19. An unknown gas sample contains only one of the compounds SO_3, CH_4, NF_3 or C_2H_2. If 1 molecule of the gas has a mass of 1.18×10^{-22} g, which type of molecule is contained in the sample?
20. General Saunders "Kamloops Fried Chicken" features the "Super Barrel", containing 2 mol of chickens (cut up and deep fried). How many drumsticks are contained in the Super Barrel? How many drumsticks, wings and thighs are in the Super Barrel altogether?

V.3. MULTIPLE CONVERSIONS BETWEEN MOLES, MASS, VOLUME AND NUMBER OF PARTICLES

Before jumping into the middle of some complex conversion factor calculations, a simple process must be understood: **how to find the number of atoms in a given number of molecules.**

This calculation simply involves counting the number of atoms in one molecule and then multiplying by the number of molecules involved.

EXAMPLE: **How many atoms are there in 5 molecules of $CuSO_4 \cdot 5H_2O$?**

1 molecule of $CuSO_4 \cdot 5H_2O$ contains 21 atoms (check this!)

$$\#\text{ of atoms} = 5\text{ molecules} \times 21\frac{\text{atoms}}{\text{molecule}} = \mathbf{105\ atoms}$$

EXAMPLE: **How many HYDROGEN atoms are there in 30 molecules of H_3PO_4?**

1 molecule of H_3PO_4 contains 3 atoms of H, so that:

$$\#\text{ of atoms of H} = 30\text{ molecules} \times \frac{3\text{ atoms of H}}{1\text{ molecule}} = \mathbf{90\ atoms}$$

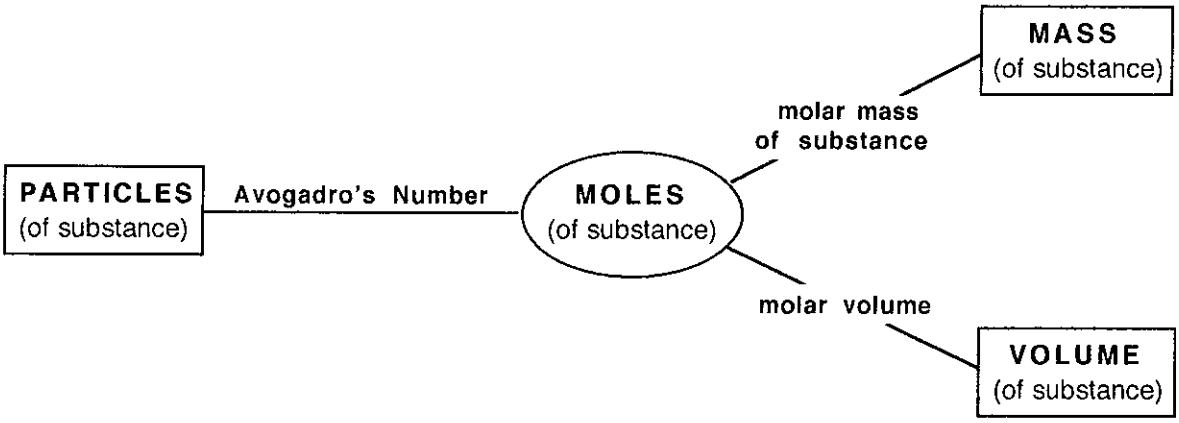
EXERCISE:

21. How many atoms are contained in 1 molecule of each of the following?
    (a) CH_3CO_2H (c) $(CH_3)_2CO$ (e) $C_{15}H_{22}O_6N_2S$
    (b) NH_4Cl (d) $(NH_4)_2SO_4$ (f) $Ni(H_2O)_4(NH_3)_2Cl_2$

The previous sections showed how to perform single–step conversions between moles and any of mass, volume, or number of particles. This section shows how to convert between mass and volume, number of particles and mass, and so on. The box below summarizes the conversion factors needed.

CONVERSION	CONVERSION FACTOR
MOLES ⟷ NUMBER OF PARTICLES	$\frac{6.02 \times 10^{23}\text{ particles}}{1\text{ mol}}$ or $\frac{1\text{ mol}}{6.02 \times 10^{23}\text{ particles}}$
MOLES ⟷ MASS	$\frac{(\textit{molar mass})\text{ g}}{1\text{ mol}}$ or $\frac{1\text{ mol}}{(\textit{molar mass})\text{ g}}$
MOLES ⟷ VOLUME (gases at STP)	$\frac{22.4\text{ L}}{1\text{ mol}}$ or $\frac{1\text{ mol}}{22.4\text{ L}}$
MOLECULES ⟷ ATOMS	$\frac{(\textit{atom count})\text{ atoms}}{1\text{ molecule}}$ or $\frac{1\text{ molecule}}{(\textit{atom count})\text{ atoms}}$

In the following calculations, keep the diagram below in mind. The mole is "central" to all conversions between mass, particles and volume: each calculation goes from **STARTING UNIT** to **MOLES** to **FINAL UNIT.**



EXAMPLE: **What is the volume occupied by 50.0 g of $NH_3(g)$ at STP?**

(Plan: Convert MASS to MOLES and then to VOLUME)

$$\text{volume} = 50.0\text{ g} \times \frac{1\text{ mol}}{17.0\text{ g}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{65.9\text{ L}}$$

Note: The first step involved converting the given amount (50.0 g) into moles.

