Unit Three: Atomic Structure & Chemical Quantities

Learning Targets	Textbook Section:
3.1) Explain how Democritus and John Dalton described atoms.	4.1
3.2) Identify instruments used to observe individual atoms.	4.1
3.3) Identify three types of subatomic particles.	4.2
3.4) Describe the structure of atoms according to the Rutherford model.	4.2
3.5) Explain what makes one element different from another.	4.3
3.6) Explain how isotopes of an element differ.	4.3
3.7) Calculate the atomic mass of an element.	4.3
3.8) Convert among the count, and mass of an element.	10.1
3.9) Explain how chemists count the number of atoms, molecules, or formula units of a substance.	10.1
3.10) Determine the molar mass of an element.	10.1
3.11) Describe how to convert the mass of a substance to the number of moles of a substance, and moles to mass.	10.2

Suggested Reading:

Chapter 4: Pages 100-119

Chapter 10: Pages 304-323

End of Chapter Practice:

Chapter 4: 35, 37, 38, 39, 40, 41, 42, 43, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 56, 57, 58, 61, 64, 66, 67, 69, 72

Chapter 10: 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65

Defining the Atom

All matter is composed of tiny fundamental particles, which we call atoms.

Atom = the smallest particle of an element that retains its identity in a chemical reaction.

* Atom comes from the word "Atomos" which is Greek for "indivisible".

The concept of the atom intrigued a number of early scientists. While these early scientists could not observe individual atoms, they still were able to propose ideas about the structure of atoms.

Democritus's Atomic Theory:

- 460 B.C. - 370 B.C.
- Greek philosopher
- First to suggest the existence of atoms
- His ideas lacked experimental support
- Reasoned that atoms were indivisible and indestructible.

The real nature of atoms and the connection between observable changes and events at the atomic level were not established for more than 2000 years after Democritus's death.

Dalton's Atomic Theory:

- 1766-1844
- English chemists and school teacher
- Through the use of experimental methods, Dalton transformed Democritus's ideas on atoms into a scientific theory.
- Studied the ratios in which elements combine in chemical reactions.
    - Based on the results of his experiments, Dalton formulated hypotheses and theories to explain observations - the result of his work was known as Dalton's Atomic Theory:
        1. All elements are composed of tiny indivisible particles called atoms.
        2. Atoms of the same element are identical. The atoms of any one element are different from those of any other element.
        3. Atoms of different elements can physically mix together or can chemically combine in simple whole-number ratios to form compounds.
        4. Chemical reactions occur when atoms are separated from each other, joined, or rearranged in a different combination.

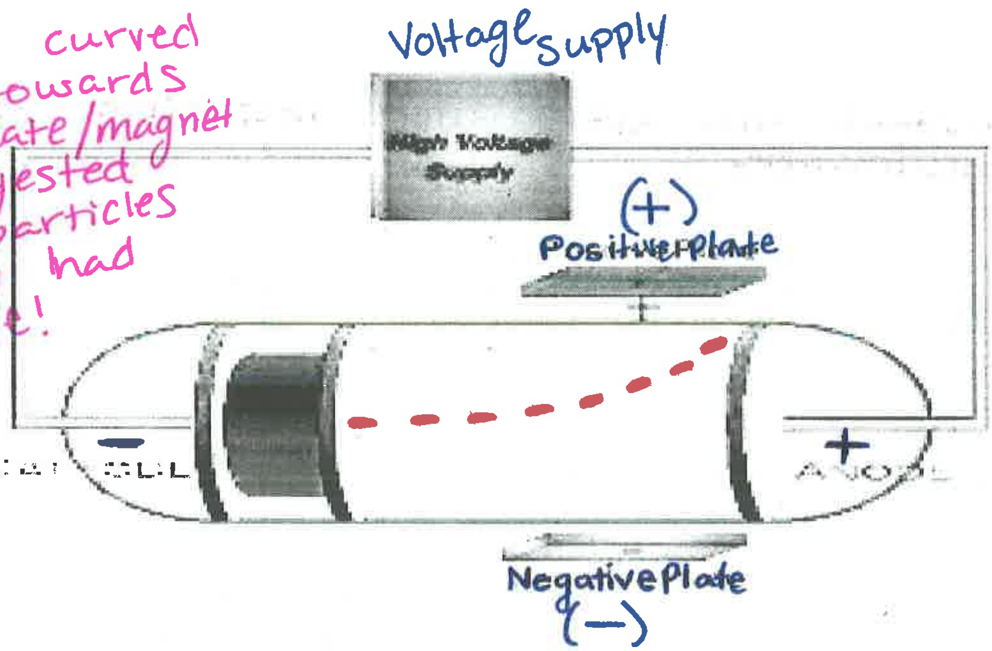
* Atoms of one element are never changed into an atom of another element due to a chemical reaction.

