A Partial Pressure and Stoichiometry Problems

Dr. Richard C. Sobers Jr.
Partial Pressure Problem

A Sample of zinc metal reacts completely with hydrochloric acid:

\[ \text{Zn(s)} + \text{2HCl(aq)} \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g) \]

The hydrogen gas is collected over water at 25°C. The gas volume is found to be 7.80L and the atmospheric pressure is 0.980atm. Calculate the mass of zinc metal that reacted.
Partial Pressure Problem

A Sample of zinc metal reacts completely with hydrochloric acid:

\[
\text{Zn(s)} + 2\text{HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g})
\]

Moles H\_2 \rightarrow Moles Zn

Moles Zn \rightarrow Mass Zn
Partial Pressure Problem

A Sample of zinc metal reacts completely with hydrochloric acid:

\[ \text{Zn(s)} + 2\text{HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g}) \]

How do we get moles of \( \text{H}_2 \)?

\[ \text{PV} = nRT \]

But first look at the experiment
Partial Pressure Problem

Gas is collected over water so that the atmosphere is not present. Water levels made equal so pressure inside is equal to that outside

But is the pressure inside due to hydrogen gas only?
Vapor Pressure Curve for Water

At 25°C:
\[ P_{\text{H}_2\text{O}} = 23.8 \text{mmHg} \]

Or
\[ P_{\text{H}_2\text{O}} = 0.0313 \text{atm} \]
Partial Pressure Problem

A Sample of zinc metal reacts completely with hydrochloric acid:

\[ \text{Zn}(s) + 2\text{HCl}(aq) \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g) \]

\[ 298\text{K} \]
\[ 7.80\text{L} \]

\[ P_{\text{H}_2} = 0.980\text{atm} - 0.313\text{atm} \]

\[ P_{\text{H}_2} = 0.949\text{atm} \]
Partial Pressure Problem

A Sample of zinc metal reacts completely with hydrochloric acid:

\[ \text{Zn(s)} + \text{2HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g}) \]

\[
\begin{align*}
P_{\text{H}_2}V &= n_{\text{H}_2}RT \\
T &= 298\text{K} \\
V &= 7.80\text{L} \\
P_{\text{H}_2} &= 0.949\text{atm} \\
R &= 0.08206\text{L\cdot atm\cdot mol}^{-1}\text{K}^{-1} \\
(0.949)(7.80) &= n(0.08206)(298) \\
n_{\text{H}_2} &= 0.303\text{moles}
\end{align*}
\]
Partial Pressure Problem

A Sample of zinc metal reacts completely with hydrochloric acid:

\[ \text{Zn}(s) + 2\text{HCl}(aq) \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g) \]

\[ \text{mol} \text{H}_2 \left( \frac{1 \text{ mol Zn}}{1 \text{ mol } \text{H}_2} \right) \left( \frac{65.39 \text{ g Zn}}{1 \text{ mol Zn}} \right) = 19.8 \text{ g Zn} \]
Stoichiometry with Gases
Moles and Volumes of Gas

Quantity (# moles) of gas A

Use PV = nRT

Or Use Molar Volume of Gas

Volume (# L) of gas A

At STP, 1 mol of a gas has a volume of 22.4L

If you know the molar volume at other pressure and temperature conditions then you can use that.
For example: The combustion of propane

\[ \text{C}_3\text{H}_8(\text{g}) + 10\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g}) \]

What volume of carbon dioxide is produced at STP if 0.500L of propane at 50.0psi and 25.0°C is combusted?
Combustion of Propane

\[ \text{C}_3\text{H}_8(g) + 10\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 4\text{H}_2\text{O}(g) \]

- **Quantity** (# moles)
  - \text{C}_3\text{H}_8
  - \text{CO}_2

- **Volume** (# L)
  - \text{C}_3\text{H}_8
  - \text{CO}_2

Use mole ratio

PV = nRT or Molar Volume
Combustion of Propane

Volume → moles of propane: \( PV = nRT \)

\[ C_3H_8(g) + 10O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \]

