Thermodynamics

Thermal expansion

The water anomaly

DETERMINE THE TEMPERATURE WHERE WATER REACHES ITS MAXIMUM DENSITY

- Measure the thermal expansion of water over a temperature range between 0°C and 15°C.
- Demonstrate the thermal anomaly.
- Determine the temperature when the density is at a maximum.

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BASIC PRINCIPLES

Water is unlike most other materials in that up to a temperature of about 4°C it initially contracts and only starts expanding at higher temperatures. Since the density is inversely related to the volume of a mass, water thus reaches its maximum density at about 4°C.

The experiment involves measuring the expansion of water in a vessel with a riser tube. The height h to which water rises up the tube is measured as a function of the water temperature ϑ. Neglecting the fact that the glass vessel also expands at higher temperatures, the total volume of the water in the vessel and in the tube is given by:

$$V(\vartheta) = V_0 + \pi \cdot \frac{d^2}{4} \cdot h(\vartheta) \qquad (1)$$

d: Internal diameter of tube,
V_0: Volume of vessel

If the expansion of the vessel is taken into account, equation (1) becomes

$$V(\vartheta) = V_0 \, (\, 1 + 3 \cdot \alpha \cdot \vartheta) + \pi \cdot \frac{d^2}{4} \cdot h(\vartheta) \qquad (2)$$

α = 3.3 10^{-6} K^{-1}: linear expansion coefficient of glass

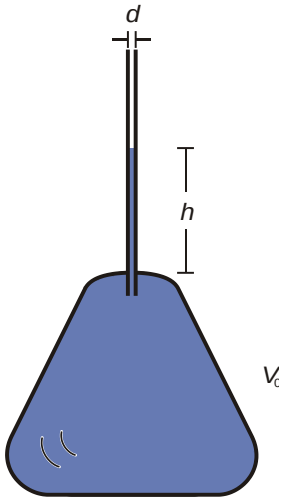

Fig. 1: Vessel with riser tube for measuring the thermal expansion of water

Fig. 2: Experiment set-up for determining the temperature of the maximum density of water

LIST OF APPARATUS

1 Apparatus for demonstrating the anomaly of water	1002889 (U14318)
1 Magnetic stirrer	1002808 (U11876)
1 Digital thermometer, single channel (U11817)	1002793
1 K-type immersion sensor	1002804 (U11854)
or	
1 Thermometer	1003013 (U16115)
1 Plastic funnel, d= 50 mm	1003568 (U8634700)
1 Silicon tubing, 1 m, 6 mm	1002622 (U10146)
1 Stand rod, 470 mm	1002934 (U15002)
1 Clamp with jaw	1002829 (U13253)
1 Stand base 150 mm	1002835 (U13270)
1 Plastic trough	4000036 (T52006)

Distilled water, crushed ice, table salt

SET-UP

- First place the stirrers into the apparatus for demonstrating the water anomaly.
- Mount the riser tube onto the glass vessel and screw it on tight.
- Connect the immersion sensor to the digital thermometer, screw the GL screw cap with the small bore onto the threaded tube at the side and insert the immersion sensor.
- As an alternative, the experiment can be conducted by using a standard thermometer. To use such an instrument, slide the GL screw cap with the large bore over the thermometer and attach it to the threaded tube at the side.
- Connect the silicon tube to the hose clip and then to the funnel.
- Set up the stand rod in the stand base. Attach the jaw clamp to the stand rod.
- Suspend the funnel from the clamp.
- In order to fill the glass vessel, open the tap and let distilled water into the funnel till the water level has reached approximately the middle of the riser tube.
- Remove any air bubbles by gently shaking the glass vessel.
- Close the tap, remove the tubing and pour the excess water back into its bottle.

EXPERIMENT PROCEDURE

- Set up the experiment as in Fig. 2.
- Prepare a mixture of crushed ice and table salt, and fill the plastic tub with this mixture.
- Place the tub on the magnetic stirrer.
- Place the apparatus in the trough as illustrated in Fig. 2.
- Use a marker pen to mark the water level in the riser pipe. Note the water level and the temperature.
- Switch on the magnetic stirrer and set it to medium speed.
- Read off the water level *h* in the riser tube and plot it as a function of temperature ϑ on a graph.
- As soon as the temperature falls below 0.5°C, remove the experiment apparatus from the trough in order to prevent the water from freezing.