EXAMPLE: **What is the mass of 1.00×10^{12} atoms of Cl?**

(Plan: Convert # OF ATOMS to MOLES and then to MASS)

$$\text{mass} = 1.00 \times 10^{12}\text{ atoms} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ atoms}} \times \frac{35.5\text{ g}}{1\text{ mol}} = \mathbf{5.90 \times 10^{-11}\text{ g}}$$

Note: The first step was to convert the given amount (1.00×10^{12} atoms) into moles.

EXAMPLE: **How many oxygen atoms are contained in 75.0 L of $SO_3(g)$ at STP?**

The calculation starts with a volume of SO_3 **MOLECULES,** converts to moles of SO_3 **MOLECULES,** then to the number of **MOLECULES** and finally the molecules are broken into the required number of **ATOMS.** Only if you are originally given a volume of ATOMS will you be able to go directly from moles of ATOMS to the number of ATOMS.

$$\#\text{ of O–atoms} = 75.0\text{ L} \times \frac{1\text{ mol}}{22.4\text{ L}} \times \frac{6.02 \times 10^{23}\text{ molecules}}{1\text{ mol}} \times \frac{3\text{ O–atoms}}{1\text{ molecule}}$$

$$= \mathbf{6.05 \times 10^{24}\text{ O–atoms}}$$

EXERCISES:

22. Find the mass, in grams, of each of the following.
    (a) 2×10^6 CO molecules
    (b) 1.25 L of $NH_3(g)$ at STP
    (c) 5×10^{14} N_2 molecules
    (d) 1 KOH molecule
    (e) 125 He atoms
    (f) 1 Ag atom
    (g) 4.15×10^{15} CH_4 molecules
    (h) 175 N atoms
    (i) 3.45 mL of $O_2(g)$ at STP
    (j) 1.00×10^8 L of $H_2(g)$ at STP

23. How many atoms are contained in each of the following?

(a) 1.00 mol of NH_4Cl	(e) 12 g of H_2O_2	(i) 125 g of CH_3Cl
(b) 2.5 mol of $O_3(g)$	(f) 55.0 mL of N_2O (g) at STP	(j) 8.30×10^{-4} mL of $BF_3(g)$ at STP
(c) 8.00 g of Fe	(g) 40.0 g of K	(k) 6.5×10^{-6} g of Kr
(d) 15.0 L of Ar(g) at STP	(h) 5.0 g of NaCl	(l) 9.5×10^{-3} g of NH_3

24. What volume at STP is occupied by each of the following?

(a) 16.5 g of $AsH_3(g)$	(e) 8.65×10^{21} molecules of $SO_2(g)$
(b) 5.65×10^{22} molecules of $POF_3(g)$	(f) 6.98×10^{15} atoms of Xe(g)
(c) 0.750 g of $O_3(g)$	(g) 28.4 mg of $H_2Te(g)$
(d) 9.04×10^{24} atoms of He(g)	(h) 3.25 kg of $C_2H_6(g)$

So far, the **volumes** used all refer to a gaseous substance at STP. If **DENSITY** is mentioned at any point in a problem, you should immediately recall that $d = m/V$ and understand the following points.

- **If the volume of a solid or liquid is the unknown,** calculate the volume from $V = m/d$. If the mass is not known, find the mass from the moles of the substance present. If the **molar volume** is the unknown, the molar mass is used in the calculation. **(Note that you cannot use the molar volume of a gas, 22.4 L, when calculating the volume of a liquid or solid.)**
- **If the density is unknown,** you will need both mass and volume to calculate: $d = m/V$. The mass can be found if the number of moles is known. If neither the mass nor volume is given, the density of a gas at STP can be found by using the mass of 1 mol and the volume of 1 mol at STP.
- **If the number of moles is unknown,** use the density and volume to calculate $m = d \cdot V$ and then convert the mass to moles.
- **If the molar mass of a gas at STP is unknown,** the data given is usually the mass and volume of a small amount of gas. In this case, find the density of the gas using the given mass and volume and then combine the density with the volume of 1 mol (22.4 L) to find the mass of 1 mol.