25.0\(^\circ\)C
0.500L
50.0psi

\[ T_{\text{prop}} = 298K \quad V_{\text{prop}} = 0.500L \quad P_{\text{prop}} = 3.40\text{atm} \]

\[ n_{\text{prop}} = \frac{PV}{RT} = 0.0695\text{mol} \]
Combustion of Propane

Moles Propane $\rightarrow$ Moles Carbon dioxide

$$\text{C}_3\text{H}_8(\text{g}) + 10\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g})$$

$$n_{\text{prop}} = 0.0695 \text{ mol}$$

$$0.0695 \text{ mol C}_3\text{H}_8 \left( \frac{3 \text{ mol CO}_2}{1 \text{ mol C}_3\text{H}_8} \right) = 0.209 \text{ mol CO}_2$$
Combustion of Propane

Volume → moles of carbon dioxide:

\[ \text{C}_3\text{H}_8(\text{g}) + 10\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g}) \]

\[ n_{\text{CO}_2} = 0.209\text{mol} \]
\[ T = 273\text{K} \quad \text{STP} \]
\[ P = 1.00\text{atm} \]

Could use PV = nRT:

\[ T = 273\text{K} \]
\[ n = 0.209\text{mol} \]
\[ P = 1.00\text{atm} \]
Combustion of Propane

Volume → moles of carbon dioxide:

\[ \text{C}_3\text{H}_8(\text{g}) + 10\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g}) \]

\[ n_{\text{CO}_2} = 0.209\text{mol} \]

Could also use the molar volume at STP (22.4L/mol):

\[ 0.209 \text{ mol CO}_2 \left( \frac{22.4 \text{ L CO}_2}{1 \text{ mol CO}_2} \right) = 4.68 \text{ L CO}_2 \]
Volume Ratios of Gases

The stoichiometric ratio applies to gas volumes if the gases are at the same temperature and pressure. This is the law of Guy-Lusaaac.

\[
C_3H_8(g) + 10O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)
\]

What volume of carbon dioxide gas at STP is produced if 0.500L (measured at STP) of propane are combusted?

\[
0.500 \text{ L } C_3H_8 \left( \frac{3 \text{ L } CO_2}{1 \text{ L } C_3H_8} \right) = 1.50 \text{ L } CO_2
\]
Volume Ratios of Gases

Quantity (# moles) of gas A

PV = nRT or Molar Volume

Volume (# L) of gas B

Stoichiometric Ratio

Stoichiometric Ratio (both at same T and P)

Quantity (# moles) of gas B

PV = nRT or Molar Volume

Volume (# L) of gas B
Volume Ratios of Gases

Back to this problem: The combustion of propane

\[ \text{C}_3\text{H}_8(\text{g}) + 10\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g}) \]

What volume of carbon dioxide is produced at STP if 0.500L of propane at 50.0psi and 25.0°C is combusted?

Can we use volume ratios instead of mole ratios?
Volume Ratios of Gases

Back to this problem: The combustion of propane

\[ \text{C}_3\text{H}_8(g) + 10\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 4\text{H}_2\text{O}(g) \]

298K        273K
3.40atm     1atm
0.500L      \( V=? \)

Can we use volume ratios instead of mole ratios?

Yes - first calculate volume of propane if at STP!
Volume Ratios of Gases

Volume (298K, 3.40atm) → Volume (STP) of propane:

\[
\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2}
\]

For propane:

\[T_1 = 298K \quad P_1 = 3.40atm \quad T_2 = 273K \quad P_2 = 1atm\]

\[V_1 = 0.500L \quad n_1 = n_2 \quad V_2 = ??\]

\[
\frac{(3.40atm)(0.500L)}{298K} = \frac{(1atm)V_2}{273K}
\]

\[V_2 = 1.56L\]
Volume Ratios of Gases

Volume propane (STP) → Volume CO$_2$ (STP):

C$_3$H$_8$(g) + 10O$_2$(g) → 3CO$_2$(g) + 4H$_2$O(g)

1.55 L
STP

V=??
STP

\[
1.56 \text{ L C}_3\text{H}_8 \left( \frac{3 \text{ L CO}_2}{1 \text{ L C}_3\text{H}_8} \right) = 4.68 \text{ L CO}_2
\]