## Measurable Property and Moles


Mass for $(\mathrm{s})$ and (l)

Volume of solution for (aq)

Volume of gas for (g)


Molar mass


Moles of pure substance
Molarity


3 ways


Moles of solute

Moles of gas

Conversion between moles
and volume of gas

- Using molar volume at STP (only for STP, which is rare)
- Using the Ideal Gas Equation

$$
n=\frac{P V}{R T} \quad V=\frac{n R T}{P}
$$

- R as a conversion factor

$$
\begin{gathered}
\frac{\mathrm{K} \cdot \mathrm{~mol}}{8.3145 \mathrm{~L} \cdot \mathrm{kPa}} \\
\text { or } \frac{8.3145 \mathrm{~L} \bullet \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{~mol}} \\
\frac{\mathrm{~K} \cdot \mathrm{~mol}}{0.082058 \mathrm{~L} \cdot \mathrm{~atm}}
\end{gathered} \text { or } \frac{0.082058 \mathrm{~L} \cdot \mathrm{~atm}}{\mathrm{~K} \cdot \mathrm{~mol}}
$$

## Standard Temperature and Pressure (STP) and Molar Volume

- Common: $0^{\circ} \mathrm{C}(273.15 \mathrm{~K})$ and 1 atm

$$
\frac{V}{n}=\frac{R T}{P}=\frac{\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{k} \mathrm{~Pa} \mathrm{a}}{\mathrm{~K} \cdot \mathrm{~mol}}\right)(273.15 \mathrm{~K})}{101.325 \mathrm{k} \mathrm{Ka}}=\left(\frac{22.414 \mathrm{~L}}{1 \mathrm{~mol}}\right)_{\mathrm{STP}}
$$

- Correct: $0^{\circ} \mathrm{C}(273.15 \mathrm{~K})$ and 1 bar (100 kPa)

$$
\frac{V}{n}=\frac{R T}{P}=\frac{\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{~mol}}\right)(273.15 \mathrm{~K})}{100 \mathrm{kPa}}=\left(\frac{22.711 \mathrm{~L}}{1 \mathrm{~mol}}\right)_{\mathrm{STP}}
$$

## Equation Stoichiometry



Start here when volume of solution is given.
Volume of solution 1
Molar mass 1
(coeffficient 2) mol 2
(coeffficient 1) mol 1
$\xrightarrow{\text { This is the core of any }}$ equation stoichiometry problem.
or $n=\frac{P V}{R T}$
Volume of gas 1 at $P_{1} \& T_{1}$

Start here when volume of gas is given.


Volume of gas 2 at $P_{2} \& T_{2}$

## Example 1

Iron is combined with carbon in a series of reactions to form pig iron, which is about $4.3 \%$ carbon. The first step in this process is the reaction of carbon with oxygen to form carbon monoxide. For this reaction, what is the maximum volume of carbon monoxide at 105 kPa and $35^{\circ} \mathrm{C}$ that could form from the conversion of $8.74 \times 10^{5} \mathrm{~L}$ of oxygen at 99.4 kPa and $27^{\circ} \mathrm{C}$ ?


## Example 1

The first step in this process is the reaction of carbon with oxygen to form carbon monoxide. For this reaction, what is the maximum volume of carbon monoxide at 105 kPa and $35^{\circ} \mathrm{C}$ that could form from the conversion of $8.74 \times 10^{5} \mathrm{~L}$ of oxygen at 99.4 kPa and $27^{\circ} \mathrm{C}$ ?