Other scientists have also contributed to our understanding of the atom:

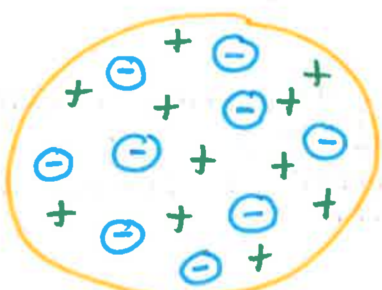
J.J. Thomson's Atomic Theory:

- 1897
- Changed the view of an atom through the discover of electrons !.
- Thomson's atomic theory suggested that the atom was made of smaller *subatomic* particles:
    - Electrons
    - Protons
- Thomson discovered that atoms emit negative particles when zapped with electricity.
    - In an experiment he found that a magnet changed the path of a cathode ray.

* The ray curved upwards towards the (+) plate/magnet which suggested that the particles in the ray had a (-) charge!



- Thomson believed:
    - An atom consisted of a sphere of positive charges with negatively charged electrons embedded in it.



* Known as the plum pudding model.

    - The positive and negative charges are equal (overall net charge is neutral).

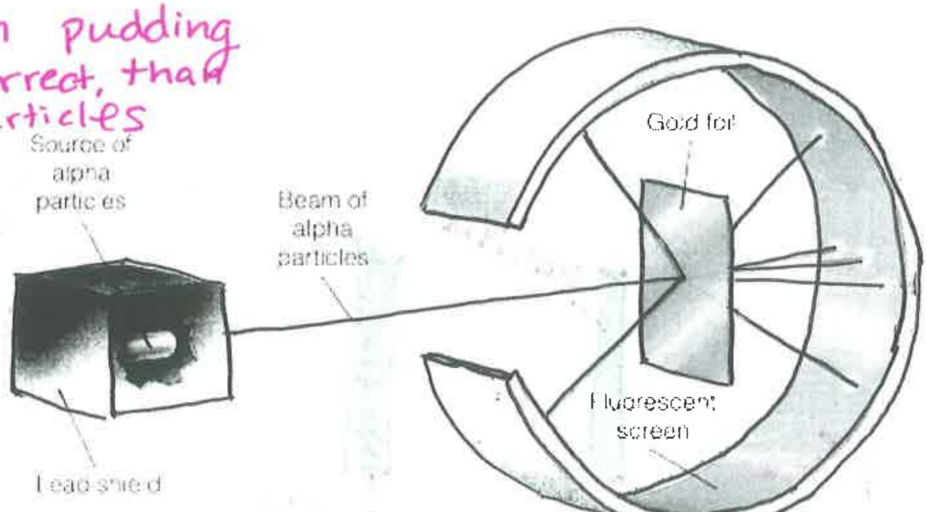
* He realized that the atom must have almost all of its mass concentrated at its center.

