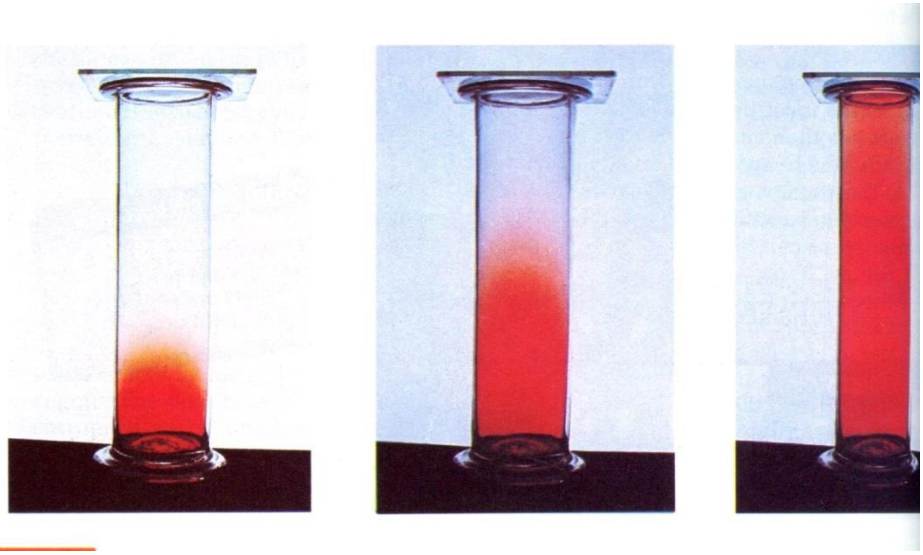
Chemistry Lecture #75: Graham's Law

Diffusion is the spontaneous spreading of particles throughout a given volume until they are uniformly distributed. Gas particles will diffuse through a container if they are concentrated in one area.

For example, if volatile liquid bromine is poured into a container, and the container is covered, the bromine will evaporate into a gas. The gas will spread or diffuse through the container until the container is filled with gas from top to bottom.

The pictures below show the brown bromine gas as it diffuses up the container.



Gas particles that are heavy move slowly. Gas particles that are light move quickly.

A heavy gas particle moves slowly.

A light gas particle moves quickly.

Graham's law states that the relative rates at which two gases under identical conditions of temperature and pressure will diffuse vary inversely as the square roots of the molar masses of the gases. Roughly speaking, it means heavy gas particles have a slower speed or velocity and light gas particles have a faster velocity.

Mathematically, Graham's law is expressed as

$$\frac{v(l)}{v(h)} = \sqrt{\frac{m(h)}{m(l)}}$$

v(l) = velocity of the lighter gas
v(h) = velocity of the heavier gas

m(h) = molar mass of the heavier gas
m(l) = molar mass of the lighter gas

Tip on calculating molar masses of gaseous elements: if an element is part of Br I N Cl H O F, it exists diatomically. Thus, the formula for bromine is Br_2, the formula for iodine is I_2, the formula for nitrogen is N_2 and so on.

Also, remember that group 8A elements (He, Ne, Ar, Kr, Xe, and Rn) are gases that exist monotomically; they do not form bonds with other atoms.

How much faster does nitrogen gas diffuse compared to radon gas?

Solution

Nitrogen is part of Br I N Cl H O F, so its molecular formula is N_2. The molar mass of nitrogen is 2 x 14.0 = 28.0 g.

Radon is a group 8A element whose molar mass is 222 g. Radon is the heavier gas.

N_2 (lighter)	Rn (heavier)
m(l) = 28.0 g	m(h) =222 g
v(l) = ?	v(h) = ?

Since we want the relative speed of nitrogen (how much faster it moves), we want to solve for v(l)/v(h).

$$\frac{v(l)}{v(h)} = \sqrt{\frac{m(h)}{m(l)}} = \sqrt{\frac{222}{28.0}} = 2.82$$

Thus, v(l)/v(h) = 2.82. Nitrogen moves 2.82 times faster than radon gas.

If helium gas diffuses at 0.0500 m/s, how fast does iodine gas diffuse at the same temperature and pressure?

Solution

I_2 - heavier	He - lighter
m(h) = 254 g/mole	m(l) = 4.00 g/mole
v(h) = ?	v(l) = 0.0500 m/s

$$\frac{v(l)}{v(h)} = \sqrt{\frac{m(h)}{m(l)}}$$

$$\frac{0.0500}{v(h)} = \sqrt{\frac{254}{4.00}}$$

$$\frac{0.0500}{v(h)} = \sqrt{63.5}$$

$$\frac{0.0500}{v(h)} = \frac{7.9686}{1}$$ cross multiply

$$7.9686\ v(h) = 0.0500\ (1)$$

$$v(h) = \frac{0.0500\ (1)}{7.9686}$$

$$v(h) = 6.27 \times 10^{-3}\ \text{m/s}$$

The rate of effusion of an unknown gas is 2.92 times faster than that of NH_3. What is the approximate molar mass of the unknown gas?

Solution

If the unknown gas is faster, it is the lighter gas. It moves 2.92 times faster than the heavier NH_3 gas. This means that if NH_3 has a velocity of 1.00 m/s, then the unknown gas has a velocity of 2.92 m/s. NH_3 has a molar mass of 17.0 g/mole. Thus,

Unknown gas/lighter gas
v(l) = 2.92 m/s
m(l) = ?

NH_3/heavier gas
v(h) = 1.00 m/s
m(h) = 17.0 g/mole

$$\frac{v(l)}{v(h)} = \sqrt{\frac{m(h)}{m(l)}}$$

$$\frac{2.92}{1.00} = \sqrt{\frac{17.0}{m(l)}}$$

$$\frac{(2.92)^2}{(1.00)^2} = \frac{17.0}{m(l)}$$

$$\frac{8.5264}{1.00} = \frac{17.0}{m(l)}$$

$$(8.5264)\ m(l) = (17.0)\ (1.00)$$

$$m(l) = \frac{(17.0)\ (1.00)}{8.5264}$$

$m(l)$ = 1.9938 or 1.99 g/mole. This is close to the molar mass of H_2 gas.