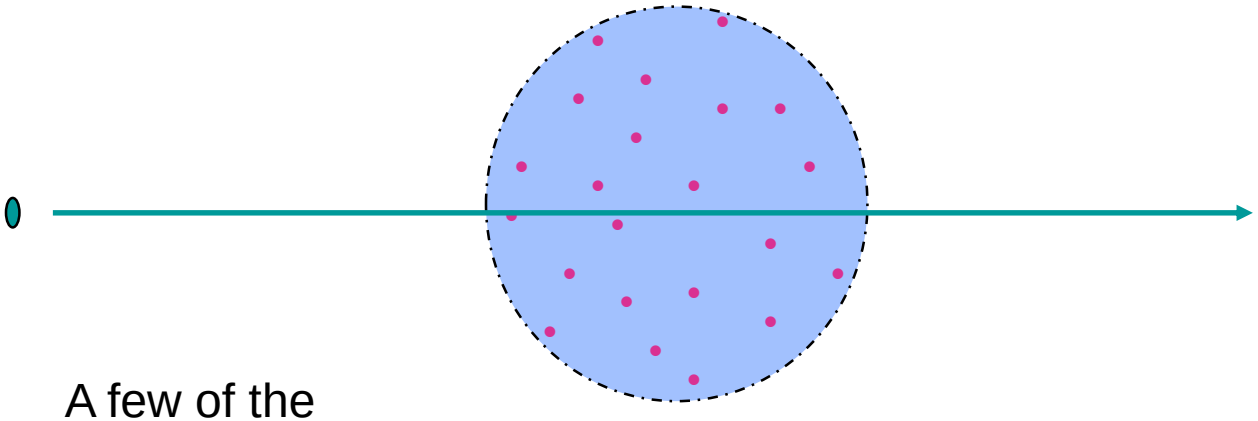
Rutherford's Gold Foil Experiment (1908-1913)



Rutherford's Conclusions

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

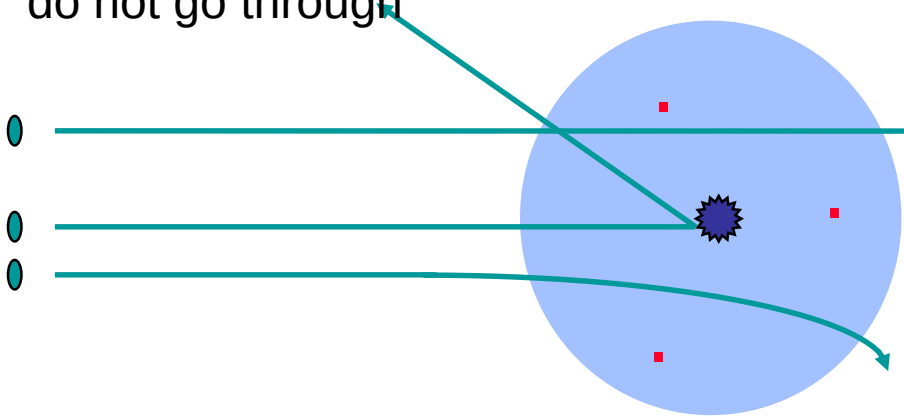
Plum Pudding Atom



If atom was like a plum pudding, all the α particles should go straight through

Nuclear Atom

A few of the α particles do not go through



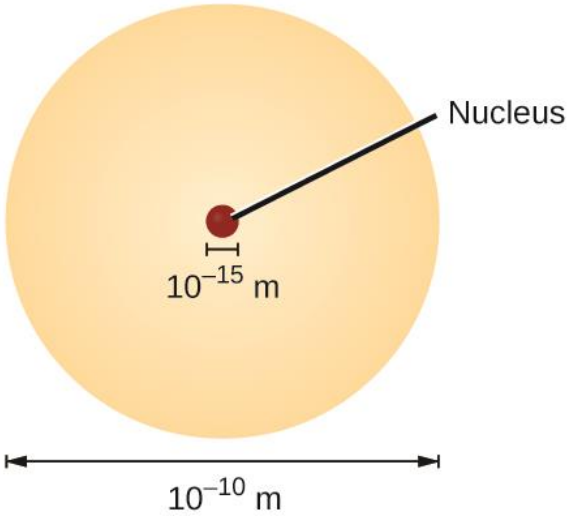
Almost all α particles go straight through

