

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:

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

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

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

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

$\alpha = 3.3 \cdot 10^{-6} \text{ K}^{-1}$: linear expansion coefficient of glass

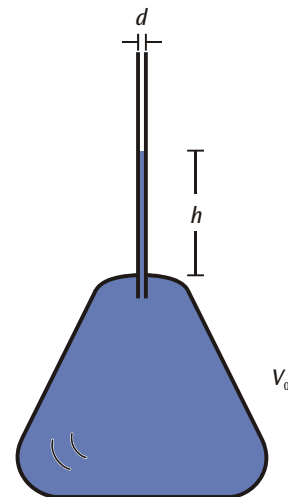


Fig. 1: Vessel with riser tube for measuring the thermal expansion of water



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 U14318	
1	Magnetic stirrer	U11876
1	Digital thermometer, single channel	U11817
1	K-type NiCr-Ni immersion sensor	U11854
or		
1	Thermometer	U16115
1	Plastic funnel, d = 50mm	U8634700
1	Silicon tubing, 1m, 6mm	U10146
1	Stand rod, 470mm	U15002
1	Clamp with jaw	U13253
1	Stand base, 150mm	U13270
1	Plastic trough	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 $h(0^\circ\text{C}) = 44.7\text{mm}$. Using Equation (3), we can now calculate the relative density of water.

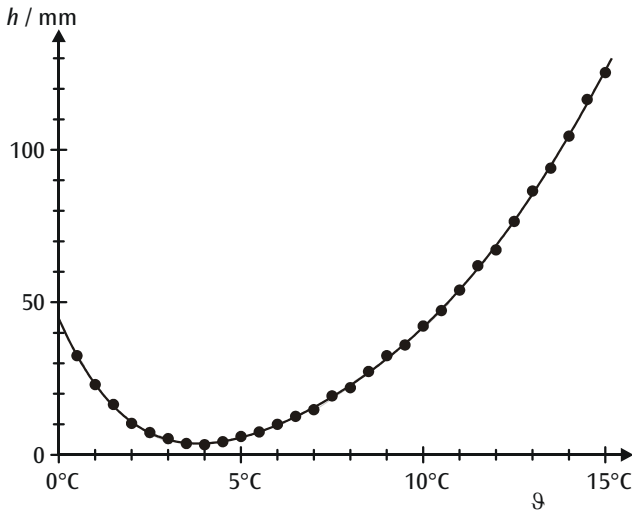


Fig. 3: Water level h as a function of temperature ϑ

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

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

The maximum value of this expression occurs when $\vartheta = 4^\circ\text{C}$ (see Fig. 4).

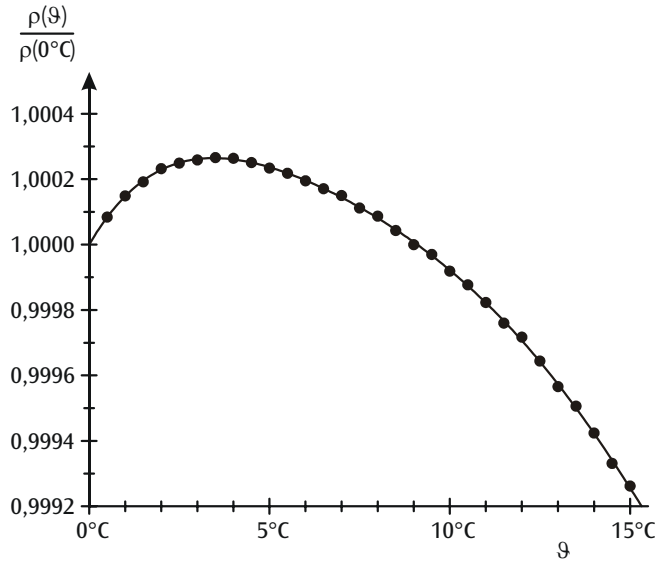


Fig. 4: Relative density of water as a function of temperature ϑ

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 .