Key Questions

1. Taking a breath of He\((g)\) makes your voice sound like Mickey Mouse. Taking a breath of SF\(_6\)(\(g\)) makes your voice sound like Darth Vader. Explain the difference.

The pitch of your voice depends on the density of the gas you exhale. Helium has a very low density, so the sound has a higher frequency. With SF\(_6\), the reverse is true. With a much higher density, the vibrations produced by your vocal chords result in a sound with much lower frequency.

2. What is the density of methane gas (m.w. = 16.04 u) at 3.00 atm when the temperature is 32 °C?

Use \(PV = nRT\) to solve for \(V\) for 1 mole of methane, then divide that volume into the mass of one mole of methane, 16.04 g.

\[
V = \frac{nRT}{P} = \frac{(1.00 \text{ mol}) (0.08206 \text{ L·atm/K·mol}) (305 \text{ K})}{3.00 \text{ atm}} = 8.34_{28} \text{ L}
\]

\[
d = \frac{16.04 \text{ g}}{8.34_{28} \text{ L}} = 1.92 \text{ g/L}
\]

3. A 1.365-g sample of a pure, unknown gas in a 1.000-L vessel at 22.15 °C has a pressure of 965.4 torr. What is the molar mass of the gas?

First, convert the given data to units compatible with \(R = 0.08206 \text{ L·atm/K·mol}\).

\[
T = (22.15 + 273.15) \text{ K} = 295.30 \text{ K}
\]

\[
P = \left(\frac{965.4 \text{ torr}}{760.0 \text{ torr}}\right) \text{ atm} = 1.270 \text{ atm}
\]

Now calculate the number of moles in the sample:

\[
n = \frac{PV}{RT} = \frac{(1.270 \text{ atm})(1.000 \text{ L})}{(0.08206 \text{ L·atm/K·mol})(295.30 \text{ K})} = 0.05241 \text{ mol}
\]

Divide the given sample mass by this number of moles to calculate the molar mass:

\[
\text{m.w.} = \frac{1.365 \text{ g}}{0.05241 \text{ mol}} = 26.04 \text{ g/mol}
\]

(The gas is acetylene, \(\text{C}_2\text{H}_2\).)
4. A mixture containing 0.226 mol He, 0.342 mol Ne, and 0.128 mol Ar is confined in a 4.00-L vessel at 25 °C.
   i. What is the total pressure of the gas?
      
      \[ n = (0.226 + 0.342 + 0.128) \text{ mol} = 0.696 \text{ mol} \]
      
      \[ P = \frac{nRT}{V} = \frac{(0.696 \text{ mol})(0.0821 \text{ L} \cdot \text{atm/K} \cdot \text{mol})(298 \text{ K})}{(4.00 \text{ L})} = 4.25 \text{ atm} = 4.26 \text{ atm} \]
   
   ii. What are the mole fractions of all the gases in the mixture?
      
      \[ \chi_{\text{He}} = \frac{0.226}{0.696} = 0.324 \]
      \[ \chi_{\text{Ne}} = \frac{0.342}{0.696} = 0.491 \]
      \[ \chi_{\text{Ar}} = \frac{0.128}{0.696} = 0.184 \]
   
   iii. What is the partial pressure of each gas in the mixture?
      
      \[ p_{\text{He}} = (0.324)(4.25 \text{ atm}) = 1.38 \text{ atm} = 1.38 \text{ atm} \]
      \[ p_{\text{Ne}} = (0.491)(4.25 \text{ atm}) = 2.09 \text{ atm} = 2.09 \text{ atm} \]
      \[ p_{\text{Ar}} = (0.183)(4.25 \text{ atm}) = 0.783 \text{ atm} = 0.783 \text{ atm} \]
   
   iv. What is the sum of the partial pressures. How does it compare to the total pressure you calculated in part i. Explain any difference.
      
      \[ p_t = (1.38 + 2.09 + 0.783) \text{ atm} = 4.25 \text{ atm} \approx 4.26 \text{ atm} \]
      The slight difference is due to rounding.

5. Two gas tanks have the same volume. One containing \( \text{N}_2(g) \) at 25 °C has a pressure 25 atm. The other containing \( \text{CO}_2 \) at 0 °C has a pressure of 50 atm.
   i. Which vessel has more molecules of gas?
      
      For a fixed volume, the pressure depends upon both temperature and amount of gas. The temperature difference in this case is too small (298 K vs. 273 K) to account for the difference in pressures, so the difference in amounts must be the major cause. The tank of \( \text{CO}_2 \), therefore, contains more molecules.
   
   ii. In which tank is the root-mean-squared (rms) velocity of molecules higher?
      
      Rms velocity is directly proportional to the square root of the absolute temperature and inversely proportional to the square root of molar mass. The nitrogen sample has the higher temperature and the lower molar mass, so its molecules are moving faster.
   
   iii. In which tank is the average kinetic energy of the molecules higher?
      
      Average kinetic energy is directly proportional to temperature, independent of the molar mass. Therefore, the nitrogen sample has the higher kinetic energy.
6. If 3.62 mL of an unknown gas effuses in the same time it takes 6.91 mL of argon (at. wt. = 39.95 u) from identical apparatus, what is the molar mass of the unknown gas?

The amounts that effuse in a given time are proportional to the rates. Therefore,

\[
\frac{r_{As}}{r_X} = \frac{6.91 \text{ mL}}{3.62 \text{ mL}} = 1.91 = \sqrt{\frac{M_X}{39.95 \text{ g/mol}}}
\]

Squaring both sides and solving for \(M_X\),

\[
3.65 = \frac{M_X}{39.95 \text{ g/mol}}
\]

\(M_X = (3.65)(39.95 \text{ g/mol}) = 146 \text{ g/mol}
\)

(The gas is SF\(_6\).)