Heat

Thermal expansion
Thermal expansion of liquids

Determining the volumetric expansion coefficient of liquids

Objects of the experiments

■ Determining the volume V_0 of the dilatometer.

■ Measuring the volume expansion of water and ethanol as a function of the temperature and determining the volumetric expansion coefficient γ.

■ Comparing the volumetric expansion coefficients of water and ethanol.

Principles

If the temperature ϑ of a liquid of volume V_0 is changed by $\Delta\vartheta$, then the volume will – as in the case of a solid – change by

$$\Delta V_0 = \gamma \cdot V_0 \cdot \Delta\vartheta \tag{I}$$

The volumetric expansion coefficient γ is practically independent of the temperature ϑ, but it does depend on the material. In general, liquids expand more than solids.

The volumetric expansion coefficient can be determined by means of a dilatometer. A dilatometer consists of a glass flask with a capillary of known radius r at the opening as a riser tube. The level h of the liquid in the riser tube is read from a mm-scale. It increases when the glass flask is uniformly warmed in a water bath and the volume of the liquid expands.

The change in the liquid level Δh corresponds to a change in volume

$$\Delta V = \pi \cdot r^2 \cdot \Delta h \tag{II}$$
with $r = (1.5 \pm 0.08)$ mm.

However It has to be taken into account that the dilatometer itself also expands because of the warming. This expansion counteracts the change in the liquid level. The change in volume of the liquid thus is

$$\Delta V_0 = \Delta V + \Delta V_D \tag{III}$$
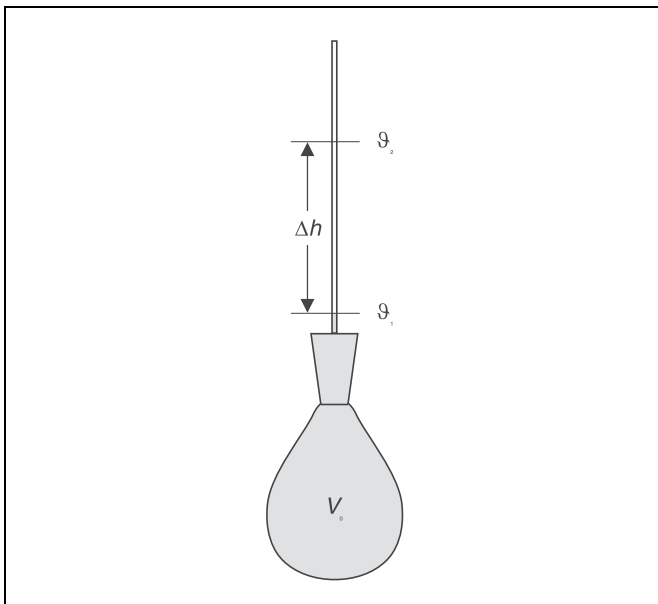
where the volume change ΔV_D of the dilatometer is

$$\Delta V_D = \gamma_D \cdot V_0 \cdot \Delta\vartheta \tag{IV}$$
with $\gamma_D = 0.84 \cdot 10^{-4}$ K^{-1}.

From (I), (III), and (IV) the volumetric expansion coefficient of the liquid is found to be

$$\gamma = \frac{1}{V_0} \cdot \frac{\Delta V}{\Delta\vartheta} + \gamma_D \tag{V}$$

Determining the volumetric expansion coefficient of liquids

Apparatus

1 dilatometer	382 15
1 thermometer, –10 to 110 °C	382 34
or	
1 temperature sensor, NiCr-Ni	666 193
1 digital thermometer with one input	666 190
1 school and lab. balance 311	315 05
1 hot plate, 150 mm dia., 1500 W	666 767
1 beaker, 400 ml, ss, hard glass	664 104
1 stand base, V-shape	300 02
1 stand rod, 47 cm	300 42
2 Leybold multiclamp	301 01
2 universal clamp, 0 … 80 mm dia.	666 555
1 ethanol, denaturated, 1 l	671 972

in addition necessary:

distilled or demineralized water

So there is still the volume V_0 of the dilatometer to be determined. This is done by determining the masses m_1 of the empty, dry dilatometer and m_2 of the dilatometer filled with pure water up to the lower end of the riser tube. Since the density ρ of water at a known temperature ϑ is known to a high accuracy (see Table 1), the volume is obtained from

$$V_0 = \frac{m_2 - m_1}{\rho} \qquad\qquad \text{(VI)}.$$

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

ϑ	$\dfrac{\rho}{g \cdot cm^{-3}}$	ϑ	$\dfrac{\rho}{g \cdot cm^{-3}}$
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

Setup and carrying out the experiment

Notes:

Measurement of the liquid level h may be considerably distorted by capillary forces of different strengths.

