Experiment Nr. 18

DETERMINATION OF THE MELTING POINT AND LATENT HEAT

Theoretical part

Latent heat is the energy absorbed or released by a substance during a change of its physical state (phase) that occurs without changing its temperature. The latent heat associated with melting a solid or freezing a liquid is called the heat of fusion; that associated with vaporizing a liquid or a solid or condensing a vapour is called the heat of vaporization. The latent heat is normally expressed as the amount of heat (in units of Joules) per mole or per unit mass of the substance undergoing a change of state.

Specific latent heat l expresses the amount of energy in the form of heat Q required to completely effect a phase change of a unit of mass m, usually 1 kg, of a substance as an intensive property:

$$l = \frac{Q}{m}$$

Intensive properties are material characteristics and are not dependent on the size or extent of the sample. Commonly quoted and tabulated in the literature are the specific latent heat of fusion and the specific latent heat of vaporization for many substances.

For example, when a pot of water is kept boiling, the temperature remains at 100 °C until the last drop evaporates, because all the heat being added to the liquid is absorbed as latent heat of vaporization and carried away by the escaping vapour molecules. Similarly, while ice melts, it remains at 0 °C, and the liquid water that is formed with the latent heat of fusion is also at 0 °C. The heat of fusion for water at 0 °C is approximately 337 kJ.kg^{-1}, and the heat of vaporization at 100 °C is about 2260 kJ.kg^{-1}. Because the heat of vaporization is so large, steam carries a great deal of thermal energy that is released when it condenses, making water an excellent working fluid for heat engines.

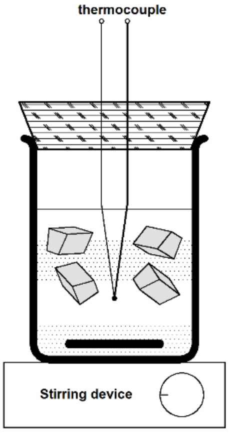
Latent heat arises from the work required to overcome the forces that hold atoms or molecules together in material. The regular structure of a crystalline solid is maintained by forces of attraction among its individual atoms, which oscillate about their average positions in the crystal lattice. As the temperature increases, these motions become increasingly violent until, at the melting point, the attractive forces are no longer sufficient to maintain the stability of the crystal lattice. However, additional heat (the latent heat of fusion) must be added (at constant temperature) in order to accomplish the transition to the even more-disordered liquid state, in which the individual particles are no longer held in fixed lattice positions but are free to move about through the liquid. A liquid differs from a gas in that the forces of attraction between the particles are still sufficient to maintain a long-range order that endows the liquid with a degree of cohesion. As the temperature further increases, a second transition point (the boiling point) is reached where the long-range order becomes unstable relative to the largely independent motions of the particles in the much larger volume occupied by a vapour or gas. Once again, additional heat (the latent heat of vaporization) must be added to break the long-range order of the liquid and accomplish the transition to the largely disordered gaseous state.

Latent heat (or specific latent heat) is usually studied by **calorimetry**. Calorimetry is the science or act of measuring changes in state variables of a body for the purpose of deriving the heat transfer associated with changes of its state due, for example, to chemical reactions, physical changes, or phase transitions under specified constraints. Calorimetry is performed with a calorimeter. A simple calorimeter just consists of a thermometer attached to a metal container filled with water. Since the calorimeter runs in an **adiabatic environment**, any heat generated by the material sample under test causes the sample to increase in temperature, thus fuelling the reaction. No adiabatic calorimeter is fully adiabatic - some heat will be lost by the sample to the sample holder.

Experiment Nr. 18a: Determination of the latent heat of melting ice

Theory of the measurement

The measurement is performed considering the adiabatic calorimetry. The calorimeter with a heat capacity K_K is filled by a specific amount of warm water (temperature t_1, mass m_V and specific heat capacity c_V). A piece of ice (temperature ϑ, and mass m_L) is placed into the calorimeter (see following figure).



After the ice cube is completely melted, the temperature of the calorimeter reaches its steady value of t_2. Considering that the temperature of the ice is equal $\vartheta = 0$ °C, the melting ice absorbs some amount of heat energy during the melting process, and, additionally some amount of heat energy during its heating to the final temperature t_2. Due to the adiabatic calorimetry, we can consider that the heat energy absorbed by the ice is equal to the heat transferred from the calorimeter filled with water. In this case, the calorimetry formula could be defined as follows:

$$m_L l + m_L c_V (t_2 - \vartheta) = (m_V c_V + K_K)(t_1 - t_2)$$

Thus, the specific latent heat *l* of the melting ice could be calculated by following formula:

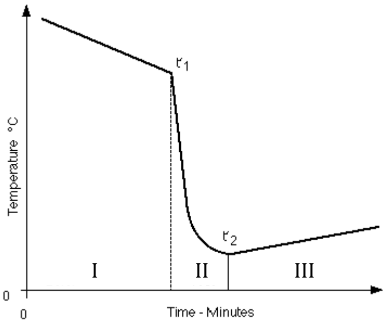
$$l = \frac{(m_V c_V + K_K)(t_1 - t_2)}{m_L} - c_V t_2$$

Measurement objective

1. Determine the specific latent heat of melting ice and consider its uncertainty to be about of 10 %.
2. Plot the dependency of the calorimeter temperature against time.
3. Compare the specific latent heat result with the value taken from the table data: $l = 333.7$ kJ.kg^{-1}.

