

Chapter Goals

Upon completion of this chapter, you should be able to:

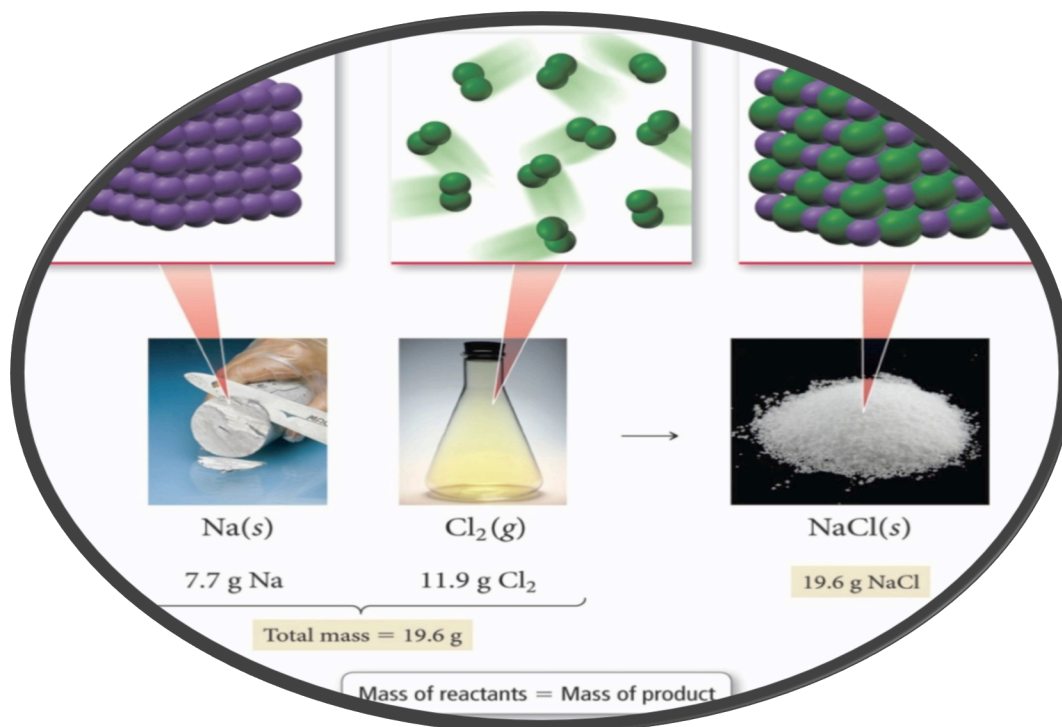
- ✓ Apply the law of multiple proportions, and conservation of mass.
- ✓ Describe what evidence about atomic structure was revealed by the experiments of Thomson, Millikan, and Rutherford.
- ✓ Know the atom in terms of composition and mass.
- ✓ Given the symbol atom or ion, determine the number of protons, neutrons, and electrons.
- ✓ Given the mass and natural abundance of all isotopes of a given element, calculate the average atomic mass of that element.
- ✓ Know the periodic table.
- ✓ Convert from mass to number of moles and to number of atoms.

✚ **Reading Assignment:** Sec 2.1 – 2.5 in Ch. 2 . Read and know the main concepts of: Atomic Theory of Matter, Dalton's Atomic Theory, Rutherford's experiment, nuclear model of the atom and Modern Atomic Theory and the Laws That Led to It.

Atomic Theory of Matter: that atoms are the fundamental building blocks of matter.

Three laws led to the development and acceptance of the atomic theory are as follows:

1. Law of conservation of mass:



2. 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.*

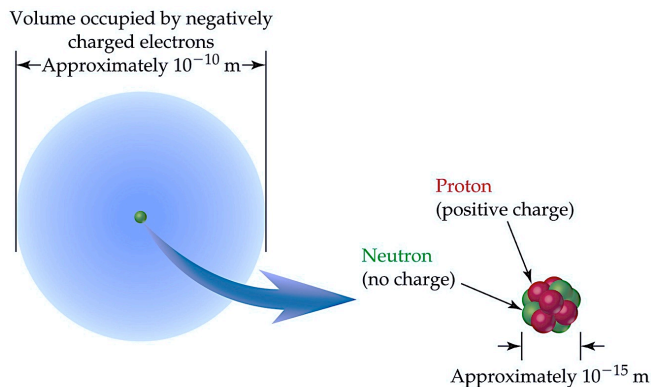
3. The Law of Multiple Proportions: *When two elements form two different compounds, the weights of one element that combine with a fixed weight of the other are in a ratio of small whole numbers the masses.*