- Conversion from units of one substance to units of another substance, both involved in a chemical equation, so it's equation stoichiometry.
- Write a balanced equation.

$$
2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO}
$$

## Example 1

For this reaction, what is the maximum volume of carbon monoxide at 105 kPa and $35^{\circ} \mathrm{C}$ that could form from the conversion of $8.74 \times 10^{5} \mathrm{~L}$ of oxygen at 99.4 kPa and $27^{\circ} \mathrm{C}$ ?

$$
2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO}
$$

- Convert from the units of substance 1 you have to moles substance 1.

$$
\mathrm{n}_{\mathrm{O}_{2}}=\frac{P V}{R T}=\frac{99.4 \mathrm{kPa}\left(8.74 \times 10^{5} \mathrm{~L}\right)}{\left(\frac{8.3145 \mathrm{E} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{~mol}}\right)(300 \mathrm{~K})}=3.48 \times 10^{4} \mathrm{~mol} \mathrm{O}_{2}
$$

## Example 1

For this reaction, what is the maximum volume of carbon monoxide at 105 kPa and $35^{\circ} \mathrm{C}$ that could form from the conversion of $8.74 \times 10^{5} \mathrm{~L}$ of oxygen at 99.4 kPa and $27^{\circ} \mathrm{C}$ ?

$$
\begin{aligned}
& 2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO} \\
& \mathrm{n}_{\mathrm{O}_{2}}= \frac{P V}{R T}=\frac{99.4 \mathrm{kPa}\left(8.74 \times 10^{5} \mathrm{~L}\right)}{\left(\frac{8.3145 \mathrm{E} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{~mol}}\right)(300 \mathrm{~K})}
\end{aligned}
$$

- Convert from moles of substance 1 to moles substance 2.
$? \mathrm{~mol} \mathrm{CO}=3.48 \times 10^{4} \mathrm{mot}_{2}\left(\frac{2 \mathrm{~mol} \mathrm{CO}}{1 \mathrm{~mol}_{2}}\right)=6.96 \times 10^{4} \mathrm{~mol} \mathrm{CO}$


## Example 1

For this reaction, what is the maximum volume of carbon monoxide at 105 kPa and $35^{\circ} \mathrm{C}$ that could form from the conversion of $8.74 \times 10^{5} \mathrm{~L}$ of oxygen at 99.4 kPa and $27^{\circ} \mathrm{C}$ ?

$$
2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO}
$$

? $\left.\mathrm{mol} \mathrm{CO}=3.48 \times 10^{4}{\mathrm{~mol} \mathrm{O}_{2}}^{\left(\frac{2 \mathrm{~mol} \mathrm{CO}}{1 \mathrm{~mol}_{2}}\right.}\right)=6.96 \times 10^{4} \mathrm{~mol} \mathrm{CO}$

- Convert from the moles of substance 2 to units of substance 2 that you want.

$$
\mathrm{V}_{\mathrm{CO}}=\frac{n R T}{P}=\frac{6.96 \times 10^{4} \mathrm{mot}\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{mot}}\right) 308 \mathrm{~K}}{105 \mathrm{kPa}}=1.70 \times 10^{6} \mathrm{~L} \mathrm{CO}
$$

## Example 1

For this reaction, what is the maximum volume of carbon monoxide at 105 kPa and $35^{\circ} \mathrm{C}$ that could form from the conversion of $8.74 \times 10^{5} \mathrm{~L}$ of oxygen at 99.4 kPa and $27^{\circ} \mathrm{C}$ ?

$$
2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO}
$$

- Or unit analysis, using R as a conversion factor.
$? \mathrm{LCO}=8.74 \times 10^{5} \mathrm{~L} \mathrm{O}_{2}$
$? \mathrm{LCO}=8.74 \times 10^{5} \mathrm{~L} \mathrm{O}_{2}\left(\frac{\mathrm{~K} \cdot \mathrm{~mol}}{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}\right)$
$? \mathrm{LCO}=8.74 \times 10^{5} \mathrm{~L}_{2}\left(\frac{\mathrm{~K} \cdot \mathrm{~mol}}{8.3145 \mathrm{~L} \cdot \frac{\mathrm{kPa}}{\mathrm{EPa}}}\right)\left(\frac{99.4 \mathrm{kPa}}{300 \mathrm{~K}}\right)$
? $\mathrm{L} \mathrm{CO}=8.74 \times 10^{5}$ Ł $\Theta_{2}\left(\frac{\mathrm{~K} \cdot \mathrm{~mol}}{8.3145 \mathrm{~L} \cdot \frac{\mathrm{k} P \mathrm{~Pa}}{}}\right)\left(\frac{99.4 \frac{\mathrm{KPa}}{3}}{300 \mathrm{~K}}\right)\left(\frac{2 \mathrm{~mol} \mathrm{CO}}{1 \mathrm{~mol} \Theta_{2}}\right)$