Measurement procedure

The calorimeter is filled with water ($m_V = 300$ g approx., $t_1 = 35$ °C approx.). Determine the mass of the empty calorimeter using digital scale. Fill the calorimeter with the desired amount of water and weigh the water-filled calorimeter again. The temperature of the calorimeter is above room temperature; the calorimeter filling should be stirred during the whole measurement procedure. The temperature is measured by a thermocouple and the data are recorded using the computer. Record the temperature evolution against time for about 5 minutes - the temperature should decrease slowly. Prepare the ice cubes and let them at the room temperature until some melted water appears on the surface. Wipe dry about 8 - 10 pieces of ice cubes and add them to the calorimeter at once. After some time, the ice cubes melt and the temperature will steady down. Wait about 5 minutes until the temperature is rising slowly and steadily. Note that the value of the room temperature should be approximately in the mid point of the range $(t_1;t_2)$ due to the balance of the heat transfer between the calorimeter and ambient environment. A typical temperature evolution could be seen in the following figure:



Determining the best corrected value of the temperature range t_1 - t_2 could be a complicated and tedious procedure. One of the preferred approximation is projecting the temperature curve using three separate linear functions describing the measurement parts "I", "II" and "III" according to the figure above. The intersection points could be defined as t_1 and t_2. The time intervals can be described as follows:

I - The temperature of the liquid is above the room temperature. A moderate decrease of the temperature could be observed due to the heat transferred from the calorimeter to the ambient environment. Record the data for about 5 minutes in this phase.
II - At the beginning of this interval, the ice cubes are added to the calorimeter. The temperature starts to decrease sharply and some dynamic effects can be observed. At the end of this interval, the calorimeter temperature should stabilize at particular minimum value. Note that the temperature change below and above the room temperature should be approximately the same due to the heat losses compensation.
III - The liquid reached the minimum temperature that is below the room temperature. A moderate increase of the temperature could be observed due to the heat transferred from the ambient environment to the calorimeter. Record the data for about 5 minutes in this phase.

Finally, determine the mass of the complete calorimeter filled by water and melted ice. Subtract the pre-test mass values to obtain the net mass of the ice cubes.

Important constants

The heat capacity of the calorimeter is $K_K = (55 \pm 5)\ \mathrm{J \cdot K^{-1}}$.

The water specific heat capacity as a function of temperature:

t [°C]	**c [J·kg^{-1}·K^{-1}]**	**t [°C]**	**c [J·kg^{-1}·K^{-1}]**	**t [°C]**	**c [J·kg^{-1}·K^{-1}]**
0	4217,8	35	4178,1	70	4189,7
5	4201,3	40	4178,4	75	4192,9
10	4192,2	45	4179,3	80	4196,4
15	4186,3	50	4180,5	85	4200,5

20	4181,8	55	4182,2	90	4205,2
25	4179,5	60	4184,3	95	4210,4
30	4178,4	65	4186,7	100	4216,0

Uncertainty calculation notes

The combined relative uncertainty of the specific latent heat is about 10 %. Specify the uncertainty range and check if the true value can be found within this range.

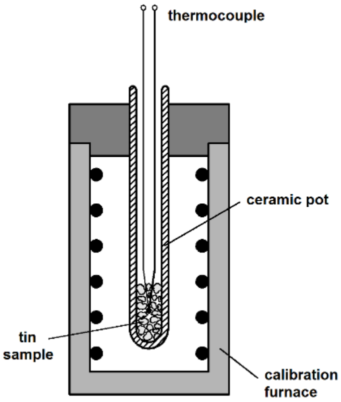
Experiment Nr. 18b: Determination of the melting and solidification point of tin

Measurement objective

1. Determine the melting and solidification point of pure tin sample.
2. Plot the evolution of temperature against time for heating and cooling the sample.

Measurement procedure

The tin sample is inserted into the calibration furnace (see the following figure). Using a precise thermocouple, the tin temperature evolution is recorded.



In the first part of the measurement (heating up), set the maximum temperature on the furnace digital panel to 255 °C. Wait until the whole tin sample is melted - the temperature of the sample should exceed the melting point (231 °C approx.) for about 10 °C. At this point set the desired temperature of the furnace to 0 °C and wait until the temperature of the sample drops to about 150 °C. Transfer the obtained data to the computer and plot the evolution of temperature as a function of time. Find and highlight the melting and solidification point of the tin sample. Note that the typical melting curve and the solidification curve could differ due to different heat transfer rate during the heating and cooling of the sample.

Uncertainty calculation notes

Do not determine the uncertainty. Compare the the melting point obtained from the graph to the value given in the tabular data.