SAMPLE MEASUREMENTS

Table 1: Level of water *h* in riser tube measured as a function of temperature ϑ

ϑ (°C)	*h* (mm)	ϑ (°C)	*h* (mm)
0.5	32.5	8.0	22.0
1.0	23.0	8.5	27.3
1.5	16.5	9.0	32.5
2.0	10.3	9.5	36.0
2.5	7.3	10.0	42.2
3.0	5.3	10.5	47.3
3.5	3.7	11.0	54.0
4.0	3.3	11.5	62.0
4.5	4.3	12.0	67.2
5.0	6.0	12.5	76.5
5.5	7.5	13.0	86.5
6.0	10.0	13.5	94.0
6.5	12.6	14.0	104.5
7.0	14.8	14.5	116.5
7.5	19.3	15.0	125.3

EVALUATION

Fig. 3 shows the curve resulting from the values in Table 1. The water level *h* in the riser pipe at 0°C is established by extrapolation. With this data, we get *h*(0°C) = 44.7mm. Using Equation (3), we can now calculate the relative density of water.

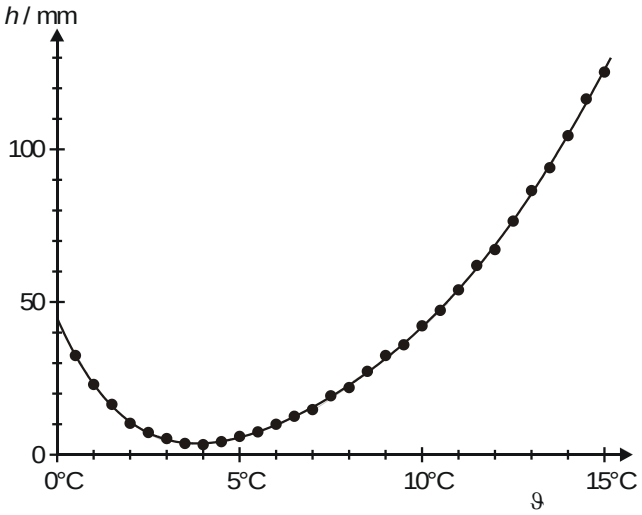

Fig. 3: Water level *h* as a function of temperature ϑ

Water density ρ is derived from equation (1) and (2) as follows:

$$\frac{\rho(\vartheta)}{\rho(0°C)} = \frac{V_0 + \pi \cdot \frac{d^2}{4} \cdot h(0°C)}{V_0\,(\,1 + 3 \cdot \alpha \cdot \vartheta) + \pi \cdot \frac{d^2}{4} \cdot h(\vartheta)} \qquad (3)$$

The maximum value of this expression occurs when ϑ = 4°C (see Fig. 4).

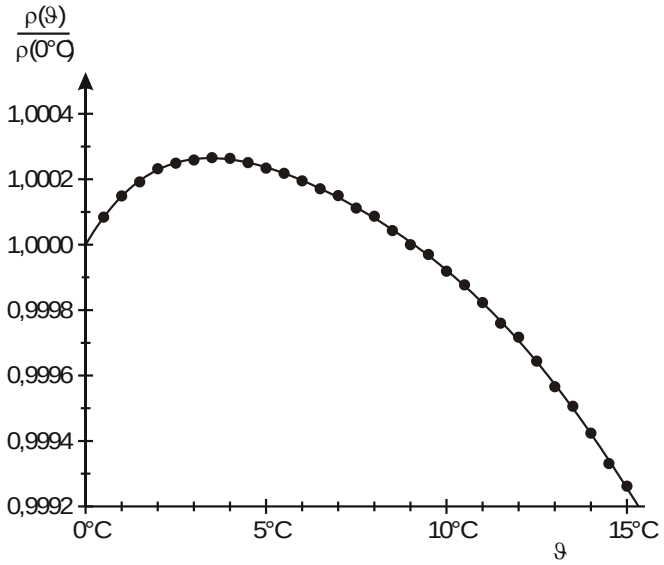

Fig. 4: Relative density of water as a function of temperature ϑ

RESULTS

The volume of water decreases as the temperature rises from 0°C to 4°C. The volume of water only increases at temperatures above 4°C.

Water attains its maximum density at approx. 4°C,