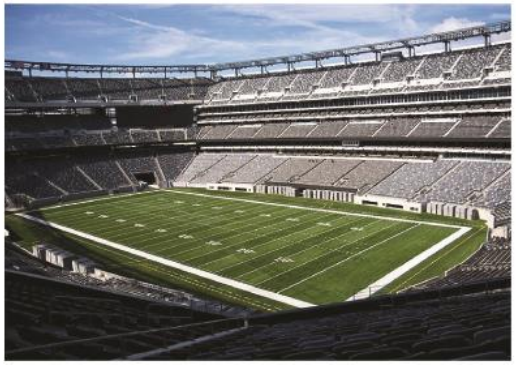
Some α particles go through, but are deflected due to +:+ repulsion from the nucleus

Rutherford's Interpretation – the Nuclear Model

1. The atom contains a tiny dense center called the **nucleus**
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

Relative Size of Atom and Nucleus





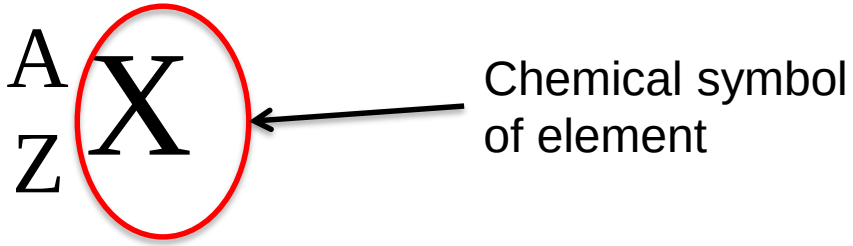
- If an atom could be expanded to the size of a football stadium, the nucleus would be the size of a single blueberry.

Structure of the Nucleus

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

Atomic Number and Mass Number

- Atomic number (Z) =
- Mass number (A) =



$${}^{4}_{2}\mathrm{He}$$

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

Complete the Table

Protons	Neutrons	Electrons	Atomic Number	Mass Number	Atomic Symbol
6	7				
		42		96	
					$^{27}_{13}Al$
			55	133	

Isotopes

- The isotopes of the same element have atoms with the same number of electrons but different numbers of neutrons.

