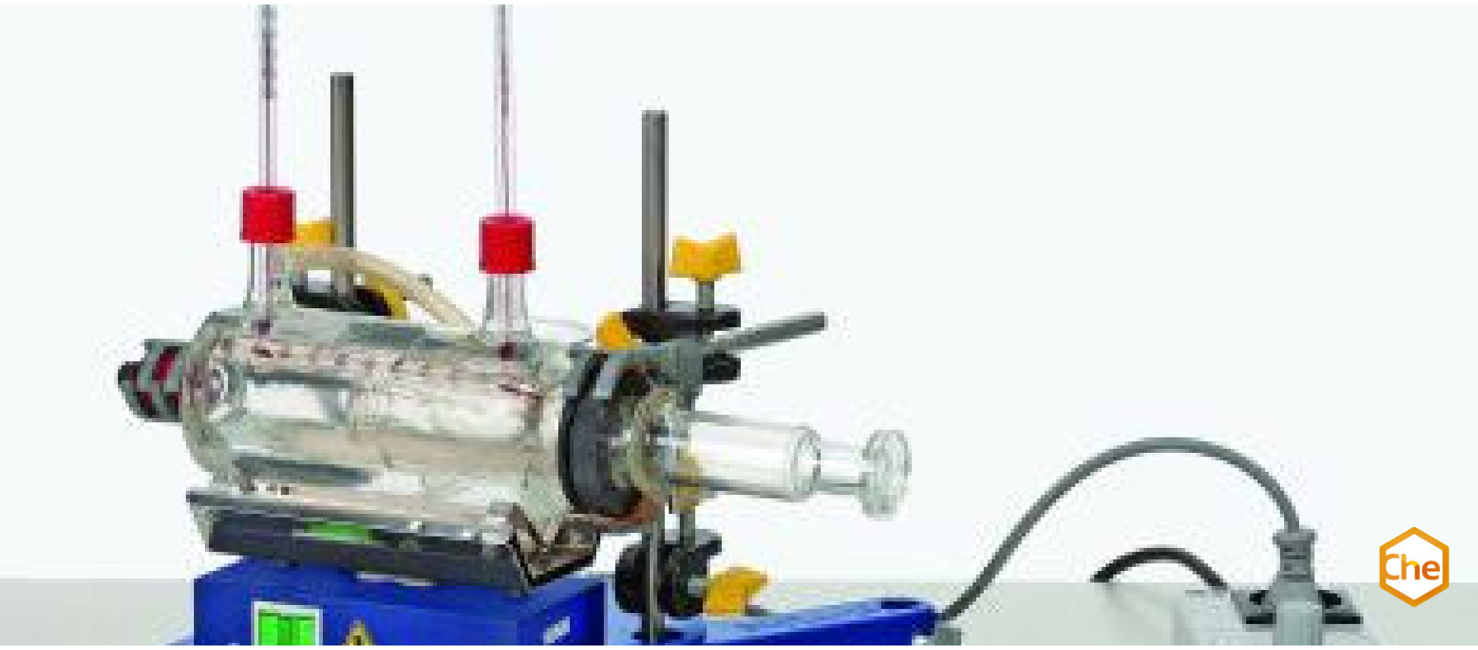
Determination of the molar mass of a liquid



The students learn how to determine the molar mass of a liquid.

Chemistry > General Chemistry > Stoichiometry

Difficulty level	Group size	Preparation time	Execution time
medium	2	10 minutes	10 minutes

This content can also be found online at:

http://localhost:1337/c/60b227966b5a0f00039aff5f

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General information

Application

Experimental setup

This experiment focuses on the determination of the molar mass of a liquid. The students will determine the molar masses of diethyl ether and methanol and discuss the results in terms of the real and ideal behaviour of vapours.

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

$$p \cdot V_{mol} = R \cdot T$$

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Other information (1/2)

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Prior knowledge

The students should be familiar with ideal and ordinary gases, equations of state for ideal gases, gas volumetry and the determination of molar masses according to the vapour density method (Victor Meyer).

