Heat

Phase transitions
Latent heat and vaporization heat

Determining the specific vaporization heat of water

0110-Sel

Objects of the experiments

- Measuring the mixing temperature ϑ_M of cold water and steam.
- Calculating the specific vaporization heat of water.

Principles

When heat is transferred to a substance at constant pressure, the temperature of the substance generally increases. If, however, a phase transition takes place, the temperature does not increase as the transferred heat is consumed in the phase transition. As soon as the phase transition is finished, the temperature increases again if the heat transfer is continued. A well-known example of a phase transition is given by the vaporization of water. The heat consumed per mass unit is called the specific vaporization heat Q_V.

In the experiment, the specific vaporization heat Q_V of water is determined by piping pure steam into a calorimeter. The steam warms cold water up to a mixing temperature ϑ_m and condenses to water, which is cooled down to the mixing temperature. The vaporization heat is transferred to the water. In addition to the mixing temperature, the initial temperature ϑ_2 and the mass m_2 of the cold water as well as the mass m_1 of the condensed water are measured so that the vaporization heat can be calculated as follows:

The heat emitted by the steam is the sum of the heat

$$\Delta Q_1 = c \cdot m_1 \cdot (100°\mathrm{C} - \vartheta_M) \qquad \text{(I)},$$

c: specific heat of water

which the condensed water emits cooling down from $\vartheta_1 \approx$ 100 °C to the mixing temperature ϑ_M, and the heat ΔQ_2, which is emitted in the process of condensation from steam to water. The latter is the heat that has to be transferred to water at a

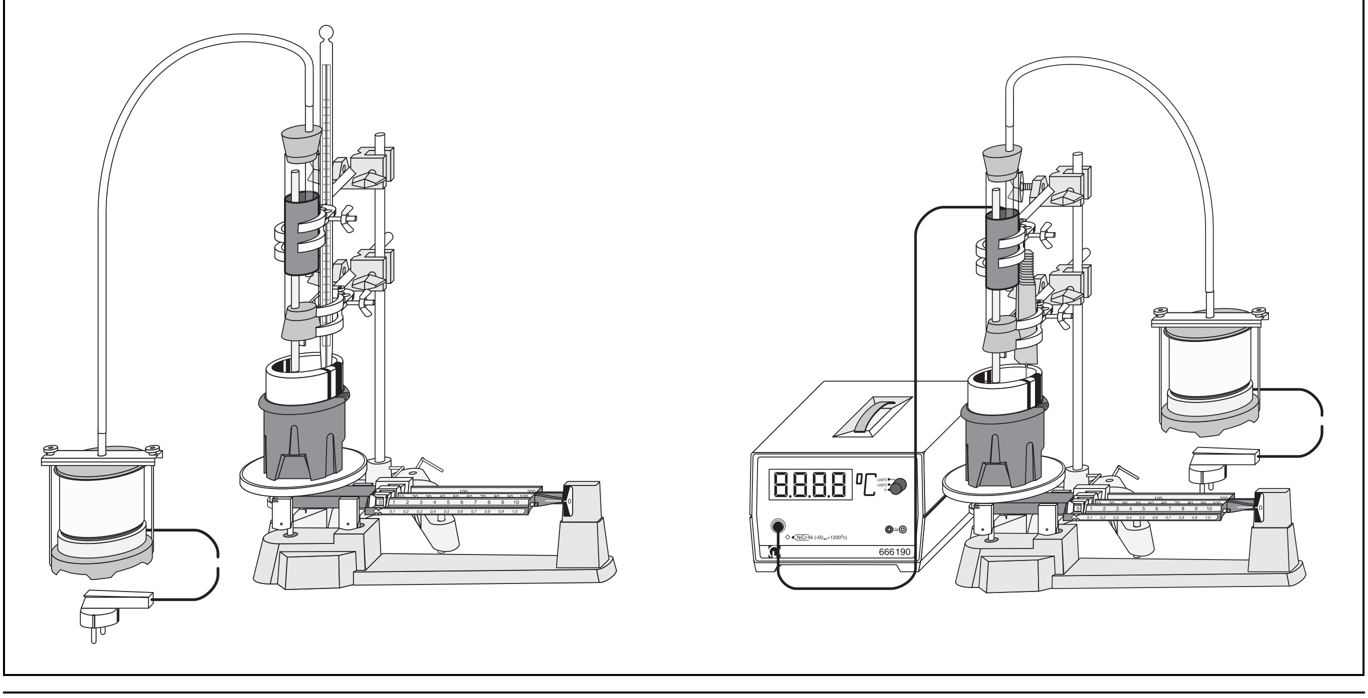

Fig. 1 Experimental setup for the determination of the specific vaporization heat of water
left: temperature measurement with a thermometer
right: temperature measurement with a temperature sensor