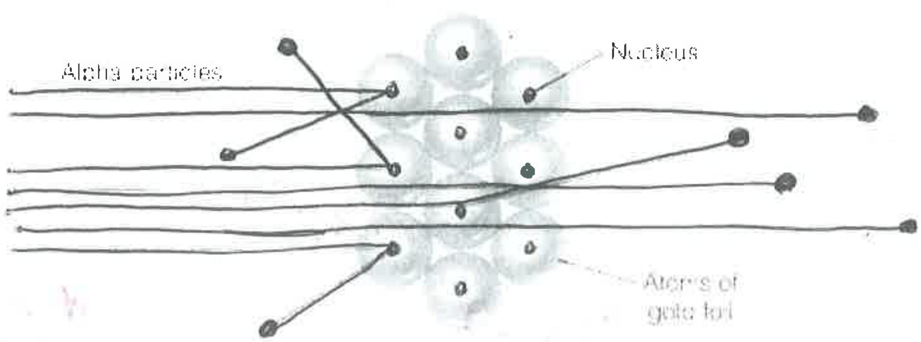
Ernest Rutherford:

- 1909
- Gold Foil Experiment
- Shot thin gold foil with alpha particles (big and positively charged). → two helium atoms stripped to their 2 electrons.
    - Rutherford concluded that atoms have a dense, positively charged nucleus (which balances the electrons negative charge).

* if the plum pudding model was correct, than the alpha particles should go right through.

however, some alpha particles were deflected or bounced back

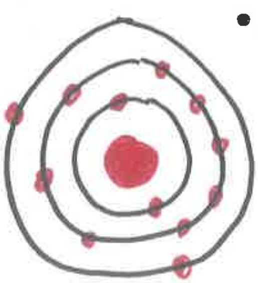




- While the nucleus contains virtually all of the mass of an atom, it only takes up one-billionth of the volume of the atom.
    - Much smaller particles (electrons) orbit the nucleus at a great distance.

Neils Bohr:

- 1913
- Refined Rutherford's model by proposing that electrons:
    - Orbit the nucleus without losing energy.
    - Could move only in fixed orbits of specific energies.
    - Electrons with low energy would orbit closer to the nucleus while electrons with high energy orbit further from the nucleus.

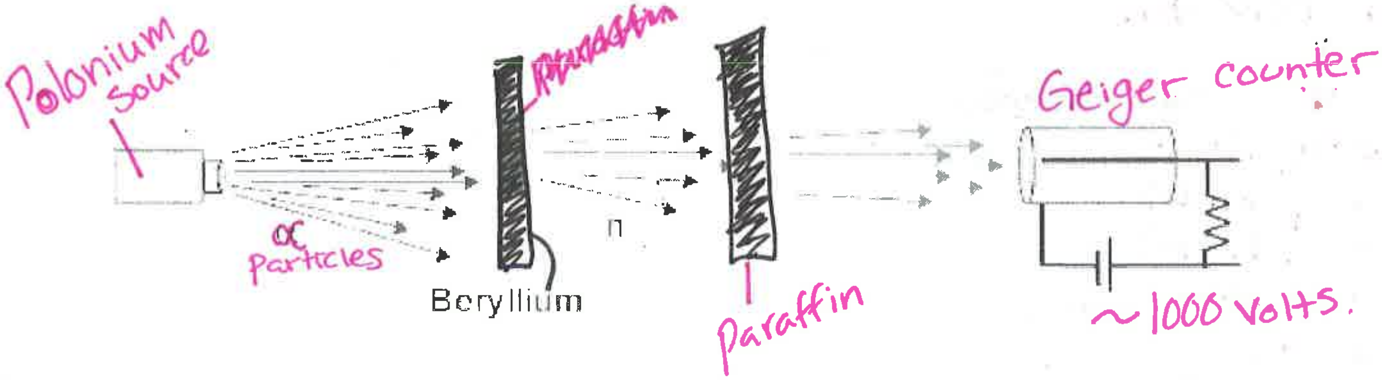


James Schrödinger:

- 1926
- Suggested that electrons were found in "probability clouds", not orbits.
    - The densest area of the cloud is where you have the greatest probability of finding the electron.