$^{35}_{17}Cl$ $^{37}_{17}Cl$

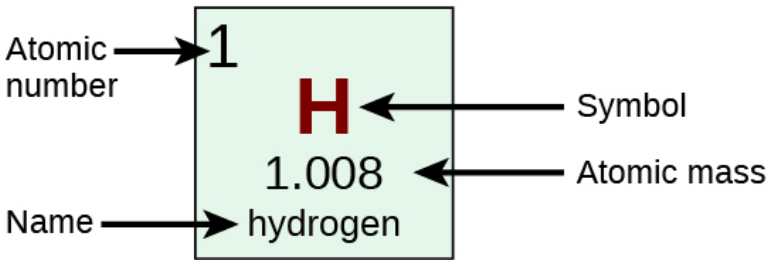
Neon

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%

Periodic Table of the Elements

Period	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.008 hydrogen																	2 He 4.003 helium
2	3 Li 6.94 lithium	4 Be 9.012 beryllium											5 B 10.81 boron	6 C 12.01 carbon	7 N 14.01 nitrogen	8 O 16.00 oxygen	9 F 19.00 fluorine	10 Ne 20.18 neon
3	11 Na 22.99 sodium	12 Mg 24.31 magnesium											13 Al 26.98 aluminum	14 Si 28.09 silicon	15 P 30.97 phosphorus	16 S 32.06 sulfur	17 Cl 35.45 chlorine	18 Ar 39.95 argon
4	19 K 39.10 potassium	20 Ca 40.08 calcium	21 Sc 44.96 scandium	22 Ti 47.87 titanium	23 V 50.94 vanadium	24 Cr 52.00 chromium	25 Mn 54.94 manganese	26 Fe 55.85 iron	27 Co 58.93 cobalt	28 Ni 58.69 nickel	29 Cu 63.55 copper	30 Zn 65.38 zinc	31 Ga 69.72 gallium	32 Ge 72.63 germanium	33 As 74.92 arsenic	34 Se 78.97 selenium	35 Br 79.90 bromine	36 Kr 83.80 krypton
5	37 Rb 85.47 rubidium	38 Sr 87.62 strontium	39 Y 88.91 yttrium	40 Zr 91.22 zirconium	41 Nb 92.91 niobium	42 Mo 95.95 molybdenum	43 Tc [97] technetium	44 Ru 101.1 ruthenium	45 Rh 102.9 rhodium	46 Pd 106.4 palladium	47 Ag 107.9 silver	48 Cd 112.4 cadmium	49 In 114.8 indium	50 Sn 118.7 tin	51 Sb 121.8 antimony	52 Te 127.6 tellurium	53 I 126.9 iodine	54 Xe 131.3 xenon
6	55 Cs 132.9 cesium	56 Ba 137.3 barium	57-71 La–Lu *	72 Hf 178.5 hafnium	73 Ta 180.9 tantalum	74 W 183.8 tungsten	75 Re 186.2 rhenium	76 Os 190.2 osmium	77 Ir 192.2 iridium	78 Pt 195.1 platinum	79 Au 197.0 gold	80 Hg 200.6 mercury	81 Tl 204.4 thallium	82 Pb 207.2 lead	83 Bi 209.0 bismuth	84 Po [209] polonium	85 At [210] astatine	86 Rn [222] radon
7	87 Fr [223] francium	88 Ra [226] radium	89-103 Ac–Lr **	104 Rf [267] rutherfordium	105 Db [270] dubnium	106 Sg [271] seaborgium	107 Bh [270] bohrium	108 Hs [277] hassium	109 Mt [276] meitnerium	110 Ds [281] darmstadtium	111 Rg [282] roentgenium	112 Cn [285] copernicium	113 Uut [285] ununtrium	114 Fl [289] flerovium	115 Uup [288] ununpentium	116 Lv [293] livermorium	117 Uus [294] ununseptium	118 Uuo [294] ununoctium

*	57 La 138.9 lanthanum	58 Ce 140.1 cerium	59 Pr 140.9 praseodymium	60 Nd 144.2 neodymium	61 Pm [145] promethium	62 Sm 150.4 samarium	63 Eu 152.0 europium	64 Gd 157.3 gadolinium	65 Tb 158.9 terbium	66 Dy 162.5 dysprosium	67 Ho 164.9 holmium	68 Er 167.3 erbium	69 Tm 168.9 thulium	70 Yb 173.1 ytterbium	71 Lu 175.0 lutetium
**	89 Ac [227] actinium	90 Th 232.0 thorium	91 Pa 231.0 protactinium	92 U 238.0 uranium	93 Np [237] neptunium	94 Pu [244] plutonium	95 Am [243] americium	96 Cm [247] curium	97 Bk [247] berkelium	98 Cf [251] californium	99 Es [252] einsteinium	100 Fm [257] fermium	101 Md [258] mendelevium	102 No [259] nobelium	103 Lr [262] lawrencium



