Gases have no definite volume. They spread out, or diffuse, and occupy all the space available to them. This spreading of gases is called diffusion. A gas will diffuse even if another gas is present in the same space. The molecules of gases are far enough apart to allow other gas molecules to fit in between.

Gases diffuse at different rates. Graham's law states that, under equal conditions of temperature and pressure, gases diffuse at rates inversely proportional to the square roots of their molecular masses. Mathematically this may be stated as:

\[
\frac{R_1}{R_2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}
\]

The term rate implies that something happens in a given period of time. The rate of diffusion of a gas is the distance its molecules travel per unit time. In an equal period of time, the distances traveled by molecules of two different gases are related by:

\[
\frac{D_1}{D_2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}
\]

This inverse relationship indicates that the distance traveled by the heavier gas (gas with greater molecular mass) will be less than that traveled by the lighter gas in the same period of time.

In this experiment, two gases (HCl and NH₃) will be introduced simultaneously into opposite ends of a glass tube. At the point where the two gases meet inside the tube, a chemical reaction will occur that produces a white powder. The equation for the reaction is:

\[
\text{HCl} \ (g) + \text{NH}_3 \ (g) \Rightarrow \text{NH}_4\text{Cl} \ (s)
\]

Using the point where the powder forms as a reference point, the distance traveled by each gas can be measured. By comparing the ratio of these distances with the ratio of the square roots of the known molecular masses of the two gases, Graham's law can be verified.
PURPOSE
Verify Graham's law by measuring the distances traveled during the same period of time by two different gases of known molecular mass.

EQUIPMENT
- glass tubing, 10 mm x 60 cm
- metric ruler
- dropper pipets (2)
- safety goggles
- cotton swabs
- lab apron or coat
- wax marking pencil

MATERIALS
- HCl(con.)
- NH₃ (ammonia)
- acetone (for drying test tubes)

SAFETY
Handle both the concentrated HCl and the concentrated NH₃ solutions with great care. Avoid getting any of either of these chemicals on your skin.

PROCEDURE
1. Obtain a 50-cm length of glass tubing (10 mm internal diameter). Make sure it is completely dry. Lay the tubing on your bench.
2. Place one cotton swab in each end of the tubing. Using a marking pencil, mark the glass to indicate the position of the end of each swab as illustrated in Figure 1.
3. Remove the cotton swabs from the tubing. Mark the stem of one of the swabs with the marker for purposes of identification. Using dropper pipettes, place about five drops of concentrated HCl on the unmarked cotton swab and five drops of concentrated NH₃ • H₂O solution on the marked cotton swab.
CAUTION: Handle these chemicals with care. They can cause painful burns if they come in contact with the skin.

4. Immediately and simultaneously insert the moistened ends of the cotton swabs into opposite ends of the tube, to the lines previously marked.

5. After several minutes, a white ring will form where the gases HCl and NH₃ meet inside the tube to form the white compound NH₄C₁ (ammonium chloride). Mark the point on the tube where the white ring is formed.

6. Remove the cotton swabs, rinse them with water, and dispose of them as instructed by your teacher.

7. Measure the distance traveled by each gas.

8. Rinse the tubing with water. It may be dried by rinsing it with acetone. CAUTION: Acetone is highly flammable.

9. The procedure can be repeated if time permits.

**OBSERVATIONS AND DATA**

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Average of 2 trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance traveled by NH₃</td>
<td>________</td>
<td>________</td>
<td>________</td>
</tr>
<tr>
<td>Distance traveled by HCl</td>
<td>________</td>
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</tr>
</tbody>
</table>

Molecular masses are:  
NH₃ = 17  
HCl = 36.5
CALCULATIONS:

1. Calculate the ratio: \[ \frac{\text{Distance NH}_3}{\text{Distance HCl}} \]  
   Trial 1

2. Calculate the ratio: \[ \frac{\text{Distance NH}_3}{\text{Distance HCl}} \]  
   Trial 2

CONCLUSION AND QUESTIONS

1. How well did the two ratios compare? Taking the experimental error into consideration, was graham’s by this experiment?

2. Compare gases with liquids and solids according to the kinetic molecular theory.

3. How could this experiment be used to find the molecular mass of an unknown gas?

4. It is known that the density of a gas at STP is its molecular mass divided by 22.4 L. Based in this information, state Graham’s law in an alternative form.