James Chadwick:

- 1932
- Identified the neutron.
    - Shot alpha particles at beryllium foil.
    - The electrically neutral particles ejected.
        - Provided evidence for the existence of neutrons in the nucleus.



Sizing Up the Atom

Atoms are incredibly small:

A pure copper coin the size of a penny contains 2×10^{22} atoms.

Earth's population is only about 7×10^{9} people.

* there is about 3×10^{12} times as many atoms in the coin as there are people on Earth!

If you were to line up 100,000,000 atoms of copper side by side how long do you think they would be?

Only 1 cm long!

Structure of the Nuclear Atom

Much of Dalton's atomic theory is still accepted today; however, there is one important change:

Atoms can be broken down into even smaller, more fundamental particles.

Atoms can be broken down into even smaller, more fundamental particles, called

Subatomic Particles

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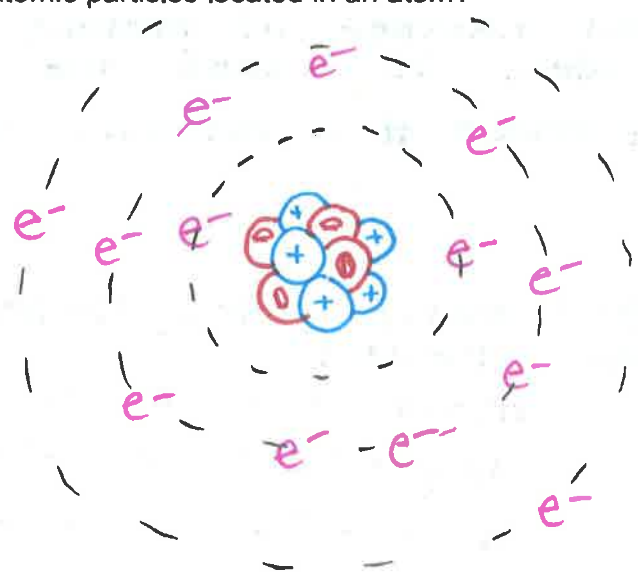
- The three kinds of subatomic particles are:
    - Electrons
    - Protons
    - Neutrons

Particle	Symbol	Charge	Actual Mass (amu)
Proton	p^+	+	1 amu
Neutron	n^0	0	1 amu
Electron	e^-	−	1/1838 amu

Where are all of the subatomic particles located in an atom?



* protons and neutrons make up the nucleus.

* Electrons are distributed around the nucleus and occupy almost all the volume of the atom.

Distinguishing Among Atoms:

If all atoms are made up of protons, neutrons, and electrons, how are atoms of hydrogen different than oxygen atoms?

Elements are different because they contain different numbers of protons.

H^{+} = 1 proton
C = 6 protons
Ne = 10 protons

Atomic Number

- Represents the number of protons in the nucleus of an atom of a specific element.
  - All hydrogen atoms have 1 proton
    ↳ the atomic number of hydrogen = 1
  - All oxygen atoms have 8 protons
    ↳ the atomic number of oxygen = 8

* Remember that atoms are electrically neutral.
↳ # of electrons (- charge) = # protons. (+ charge)

Mass Number

- Most of the mass of an atom is concentrated in its nucleus and depends on the number of protons and neutrons.
  - The total number of protons and neutrons in an atom is called the mass number.

Neutrons = mass # - atomic number

The composition of an atom can be represented in shorthand notation using the atomic number and mass number.

Mass #

$^{9}_{4}Be$

Atomic #

How many protons, electrons, neutrons are there?

Atomic # = # of protons
protons = # electrons
neutrons = mass# - atomic

Protons: 4

Electrons: 4

Neutrons: 9 - 4 = 5

Practice:
How many protons, electrons, and neutrons are in each atom?

