Question: An unknown gas is found to effuse at a rate that is 1.864 times faster than Br2 at the same temperature. What is the identity of the gas?

A. Cl_2
B. Ar
C. NO_2
D. CH_4
E. O_2

Hint: Based on the information given, is the unknown heavier or lighter than Br_2?

Concepts: To answer this question we need to understand what is meant by the effusion of a gas and the mathematical relationship between two gases' rates of effusion.

Connections:

What is given? We are given the relationship between the effusion rates of bromine and an unknown gas sample.

What do I want to know? We want to know the identity of the unknown gas.

We are also told that the conditions for the measurement of effusion are the same for both gases.

To determine the identity of the gas we need to understand what effusion is. Effusion is explained in Lesson 12.2 and including a visualization that is helpful in understanding the process. The rate of effusion is the speed at which a gas moves through a tiny hole in the container holding the sample in a given amount of time. Because the conditions for the measurement of the effusion rates of the gases is the same (things like T, P, size of the opening will all be the same), the rates of effusion will only be related to the molar mass of the gas. The relationship between two rates of effusion for two gases is expressed mathematically as the ratio of two rates being inversely proportional to the square roots of their molar masses. This is known as Graham's Law:

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

For this relationship to work the r_1 and r_2 must be just that: rates. A rate is NOT a time. It is defined as an amount in a given length of time. Therefore, 4s is a time. 1 L is an amount. 1L/4s or 0.25 L/s is a rate. Graham's Law of Effusion must use rates!

Be sure you fully understand the information above before moving on to the solution below.

Solution: To solve this problem, we need to know how to effectively utilize Graham's Law.

We know that the unknown sample effuses at a rate that is 1.864 times faster than bromine (Br_2). We can summarize this by writing

rate of effusion of unknown = $r_x = 1.864 \times r_{Br_2}$

Rearranging this becomes $\frac{r_x}{r_{Br_2}} = 1.864$

Graham's Law tells us that the ratio of the rates is related to the molar masses of the gases:

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

If r_1 is the rate of effusion of our unknown = r_x, and r_2 is the rate of effusion of Br_2, then M_2 will the molar mass of Br_2 and M_x will be the molar mass of our unknown.

$$\frac{r_x}{r_{Br_2}} = 1.864 = \frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

We know the molar mass of bromine: 159.81 g/mol. The only thing we don't know is the molar mass of the unknown. We can solve for it and determine the identity of the unknown gas.

$$\frac{r_x}{r_{Br_2}} = 1.864 = \sqrt{\frac{159.81}{M_x}}$$

$$(1.864)^2 = \left(\sqrt{\frac{159.81}{M_x}}\right)^2$$

$$3.47 = \frac{159.81}{M_x}$$

$$(3.47)M_x = 159.81$$

$$M_x = 45.99\ g/mol$$

The only answer choice with a molar mass of 46 g/mol is C, nitrogen dioxide (NO_2).