Color Code

Metal	**Solid**
Metalloid	**Liquid**
Nonmetal	**Gas**

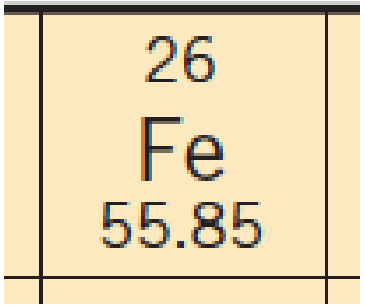
Atomic Mass and Average Atomic Mass

- Atomic mass units (amu)
  - 1 atom of ^{12}C has a mass of exactly 12 amu
  - 1 amu equals exactly 1/12 the mass of 1 atom of ^{12}C

Note: atomic mass ≠ mass number

- Average atomic mass in the periodic table
  - Necessary due to the presence of isotopes

Where can you find atomic mass?



Atomic Mass Number (A) vs Atomic Mass

- Atomic mass number: # of protons + # of neutrons (whole number)

$$^{20}_{10}\mathrm{Ne}$$

- Atomic Mass (amu): relative mass compared to ^{12}C (12 amu)

$$^{20}_{10}\mathrm{Ne}$$

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

Average Atomic Mass in Periodic Table

- Naturally found Cl is a mixture of two isotopes: 75.77 % of ^{35}Cl (34.97amu) and 24.23 % ^{37}Cl (36.97 amu). What is its average atomic mass?

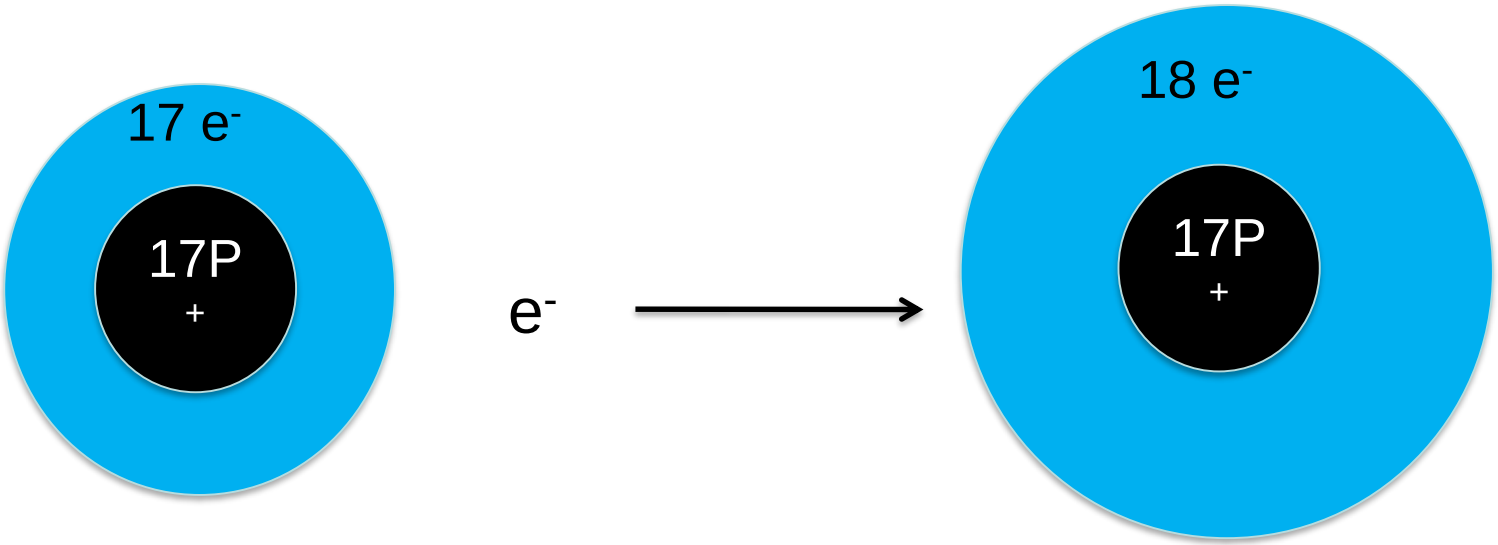
Charged Atoms

- When atoms gain or lose electrons by chemical reactions , they acquire a charge
- Charged atoms or groups of atoms 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**

