CHEM 355
EXPERIMENT 7

Viscosity of gases: Estimation of molecular diameter

Expressed most simply, the viscosity of a fluid (liquid or gas) relates to its resistance to flow. The viscosity of a gas is determined in particular by the rate of transfer of the flow momentum from faster moving layers (laminas) to slower ones. The so-called transpiration methods provide a convenient way of measuring gas viscosities. In the approach used here, the flow rate of the gas (which is inversely proportional to its viscosity) is recorded by monitoring the evacuation of a vessel through a capillary tube under a constant pressure differential.

Figure 1. Experimental set up

The rate of gas flow along the tube can be calculated using Poiseuille's equation.

$$\frac{dV}{dt} = \frac{(P_1^2 - P_2^2) \cdot \pi \cdot r^4}{16 \cdot \eta \cdot l \cdot P} \qquad (1)$$

where $\frac{dV}{dt}$ is volume rate of flow

P_1, P_2 are pressure at the high and low pressure ends of the capillary

r is radius of the capillary tube

l is length of the capillary tube

P is pressure at which the volume is measured (here P_1)

From the constant pressure differential used in this experiment and the known dimensions of the capillary, the evacuation rate data measured can be used to calculate absolute values of the gas viscosities.

Note: Due to the r^4 term in (Eqn.1) minor irregularities in the radius of the capillary can have a significant effect on the viscosity values determined. It is therefore better to calibrate the dimensions of the capillary by measuring the volume flow rate for a reference gas of known viscosity.

In terms of the kinetic theory of gases, these values can be further interpreted on a molecular level. The gas kinetic expression for the viscosity η of a gas undergoing laminar flow is the following:

$$\eta = \frac{1}{3} \cdot m \cdot \lambda \cdot \bar{u} \cdot n \qquad (2)$$

Where;

m= mass of a molecule

λ = mean free path

c= mean molecular speed

N = number of molecules per unit volume (number density)= N/V

The mean free path for an ensemble of molecules having a Maxwell distribution of molecular velocities is;

$$\lambda = \frac{V}{\sqrt{2} \cdot \pi \cdot d^2 \cdot N} \qquad (3)$$

Where;

N = number of molecules per unit volume (number density)

d = hard sphere collision diameter

Substituting (3) into (2) the following is obtained;

$$\eta = \frac{m \cdot \bar{u}}{3\sqrt{2} \cdot \pi \cdot d^2} \qquad (4)$$

Mean molecular speed is;

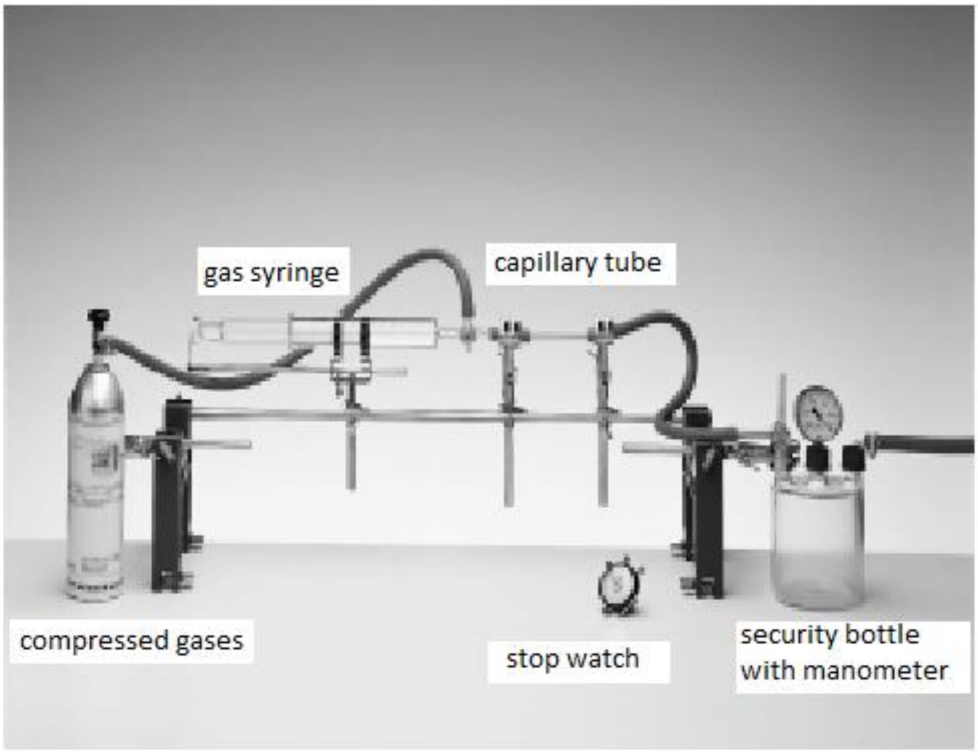
$$\bar{u} = \sqrt{\frac{8 \cdot k \cdot T}{\pi \cdot m}} \qquad (5)$$

