Week 10/Th: Units ‘25 & 26’ Gases

Unit 23,24: Structure & Orbitals
-- Molecular polarity
-- Molecular Shapes and Orbitals
-- Valence bond theory
-- sigma and pi bonds

Unit 25: Gases
-- properties of gases
-- ABC gas laws

Unit 26: Gas mixtures
-- D gas law, mixtures (solutions)
-- partial pressures

Unit 27: Kinetic Theory of Gases

Issues:
Why is this man playing with a pool of mercury?
http://www.marin.edu/~jim/photos/spain/spain2.html

Homework continues this week, due Saturday 8AM

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Review of variable quantities for gases: Four variables – P, T, V and amount (moles or mass)

Intensive … do not depend on size
Extensive … depend on size (extent)

Pressure is defined as the force per unit area and the definition comes directly from a simple experiment done by Torricelli about 250 years ago:

Closed ended tubes filled with Hg were stuck into a vat of Hg! They found a balancing height of Hg, independent of length, diameter, shape, etc. of the tube.

http://catalogue.museogalileo.it
Week 10/Th: Gas Variables: Pressure

\[ F_{\text{down}} = mg = F_{\text{up}} = F_{\text{atm}} \]

\[ F_{\text{down}} = \text{Volume} \times \rho_{\text{Hg}} g \]

\[ F_{\text{down}} = (\pi r^2 h) \rho_{\text{Hg}} g \]

\[ P \equiv \frac{F_{\text{atm}}}{A} = \frac{(\pi r^2 h) \rho_{\text{Hg}} g}{\pi r^2} = h \rho_{\text{Hg}} g \]

**TABLE 4.1 Pressure Units**

SI unit: pascal (Pa)
1 Pa = 1 kg·m\(^{-1}\)·s\(^{-2}\) = 1 N·m\(^{-2}\)

Conventional units*
1 bar = 10\(^5\) Pa = 100 kPa
1 atm = 1.01325 × 10\(^5\) Pa = 101.325 kPa

1 atm = 760 Torr
1 atm = 14.7 lb·inch\(^{-2}\) (psi)
Avogadro: Equal volumes of gas contain the same number of particles (at the same temperature & pressure).  \( V \propto n \)

Boyle: the pressure and volume of a fixed amount of gas are inversely proportional.  \( P \propto \frac{1}{V} \)
Charles: the volume and absolute temperature of a fixed amount of a gas are directly proportional. \( V \alpha T \)
Temperature is defined on a linear scale with two reference points, or a point and a slope:

Celsius A.K.A. Centigrade:
(a) melting point of ice (0 °C)
(b) boiling point of water at 1 atm (100 °C)

Kelvin or “thermodynamic” temperature:
(a) intercept that comes from the behavior of gases
(b) slope from the Celsius scale

Fahrenheit scale is not calibrated anymore.

"placing the thermometer in a mixture of sal ammoniac or sea salt, ice, and water a point on the scale will be found which is denoted as zero. A second point is obtained if the same mixture is used without salt. Denote this position as 30. A third point, designated as 96, is obtained if the thermometer is placed in the mouth so as to acquire the heat of a healthy man."

(D. G. Fahrenheit, Phil. Trans. (London) 33, 78, (1724)
The "ideal gas law"

\[ PV = nRT \]
Week 10/Th: Gas Law Questions in Notes

\[ PV = nRT \] 

For a fixed amount, i.e., number of moles:

\[ \frac{PV}{T} = nR \]

\[ \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3} = nR \]

Q1: 2.0 L of an ideal gas is heated from 50 to 150 °C under a constant pressure of 1.0 atm. What happens to the volume? [What is the final volume?]