Anion

$$Cl + e^- \rightarrow Cl^-$$

Cl gained one electron



Cl

Cl^-

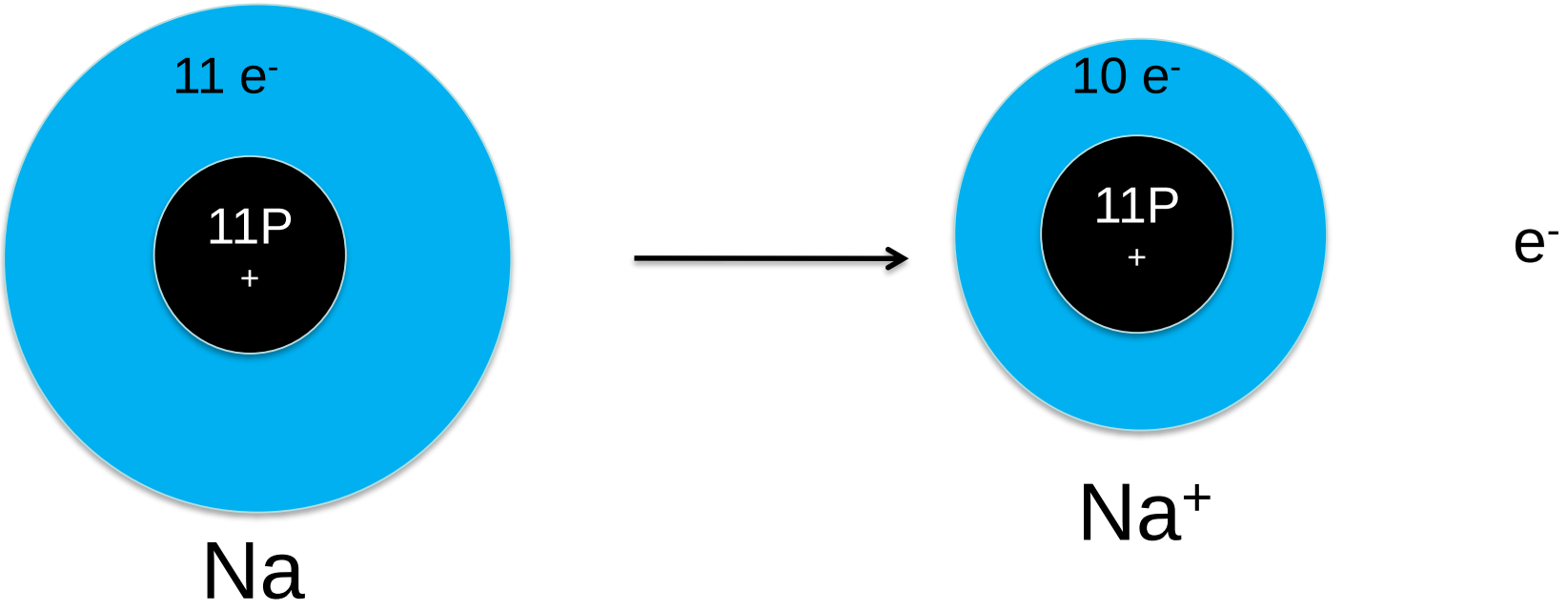
Anion

	Cl	Cl^-
# of electrons	17	18
# of protons	17	17
Net charge	0	-1

