Determination of the molar mass of a liquid

(Item No.: P3010501)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Chemistry	University	General Chemistry	Molar Mass	Determination of the molar mass of a liquid

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	10 Minutes	10 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

ideal and ordinary gases, equations of state for ideal gases, gas volumetry, determination of molar masses according to the vapour density method (Victor Meyer)

Overview

Short description

Principle

The molar mass of a liquid is to be determined by evaporating a liquid at constant temperature and pressure, and measuring the volume of vapour formed using a calibrated gas syringe.

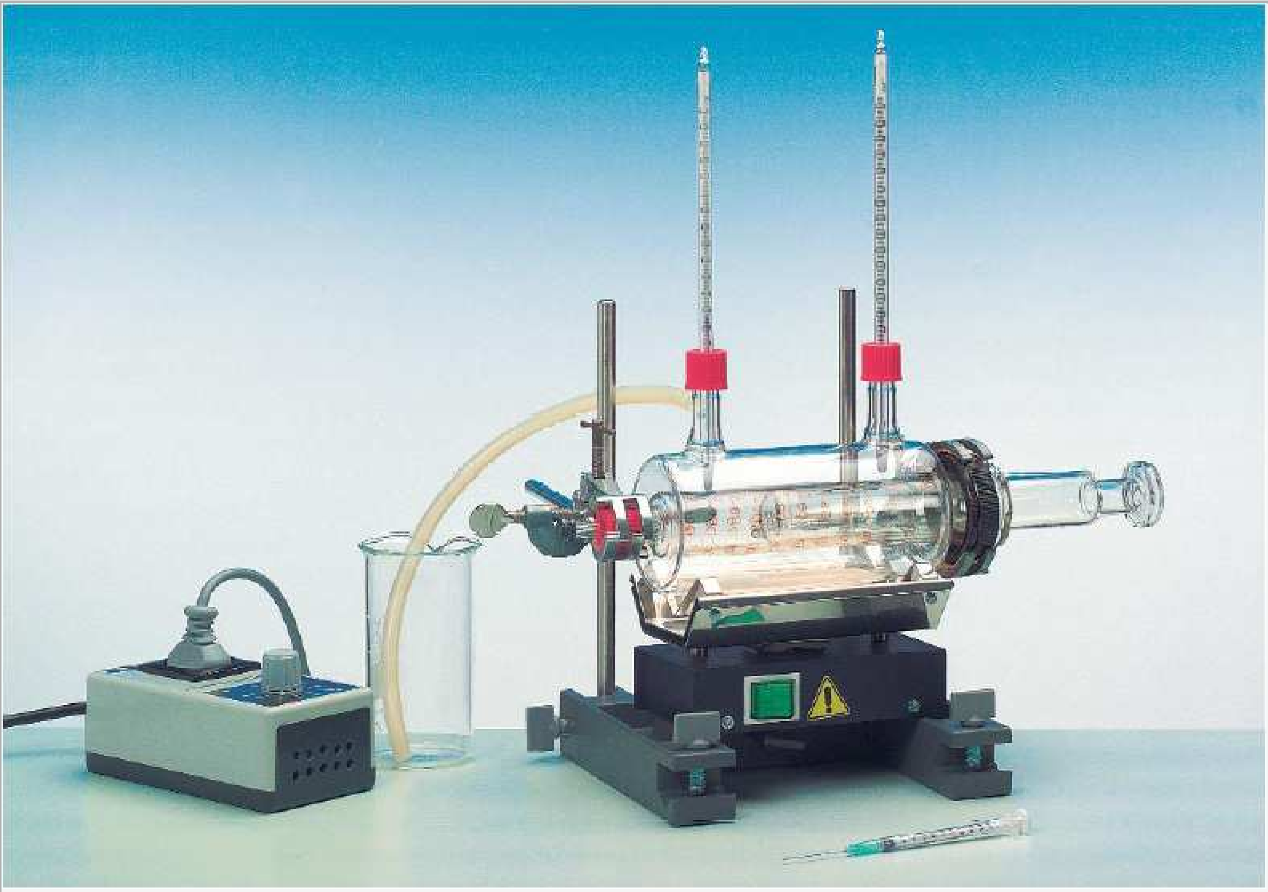
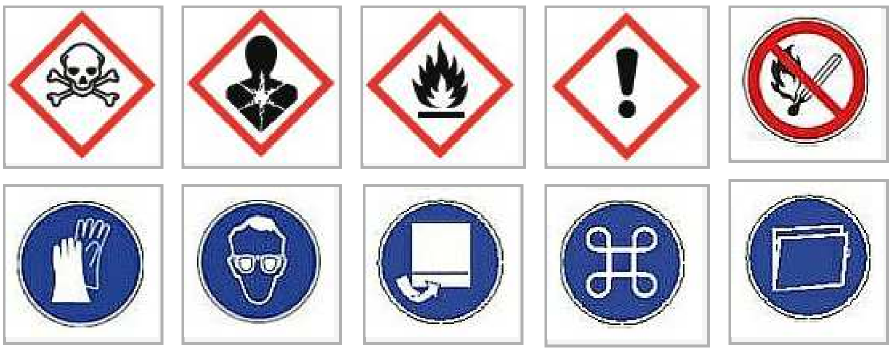