Substituting (5) into (4) and rearranging leads to;

$$d^2 = \frac{2}{3\eta} \cdot \sqrt{\frac{k \cdot T \cdot m}{\pi^3}} \qquad (6)$$

Purpose: The aim of this experiment is to measure the viscosities of the various gases. The kinetic theory of gases is used to determine molecular diameter of the gases used in this experiment.

Apparatus and Chemicals:



Gas syringe (100 ml, with 3-way cock)

Capillary tube (glass, d_i = 0.15 mm, l = 100 mm)

Security bottle with manometer

Water jet pump

Stop watch

Weather monitor, LCD

Vernier caliper

Fine control valve

Compressed gases (nitrogen, carbon dioxide, argon and helium)

Procedure:

1. Set up the experiment as shown in Fig. 1, but **first ensure that the syringe plunger stop is positioned to prevent the plunger from being fully removed from the barrel**.
2. Disconnect the syringe from the flow line, turn the 3-way stopcock to connect the gas bottle to the syringe and fill the syringe with nitrogen gas (about 50 mL). Turn the stopcock to connect the syringe to the exit tube and lightly press the plunger to expel nitrogen. Turn the stopcock to reconnect the syringe to the gas bottle. Rinse the syringe in this manner three times, then leave it filled and connected to the gas line.
3. Switch on the pump and evacuate the flow line up to the stopcock by pumping for ten minutes.
4. Once the flow line is evacuated and while the pump is still on, turn the stopcock to connect the syringe to the flow line. Start the stopwatch when the syringe volume has reached 50 ml and stop it as soon as the syringe is empty. Record the elapsed time for evacuation of the syringe. Record also the ambient laboratory temperature and atmospheric pressure.
5. Repeat the measurement twice. Carry out the same rinsing and measuring procedure for the gases carbon dioxide, helium, and argon.

Treatment of Data:

1. From the constant pressure differential used in this experiment and the known dimensions of the capillary, the evacuation rate data measured can be used to calculate absolute values of the gas viscosities. Calculate η for different nitrogen, carbon dioxide, argon and helium using Poiseuille's equation (Eq. 1).

2. Calculate collision diameter of each gas using equation 6.

Questions:

1. Compare the theoretical and experimental values and discuss the possible source of errors.

2. Discuss the temperature and pressure effect on viscosity of gases.

3. Explain the reason why evacuation time of Ar is higher than the other gases.

DATA SHEET

Experiment 7. Viscosity of gases: Estimation of molecular diameter

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Group Number: Date:

Student name:

Assistant name and signature:

Table 1.

Gas	Evacuation time/s	Temperature/ °C
N_2		
CO_2		
Ar		
He		

Evacuation volume: 50 mL

P_1=

P_2=

Capillary radius, r = 0.075 mm

Capillary lenght, l = 98 mm