## Example 1

For this reaction，what is the maximum volume of carbon monoxide at 105 kPa and $35^{\circ} \mathrm{C}$ that could form from the conversion of $8.74 \times 10^{5} \mathrm{~L}$ of oxygen at 99.4 kPa and $27^{\circ} \mathrm{C}$ ？

$$
2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO}
$$

－Or unit analysis，using R as a conversion factor．

$$
\begin{aligned}
& ? \mathrm{LCO}=8.74 \times 10^{5} \mathrm{亡} \theta_{2}\left(\frac{\mathrm{~K} \cdot \mathrm{~mol}}{8.3145 亡 \cdot \mathrm{kPa}}\right)\left(\frac{99.4 \mathrm{kPa}}{300 \mathrm{~K}}\right)\left(\frac{2 \operatorname{mot~CO}}{1 \operatorname{mot} \theta_{2}}\right)\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{mot}}\right) \\
& ? \mathrm{LCO}=8.74 \times 10^{5} 亡 \theta_{2}\left(\frac{\mathrm{~K} \cdot \mathrm{~mol}}{8.3145 \mathrm{E} \cdot \mathrm{kPa}}\right)\left(\frac{99.4 \mathrm{kPa}}{300 \mathrm{~K}}\right)\left(\frac{2 \operatorname{mot~CO}}{1 \operatorname{mol} \theta_{2}}\right)\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{mot}}\right)\left(\frac{308 \mathrm{~K}}{105 \mathrm{kPa}}\right) \\
& ? \mathrm{LCO}=8.74 \times 10^{5} 亡 \theta_{2}\left(\frac{\mathrm{~K} \cdot \mathrm{~mol}}{8.3145 £ \cdot \mathrm{kPa}}\right)\left(\frac{99.4 \mathrm{kPa}}{300 \mathrm{~K}}\right)\left(\frac{2 \operatorname{mot~CO}}{1 \operatorname{mot} \theta_{2}}\right)\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{mot}}\right)\left(\frac{308 \mathrm{~K}}{105 \mathrm{kPa}}\right) \\
& \\
& =1.70 \times 10^{6} \mathrm{LCO}
\end{aligned}
$$

## Example 2

In the reaction of carbon with oxygen to form carbon monoxide, what minimum volume of oxygen at STP (273.15 K and 1 bar ) is necessary to convert 125 Mg of carbon to carbon monoxide?

$$
2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO}
$$



## Example 2

- In the reaction of carbon with oxygen to form carbon monoxide, what minimum volume of oxygen at STP (273.15 K and 1 bar ) is necessary to convert 125 Mg of carbon to carbon monoxide?

$$
2 \mathrm{C}+\mathrm{O}_{2} \rightarrow 2 \mathrm{CO}
$$

$$
\begin{aligned}
? \mathrm{~L} \mathrm{O}_{2} & =125 \mathrm{Mg} \ell\left(\frac{10^{6} \mathrm{~g}}{1 \mathrm{gg}}\right)\left(\frac{1 \mathrm{mot} \epsilon}{12.011 \mathrm{~g} \ell}\right)\left(\frac{1 \mathrm{mot} \theta_{2}}{2 \mathrm{mot} \epsilon}\right)\left(\frac{22.711 \mathrm{~L} \mathrm{O}_{2}}{1 \mathrm{mot}_{2}}\right)_{\text {STP }} \\
& =1.18 \times \mathbf{1 0}^{5} \mathbf{L ~ O}_{\mathbf{2}}
\end{aligned}
$$