Apparatus

1 Dewar vessel calorimeter with base	386 48
1 school and lab. balance 610 Tare, 610 g	315 23
1 thermometer, –10° to + 110 °C	382 34
or	
1 temperature sensor NiCr-Ni	666 193
1 digital thermometer	666 190
1 steam generator, 550 W/230 V	303 28
1 water separator	384 17
1 silicone tubing, int. dia. 7 × 1.5 mm, 1 m	667 194
1 beaker, 400 ml, ss, hard glass	664 104
1 stand base, V-shape, 20 cm	300 02
1 stand rod, 47 cm	300 42
2 Leybold multiclamps	301 01
2 universal clamps, 0 … 80 mm dia.	666 555

Additionally required:

distilled water

temperature of $\vartheta_1 \approx 100\,°\text{C}$ in order that it vaporizes again; therefore we have

$$\Delta Q_2 = m_1 \cdot Q_V \qquad \text{(II).}$$

The heat absorbed by the cold water in mixing with the steam is

$$\Delta Q_3 = c \cdot m_2(\vartheta_M - \vartheta_2) \qquad \text{(III).}$$

At the same time, the calorimeter absorbs heat, which can be calculated since the water equivalent m_K of the calorimeter is known:

$$\Delta Q_4 = c \cdot m_K(\vartheta_M - \vartheta_2) \text{ with } m_K = 20\text{ g} \qquad \text{(IV).}$$

As the emitted heat $\Delta Q_1 + \Delta Q_2$ and the absorbed heat $\Delta Q_3 + \Delta Q_4$ are equal,

$$\frac{Q_V}{c} = \frac{(m_2 + m_K)}{m_1} \cdot (\vartheta_M - \vartheta_2) - (100°\text{C} - \vartheta_M) \qquad \text{(V)}$$

is found.

Setup

The experimental setup is illustrated in Fig. 1. While the experiment is carried out, the Dewar vessel is placed on the school and lab. balance.

- Clamp the thermometer or the temperature sensor NiCr-Ni.
- Fill distilled water into the steam generator to a height of about 2 cm, put the lid on, and carefully close the gripping device.
- Shift the steam inlet tube of the water separator so that the distance to the lower stopper is larger than the distance to the upper stopper. Shift the steam outlet tube until it almost reaches the upper stopper.
- Use the silicone tubing to connect the steam outlet tube of the steam generator to the steam inlet tube of the water separator. Do not clamp the water separator yet.

Carrying out the experiment

Filling cold water into the Dewar vessel:

- Read the mass of the empty Dewar vessel.
- Fill about 150 g of distilled water into the vessel and determine its mass m_2 and temperature ϑ_2.
- Clamp the water separator so that the steam outlet tube is by about 1 cm higher than the middle of the bottom of the Dewar vessel. If necessary, extend the tube with a short piece of silicone tubing.
- Determine the total mass of the arrangement.

Piping steam into the vessel:

- Put the water separator into the beaker and make certain that the silicone tubings are well-fixed.
- Connect the steam generator to the mains and wait for the steam to escape.
- Clamp the water separator over the Dewar vessel once more and observe the increase of the total mass and the rise of the temperature.
- After the total mass has increased by about 20 g, switch the steam generator off, and quickly determine the mixing temperature ϑ_M.

Measuring example

Mass m_2 of the cold water:	153.8 g
Temperature ϑ_2 of the cold water:	28.1 °C
Apparent mass after immersion of the water separator:	154.3 g
Mass after the steam has been piped in:	174.0 g
Mixing temperature ϑ_M of the warmed water:	88.3 °C

Evaluation and results

$m_1 = 174.0\text{ g} - 154.3\text{ g} = 19.7\text{ g}$

$m_2 = 153.8\text{ g}$

$\vartheta_M = 88.3\,°\text{C}$

$\vartheta_2 = 28.1\,°\text{C}$

Water equivalent of the Dewar vessel: $m_K = 20\text{ g}$

Specific heat of water: $c = 4.19\,\frac{\text{kJ}}{\text{kg} \cdot \text{K}}$

Inserting these values into Eq. (V) leads to

$$\frac{Q_V}{c} = 520\text{ K and } Q_V = 2.18 \cdot 10^3\,\frac{\text{kJ}}{\text{kg}}.$$

Value quoted in the literature:

$$Q_V = 2.257 \cdot 10^3\,\frac{\text{kJ}}{\text{kg}}.$$