- J. J. Thomson had discovered the electron, a negatively charged, low mass particle present within all atoms. (Cathode ray experiment)
- Millikan's Oil Drop Experiment: Determined the charge of an electron
- **Rutherford's Gold Foil Experiment:**
 - ✓ Alpha (α) particles are helium nuclei
 - ✓ Particles were fired at a thin sheet of gold foil
 - ✓ Particle hits on the detecting screen (film) are recorded
- ✓ <https://www.khanacademy.org/science/chemistry/electronic-structure-of-atoms/history-of-atomic-structure/v/rutherfords-gold-foil-experiment>

• **Atom: is the smallest identifiable unit of an element.**

▶ **Diameter of a nucleus is only about 10^{-15} m.**

➤ **Diameter of an atom is only about 10^{-10} m.**



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TABLE 2.1 Subatomic Particles

| | Mass (kg) | Mass (amu) | Charge (relative) | Charge (C) |
|----------|---------------------------|------------|-------------------|----------------------------|
| Proton | 1.67262×10^{-27} | 1.00727 | +1 | $+1.60218 \times 10^{-19}$ |
| Neutron | 1.67493×10^{-27} | 1.00866 | 0 | 0 |
| Electron | 0.00091×10^{-27} | 0.00055 | -1 | -1.60218×10^{-19} |

▶ **The relative size of a nucleus in an atom is the same as that of a pea in the middle of this stadium.**

➤ Periodic Table ➔

Elements are symbolized by one or two letters

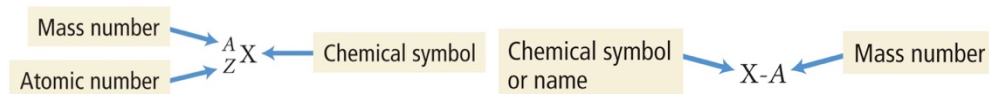
Atomic Number:

Atomic Mass :

of Neutrons:

| |
|-------|
| 6 |
| C |
| 12.01 |

Isotope: Atoms of the same element have the same number of protons but a different number of neutrons.



| | | |
|-------------|-----------------|-----------------|
| Isotope | ^{12}C | ^{13}C |
| Mass | 12.00 amu | 13.00 amu |
| % abundance | 98.90% | 1.10% |

→ atomic mass unit (amu), An amu is a very, very, very,.... tiny fraction of a gram

$$1 \text{ amu} = \frac{1 \text{ gram}}{6.022 \times 10^{23}} = 1.661 \times 10^{-24} \text{ g}$$

We must account for the **natural abundance** of each isotope when we determine the **atomic mass** of an element

$$\begin{aligned} \text{Atomic mass} &= \sum_n (\text{fraction of isotope } n) \times (\text{mass of isotope } n) \\ &= (\text{fraction of isotope 1} \times \text{mass of isotope 1}) \\ &+ (\text{fraction of isotope 2} \times \text{mass of isotope 2}) \\ &+ (\text{fraction of isotope 3} \times \text{mass of isotope 3}) + \dots \end{aligned}$$

☞ Naturally occurring chlorine consists of 75.77% chlorine-35 atoms (mass 34.97 amu) and 24.23% chlorine-37 atoms (mass 36.97 amu). We can calculate its atomic mass:

☞ Boron is 19.9% ^{10}B and 80.1% ^{11}B . That is, ^{11}B is 80.1 percent abundant on earth. What is the atomic weight for Boron?

Periodic Table:

- Elements are arranged in order of increasing **atomic number**.
- The rows on the periodic chart are periods.
- Columns are groups.
- Elements in the same group have similar chemical properties.
- A repeating pattern of reactivities.

Periodic Table of the Elements lists all known elements according to their atomic numbers

Periodic Table of the Elements

Representative (main-group) elements

| | |
|----|--------------------|
| 1 | IA |
| 1 | H 1.0079 |
| 2 | IIA |
| 3 | Li 6.941 |
| 4 | Be 9.012 |
| 11 | Na 22.990 |
| 12 | Mg 24.305 |
| 19 | K 39.098 |
| 20 | Ca 40.078 |
| 37 | Rb 85.468 |
| 38 | Sr 87.62 |
| 55 | Cs 132.905 |
| 56 | Ba 137.327 |
| 87 | Fr 223 |
| 88 | Ra 226.025 |

