Determining the density of liquids using the pycnometer in accordance with *Gay-Lussac*

Objects of the experiments

- Determining the volume of the pycnometer.
- Determining the density of ethanol-water solutions as a function of the volume concentration of the ethanol.

Principles

The density of a liquid is defined as the ratio

$$\rho = \frac{m}{V} \quad \text{(I)},$$

m: mass, *V:* volume.

This density can be measured with a high degree of accuracy by means of a pycnometer in accordance with Gay-Lussac, a pear-shaped glass flask with a capillary stopper fitted into the opening. Two measurements are to be carried out:

In order to determine the volume V of the pycnometer, the pycnometer is weighed twice and as precisely as possible, once when it is empty and once again when it is filled with water of known temperature ϑ. Since high precision data of the density of water as a function of the temperature is available in tables, ρ can be inserted in Eq. (I) to calculate the volume of the pycnometer. The mass m of the measuring liquid is then determined by carefully filling the liquid into the pycnometer and weighing the pycnometer again.

In the experiment, the mixture of two liquids with different densities ρ_1 and ρ_2 is studied. With regard to the density ρ of the mixture (more precisely: the solution) consider the following:

The partial volumes V_1 and V_2 correspond to the partial masses

$$m_1 = \rho_1 \cdot V_1 \text{ and } m_2 = \rho_2 \cdot V_2 \quad \text{(II)}.$$

The total mass of the solution is certainly equal to the sum of the partial masses, and therefore

$$m = \rho_1 \cdot V_1 + \rho_2 \cdot V_2 \quad \text{(III)}.$$

In the case of an ideal solution, the partial volumes add to the total volume

$$V = V_1 + V_2 \quad \text{(IV)}.$$

From this

$$\rho = \rho_1 \cdot \frac{V_1}{V_1 + V_2} + \rho_2 \cdot \left(1 - \frac{V_1}{V_1 + V_2}\right) \quad \text{(V)}$$

follows, i.e. the density of the ideal solution has a linear dependence on the volume concentration

$$c = \frac{V_1}{V_1 + V_2} \quad \text{(VI)}.$$

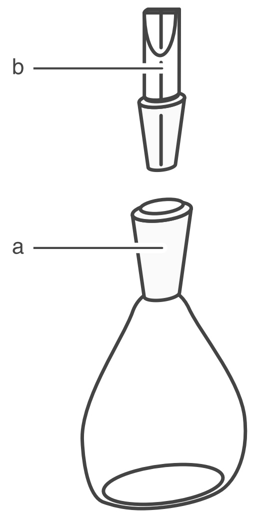

Fig. 1 Pycnometer after *Gay-Lussac*
a ground opening
b stopper with capillary hole

Apparatus

1 pycnometer, 50 ml	666 145
1 school and lab. balance 311	315 05
1 stirring thermometer, –30 to +110 °C . . .	382 21
2 graduated cylinder, 100 ml: 1	665 754
1 ethanol, denaturated, 1 l	671 972

Setup and carrying out the experiment

Note: Air bubbles in the pycnometer and changes in temperature may cause measuring errors.

a) Determining the volume *V* of the pycnometer:

– Determine the mass m_0 of the empty, dry pycnometer.

– Fill the pycnometer with pure water up to the bottom third of the ground opening, allow air bubbles to escape, carefully put the stopper into the opening and carefully wipe off the water coming out.

The hole in the stopper must now be filled up to the top.

– Determine the mass m_1 of the pycnometer filled with water.

– Determine the temperature ϑ of the water with the thermometer, and read the density of the water from Table 1.

Table 1: Values quoted in the literature for the density ρ of pure water as a function of the temperature ϑ:

ϑ	$\frac{\rho}{\text{g} \cdot \text{cm}^{-3}}$	ϑ	$\frac{\rho}{\text{g} \cdot \text{cm}^{-3}}$
15 °C	0.999099	23 °C	0.997540
16 °C	0.998943	24 °C	0.997299
17 °C	0.998775	25 °C	0.997047
18 °C	0.998596	26 °C	0.996785
19 °C	0.998406	27 °C	0.996515
20 °C	0.998205	28 °C	0.996235
21 °C	0.997994	29 °C	0.995946
22 °C	0.997772	30 °C	0.995649

b) Determining the density of ethanol-water solutions:

– Repeat the measurement with pure ethanol and, subsequently, with ethanol-water solutions.

