Form 4 Chapter 4: Heat

Understanding Thermal Equilibrium
1. When two objects A and B which are at different temperatures are in contact, heat is transferred from the hotter object A to the colder object B.
2. The temperature of A decreases as it releases heat while the temperature of B increases as heat is absorbed from A. When the temperatures of both the objects are equal, thermal equilibrium has been achieved. At thermal equilibrium, the rates of heat transfer between A and B are equal, or the net rate of heat transfer between the two objects is zero. Both of them have the same temperature.
3. When the temperature increases, the quantity of heat released also increases.

Change in the Physical Properties of Materials with Temperature
1. The thermometric property of an object is the physical property of the object that is sensitive and changes linearly with the change in temperature of the object.
2. The thermometric property of a substance is important in the construction of a thermometer to measure temperature.

Calibration of a Mercury-in-Glass Thermometer in Degree Celsius

1. Impurities like sugar or salt will increase the boiling point and lower the freezing point.

Liquid-in-Glass Thermometer – Mercury Thermometer
1. The working principle is thermal equilibrium where the thermometer functions on the expansion and contraction of mercury with temperature.
2. When thermal equilibrium is achieved, no net flow of heat. The body and the thermometer have the same temperatures.
3. The advantages of using **mercury** in thermometers:
   (a) **High boiling point** (500 °C) and low melting point (-39 °C).
   (b) **Good conductor of heat** / sensitive to heat.
   (c) **Expands and contracts uniformly** with temperature.
   (d) **Opaque** where it can be seen clearly and easily (not transparent).
   (e) High cohesive force (does not stick to the wall of the capillary tube).
4. When the temperature of the surroundings **increases**, heat is transferred to the mercury and it **expands**. The expansion of mercury increases the length of the mercury column in the capillary tube (**volume increases**).

**Ways to Increase Sensitivity of Mercury Thermometer**
1. Reducing the thickness of the glass bulb - heat transfers faster between the mercury.
2. **Reducing the size of the glass bulb** - absorbs heat from the surroundings at a higher rate.
3. Using a capillary tube with a **finer bore** (smaller diameter) - increases rate of expansion & contraction of the mercury.
4. Thicker capillary wall – to avoid heat transfer from the surrounding.

**Mercury Meniscus**
1. If you accidentally spilt mercury, there will be many spherical droplets (big cohesive force) and they do not wet the surface (small adhesive force).

**Specific Heat Capacity**
Specific heat capacity of a substance is the **amount of heat that must be supplied to increase the temperature by 1°C for a mass of 1 kg of the substance.**

\[
Q = mc\theta
\]

- \( m = \text{mass} \) (kg)
- \( c = \text{specific heat capacity} \) (J kg\(^{-1}\) °C\(^{-1}\))
- \( \theta = \text{temperature change} \) (°C)

1. Substances with **smaller** specific heat capacity can be **heated up faster**.
2. Water can be used as cooling agent because it has **high heat capacity, high boiling point, easily available and not corrosive**. It can absorb big amount of heat with a small increase in temperature.
3. At night, land cools down faster than sea because **specific heat capacity of sea water is greater than land**. Water can absorb big amount of heat with little increase in temperature.
4. When specific heat capacity is higher, the slower the flow of heat. Hence, the temperature is low.
5. Specific heat capacity in iron is lower than a piece of wood. Heat transfer is faster in iron rather than in a piece of wood.

### Specific Latent Heat

\[ Q = mL \]

- **Q** = Heat Change \((J\ or\ Nm)\)
- **m** = mass \((kg)\)
- **L** = specific latent heat \((J\ kg^{-1})\)