Q2: To what value must the pressure be increased (at 150 °C) to reduce the volume back to 2.0L?
The mass density, mass per unit volume, can change but it is easily calculated from the Ideal Gas Equation:

\[ PV = nRT \]

\[ \frac{P}{RT} = \frac{n}{V} = \text{moles} \]

\[ \text{Moles/Volume} \] is a form of density

\[ \text{MM} \frac{P}{RT} = \text{MM} \frac{n}{V} \]

\[ \text{Molar Mass} \] is \textit{molar mass}

\[ \text{MM} \frac{P}{RT} = \frac{\text{mass}}{V} = \rho_{\text{GAS}} \]

\[ \text{mass/Volume} \] is more familiar density
Consider a mixture of two ideal gases (one is “A”mber and the other “B”lueberry)

\[ P_A = \frac{n_A RT}{V} \]
\[ P_B = \frac{n_B RT}{V} \]

Ideal gases will not react with one-another. Each gas exerts its own partial pressure.
Week 10/Th: Gas Laws: Partial Pressure

\[ P_{\text{Total}} = P_A + P_B = \frac{(n_A + n_B)RT}{V} \]

\[ \frac{P_A}{P_{\text{Total}}} = \frac{n_A RT}{(n_A + n_B)RT} = \frac{n_A}{n_A + n_B} \]

\[ \frac{P_B}{P_{\text{Total}}} = \frac{n_B RT}{(n_A + n_B)RT} = \frac{n_B}{n_A + n_B} \]

The *mole fraction* is another intensive variable plus we get another equation.

\[ \chi_A + \chi_B = 1 \]

\[ P_i = \chi_i P_{\text{Total}} \]
A 4.0L vessel contains 1.0 mole of He, 2.0 moles of N$_2$, and 2.0 moles of H$_2$ at a pressure of 10.0 atm. What is the partial pressure of N$_2$ in this vessel? Then 3.0 moles of N$_2$ are added to the same vessel without changing the temperature, what is the new partial pressure of N$_2$ and what is the (new) total pressure?

\[
P_{N_2} = \frac{n_{N_2}}{(n_{He} + n_{N_2} + n_{H_2})} P_{Total}
\]

\[
P_{N_2} = \frac{2.0 \text{ mol}}{2.0 + 2.0 + 2.0 \text{ mol}} \times 10.0 \text{ atm}
\]

\[
P_{N_2} = 4.0 \text{ atm}
\]
A 4.0L vessel contains 1.0 mole of He, 2.0 moles of N\(_2\), and 2.0 moles of H\(_2\) at a pressure of 10.0 atm. What is the partial pressure of N\(_2\) in this vessel? Then 3.0 moles of N\(_2\) are added to the same vessel without changing the temperature, what is the new partial pressure of N\(_2\) and what is the (new) total pressure?

\[
P_{N_2} = \frac{n_{N_2}}{(n_{He} + n_{N_2} + n_{H_2})} P_{Total}^{After}
\]
3) A mixture has 40g of He and 40g of O\textsubscript{2} at 2.0 atm pressure. What is the partial pressure of He in this mixture?

\[ P_{He} = \frac{n_{He}RT}{V} \]

\[ P_{He} = \frac{40 \text{ g}/40.026 \text{ mol} \times 1 \text{ atm}}{9.9989 \text{ mol} + 1.2525 \text{ mol}} = 1.88 \text{ atm} \]

\[ \texttt{But the temperature and volume aren’t given??} \]
2) Two gases mix and react, gases form as much product as possible. What is the final pressure? Assume constant temperature, notice that the volume is constant at 6 L after opening the valve.

**First:** open valve and gases mix, no reaction

\[
\begin{align*}
P_{\text{total}} &= P_{\text{NO}} + P_{\text{O}_2} + P_{\text{NO}_2} \\
&= 0.5 \text{ atm} \times \frac{4 \text{ L}}{6 \text{ L}} + 1.00 \text{ atm} \times \frac{2 \text{ L}}{6 \text{ L}} \\
&= \frac{2}{6} \text{ atm} + \frac{2}{6} \text{ atm} + 0
\end{align*}
\]

**Second,** Gases react: \(2 \text{ NO(g)} + \text{ O}_2 (g) \rightarrow 2 \text{ NO}_2 (g)\)

Initial \(P, (\text{const.} \ T, V)\) \(\frac{2}{6} \ \ \frac{2}{6} \ \ \ 0 \ \ \text{atm}\)

Limiting Reagent Problem …

Final \(P, (\text{const.} \ T, V)\) \(0 \ \ 1/6 \ \ 2/6 \)

\[
\begin{align*}
P_{\text{total}} &= P_{\text{NO}} + P_{\text{O}_2} + P_{\text{NO}_2} \\
&= 0 + \frac{1}{6} + \frac{1}{3} = \frac{3}{6} = \frac{1}{2} \text{ atm}
\end{align*}
\]