C3. Determining the Heat of Fusion of Ice Using the Calorimetric Method

The aim of the exercise *is to understand the phenomenon of melting, phase transitions, and latent heat, and—using the principle of thermal balance—to experimentally determine the heat of fusion of ice.*

Melting is a phase transition from a solid to a liquid. This process involves heat absorption ***Q*** and an increase in **entropy***

*__Entropy__ is a state function describing spontaneous processes' direction in thermodynamic systems. It is a statistical measure of disorder, expressed in joules per kelvin [J/K].

Latent heat is the energy required for a phase transition. In the case of melting, this energy is called **the heat of fusion**.
The heat of fusion L is the amount of heat required to melt 1 kg of a substance at its melting temperature:

$$L = \frac{Q}{m} \quad (1)$$

where m is the mass. The heat of fusion is given in J/kg.

For **crystalline solids**, melting occurs at a specific temperature, known as the **melting point**, at constant external pressure. The supplied heat weakens crystalline bonds rather than increasing the kinetic energy of atoms (hence the term **latent heat**). As a result, during the melting of crystalline solids, **temperature remains constant** (Figure 1, line 1).
For **amorphous substances** (e.g., glass, resin, polymers), melting does not occur at a single temperature; instead, the material gradually softens as it is heated (Figure 1, line 2).

Freezing is the reverse process of melting and occurs at the same temperature.

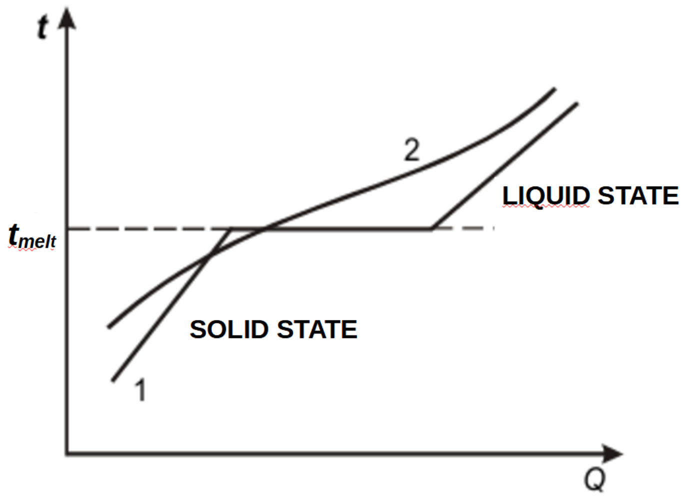

Figure 1

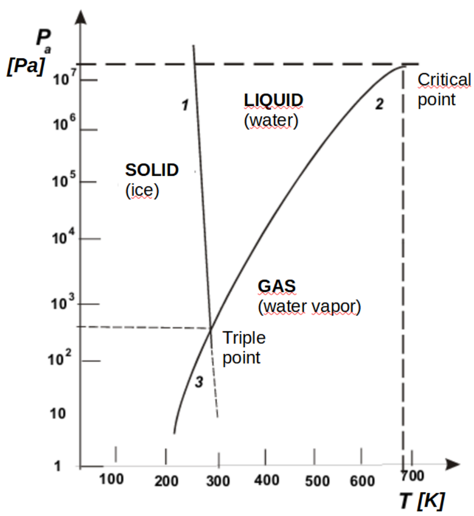

Figure 2

Both melting and boiling points depend on pressure (Figure 2). The **triple point** represents the conditions where a substance can exist in solid, liquid, and gas phases at the same time.

In this experiment, the heat of the fusion of ice is determined using a calorimeter with mass $\boldsymbol{m_c}$ and specific heat capacity $\boldsymbol{c_k}$ The calorimeter is filled with water with mass $\boldsymbol{m_w}$ and specific heat capacity $\boldsymbol{c_w}$. At the time when the temperature of water in the calorimeter is constant, a piece of melting ice with mass $\boldsymbol{m_i}$ at **0°C** is introduced into the calorimeter. Heat exchange occurs until the system reaches thermal equilibrium at a final temperature $\boldsymbol{t_e}$.