$^{20}_{10}Ne$ protons = 10 electrons = 10 Neutrons ~~Atomic #~~ = 10

$^{108}_{47}Ag$ protons = 47 electrons = 47 Neutrons ~~Atomic #~~ = 61

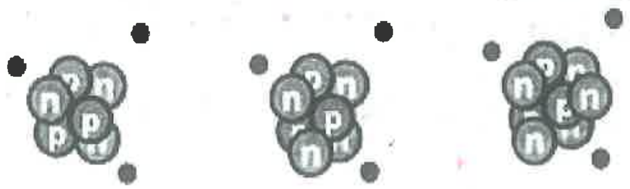
$^{23}_{11}Na$ Protons = 11 electrons = 11 Neutrons ~~Atomic #~~ = 12

$^{207}_{82}Pb$ protons = 82 electrons = 82 Neutrons ~~Atomic #~~ = 125

$^{32}_{16}S$ Protons = 16 electrons = 16 Neutrons ~~Atomic #~~ = 16

Isotopes
Atoms that have the Same number of protons but different numbers of neutrons.
If elements have different numbers of neutrons what else is different?
They will have different mass numbers!
* Mass # = protons + neutrons
Despite isotopes having different numbers of neutrons, isotopes are chemically alike because they have identical numbers of protons + electrons.

$^{6}_{3}Li$ $^{7}_{3}Li$ $^{8}_{3}Li$



Calculating Atomic Mass

The atomic mass of an element is a weighted average mass of the atoms in a naturally occurring sample of the element.

- A weighted average mass reflects both the mass and the relative abundance of the isotopes as they occur in nature.

Atomic mass is measured in atomic mass units (amu).

- One twelfth of the mass of a carbon-12 atom = 1 amu

To calculate the atomic mass of an element, multiply the mass of each isotope by its natural abundance, expressed as a decimal, and then add the products.

$$\text{Atomic mass} = \left(\left(\text{mass of isotope \#1}\right)\cdot\left(\text{natural abundance isotope \#1}\right)\right) + \left(\left(\text{mass of isotope \#2}\right)\cdot\left(\text{natural abundance isotope \#2}\right)\right)$$

* You should check your answers by looking at the mass of the most abundant isotope and compare it to your calculated answer.

Practice:

Find the atomic mass of a sample of chlorine atoms. Assume that 75.77% of the sample is Cl-35 and 24.23% of the sample Cl-37.

$$\begin{aligned}\text{Atomic mass} &= (35 \cdot 0.7577) + (37 \cdot 0.2423)\\ &= (26.4425) + (8.9651)\\ &= 35.4076\\ &= \boxed{35.41\text{ amu}}\end{aligned}$$

Carbon has two stable isotopes: carbon-12, which has a natural abundance of 98.89%, and carbon-13, which has a natural abundance of 1.11%. The mass of carbon-12 is 12.000 amu; the mass of carbon-13 is 13.003 amu. Find the atomic mass of carbon.

$$\begin{aligned}\text{Atomic mass} &= (12.000 \cdot 0.9889) + (13.003 \cdot 0.0111)\\ &= (11.8668) + (0.1443333)\\ &= \boxed{12.01\text{ amu}}\end{aligned}$$

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The Mole-A Measurement of Matter:

We can use conversion factors to convert between the count, mass and volume.

By count: 1 dozen apples: 12 apples

By mass: 1 dozen apples: 2.0 kg apples

By volume: 1 dozen apples: 0.20 bushel apples

Practice:

What is the mass of 90 average-sized apples if 1 dozen of the apples has a mass of 2.0 kg?

Number of Apples → dozens of apples → mass of apples

$$\left(\frac{90\ \cancel{\text{apples}}}{1}\right) \times \left(\frac{1\ \cancel{\text{dozen}}}{12\ \cancel{\text{apples}}}\right) \times \left(\frac{2.0\ \text{kg apples}}{1\ \cancel{\text{dozen}}}\right) = \boxed{15\ \text{kg apples}}$$

Assume 1 dozen oranges has a mass of 1.5 kg and that there are 14 orange slices in each orange. How many slices are in 6 kg of oranges? (ignore sig figs for this one).