Keep the capillary clean, and, if necessary, clean it with an appropriate purifying solution, then rinse it with distilled water.

a) Calibration of the dilatometer:

– Determine the mass m_1 of the empty dilatometer.
– Fill the flask with pure water up to the bottom third of the ground opening.
– To eliminate air bubbles, heat the dilatometer in the water bath almost to boiling without the riser tube attached.
– Allow the water bath to cool off to room temperature; top off the liquid level as necessary. Take down the temperature ϑ.
– Attach the riser tube, press your finger on the opening, then remove the riser tube and allow it to drain.
– Replace the riser tube on the flask, dry the dilatometer and measure the mass m_2 of the water-filled dilatometer.

b) Measuring the volume expansion of water and ethanol:

Note: After the hot plate has been switched off, the heating of the liquid continues for some time so that the dilatometer may run over.

Especially when filling in ethanol, switch the hot plate early enough.

The experimental setup is illustrated in Fig. 1.

– Dip the dilatometer into the heating bath so that the riser tube sticks out.
– Switch the hot plate on at the lowest step, and switch it off when the liquid level in the dilatometer is just below the highest mark of the scale.
– Wait until the liquid level has reached its maximum, then allow the water bath to cool down by about 1–2 K.
– Let the water bath continue cooling down, and determine the level h of the water in the riser tube as a function of the temperature (see Table 2).
– Then fill in ethanol into the thoroughly dried dilatometer, warm it up in the water bath, and repeat the measurement of the liquid level h as a fnction of the temperature (see Table 3).

Measuring example

a) Calibration of the dilatometer:

m_1 = 31.29 g

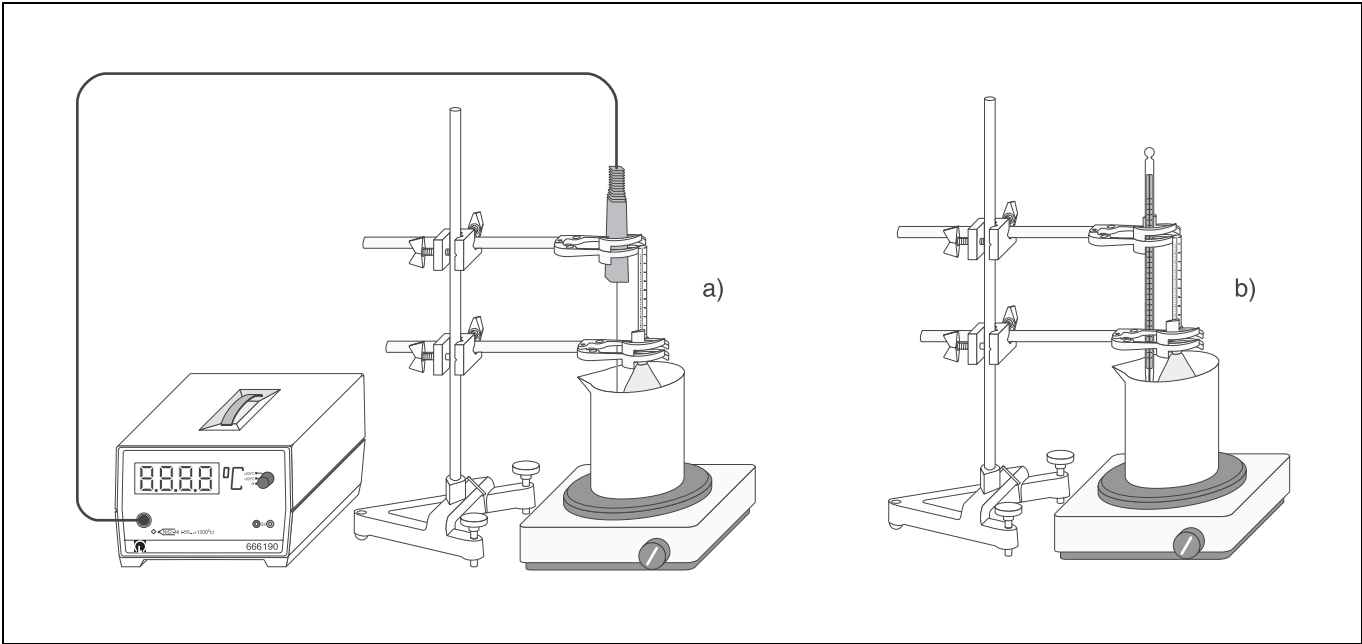m_2 = 88.01 g

ϑ = 22 °C

Fig. 1 Experimental setup for the determination of the volumetric expansion coefficient of liquids.
a) Use of the temperature sensor   b) Use of the thermometer

b) Measuring the volume expansion of water and ethanol:

Table 2: The level *h* of pure water as a function of the temperature ϑ.