Cation

$$Na \rightarrow Na^{+} + e^{-}$$

Na lost one electron



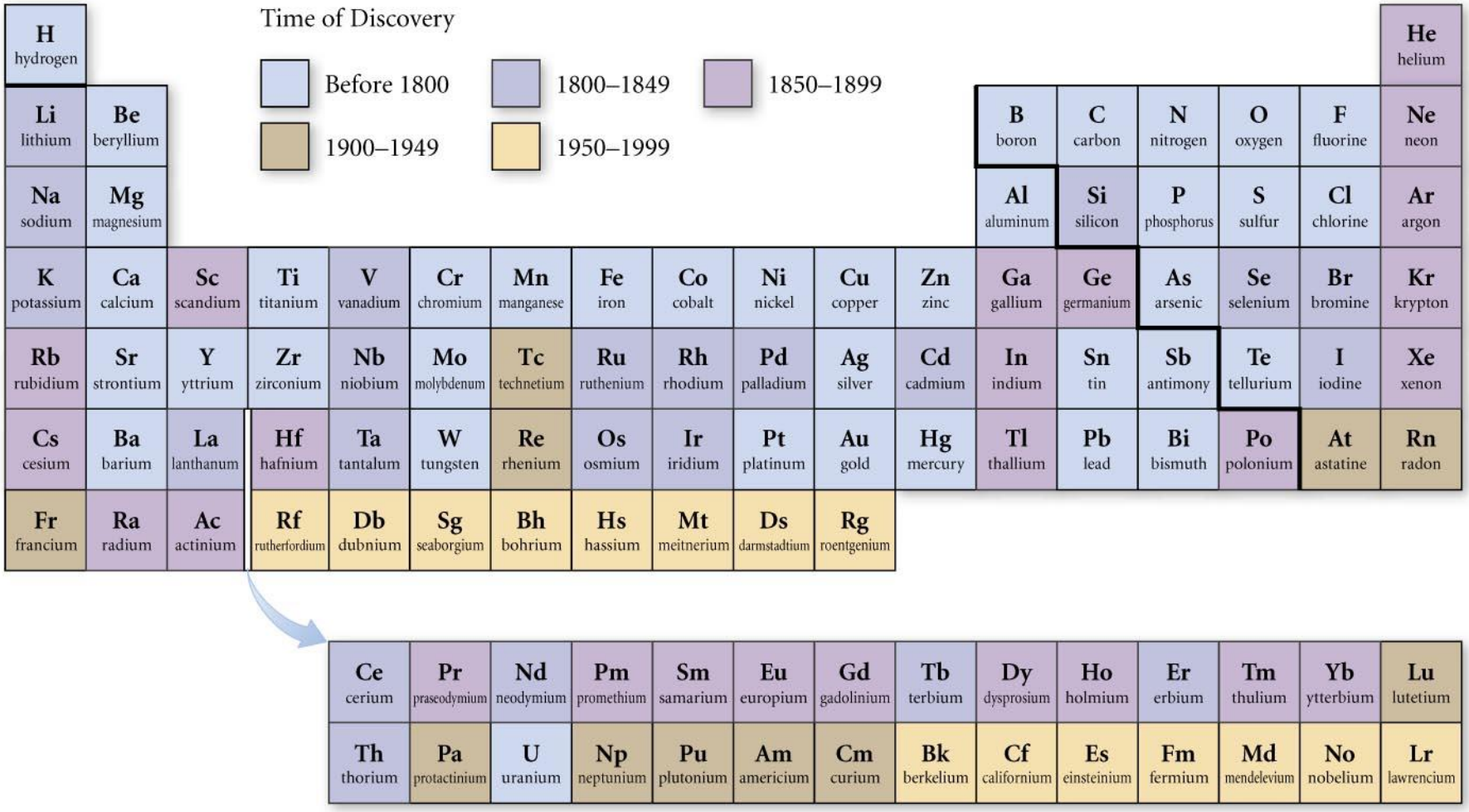
Cation

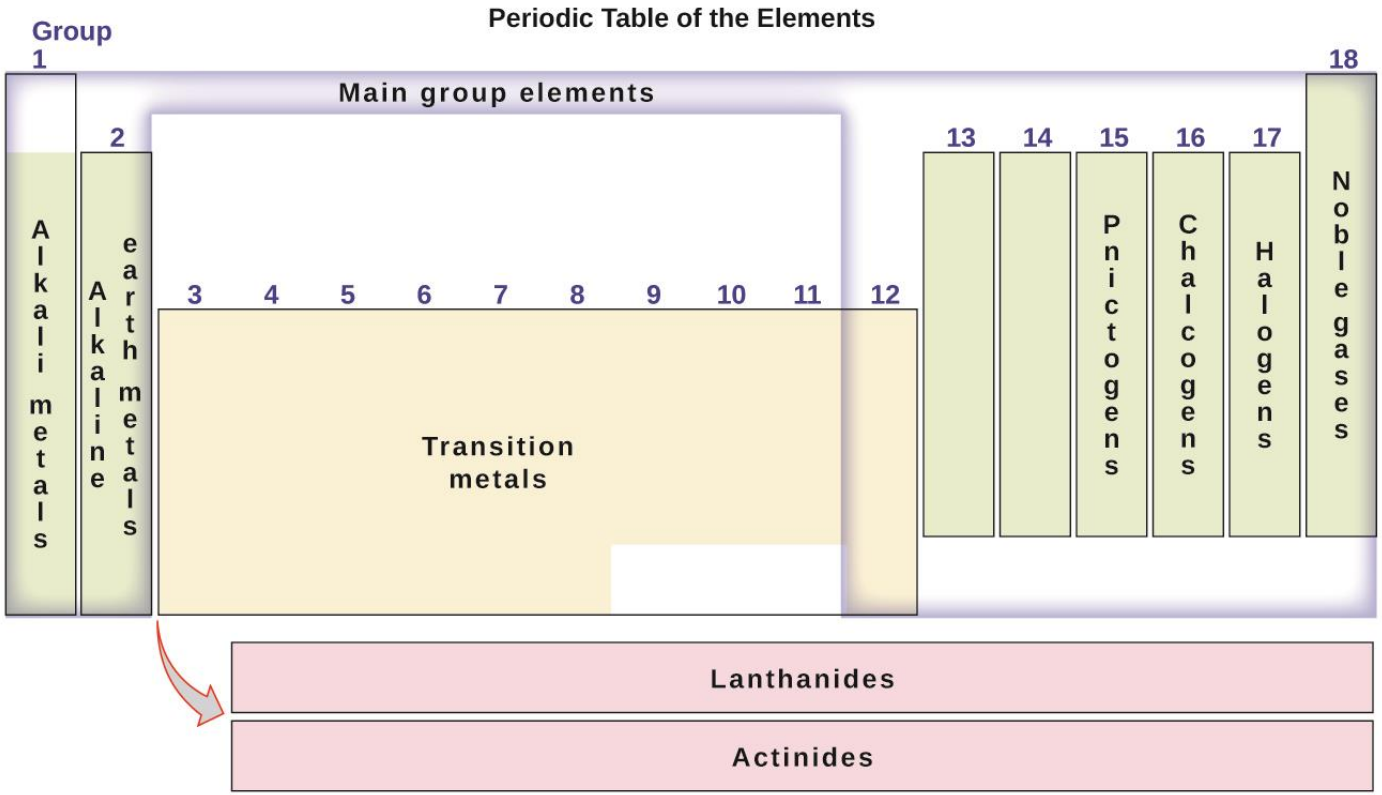
	Na	Na^+
# of electrons	11	10
# of protons	11	11
Net charge	0	+1

Practice – Complete the Table

Atomic Number	Protons	Electrons	Ion Charge	Ion Symbol
16		18		
	12		2+	
				Al^{3+}
		36	1−	

