Specific heat capacity and specific latent heat

Specification references:
- P3.2.2 Temperature changes in a system and specific heat capacity
- P3.2.3 Changes of heat and specific latent heat

Aims
This is an activity that has been designed to help you improve your literacy skills. In this activity you will learn more about the terms specific heat capacity and specific latent heat in relation to the thermal behaviour of bodies. You will practise answering questions that involve some of the key command words and scientific terms that you will encounter in the topic of thermal physics.

Learning outcomes
After completing this worksheet, you should be able to:
- define the terms ‘specific heat capacity’ and ‘specific latent heat’
- describe situations when these terms would be used
- describe what happens when a body changes state
- apply equations of specific heat capacity and latent heat to real problems.

Setting the scene
Thermal physics is a key area of physics that deals with what happens when bodies are heated or when they transfer heat to the surroundings. There are often misconceptions regarding temperature changes that occur when bodies melt or freeze and these issues will be dealt with here.

Task
Read the information about thermal energy changes and then answer the questions that follow. You will need to perform calculations using some of these values:

- Specific heat capacity of ice = 2108 J/kg °C
- Specific heat capacity of water = 4200 J/kg °C
- Specific latent heat of fusion of water = 334 000 J/kg
- Specific latent heat of vaporisation of water = 2 260 000 J/kg
- Specific latent heat of fusion of copper = 207 000 J/kg

Specific heat capacity and specific latent heat
When water changes phase, thermal energy is exchanged between the water and its surroundings. The water either absorbs or releases heat depending on the phase change. This type of thermal energy (or heat) is called latent heat, because the energy is stored or hidden until the phase change occurs. The specific latent
heat is the energy required to cause 1 kg of material to change state at a constant
temperature.

Heat is \textit{absorbed} when water changes from a liquid to a gas (water vapour).
The energy that is absorbed gives the molecules the extra motion that is needed
to escape the surface of the liquid to become a gas. This process is known as
evaporation, and the absorption of heat is called the \textbf{latent heat of evaporation}
(or latent heat of vaporisation). When the solid phase (ice) changes to a liquid,
melting occurs and heat is also absorbed.

Heat is \textit{released} when water changes from a gas (water vapour) to a liquid.
This happens as warm and humid air rises through the atmosphere into cooler
temperatures. Cooler air cannot hold as much moisture, so the water vapour
condenses. The latent or hidden heat is then released, which is why this process
is known as the \textbf{latent heat of condensation}. Heat is also released when water
changes from the liquid phase to the solid phase (which is called freezing).

\textbf{Specific heat capacity}

Temperature and heat are not the same thing.

- Temperature is a measure of how hot something is, which is directly related to
  the average kinetic energy of the atoms or molecules inside it.

- Heat is a measure of the thermal energy contained in an object.

Temperature is measured in °C, and heat is measured in J. When thermal energy
is transferred to an object by heating, its temperature increase depends on:

- the mass of the object
- the substance the object is made from
- the amount energy transferred to the object.

For a particular object, the more thermal energy transferred to it by heating, the
greater its temperature increase, so the greater the average kinetic energy of its
particles will be. This is not true when there is a change in phase occurring since
the temperature remains constant.

\textbf{Specific heat capacity}

The specific heat capacity of a substance is the amount of energy needed to
change the temperature of 1 kg of the substance by 1 °C. Different substances
have different specific heat capacities. The table shows some examples.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific heat in J/kg K</th>
</tr>
</thead>
<tbody>
<tr>
<td>aluminium</td>
<td>878</td>
</tr>
<tr>
<td>copper</td>
<td>381</td>
</tr>
<tr>
<td>iron</td>
<td>438</td>
</tr>
<tr>
<td>lead</td>
<td>126</td>
</tr>
<tr>
<td>ethanol</td>
<td>2410</td>
</tr>
<tr>
<td>water</td>
<td>4200</td>
</tr>
</tbody>
</table>
Calculating specific heat capacity

Here is the equation relating energy to specific heat capacity:

\[ E = m \times c \times \Delta \theta \]

