Estimating the size of oil molecules

Objects of the experiment

- Estimation of the size of oil molecules.

Fig. 1: Experimental setup to estimate the size of oil molecules.

Principles

One important issue in atomic physics is the size of an atom. An investigation of the size of molecules makes it easier to achieve useable order of magnitude by experimental means.

A rough estimation of the diameter of the molecule can be made with the help of the oil spot experiment. A drop of solution of glycerinetrioleate in petroleum gas is put on a grease-free water surface sprinkled with lycopodium spores. The drop spreads out on the water surface and the petroleum gas evaporates very quickly. As the lycopodium spores are pushed aside by the oil spot, the area of the oil spot can be determined easily. The thickness of the oil layer can be calculated from the volume of the oil drop and the area of the spot.

Since the same volumes of oil produce the same size of oil spots within the limits of the measuring accuracy, and because the spot area of several oil drops is proportional to the number of drops, we can conclude that the oil layers are monomolecular.

The molecular diameter can be determined as follows:

If V is the volume of one drop of oil which creates a circular spot with a diameter d (or radius r= d/2), then the thickness d_M of the oil layer is given by:

$$d_M = \frac{V}{A} = \frac{V}{\pi \cdot r^2} \qquad \text{(I)}$$

V: volume of one drop of oil

A: area of the oil spot

The glycerinetrioleate molecules as well as its atoms are in a simplified model considered to be cubic, i.e. and they have equilateral sides. The volume of the glycerinetrioleate molecule is then given by:

$$V_M = d_M^3 \qquad \text{(II)}$$

Bi 1005

LD Didactic GmbH · Leyboldstrasse 1 · D-50354 Huerth / Germany · Phone: (02233) 604-0 · Fax: (02233) 604-222 · e-mail: info@ld-didactic.de

Apparatus

1 Crystallization dish, 230 mm Ø 664 179
1 Burette, amber glass, 10 ml 665 844
1 Beaker, 50 ml, tall form 664 110
1 Graduated cylinder with plastic base, 10 ml 665 751
1 Graduated cylinder with plastic base, 100 ml 665 754

1 Stand base, V-shaped, 20 cm 300 02
1 Stand rod, 75 cm 300 43
1 Leybold multiclamp 301 01
1 Universal clamp, 0-80 mm 666 555

1 Distilled Water, 5 l 675 3410
1 Glycerinetrioleate, 100 ml 672 1240
1 Benzine, 1 l, 40-70 °C 674 2220
1 Lycopodium spores, 25 g 670 6920

Setup

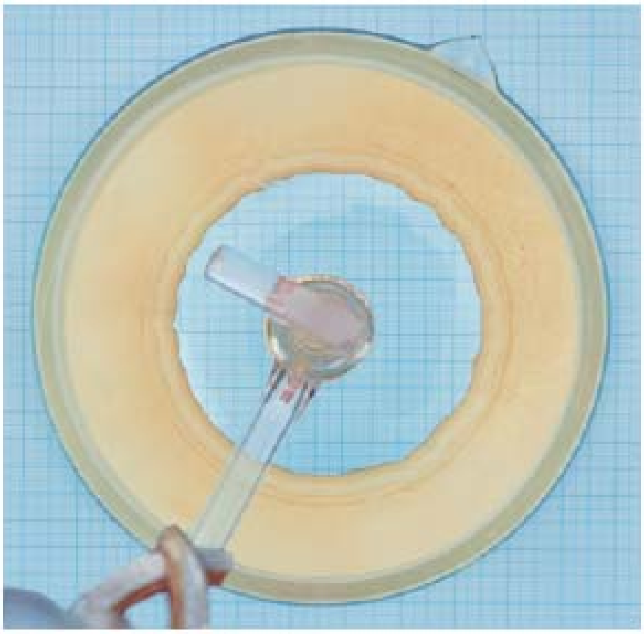
Note: The experiment will be only successful if all parts which are made of glass (crystallization basin, measuring cylinder, burette and tap) are absolutely greaseless.
This is achieved by vigorously cleaning out parts first with dishwashing detergent and by rinsing any residues with a lot of distilled water. Then, the glass parts are degreased by cleaning them with petroleum gas.