<table>
<thead>
<tr>
<th>Electric Heater</th>
<th>Mixing 2 Liquids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Supply, (E = Pt)</td>
<td>Heat Gain by Liquid 1 = Heat Loss by Liquid 2</td>
</tr>
<tr>
<td>Energy Receive, (Q = mc\theta)</td>
<td>(m_1c_1\theta_1 = m_2c_2\theta_2)</td>
</tr>
<tr>
<td>Energy Supply, (E = \text{Energy Receive, } Q)</td>
<td>(Q = \text{Heat Change } (J\ or\ Nm))</td>
</tr>
<tr>
<td>(Pt = mc\theta)</td>
<td>(m = \text{Mass})</td>
</tr>
<tr>
<td>(E = \text{Electrical Energy} (J\ or\ Nm))</td>
<td>(c = \text{Specific Heat Capacity} (J\ kg^{-1}\cdot°C^{-1}))</td>
</tr>
<tr>
<td>(P = \text{Power of the Electric Heater} (W))</td>
<td>(\theta = \text{Temperature Change} (°C))</td>
</tr>
<tr>
<td>(t = \text{Time (in second)} (s))</td>
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</table>

**Sea Breeze**

1. During the day, the sun heats the surface of the land faster than the surface of the sea.
2. This is because the specific heat capacity of the land is lower than that of water.
3. When the air above the land is heated up by the hot sand, it expands and rises upwards creating a region of low pressure.
4. The cool air which is at a higher pressure, above the surface of the sea moves towards the land to fill the space vacated by the rising hot air; an air convection current is thus formed.
5. As a result, the wind blows from the sea towards the land in the daytime. This air movement is called a sea breeze.
Heating and Cooling Curves

1. Figure shows the heating curve of a substance which is heated at fixed rate. 
   **Assumption:** No heat loss to surrounding.

   *Latent heat of fusion is absorbed during the process of melting.*
   *The heat is used to break the bond between molecules.*
   *At stage B to C, effect of heat.*
   *Change of state taking place (BC) & (DE).*

2. The figure shows the cooling curve of a substance which is cooled at a fixed rate.

   *Latent heat of fusion is released and the molecules are not able to overcome the forces of attraction and atmospheric pressure. The kinetic energy and temperature remain constant.*
   *The liquid starts to freeze/solidity.*
   *Latent heat of fusion is released and the molecular bonds between molecules reform.*
   *The kinetic energy and temperature do not decrease.*
3. The transfer of heat during changes of phase does not cause a change in temperature. However, when there is no change of phase, the heat absorbed increases the temperature of the substance being heated.

4. The heat absorbed or released when a substance undergoes a change in phase without a change in temperature is the latent heat.

**To Determine the Specific Latent Heat of Fusion of Ice**

| Latent heat of fusion of substances | is the heat required to change 1 kg of the substances from solid to liquid state without a change in temperature. |

**1. Apparatus / Materials**
- 100 W electric/immersion heater, power supply, beakers, stopwatch, pure ice, retort stand, weighing balance, and filter funnel.

**2. Arrangement of Apparatus**

a) **Set A: Control Experiment**
- Immersion heater A, ice, filter funnel, beaker A, water.

b) **Set B**
- Immersion heater B, ice, filter funnel, beaker B, water.

**3. Procedure**
1. The apparatus is arranged as shown in Figure.
2. The masses of the empty beakers in sets A and B are measured using the weighing balance.
3. The immersion heater A is switched off as set A is used to determine the mass of ice melted by heat from the surroundings but the immersion heater B is switched on.
4. When water starts dripping from the filter funnels at a constant rate, the stopwatch is started and the empty beakers are placed below the filter funnels.
5. After $t$ seconds of heating, the heater B is switched off and the masses of both beakers of water, A and B are measured using the weighing balance.
(4) Calculation
Assuming that there is no heat loss to the surroundings:
Heat released = Heat absorbed
\[ P_t = m\ell \]
Specific heat capacity, \( \ell = \frac{P_t}{m} \)
P = Electrical power of electric / immersion heater in watts, W
\( t \) = Heating time in seconds, s
\( P_t \) = Electrical energy supplied by heater in joules, J
\( m = m_b - m_a \) = Mass of ice melted by immersion heater in kilograms, kg
\( m_a \) = Total mass of water and beaker A – Mass of empty beaker A
\( m_a \) = Mass of water melted by heat from the surroundings
\( m_b \) = Total mass of water and beaker B – Mass of empty beaker B
\( m \ell \) = Mass of water melted by heat from the surroundings and heat from heater B
\( m \ell \) = Heat energy absorbed by melting ice in joules, J