– Clean the pycnometer carefully each time, fill it with the liquid up to the bottom third of the ground opening, allow air bubbles to escape and after putting the stopper into the opening, make sure that the hole in the stopper is filled up to the top.

– Determine the mass m_2 of the pycnometer filled with the liquid and record it together with the volume concentration *c* of the ethanol.

The following procedure is recommended in order to prepare an ethanol-water solution of a desired volume concentration *c* of the ethanol:

– Fill the volume $V_1 = c \cdot 100$ ml of ethanol into graduated cylinder 1.

– Fill the volume $V_2 = (1 - c) \cdot 100$ ml of water into graduated cylinder 2.

– Carefully mix both liquids in one graduated cylinder.

Measuring example and evaluation

a) Determining the volume *V* of the filling:

empty pycnometer:	$m_0 = 31.81$ g
filled with water:	$m_1 = 82.07$ g
temperature of the water:	$\vartheta = 22$ °C, $\rho_{\text{water}} = 0.99777$ g cm^{-3}

$$V = \frac{m_1 - m_0}{\rho_{\text{water}}} = 50.37 \text{ cm}^3$$

b) Determining the density of ethanol-water solutions

Table 2: Measuring results for the density $\rho = \frac{m_2 - m_0}{V}$ as a function of concentration *c* of the ethanol

c	$\frac{m_2}{\text{g}}$	$\frac{m_2 - m_0}{\text{g}}$	$\frac{\rho}{\text{g} \cdot \text{cm}^{-3}}$
1.0	71.48	39.67	0.7876
0.9	73.26	41.45	0.8229
0.8	74.65	42.84	0.8505
0.7	76.01	44.20	0.8775
0.6	77.14	45.33	0.8999
0.5	78.24	46.43	0.9218
0.4	79.20	47.39	0.9408
0.3	80.01	48.20	0.9569
0.2	80.70	48.89	0.9706
0.1	81.33	49.52	0.9831
0	82.07	50.26	0.9978

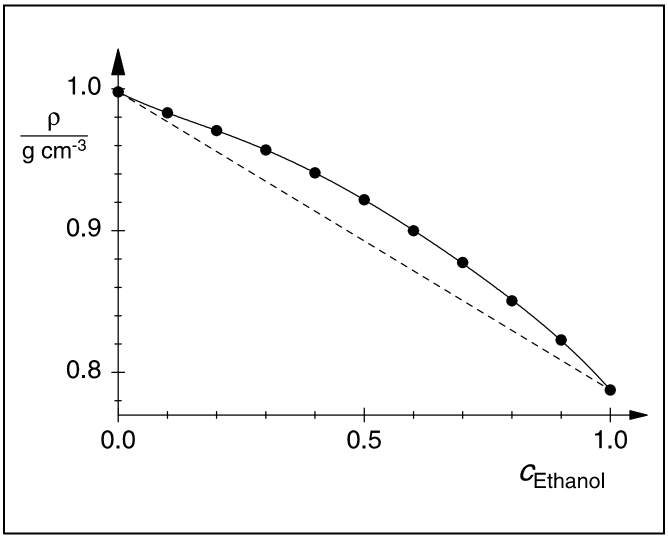

Fig. 2 The density ρ of an ethanol-water solution as a function of the volume concentration of the ethanol

In Fig. 2, the measuring results are plotted as circles. They are considerably higher than the dashed line, which represents the linear relation expected according to Eq. (V).

Alcohol and water form a real solution which shows a volume contraction so that the volume V turns out to be smaller than the value calculated from Eq. (IV).

Supplementary information

The total consumption of ethanol can be considerably reduced if the concentrations are suitably halved in one series of measurements by mixing 50 ml of a solution with 50 ml of pure water.

The following dilutions are possible:

$c = 1 \rightarrow c = 0.5$;
$c = 0.8 \rightarrow c = 0.4 \rightarrow c = 0.2 \rightarrow c = 0.1$
$c = 0.6 \rightarrow c = 0.3$

The volume contraction is neglected here in the calculation of the concentration.