The setup is shown in Fig. 1. For determining the diameter of the oil spot a graph paper is used under the crystallization dish.

The glycerinetrioleate is dissolved in benzine in a ratio of 1:1000.

To avoid wasting chemicals, 9 ml benzine are added to 1 ml of glycerinetrioleate, then 99 ml benzine are added to 1 ml of this solution.

Fig. 2: Determining the diameter of the oil spot.



Carrying out the experiment

- Pour the prepared glycerinetrioleate/benzine solution into the burette.
- Pour distilled water into the degreased crystallization dish until the filling height is of approximately 1 cm.
- Then shake a fine layer of lycopodium spores onto the water surface, by rubbing a degreased dust cloth with the lycopodium powder and shaking it with care over the crystallization dish.
- Locate the burette over the crystallization dish as shown in Fig. 1.
- Place the beaker 50 ml between burette and dish and open the tap slightly until it starts dropping.
- The number of drops per cubic centimetre of solution is determined with a drop velocity of approximately 1 drop/ second.
- Without changing the position of the valve let one drop fall on the water surface of the crystallization dish to determine the volume of one drop.
- Lock the tap and read the diameter d of the oil spot from the scale of the graph paper (Fig. 2).
- Repeat the experiment to obtain mean values.

Measuring example and evaluations

a) Determination of the volume V of oil of a drop of solution

- 1 ml of solution contains $\frac{1}{1000}$ cm^3 of glycerinetrioleate

- 2.25 ml of solution contains 100 drops. This means

1 drop = $\frac{2.25}{100}$ cm^3 of solution

1 drop contains $V = \frac{2.25}{100 \cdot 1000}\ \text{cm}^3 = 2.25 \cdot 10^{-5}\ \text{cm}^3$ of glycerinetrioleate

b) Determination of the area of an oil spot

- The diameter of the oil spot is determined to d = 12.5 cm.
Hence the measured radius can be determined to:

$r = \frac{12.5}{2}$ cm

- With r follows for the area A

$$A = \pi \left(\frac{12.5}{2}\right)^2 \text{cm}^2 = \pi \cdot 6.25^2\ \text{cm}^2$$

c) Calculating the thickness of the monomolecular oil layer

The thickness of the oil layer is given

$$d_M = \frac{V}{A}$$

$$d_M = \frac{2.25 \cdot 10^{-5}}{\pi \cdot 6.25^2}\ \text{cm} = 1.8\cdot 10^{-7}\ \text{cm} = 1.8\cdot 10^{-9}\ \text{m}$$

Results

A rough estimation for the diameter of the molecule is
$d = 10^{-9}$ m.

Supplementary information

A possible extension for evaluating the experiment is given as follows:

The atomic composition of the glycerinetrioleate molecule is given by: $C_{57}H_{104}O_6$. The number of atoms per molecule is therefore n = 167.

As mean diameter of an atom we obtain:

$$d_A = \sqrt[3]{\frac{\text{volume of the molecule}}{\text{number of atoms per molecule}}} = \frac{d_M}{\sqrt[3]{n}}$$

$$d_A = \frac{1.8 \cdot 10^{-9}}{5.51}\ \text{m} = 3.27\cdot 10^{-10}\ \text{m}$$

Estimating the Avogadro constant N_A:

According to Ostwald the same number of particles, namely $6.02\cdot 10^{23}$, is contained in one mol of any material (Avogadro constant N_A). This number can be calculated approximately as follows. Using the assumption of cubic molecules:

$$N_A = \frac{\text{molar volume}}{\text{volume of one molecule } V_M}$$

with

$$\text{molar volume} = \frac{\text{relative molar mass } m_M}{\text{density } \rho}$$

From this we can conclude:

$$N_A = \frac{m_M}{\rho \cdot d_M^3}$$

With the values of glycerinetrioleate:

$$\rho = 0.91\ \frac{g}{cm^3}$$

$$m_M = 885.4\ \frac{g}{mol}$$

we obtain with the simplified model here

$$N_A = 1.67\cdot 10^{23}\ \frac{1}{mol}$$