$$
\begin{aligned}
? \mathrm{~L} \mathrm{O}_{2} & =125 \mathrm{Mg} E\left(\frac{10^{6} \mathrm{~g}}{1 \mathrm{gg}}\right)\left(\frac{1 \mathrm{mot} \mathrm{E}}{12.011 \mathrm{~g} \mathrm{E}}\right)\left(\frac{1 \mathrm{mot} \mathrm{O}_{2}}{2 \mathrm{mot} \mathrm{C}}\right)\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{~mol}}\right)\left(\frac{273.15 \mathrm{~K}}{1 \mathrm{bar}}\right)\left(\frac{1 \mathrm{bar}}{100 \mathrm{kPa}}\right) \\
& =1.18 \times \mathbf{1 0}^{5} \mathbf{L ~ O}_{\mathbf{2}}
\end{aligned}
$$

## Example 3

Sodium hypochlorite, NaOCl , found in household bleaches, can be made from a reaction using chlorine gas and aqueous sodium hydroxide:
$\mathrm{Cl}_{2}(g)+2 \mathrm{NaOH}(a q) \rightarrow \mathrm{NaOCl}(a q)+\mathrm{NaCl}(a q)+\mathrm{H}_{2} \mathrm{O}(l)$
What minimum volume of chlorine gas at 101.4 kPa and $18.0^{\circ} \mathrm{C}$ must be used to react with all the sodium hydroxide in 3525 L of 12.5 M NaOH ?


## Example 3

$$
\mathrm{Cl}_{2}(g)+2 \mathrm{NaOH}(a q) \rightarrow \mathrm{NaOCl}(a q)+\mathrm{NaCl}(a q)+\mathrm{H}_{2} \mathrm{O}(l)
$$

What minimum volume of chlorine gas at 101.4 kPa and $18.0^{\circ} \mathrm{C}$ must be used to react with all the sodium hydroxide in 3525 L of 12.5 M NaOH ?
? $\mathrm{LCl}_{2}=3525 \pm \mathrm{NaOH}$ sotm $\left(\frac{}{1 \mathrm{~L} \mathrm{NaOH} \text { sotn }}\right)$
? $\mathrm{L} \mathrm{Cl}_{2}=3525 \mathrm{~L} \mathrm{NaOH}$ solm $\left(\frac{12.5 \mathrm{~mol} \mathrm{NaOH}}{1 \mathrm{~L} \mathrm{NaOH} \text { soln }}\right)$
? $\mathrm{L} \mathrm{Cl}_{2}=3525 \mathrm{~L} \mathrm{NaOH} \mathrm{soltr}\left(\frac{12.5 \mathrm{~mol} \mathrm{NaOH}}{1 \mathrm{LNaOH} \text { sotn }}\right)\left(\frac{1 \mathrm{~mol} \mathrm{Cl}_{2}}{2 \mathrm{~mol} \mathrm{NaOH}}\right)$

## Example 3

$$
\mathrm{Cl}_{2}(g)+2 \mathrm{NaOH}(a q) \rightarrow \mathrm{NaOCl}(a q)+\mathrm{NaCl}(a q)+\mathrm{H}_{2} \mathrm{O}(l)
$$

What minimum volume of chlorine gas at 101.4 kPa and $18.0^{\circ} \mathrm{C}$ must be used to react with all the sodium hydroxide in 3525 L of 12.5 M NaOH ?

$$
\left.\begin{array}{rl}
? \mathrm{~L} \mathrm{Cl}_{2} & =3525 \mathrm{~L} \mathrm{NaOH} \text { sotr }\left(\frac{12.5 \mathrm{~mol} \mathrm{NaOH}}{1 \mathrm{~L} \mathrm{NaOH} \text { soln }}\right)\left(\frac{1 \mathrm{~mol} \mathrm{Cl}}{2}\right. \\
2 \mathrm{~mol} \mathrm{NaOH}
\end{array}\right)\left(\frac{8.3145 \mathrm{~L} \cdot \mathrm{kPa}}{\mathrm{~K} \cdot \mathrm{mot}}\right)
$$

