Experiment 9

The latent heat of water

1- Objects of the experiments

- Measuring the mixing temperature T_M^{ws} of cold water and steam.
- Calculating the latent heat of vaporization, L_v, of water.
- Measuring the mixing temperature T_M^{iw} of ice and water.
- Calculating the latent heat of fusion, L_f, of ice.

2- Principles

A substance often undergoes a change in temperature when energy is transferred between it and its surroundings. There are situations, however, in which the transfer of energy does not result in a change in temperature. This is the case whenever the physical characteristics of the substance change from one form to another; such a change is commonly referred to as a phase change. Two common phase changes are from solid to liquid (melting) and from liquid to gas (boiling). All such phase changes involve a change in internal energy but no change in temperature. The increase in internal energy in boiling, for example, is represented by the breaking of bonds between molecules in the liquid state; this bond breaking allows the molecules to move farther apart in the gaseous state, with a corresponding increase in intermolecular potential energy.

As you might expect, different substances respond differently to the addition or removal of energy as they change phase because their internal molecular arrangements vary. Also, the amount of energy transferred during a phase change depends on the amount of substance involved. If a quantity *Q* of energy transfer is required to change the phase of a mass *m* of a substance, the ratio $L = Q/m$ characterizes an important thermal property of that substance. Because this added or removed energy does not result in a temperature change, the quantity *L* is called the latent heat of the substance. The value of *L* for a substance depends on the nature of the phase change, as well as on the properties of the substance.

From the definition of latent heat, and again choosing heat as our energy transfer mechanism, we find that the energy required to change the phase of a given mass *m* of a pure substance is

$$Q = \pm mL \qquad (1)$$

Latent heat of fusion L_f is the term used when the phase change is from solid to liquid, and latent heat of vaporization L_v is the term used when the phase change is from liquid to gas (the liquid "vaporizes"). The positive sign in Equation 1 is used when energy enters a system, causing melting or vaporization. The negative sign corresponds to energy leaving a system, such that the system freezes or condenses.

2-1- Latent heat of vaporization of water

A well-known example of a phase transition is given by the vaporization of water. The heat consumed per mass unit is called the latent heat of vaporization L_V.

In the experiment, the latent heat of vaporization L_V of water is determined by piping pure steam into a calorimeter. The steam warms cold water up to a mixing temperature T_M^{ws} and condenses to water, which is cooled down to the mixing temperature. The latent heat is transferred to the water. In addition to the mixing temperature, the initial temperature T_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 latent heat can be calculated as follows:

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

$$Q_1 = c.m_1.\left(T_M^{ws} - 100\right) \langle\ 0 \qquad (2),$$

c: specific heat of water ($c = 4.19 kJ/kg.K$)

which the condensed water emits by cooling down from T_1 = 100ºC to the mixing temperature T_M^{ws}, and the heat Q_2, which is emitted in the process of condensation from steam to water at temperature T_1 ~ 100ºC; therefore we have

$$Q_2 = -m_1.L_V\ \langle\ 0 \qquad (3).$$

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

$$Q_3 = c.m_2.\left(T_M^{ws} - T_2\right) \rangle\ 0 \qquad (4).$$

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

$$Q_4 = c.m_K.\left(T_M^{ws} - T_2\right) \rangle\ 0 \qquad (5)$$

with $m_K = 20\ g$

As the emitted heat $-Q_1 - Q_2$ and the absorbed heat $Q_3 + Q_4$ are equal ($-Q_1 - Q_2 = Q_3 + Q_4$: conservation of energy),

$$\frac{L_V}{c} = \frac{\left(m_2 + m_K\right)}{m_1}.\left(T_M^{ws} - T_2\right) - \left(100 - T_M^{ws}\right) \qquad (6)$$

is found.

2-2- Latent heat of fusion of water:

Another well-known example of a phase transition is given by the melting process (transformation of ice to water). The heat absorbed per mass unit is called the latent heat of fusion L_f.

In the experiment, L_f is determined by means of a calorimeter filled with ice. The ice cools warm water to the mixing temperature T_M^{iw} and melts to water with the mixing temperature T_M^{iw}. In addition, it absorbs the latent heat. Besides the mixing temperature, the initial temperature T_2 and the mass m_2 of the warm water as well as the mass m_1 of the ice are measured so that the latent heat can be calculated as follows:

The heat absorbed by the ice is the sum of the heat

$$Q_1 = c.m_1.\left(T_M^{iw} - 0\right) \rangle\, 0 \qquad (7)$$

c: specific heat of water ($c = 4.19 kJ/kg.K$)

which the melted water absorbs in warming up from T_1~ 0ºC to the temperature T_M^{iw}, and the heat,

$$Q_2 = m_1.L_f \rangle\, 0 \qquad (8)$$

which is absorbed in the process of melting from ice to water. The heat taken from the warm water when it is mixed with ice is:

$$Q_3 = c.m_2.\left(T_M^{iw} - T_2\right) \langle\, 0 \qquad (9)$$

At the same time heat is taken from the calorimeter. This heat can be calculated since the water equivalent m_K of the calorimeter is known*:*

$$Q_4 = c.m_K.\left(T_M^{iw} - T_2\right) \langle 0 \qquad (10)$$

with $m_K = 20g$.