Kg oranges → dozen → slices

$$\left(\frac{6\ \cancel{\text{kg}}\ \text{oranges}}{1}\right) \times \left(\frac{1\ \cancel{\text{dozen}}}{1.5\ \cancel{\text{kg}}}\right) \times \left(\frac{12\ \cancel{\text{oranges}}}{1\ \cancel{\text{dozen}}}\right) \times \left(\frac{14\ \text{slices}}{1\ \cancel{\text{orange}}}\right) =$$

$$\boxed{672\ \text{slices}}$$

What is a Mole?

* In Latin Mole = "a mass"

1 mole = 6.02×10^{23} particles.

* The amount of matter that contains as many objects as the number of atoms in 12g of C-12.

The term representative Particle refers to the species present in a substance, usually atoms, molecules, particles, or formula units.

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Converting Between Number of Particles and Moles:

Avogadro's Number

1 mol = 6.02×10^{23} particles

Practice:

Magnesium is a light metal used in the manufacture of aircraft, automobile wheels, and tools. How many moles of magnesium is 1.25×10^{23} atoms of magnesium?

$$\left(\frac{1.25\times10^{23}\ \cancel{\text{atoms}}\ \text{Mg}}{1}\right) \times \left(\frac{1\ \text{mol Mg}}{6.02\times10^{23}\ \text{Mg}\ \cancel{\text{atoms}}}\right) = \boxed{0.208\ \text{mol Mg}}$$

How many moles is 2.80×10^{24} atoms of silicon?

$$\left(2.80\times10^{24}\ \cancel{\text{atoms}}\ \text{Si}\right) \times \left(\frac{1\ \text{mol Si}}{6.02\times10^{23}\ \text{Si}\ \cancel{\text{atoms}}}\right) = \boxed{4.65\ \text{mol Si}}$$

How many moles is 2.17×10^{23} representative particles of bromine?

$$\left(2.17\times10^{23}\ \cancel{\text{particles Br}}\right) \times \left(\frac{1\ \text{mol Br}}{6.02\times10^{23}\ \cancel{\text{particles Br}}}\right) = \boxed{0.360\ \text{mol Br}}$$

Molar Mass

Quantities measured in grams are convenient for working in the laboratory, so chemists have converted the relative scale of masses of the elements in amu to a relative scale of masses in grams.

- The atomic mass of an element expressed in grams is the mass of a mole of the element.
  - The mass of one mole of an element is the Molar mass of the element.

molar mass = g/mol

To calculate the molar mass of a compound, find the number of grams of each element in one mole of the compound. Then add the masses of the elements in the compound.

Practice:

What is the molar mass of 1 molecule of SO_3?

S: (32.1 amu) × (1) = 32.1 amu

O: (16.0 amu) × (3) = 48.0 amu

$\boxed{80.1 \text{ amu}}$

Now Substitute the unit grams for amu to find molar mass!

$\boxed{80.1 \text{ g/mol}}$

The decomposition of hydrogen peroxide (H_2O_2) provides sufficient energy to launch a rocket. What is the molar mass of hydrogen peroxide?

H: (1.01 amu) × (2) = 2.02 amu

O: (16.0 amu) × (2) = 32.0 amu

$\boxed{34.02 \text{ amu}}$

Now Substitute the unit grams for amu to find molar mass!

$\boxed{34.02 \text{ g/mol}}$

Find the molar mass of PCl_3.

P: (30.97) × (1) = 30.97 amu

Cl: (35.45) × (3) = 106.35 amu

$\boxed{137.32 \text{ amu}}$

Now Substitute the unit grams for amu to find molar mass!

$\boxed{137.32 \text{ g/mol}}$

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Mole-Mass Relationship

Suppose you need a given number of moles of a substance for a laboratory experiment. How can you measure this amount?