EXAMPLE: **What is the volume occupied by 3.00 mol of ethanol, $CH_3CH_2OH(l)$? (d = 0.790 g/mL)**

Note: Plan the calculation by working from the final unit to the starting unit. You are asked for the VOLUME, and since ethanol is not a gas you can't use "22.4 L". DENSITY relates VOLUME to MASS. In turn, MASS is related to the starting unit, MOLES.

$$\#\text{ of millilitres} = 3.00\text{ mol} \times \frac{46.0\text{ g}}{1\text{ mol}} \times \frac{1\text{ mL}}{0.790\text{ g}} = \mathbf{175\ mL}$$

EXAMPLE: **How many moles of Hg(l) are contained in 100 mL of Hg(l)? (d = 13.6 g/mL)**

(Plan: Convert VOLUME to MASS and then to MOLES)

$$\#\text{ of moles} = 100\text{ mL} \times \frac{13.6\text{ g}}{1\text{ mL}} \times \frac{1\text{ mol}}{200.6\text{ g}} = \mathbf{6.78\ mol}$$

EXAMPLE: **What is the density of $O_2(g)$ at STP?**

The calculation requires a suitable mass and volume. There are NO numbers given with which to work, but ... the term "STP" suggests a volume of 22.4 L for one mole of gas and the mass of one mole of $O_2(g)$ is 32.0 g.

$$\text{density} = \frac{m}{V} = \frac{\text{mass of 1 mol}}{\text{volume of 1 mol}} = \frac{32.0\text{ g}}{22.4\text{ L}} = \mathbf{1.43\ \frac{g}{L}}$$

(h) What is the molar mass of a molecule having a mass of 6.23×10^{-22} g?
(i) How many atoms are there in 3 molecules of $CH_3COOCH_2CH_3$?
(j) If 5.54 mL of carbon oxysulphide gas has a mass of 14.9 mg at STP, what is the molar mass of carbon oxysulphide?
(k) How many moles are in 125 g of PbC_2O_4?
(l) What is the molar mass of 0.546 mol of a substance having a mass of 73.1 g?
(m) How many moles are in 1.85×10^{24} molecules of CsI?
(n) What is the volume of 0.0694 mol of molybdenite, MoS_2, having a density of 4.80 g/mL?
(o) How many molecules are there in 5.00 g of $OF_2(g)$?
(p) What is the density of a calcite crystal, $CaCO_3$, if 0.0316 mol of $CaCO_3$ has a volume of 1.167 mL?
(q) How many moles of sugar, $C_{12}H_{22}O_{11}$, are contained in 100.0 mL of sugar? (density = 1.58 g/mL)
(r) What volume at STP is occupied by 275 mg of $GeH_4(g)$?
(s) What is the molar volume of mercury? (density = 13.55 g/mL)

V.4. PERCENTAGE COMPOSITION

The **PERCENTAGE COMPOSITION** is the percentage (by mass) of the species in a chemical formula.

EXAMPLE: **What is the percentage composition of CH_4?**

Assume there is 1 mol of the compound. molar mass = 16.0 g
total mass of C in compound = 12.0 g
total mass of H in compound = 4.0 g

$$\% \text{ of C in compound} = \frac{12.0\text{ g}}{16.0\text{ g}} \times 100\% = \mathbf{75.0\%}$$

$$\% \text{ of H in compound} = \frac{4.0\text{ g}}{16.0\text{ g}} \times 100\% = \mathbf{25.0\%}$$

EXAMPLE: **What is the percentage composition of H_2SO_4?**

Assume there is 1 mol of the compound. molar mass = 98.1 g
total mass of H in compound = 2 x 1.0 g = 2.0 g
total mass of S in compound = 1 x 32.1 g = 32.1 g
total mass of O in compound = 4 x 16.0 g = 64.0 g

$$\% \text{ of H in compound} = \frac{2.0\text{ g}}{98.1\text{ g}} \times 100\% = \mathbf{2.0\%}$$

$$\% \text{ of S in compound} = \frac{32.1\text{ g}}{98.1\text{ g}} \times 100\% = \mathbf{32.7\%}$$

$$\% \text{ of O in compound} = \frac{64.0\text{ g}}{98.1\text{ g}} \times 100\% = \mathbf{65.2\%}$$

EXAMPLE: **What is the percentage of water in $CuSO_4 \cdot 5H_2O$?**

Assume there is 1 mol of the compound. molar mass = 249.6 g
total mass of H_2O in compound = 5 x 18.0 g = 90.0 g

$$\% \text{ of } H_2O \text{ in molecule} = \frac{90.0\text{ g}}{249.6\text{ g}} \times 100\% = \mathbf{36.1\%}$$