ϑ	$\dfrac{h}{cm}$	ϑ	$\dfrac{h}{cm}$
60 °C	9.5	45 °C	4.25
59 °C	9.3	44 °C	3.9
58 °C	8.9	43 °C	3.55
57 °C	8.6	42 °C	3.2
56 °C	8.2	41 °C	2.9
55 °C	7.85	40 °C	2.6
54 °C	7.5	39 °C	2.3
53 °C	7.1	38 °C	2.0
52 °C	6.75	37 °C	1.7
51 °C	6.4	36 °C	1.4
50 °C	6.0	35 °C	1.1
49 °C	5.7	34 °C	0.8
48 °C	5.3	33 °C	0.55
47 °C	4.95	32 °C	0.3
46 °C	4.6		

Tab. 3: The level *h* of ethanol as a function of the temperature ϑ.

| ϑ	$\dfrac{h}{cm}$	ϑ	$\dfrac{h}{cm}$
38 °C	9.9	32 °C	4.6
37 °C	9.1	31 °C	3.7
36 °C	8.25	30 °C	2.7
35 °C	7.4	29 °C	1.8
34 °C	6.5	28 °C	0.9
33 °C	5.55		

Evaluation and results

a) Calibration of the dilatometer:

mass difference: $m_2 - m_1 = 56.72$ g

density ρ at $\vartheta = 22$ °C: $\rho = 0.9978$ g cm^{-3} (cf. Table 1)

From (VI) you obtain: $V_0 = 56.85$ cm^3

b) Measuring the volume expansion of water and ethanol:

Fig. 2 shows a graph of the volume change ΔV as a function of the temperature difference $\Delta\vartheta = \vartheta - \vartheta_0$ ($\vartheta_0 = 32$ °C for water and 28 °C for ethanol respectively, cf. Tables 2 and 3) calcu-

Fig. 2 Thermal volume expansion ΔV of water (circles) and ethanol (boxes) as functions of the temperature difference $\Delta\vartheta$.
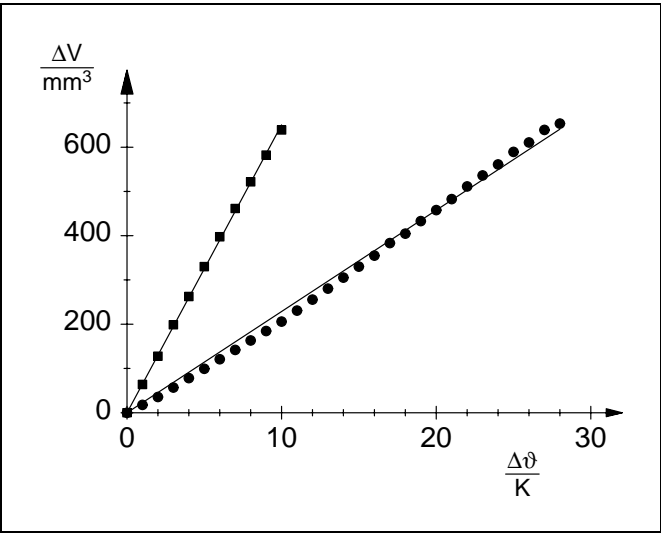
lated according to Eq. (II) from the change $\Delta h = h - h_0$ in the level. The slope of the straight line drawn through the origin is

$$\frac{\Delta V}{\Delta \vartheta} = 22.9 \, \frac{mm^3}{K}$$

for water and

$$\frac{\Delta V}{\Delta \vartheta} = 65.0 \, \frac{mm^3}{K}$$

for ethanol. With Eq. (V) the volumetric extension coefficient is obtained:

$\gamma = 4.9 \cdot 10^{-4} \, K^{-1}$ (water), $\gamma = 12.3 \cdot 10^{-4} \, K^{-1}$ (ethanol).

In the case of water, there is a systematic deviation of the measuring values from the straight line through the origin. The volumetric expansion coefficient of water is not constant, but increases with temperature in the range between 30 °C and 60 °C which has been considered here.

The volumetric expansion coefficient of ethanol is considerably larger than that of water. Since it does not change even in wider temperature ranges, it is a suitable thermometer liquid.

Supplementary note:

The thermal anomaly of water, that is, the decrease of the volume of water in the temperature range between 0 °C and 4 °C, will be studied in the experiment P2.1.3.1.