- \( E \) is the energy transferred in joules, J
- \( m \) is the mass of the substances in kg
- \( c \) is the specific heat capacity in J/kg °C
- \( \Delta \theta \) (‘delta theta’) is the temperature change in degrees Celsius, °C

For example, how much energy must be transferred to raise the temperature of 8 kg of water from 30 °C to 70 °C?

\[
E = m \times c \times \Delta \theta \quad (\Delta \theta = 70 - 30 = 40 \, ^\circ \text{C})
\]

\[
E = 8 \times 4200 \times 40
\]

\[= 1344000 \, \text{J or 1344 kJ or 1.344 MJ}\]

Questions

1. a Define:
   i. specific heat capacity

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   ii. specific latent heat.

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   b. State the meaning of the word ‘latent’.

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2. Explain why both the ‘specific latent heat’ and the ‘specific heat capacity’ are needed for calculations in the area of thermal physics.

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3 Explain the importance of the word ‘specific’ in the definitions for specific heat capacity and specific latent heat.

4 Calculate the energy required to:
   a convert 85 kg of ice to water
   b convert 12 kg of copper from a solid to a liquid
   c heat 500 g of water from 24 °C to 75 °C
   d convert 40 kg of ice at −5 °C to steam at 100 °C.

5 Describe the potential uses of materials with:
   a high specific heat capacities
   b low specific latent heats of vaporisation.
6 The terms ‘phases of matter’ and ‘states of matter’ are often used to mean the same thing. However, they do actually have different meanings. For example, carbon dioxide can exist as a gas and a solid at room temperature. Based on this information, write a sentence that describes this by using the words state and phase.

7 Explain why the value for the specific latent heat of vaporisation of water is greater than the value for the specific latent heat of fusion of water.

8 Explain why:
   a specific heat capacity can be stated in J/kg K or J/kg °C with the same value
   b specific latent heat has units of J/kg and not J/kg °C.
Answers to questions

1 a i Specific heat capacity is the energy required to raise the temperature of unit mass (1 kg) by unit temperature (1 K or 1 °C).

ii Specific latent heat is the energy required to cause the change of state of unit mass (1 kg) at a constant temperature.

b hidden

2 The specific heat capacity is needed to determine the energy absorbed or released when a body is heated or cooled in a constant state or phase of matter. The specific latent heat is required to determine the energy absorbed or released when a body melts or freezes (latent heat of fusion) or when it boils or condenses (latent heat of vaporisation).

3 The term ‘specific’ refers to 1 kg of the material in question.

4 a Using \( E = mL_f \) gives
\[
E = 85 \times 334\,000 = 28\,390\,000 \text{ J}
\]

b Using \( E = mL_f \) gives
\[
E = 12 \times 207\,000 = 2\,484\,000 \text{ J}
\]

c Using \( E = mc\Delta\theta \) gives
\[
E = 0.5 \times 4200 \times (75 - 24) = 107\,100 \text{ J}
\]

d This requires five steps:
- Energy required to heat 40 kg of ice at −5 °C to 0 °C = 40 \times 2108 \times 5 = 421\,600 \text{ J}
- Energy required to melt 40 kg of ice at 0 °C = 40 \times 334\,000 = 13\,360\,000 \text{ J}
- Energy required to heat 40 kg of water at 0 °C to water at 100 °C = 40 \times 4200 \times 100 = 16\,800\,000 \text{ J}
- Energy required to convert 40 kg of water at 100 °C to steam at 100 °C = 40 \times 2\,260\,000 = 90\,400\,000 \text{ J}

Giving a total of 120\,981\,600 \text{ J}.

5 a cooling systems and for use in heaters and central heating systems

b to cool objects down by evaporation.

6 For example, the states of carbon dioxide at room temperature are the gas phase and the solid phase.

7 More energy is required to convert 1 kg of liquid to gas than from a solid to a liquid. This is due to the expansion of the liquid and increase in volume as it changes to a gas which requires work to be done on the atmosphere.

8 a A change in temperature of 1 K is the same as a change in temperature of 1 °C, so both units can be used.

b There is no change in temperature when performing calculations with specific latent heat – just a change in state or phase, so K or °C are not required in the calculation.