Transition metals

| | | | | | | | | | |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|---------|
| 9 | | | | | | | | | |
| VIII B | | | | | | | | | |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn |
| 44.956 | 47.88 | 50.942 | 51.996 | 54.938 | 55.845 | 58.933 | 58.69 | 63.546 | 65.39 |
| 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd |
| 88.906 | 91.224 | 92.906 | 95.94 | 98 | 101.07 | 102.906 | 106.42 | 107.868 | 112.411 |
| 57 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 |
| La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg |
| 138.906 | 178.49 | 180.948 | 183.84 | 186.207 | 190.23 | 192.22 | 195.08 | 196.967 | 200.59 |
| 89 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 |
| Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn |
| 227.028 | 261 | 262 | 263 | 262 | 265 | 266 | 269 | 272 | 277 |

Representative (main-group) elements

| | | | | | |
|---------|--------|---------|--------|---------|--------|
| 13 | 14 | 15 | 16 | 17 | 18 |
| IIIA | IVA | VA | VIA | VIIA | VIIIA |
| 5 | 6 | 7 | 8 | 9 | 10 |
| B | C | N | O | F | He |
| 10.811 | 12.011 | 14.007 | 15.999 | 18.998 | 4.003 |
| 13 | 14 | 15 | 16 | 17 | 18 |
| Al | Si | P | S | Cl | Ar |
| 26.982 | 28.086 | 30.974 | 32.066 | 35.453 | 39.948 |
| 31 | 32 | 33 | 34 | 35 | 36 |
| Ga | Ge | As | Se | Br | Kr |
| 69.723 | 72.61 | 74.922 | 78.96 | 79.904 | 83.8 |
| 49 | 50 | 51 | 52 | 53 | 54 |
| In | Sn | Sb | Te | I | Xe |
| 114.82 | 118.71 | 121.76 | 127.60 | 126.905 | 131.29 |
| 81 | 82 | 83 | 84 | 85 | 86 |
| Tl | Pb | Bi | Po | At | Rn |
| 204.383 | 207.2 | 208.980 | 209 | 210 | 222 |
| 113 | 114 | 115 | 116 | 117* | 118 |
| Uut | Uuq | Uup | Uuh | — | Uuo |

Lanthanides (rare earths)

| | | | | | | | | | | | | | |
|---------|---------|---------|---------|--------|---------|--------|---------|-------|--------|--------|---------|--------|---------|
| 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 |
| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
| 140.115 | 140.908 | 144.24 | 145 | 150.36 | 151.964 | 157.25 | 158.925 | 162.5 | 164.93 | 167.26 | 168.934 | 173.04 | 174.967 |
| 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 89 |
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |
| 232.038 | 231.036 | 238.029 | 237.048 | 244 | 243 | 247 | 247 | 251 | 252 | 257 | 258 | 259 | 262 |

Actinides

Key to box contents

| | |
|-----------|------------------------|
| 2 | ← Atomic number |
| He | ← Element symbol |
| 4.003 | ← Atomic mass (in amu) |

Key to box colors

| | |
|--|-----------------------------------------|
| | Representative (main-group) elements |
| | Transition metals |
| | Lanthanides (rare earths) and actinides |

* Element 117 is currently under review by IUPAC.

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Representative elements

| | | | | | | | | | | | | | | | | | |
|---------------|-----------------------|---------------------|--|--|--|--|--|--|--|--|----------|-----------------|----------|----------|------------|----------|-------------|
| 1 1A | | | | | | | | | | | | | | | | 18 8A | |
| 2 2A | | | | | | | | | | | 13 3A | 14 4A | 15 5A | 16 6A | 17 7A | 18 8A | |
| Alkali metals | Alkaline-earth metals | Transition elements | | | | | | | | | | No common names | | | chalcogens | Halogens | Noble gases |
| Alkali metals | Alkaline-earth metals | | | | | | | | | | | | | | chalcogens | Halogens | Noble gases |
| Alkali metals | Alkaline-earth metals | | | | | | | | | | | | | | chalcogens | Halogens | Noble gases |

- ✓ Atoms are neutral due to balanced numbers of protons and electrons.
- ✓ **Ions** are when this balance is not present. Either an electron is added or removed
- **Charges on Common Ions:**

Complete the following

| Element | # e lose or gain | charge of ion | symbol of ion | cation or anion |
|---------|---------------------|------------------|------------------|--------------------|
| Al | _____ | _____ | _____ | _____ |
| Cl | _____ | _____ | _____ | _____ |
| Ca | _____ | _____ | _____ | _____ |
| N | _____ | _____ | _____ | _____ |

For main group elements: atoms tend to have the same number of e⁻'s as nearest Group 8A atom. (Isoelectronic)

| 1A | 2A | 3A | 4A | 5A | 6A | 7A | 8A |
|-----------------|------------------|----|----|----|----|-----------------|----|
| H ⁺ | | | | | | H ⁻ | |
| Li ⁺ | | | | | | F ⁻ | |
| Na ⁺ | Mg ²⁺ | | | | | Cl ⁻ | |
| K ⁺ | Ca ²⁺ | | | | | Br ⁻ | |
| Rb ⁺ | Sr ²⁺ | | | | | I ⁻ | |
| Cs ⁺ | Ba ²⁺ | | | | | | |

Legend:
 Metals
 Transition metals
 Metalloids
 Nonmetals

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Now let's scale things up:

➤ **Molar mass**

- is the atomic mass expressed in grams.