Discovery of Elements and Their Periodic Properties

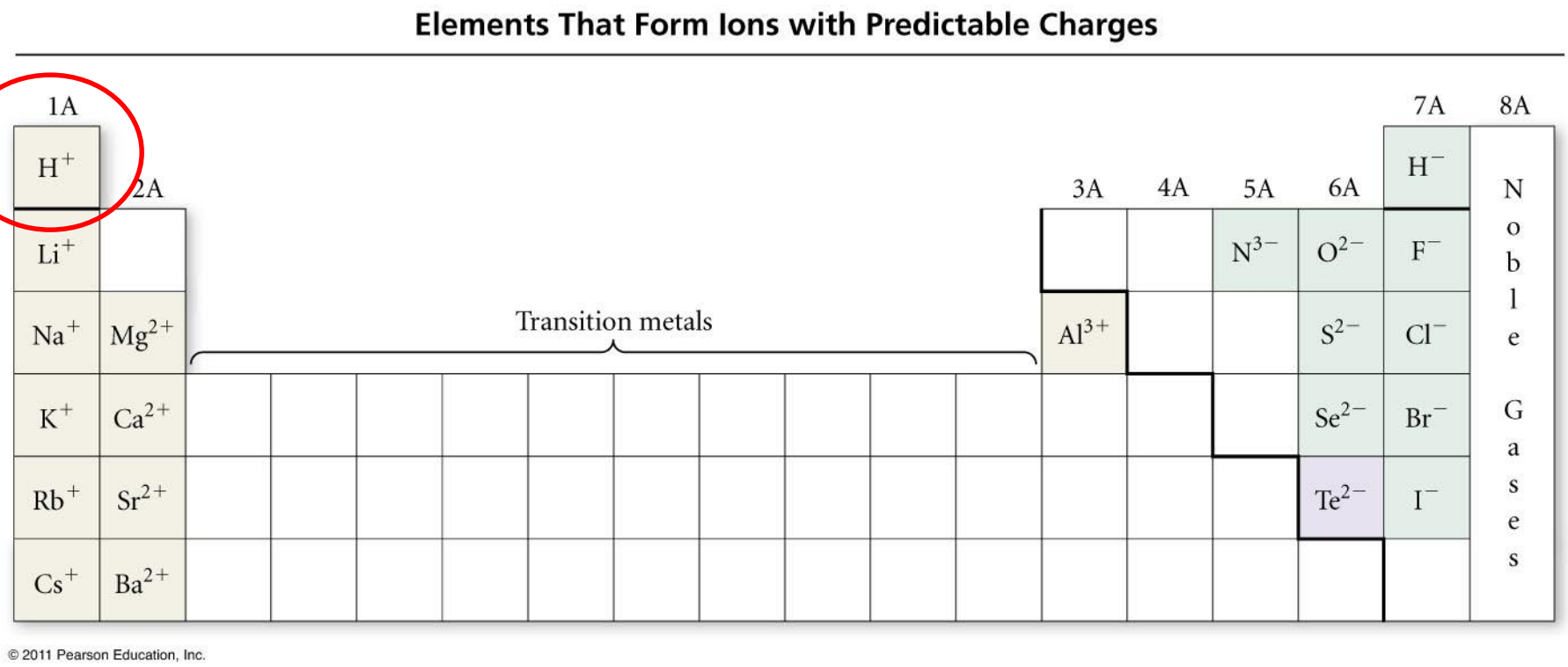



Periodic Table of the Elements
Group
1
18
Main group elements
2
13
14
15
16
17
Alkali metals
Alkaline earth metals
3
4
5
6
7
8
9
10
11
12
Transition metals
Pnictogens
Chalcogens
Halogens
Noble gases
Lanthanides
Actinides

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 always form positively charged cations
- For many main group metals, the charge = the group number
- Nonmetals form negatively charged anions
- For nonmetals, the charge = the group number − 8

Ion Charge and the Periodic Table



H: +1 for HF, HCl, HBr, H_2O, etc (when combined with nonmetals)

H:-1 for LiH, NaH, CaH_2, etc (when combined with metals)

Practice – What is the charge on each of the following ions?

- potassium cation
- sulfide anion
- calcium cation
- bromide anion
- aluminum cation