As the absorbed heat $Q_1 + Q_2$ and the emitted heat $Q_3 + Q_4$ are equal, ($Q_1 + Q_2 = -Q_3 - Q_4$: conservation of energy),

$$\frac{L_f}{c} = \frac{(m_2 + m_K)}{m_1}.\left(T_2 - T_M^{iw}\right) - \left(T_M^{iw} - 0\right) \qquad (11)$$

is found.

3- List of Equipments

Apparatus	Catalogue Number
1 Dewar vessel calorimeter with base	386 48
1 balance	315 23
1 thermometer, -10° to + 110°C	382 34
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 multiclamps	301 01
2 universal clamps, 0 … 80 mm dia.	666 555
1 immersion heater	303 25
1 plastic beaker, 1000 ml	590 06
Additionally required: - distilled water - about 100 g ice cubes	

4- Latent heat of vaporization of water

4-1- Setup

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

- Clamp the thermometer.
- Fill distilled water into the steam generator to a height of about 2cm, 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.

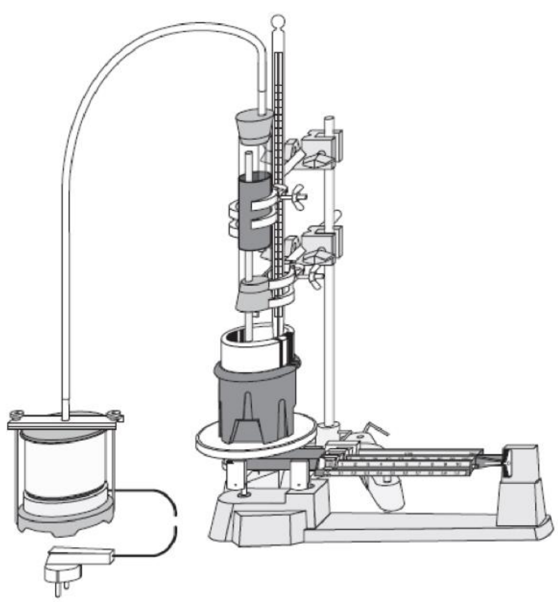

Figure 1. Experimental setup for the determination of the latent heat of vaporization of water.

4-2- Carrying out the experiment

<u>Filling cold water into the Dewar vessel:</u>

- Read the mass of the empty Dewar vessel.

- Fill about 150g of distilled water into the vessel and determine its mass m_2 and temperature T_2.

- Clamp the water separator so that the steam outlet tube is by about 1cm 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 20g, switch the steam generator off, and quickly determine the mixing temperature T_M^{ws} .

- Determine the value of L_v by using Equation (6).

- Compare the value of L_v determined experimentally to the value quoted in the literature for which $L_v = 2257 kJ/kg$.

- Discuss your results

5- Latent heat of fusion of water

5-1- Setup

The experimental setup is illustrated in Fig. 2. While the experiment is carried out, the Dewar vessel is placed on the balance.

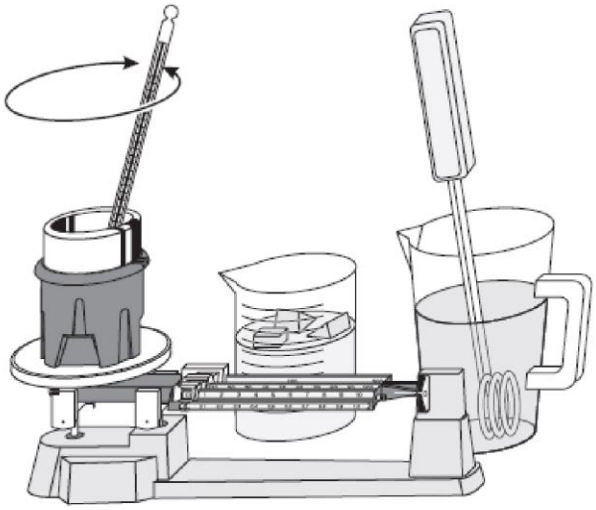

Figure 2. Experimental setup for the determination of the latent heat of fusion of water.

- Put the ice cubes into the beaker, which should be filled with cold water to a quarter so that the ice reaches a temperature of 0ºC (check with the thermometer).
- Place the thermometer into the Dewar vessel.

5-2- Carrying out the experiment

- Read the mass of the empty Dewar vessel.
- Warm water up to a temperature between 40ºC and 50ºC in the plastic beaker.
- Fill about 200g of the warm water into the Dewar vessel and determine its mass m_2 and temperature T_2 (stir).
- Put 50g of “dry” ice cubes into the warm water.
- Stir until the ice has completely melted and read the temperature T_M^{iw}.
- Determine the value of L_f by using Equation (11).
- Compare the value of L_f determined experimentally to the value quoted in the literature for which $L_f = 334kJ/kg$.
- Discuss your results