Fig. 1. Experimental set-up.

Safety instructions



Diethyl ether
H224: Extremely flammable liquid and vapour
H302: Harmful if swallowed
H336: May cause drowsiness or dizziness
EUH019: May form explosive peroxides
EUH066: Repeated exposure may cause skin dryness or cracking
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P240: Ground/bond container and receiving equipment.

Methanol
H225: Highly flammable liquid and vapour
H311: Toxic in contact with skin
H331: Toxic if inhaled
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P233: Keep container tightly closed.
P280: Wear protective gloves/protective clothing/eye protection/face protection.

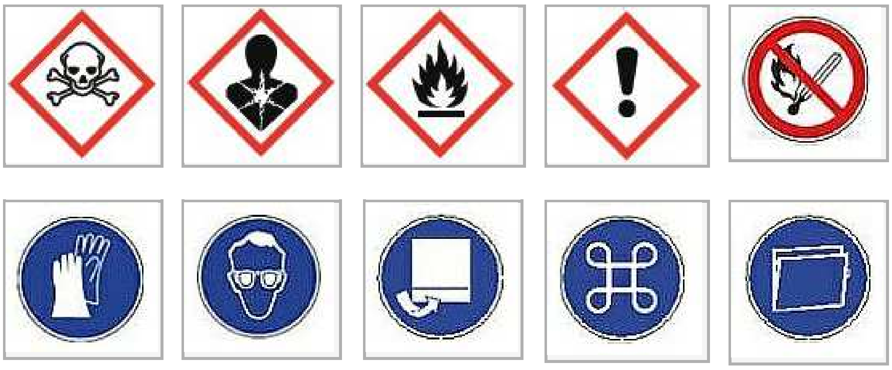
Equipment

Position No.	Material	Order No.	Quantity
1	Set gas laws with glass jacket, 230 V	43003-88	1
2	Lab thermometer,-10..+150C	38058-00	2
3	Weather monitor, 6 lines LCD	87997-10	1
4	Syringe 1ml, Luer, 10 pcs	02593-03	1
5	Cannula 0.6x60 mm, Luer, 20 pcs	02599-04	1
6	Precision Balance, Sartorius ENTRIS623-1S, 620 g / 0,001 g	49294-99	1
7	Power regulator	32288-93	1
8	Methanol 500 ml	30142-50	1
9	Diethyl ether 250 ml	30007-25	1
10	Water, distilled 5 l	31246-81	1
11	Boiling beads, 200 g	36937-20	1

Tasks

1. Determine the molar masses of diethyl ether and methanol.
2. Discuss the results in terms of the real and ideal behaviour of vapours.

Setup and procedure



Set up the experiment as shown in Fig. 1.

Insert the 100 ml gas syringe in the glass jacket (for additional information, see the instruction manual for the glass jacket). Push the plunger of the dry and clean glass syringe to the 5 ml graduation. This small volume of air must be enclosed in the syringe to make the injection of the liquid to be investigated easier. Close the capillary tube end of the glass syringe which protrudes out of the glass jacket with a rubber cap so that the syringe is gas tight. The syringe must be pulled back far enough into the glass jacket so that the rubber cap abuts directly on the connection sleeve of the glass jacket to avoid a cooling surface on the capillary tube.

