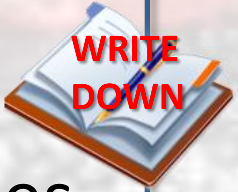
Graham's Law

The Rate of Effusion

Effusion

- A helium balloon will fall in a couple days because the helium escapes from the balloon slowly through microscopic holes.
- The passage of the gas through microscopic holes is called *effusion.*
- As the temperature increases, molecules move faster, and the effusion rate increases.



Temperature and Effusion

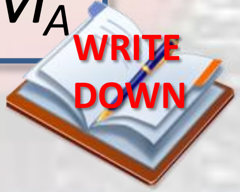
- Temperature is the average kinetic energy of the molecules.
- Kinetic energy (K.E.) is related to both the mass(*m*) and speed (*v*) of the molecules as follows: $K.E. = \frac{1}{2} mv^2$.
- For two gases at the same temperature, only the masses effect the relative rate of effusion.

Deriving an Equation

- *For gas A and gas B at the same temperature:*
  - $T_A = T_B$ so $\frac{1}{2}m_A v_A^2 = \frac{1}{2}m_B v_B^2$
  - For any molecule, the ratio of molar mass (*M*) to molecular mass (*m*) is Avogadro's number, so $\frac{M_A}{m_A} = \frac{M_B}{m_B}$. *M* can be substituted for *m* above.
  - $\frac{1}{2}M_A v_A^2 = \frac{1}{2}M_B v_B^2$
  - This can be reduced to $M_A v_A^2 = M_B v_B^2$
  - As a result $\frac{v_A^2}{v_B^2} = \frac{M_B}{M_A}$ and $\frac{v_A}{v_B} = \frac{\sqrt{M_B}}{\sqrt{M_A}}$

The Equation for Graham's Law

- The equation that was just derived, $\frac{v_A}{v_B} = \frac{\sqrt{M_B}}{\sqrt{M_A}}$, is Graham's Law.
- It is usually stated: $$\frac{\textit{rate of effusion of A}}{\textit{rate of effusion of B}} = \frac{\sqrt{M_B}}{\sqrt{M_A}}$$



- Graham's law makes it possible to:
  - Calculate the ratio of effusion rates for two gases.
  - Calculate the molar mass of an unknown gas if the ratio of its diffusion rate to a known gas is measured.

Calculating Relative Effusion Rates

- How does the rate of effusion of fluorine compare to the rate of effusion of chlorine?

$$\frac{\textit{rate of effusion of } F_2}{\textit{rate of effusion of } Cl_2} = \frac{\sqrt{71.0}}{\sqrt{38.0}} = 1.37$$

Calculating Molar Mass Based on Effusion Rates

- What is the molar mass of a gas that effuses at 1.37 times the speed of oxygen?
  - $\dfrac{\textit{rate of effusion of A}}{\textit{rate of effusion of } O_2} = \dfrac{\sqrt{M_{O_2}}}{\sqrt{M_A}}$
  - $1.37 = \dfrac{\sqrt{32.0\ g/mol}}{\sqrt{M_A}}$ *so* $(1.37)^2 = \dfrac{32.0\ g/mol}{M_A}$
  - $M_A = \dfrac{32.0\ g/mol}{(1.37)^2} = 17.0\ g/mol$