Scientific 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.

Other information (2/2)

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Learning objective

The students learn how to determine the molar mass of a liquid.

Tasks

The students will determine the molar masses of diethyl ether and methanol and discuss the results in terms of the real and ideal behaviour of vapours.

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Safety instructions

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- Use suitable protective gloves, safety goggles, and suitable clothing.
- For this experiment the general instructions for safe experimentation in science lessons apply.
- For H- and P-phrases please consult the safety data sheet of the respective chemical.

Theory

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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

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

or

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

p Pressure
V Volume
V_{mol} Molar Volume
R Gas constant $(8.31433 Pa \cdot m^3 \cdot K^{-1} \cdot mol^{-1})$
T Absolute Temperature
n Number of moles

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Equipment

Position	Material	Item 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, 100 pcs	02593-10	1
5	Cannula 0.6x60 mm, Luer, 20 pcs	02599-10	1
6	Boiling beads, 200 g	36937-20	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

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Setup and procedure

Setup and Procedure (1/3)

- Set up the experiment as shown in Fig. right.
- 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.

Experimental setup

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Setup and Procedure (2/3)

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- 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.

Setup and Procedure (3/3)

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- 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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Evaluation

Evaluation (1/7)

Theory and evaluation (1/3)

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

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

or

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

p Pressure
V Volume
V_{mol} Molar Volume
R Gas constant
$(8.31433 Pa \cdot m^3 \cdot K^{-1} \cdot mol^{-1})$
T Absolute Temperature
n Number of moles with

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

m Mass
M Molar mass

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Evaluation (2/7)

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Theory and evaluation (2/3)

equation (1) gives

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

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:

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

Evaluation (3/7)

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Theory and evaluation (3/3)

Multiplication and simplification of equation (4) leads to

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

where
a, b van der Waals constants

With $V_{mol} = V/n$ 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.

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Evaluation (4/7)

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Data and results

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

Methanol: $M_{ideal} = 32,5 g/mol$
$M_{real} = 32,2 g/mol$
Diethyl ether: $M_{ideal} = 74,6 g/mol$
$M_{real} = 73,5 g/mol$

Literature values:

Methanol: $a = 9.46 \cdot\ 10^5 Pa \cdot\ I^2 \cdot\ mol^{-2}; b = 0.0658 I \cdot\ mol^{-1}; M = 32.04 g/mol$
Diethyl ether: $a = 17.4 \cdot\ 10^5 Pa \cdot\ I^2 \cdot\ mol^{-2}; b = 0.133 I \cdot\ mol^{-1}; M = 74.12 g/mol$

Evaluation (5/7)

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How is the molar mass of a liquid to be determined?

- [ ] None of the answers is correct.
- [ ] 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.
- [ ] It is not possible to determine the molar mass of a liquid.

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Evaluation (6/7)

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By what is the equation of state for ideal gase given?

- [ ] There is no equation of state for ideal gases, so it can not be given by anything.
- [ ] The equation of state for ideal gases is given by $p \cdot V = n \cdot R \cdot T$.
- [ ] None of the answers is correct.
- [ ] The equation of state for ideal gases is given by $p \cdot V_{mol} = R \cdot T$.

Überprüfen

Evaluation (7/7)

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What must be used to account for the real behaviour of the vapour

- ○ To account for the real behaviour of the vapour, the van der Waals equation of state for ordinary gases must be used.
- ○ To account for the real behaviour of the vapour, the electric pair bond equation of state for ordinary gases must be used.
- ○ To account for the real behaviour of the vapour, the hydrogen bond equation of state for ordinary gases must be used.

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Slide	Score / Total
Slide 17: Molar mass of a liquid	1/1
Slide 18: Ideal gases	1/1
Slide 19: Real behaviour of the vapour	0/1

Total Score 2 / 3

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