Mount the glass jacket on the support rods, fill it up to 1 cm above the gas syringe with distilled water and add a few boiling beads. Attach a piece of silicone tubing to the hose connection of the tubular sleeve through which the water that expands during heating can drain into a beaker. Insert the thermometers in the upper tubular glass sleeves.

Switch on the heating apparatus and adjust the power regulator so that the water is brought to gentle boiling. When the water has reached a constant temperature, perform the measurements as follows: Draw a small quantity of the liquid to be investigated (e.g. approx. 0.12 ml of methanol or approx. 0.3 ml of diethyl ether) into the injection syringe without bubbles. Clean the cannula externally with a paper towel and determine the total weight of the syringe with cannula and substance to an accuracy of 1 mg. Record the exact volume of air contained in the gas syringe. Now rapidly inject the substance through the rubber cap. Ensure that the whole test substance has been injected into the cylinder of the gas syringe and nothing has remained in the capillary tube. Let the injection syringe stuck in the rubber cap until the vapour volume no longer changes. Ensure that pressure equilibrium between the syringe and the atmosphere has been reached by turning the cylinder of the glass syringe slightly, then read off the volume of the vaporised liquid. Reweigh the empty syringe and calculate the mass of the substance.

Perform three measurements for each of the two liquids in this manner. After each measurement, remove the rubber cap from the gas syringe and rinse the syringe with air by pushing the plunger backwards and forwards several times.

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Theory and evaluation

The method for the determination of the molar mass of pure liquids which can be completely evaporated without decomposition which is described above is based on the theory of ideal gases. The equation of state for ideal gases is given by

$$p \cdot V_{\mathrm{mol}} = R \cdot T \quad (1)$$

or

$$p \cdot V = n \cdot R \cdot T$$

p Pressure

V Volume

V_{mol} Molar volume

R Gas constant (8.31433 Pa · m^3 · K^{-1} · mol^{-1})

T Absolute Temperature

n Number of moles

With

$$n = \frac{m}{M} \quad (2)$$

m Mass

M Molar mass

equation (1) gives

$$M = \frac{m \cdot R \cdot T}{p \cdot V} \quad (3)$$

Equation (3) is only valid when the vapour behaves like an ideal gas which is the case at temperatures of more than 20 K above their boiling point.

To account for the real behaviour of the vapour, the van der Waals equation of state for ordinary gases must be used:

$$\left(p + \frac{a}{V_{\mathrm{mol}}^2}\right) \cdot (V_{\mathrm{mol}} - b) = R \cdot T \quad (4)$$

Multiplication and simplification of equation (4) leads to

$$p \cdot V_{\mathrm{mol}} = R \cdot T + \left(b - \frac{a}{RT}\right) \cdot p \quad (5)$$

where

a , b van der Waals constants

With $V_{\mathrm{mol}} = V/n$ and $n = m/M$, the following equation can be derived:

$M = \frac{m \cdot R \cdot T}{p \cdot V} + \frac{m \cdot (b - \frac{a}{RT})}{V}$ (6)

which takes into account the real behaviour of an ordinary vapour in the determination of molar masses.

Data and results

In an exemplary measurement, the following values were obtained for the two vaporised substances:

Methanol: $M_{\mathrm{ideal}} = 32.5\ \mathrm{g/mol}$

$M_{\mathrm{real}} = 32.2\ \mathrm{g/mol}$

Diethyl ether: $M_{\mathrm{ideal}} = 74.6\ \mathrm{g/mol}$

$M_{\mathrm{real}} = 73.5\ \mathrm{g/mol}$

Literature values:

Methanol: $a = 9.46 \cdot 10^5 \mathrm{Pa} \cdot \mathrm{l}^2 \cdot \mathrm{mol}^{-2}$; $b = 0.0658\ \mathrm{l} \cdot \mathrm{mol}^{-1}$; $M = 32.04\ \mathrm{g/mol}$

Diethyl ether: $a = 17.4 \cdot 10^5 \mathrm{Pa} \cdot \mathrm{l}^2 \cdot \mathrm{mol}^{-2}$; $b = 0.133\ \mathrm{l} \cdot \mathrm{mol}^{-1}$; $M = 74.12\ \mathrm{g/mol}$