To convert between moles and mass you must use the molar mass of an element or a compound. The conversion factors for these calculations are based on the relationship:

Molar mass = 1 mol

$$\left(\frac{\text{molar mass}}{1 \text{ mol}}\right) \text{ or } \left(\frac{1 \text{ mol}}{\text{molar mass}}\right)$$

Practice:

Items made out of aluminum, such as aircraft parts and cookware, are resistant to corrosion because the aluminum reacts with oxygen in the air to form a coating of aluminum oxide (Al_2O_3). This tough, resistant coating prevents any further corrosion. What is the mass, in grams, of 9.45 mol of aluminum oxide?

Known:
9.45 mol Al_2O_3

Unknown:
? g Al_2O_3

$\text{mol} \xrightarrow{\text{molar mass}} \text{grams}$

1) Find molar mass (mass of 1 mole)

Al: (26.98)(2) = 53.96
O: (16.00)(3) = + 48.00
101.96 g/mol

2) use conversion factor to solve.

$$\left(9.45 \cancel{\text{mol}}\ Al_2O_3\right)\left(\frac{101.96 \text{ g}}{1 \cancel{\text{mole}}\ Al_2O_3}\right) = \boxed{964 \text{ g } Al_2O_3}$$

Find the mass, in grams, of 4.52×10^{-3} mol $C_{20}H_{42}$.

mol → grams

Known:
4.52×10^{-3} mol $C_{20}H_{42}$

Unknown:
? g $C_{20}H_{42}$

1) Find molar mass (mass of 1 mole)

C: (12.01)(20) = 240.2
H: (1.01)(42) = + 42.42
282.62 g/mol

2) use conversion factor to solve.

$$\left(4.52 \times 10^{-3} \cancel{\text{mol}}\ C_{20}H_{42}\right)\left(\frac{282.62 \text{ g}}{1 \cancel{\text{mol}}\ C_{20}H_{42}}\right) = \boxed{1.28 \text{ grams } C_{28}H_{42}}$$

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When iron is exposed to air, it corrodes to form red-brown rust. Rust is iron (III) oxide (Fe_2O_3). How many moles of iron (III) oxide are contained in 92.2 g of pure iron (III) oxide?

grams → moles

Known: 92.2 g Fe_2O_3

Unknown: moles Fe_2O_3

1) Fe: (55.85)(2) = 111.70
O: (16.00)(3) = 48.00
\+ 159.70 g/mol

2) $\left(92.2\cancel{g}\ Fe_2O_3\right)\left(\frac{1\ mol\ Fe_2O_3}{159.7\ \cancel{g\ Fe_2O_3}}\right) = \boxed{0.577\ moles\ Fe_2O_3}$

Find the number of moles in 3.70 x 10^{-1} g of boron.

grams → moles

Known: 3.70×10^{-1} g B

Unknown: mol B

1) B: (10.81)(1) = 10.81 g/mol

2) $\left(3.70\times10^{-1}\ \cancel{g}\ B\right)\left(\frac{1\ mol\ B}{10.81\ \cancel{g}\ B}\right) = \boxed{0.0342\ mol\ B}$

Calculate the number of moles in 75.0 g of dinitrogen trioxide. (N_2O_3)

grams → moles

Known: 75.0 g N_2O_3

Unknown: mol N_2O_3

1) N: (14.01)(2) = 28.02
O: (16.00)(3) = 48.00
\+ 76.02 g/mol

2) $\left(75.0\ \cancel{g\ N_2O_3}\right)\left(\frac{1\ mol\ N_2O_3}{76.02\ \cancel{g\ N_2O_3}}\right) = \boxed{0.987\ mol\ N_2O_3}$

Converting Moles to Number of Atoms:

Propane is a gas used for cooking and heating. How many atoms are in 2.12 moles of propane (C_3H_8)

1) Analyze:

moles $\rightarrow$ molecules $\rightarrow$ atoms

2) Calculate:

$$\left(2.12 \text{ mol } C_3H_8\right) \times \left(\frac{6.02\times10^{23} \text{ molecules}}{1 \text{ mol } C_3H_8}\right) \times \left(\frac{11 \text{ atoms}}{1 \text{ molecule}}\right)$$

$$\boxed{1.40\times10^{25} \text{ atoms}}$$