OR

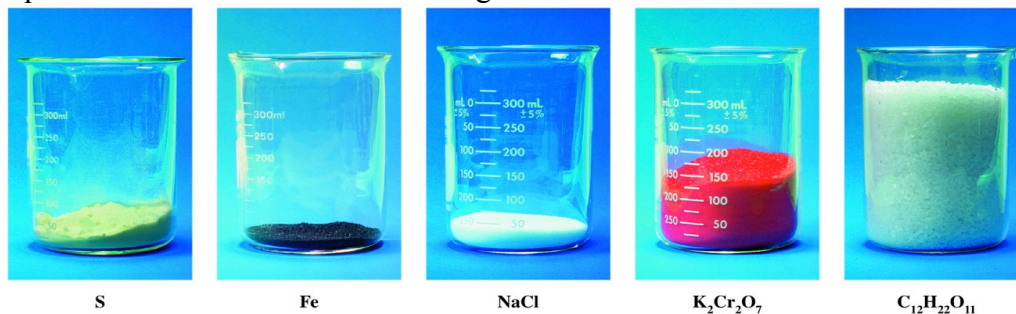
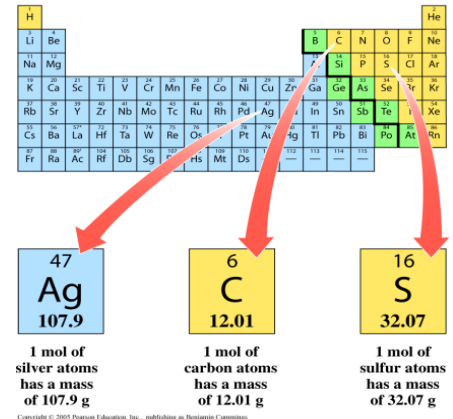
- The mass of one mole of substance in grams
- **Molar mass** = Mass of 1 mole of a substance.
 = Mass of 6.022×10^{23} molecules of a substance.
 = Molecular (formula) weight of substance in

grams.

- ▶ **Molecular weight:** The sum of atomic weights of all atoms in a molecule. Used for **covalent compounds**.

- ▶ **Formula weight:** The sum of atomic weights of all atoms in one formula unit of any compound. Used for **ionic compounds**.

- ▶ **Mole:** One mole of any substance is the amount whose mass in grams (molar mass) is numerically equal to its molecular or formula weight.



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Avogadro's number and the mole (A Chemist's "Dozen")

- **Avogadro's number:** The number of molecules or formula units in a mole. $N_A = 6.022 \times 10^{23}$
 ► 6.022×10^{23} marbles = (This many marbles would cover the earth to a depth of 50 miles)

26.98 g aluminum = 1 mol aluminum = 6.022×10^{23} Al atoms



12.01 g carbon = 1 mol carbon = 6.022×10^{23} C atoms



4.003 g helium = 1 mol helium = 6.022×10^{23} He atoms

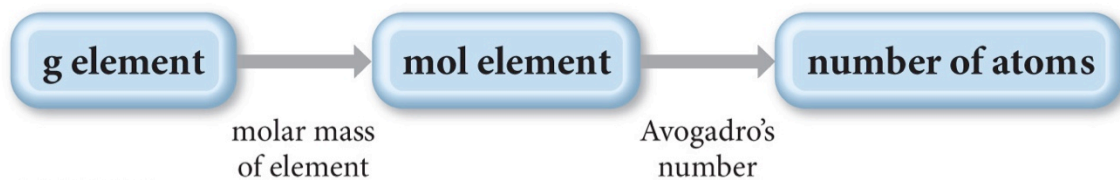


12 eggs =

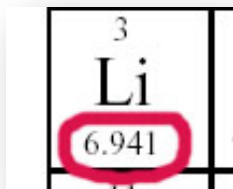
12 carbon atoms =

6.022×10^{23} eggs =

6.022×10^{23} carbon atoms =

Conceptual Plan

How many grams of lithium are in 3.50 moles of lithium?



How many moles of lithium are in 18.2 grams of lithium?



How many atoms of lithium are in 3.50 moles of lithium?