Heat Exchange Calculations

During the melting process:

1. Heat is absorbed:
    a. By ice during melting:
$$Q_1 = m_i L \tag{2}$$
    b. By melted ice warming up to $\boldsymbol{t_e}$:
$$Q_2 = m_i c_w (t_e - t_{melt}) \tag{3}$$
2. Heat is released:
    a. By the calorimeter:
$$Q_3 = m_c c_c (t_s - t_e) \tag{4}$$
    b. By the water initially poured to the calorimeter:
$$Q_4 = m_w c_w (t_s - t_e) \tag{5}$$

Applying the principle of thermal balance (heat absorbed is equal to the heat released): $\boldsymbol{Q_1+Q_2=Q_3+Q_4}$, which leads to the formula:

$$m_i L + m_i c_w (t_e - t_{melt}) = m_c c_c (t_s - t_e) + m_w c_w (t_s - t_e) \tag{6}$$

Rearranging for $\boldsymbol{L}$:

$$L = \frac{(m_c c_c + m_w c_w)(t_s - t_e)}{m_i} - c_w (t_e - t_{melt}) \tag{7}$$

C3. Measurement and calculation protocol

Pair No.:	Student's name and surname:	Field of study: Group:
Date:	Teacher's name and surname:	Passing information:

Measuring protocol:

Equipment: Calorimeter (consisting of: inner vessel, thermal insulation, lid, manual stirrer), laboratory balance, thermometer, water (distilled), ice (cube)

Precautions: ensure that the ice is melting (reached the temperature of 0°C) before putting it into the calorimeter.

Measuring steps:

1. Weigh the calorimeter's inner vessel with the stirrer: m_c.
2. Fill the calorimeter with water (about half full) and weigh it again: m_{cw}.
4. Calculate the water mass: $m_w = m_{cw} - m_c$
5. Place the calorimeter in thermal insulation and measure the initial water temperature: t_s
6. Introduce a dry piece of melting ice into the calorimeter and close the lid.
7. Stir the water and monitor the temperature drop. Record the lowest equilibrium temperature: t_e.
8. Weigh the calorimeter with the melted ice water: m_{cwi}.
9. Calculate the ice mass: $m_i = m_{cwi} - m_{cw}$

Data table

calorimeter mass m_c [kg]	mass of calorimeter with water m_{cw} [kg]	water mass m_w [kg]	mass of calorimeter with water and ice m_{cwi} [kg]	ice mass m_i [kg]	initial temperature t_s [°C]	final (equilibrium) temperature t_e [°C]

Uncertainties:

$\Delta m_c = \Delta m_{cw} = \Delta m_{cwi} =$ …………………[kg]

$\Delta m_w = \Delta m_c + \Delta m_{cw} =$ ………………[kg]

$\Delta m_i = \Delta m_{cwi} + \Delta m_{cw} =$ ……………….[kg]

$\Delta t_s = \Delta t_e =$ …………..[°C]

Heat of fusion L $\left[\frac{kJ}{kg}\right]$	
Heat of fusion uncertainty ΔL $\left[\frac{kJ}{kg}\right]$	
Final result (rounded) $(L \pm \Delta L)$ $\left[\frac{kJ}{kg}\right]$	

Data analysis and calculations:

1. Calculate the heat of fusion according to the formula:

$$L = \frac{(m_c c_c + m_w c_w)(t_s - t_e)}{m_i} - c_w(t_e - t_{melt}),$$

where:

- ✓ Specific heat of aluminum calorimeter: c_c=0.896 [kJ/(kg K)]
- ✓ Specific heat of water: c_w=4,19 [kJ/(kg K)]
- ✓ Melting temperature: t_{melt} = 0 [°C]

2. Calculate uncertainty of L using total differentiation method:

$$\Delta L = \left|\frac{c_c(t_s - t_e)}{m_i}\right| \Delta m_c + \left|\frac{c_w(t_s - t_e)}{m_i}\right| \Delta m_w + \left|\frac{(c_c m_c + c_w m_w)(t_s - t_e)}{m_i^2}\right| \Delta m_i +$$

$$+ \left|\frac{(c_c m_c + c_w m_w)}{m_i}\right| \Delta t_s + \left|-\frac{(c_c m_c + c_w m_w)}{m_i} - c_w\right| \Delta t_e$$

3. Finally present the result for each sample as $(L \pm \Delta L)$ in SI units