(5) Discussion
1. Set A, the control experiment, is used to determine the mass of ice melted by heat from the surroundings. To prevent heat loss to the surroundings, the immersion heater must be fully immersed in the ice cubes.
2. The stopwatch is only started when the immersion heater reaches a constant temperature and the rate of water dripping from the filter funnel (the rate of melting the ice) is constant.
3. The value of the specific latent heat of fusion of pure ice, \( \ell \) in the experiment is larger than the standard value of \( \ell \) because the mass of ice melted by immersion heater, \( m \) is less than expected due to some heat loss to the surroundings.
4. Way to get a more accurate value - heater must be fully immersed in ice.
5. Besides that, the heating time is increased to replace the heat loss to the surroundings and thus increasing the value of \( \ell \).
6. The assumptions that can be made in this experiment to obtain the standard value of \( \ell \):
   (a) **Assume that there is no heat loss** to the surroundings.
   (b) **Assume that the heat released is equal** to the heat absorbed.

1. The **composite substances**:
   (a) Used should be **strong** so that is unbreakable.
   (b) **Resistant to heat**, can withstand high temperature, not melt easily.
   (c) **Resistant to corrosion**, does not corrode easily & can be used for longer time.
2. **Properties of wok & oil**:
   (a) **High thermal conductivity** – conduct heat faster.
   (b) **High melting point** – can withstand high temperature.
   (c) **Low** specific heat capacity of oil – heat up faster.
   (d) **High boiling point of oil** – will not change to vapour easily.
Specific Latent Heat of Vaporization, L

1. Specific latent heat of vaporization, L is the quantity of heat energy required to change 1 kg liquid to vapour at a constant temperature.

2. If the heat energy is supplied by an electric / immersion heater:

\[
\begin{align*}
Q &= mL \\
Q &= Pt \\
Pt &= mL
\end{align*}
\]

- \(Q\) = Heat energy in joules, J
- \(m\) = Mass of substance in kilograms, kg
- \(L\) = Specific latent heat of vaporization, in J kg\(^{-1}\)
- \(P\) = Power of electric / immersion heater in watts, W
- \(t\) = Heating time in seconds, s

3. **Evaporation** is the process where liquid molecules on the surface transform to gas below the boiling point of the liquid.

4. Using kinetic theory of matter, the water absorbs heat from the body and the bonds between water molecules are broken during evaporation.

5. The water molecules on the surface have maximum kinetic energy. Latent heat (of vaporization) is absorbed from the body and changes water into gas.

6. Someone who is sweating feels cool when he is under a rotating fan.
   - (a) The sweat evaporates.
   - (b) Latent heat of vaporization is absorbed from our body. The body feels cool because heat is removed.
   - (c) When the fan is rotating, air movement / velocity increases.
   - (d) This will increase the evaporation rate.

7. Liquid that has:
   - (a) Specific heat capacity of large value - will heat up slowly, can absorb big amount of heat.
   - (b) High boiling point - vaporize slowly, the volume decreases slowly.

8. Hot water being added to cold water, assuming that no heat is lost to the surrounding. The heat lost by hot water is greater than heat gained by cold water.

9. **Solar water – heating system:**
   - (a) Use insulator behind the absorber panel – to prevent loss of heat energy.
   - (b) Use an absorber panel which is painted black – black surface is a good absorber of radiation & absorbs heat further.
   - (c) Storage tank place at higher level – give higher pressure.
   - (d) Use glass cover on top of panel – trap heat energy.
   - (e) Low specific heat capacity – heats up quickly and releases heat quickly to the water.

10. **Cooling pad is used to lower temperature of a person having a fever.**
    - (a) Gel is in solid state. Solid has a lower specific heat capacity.
    - (b) Low specific heat capacity material is able to absorb heat faster.
    - (c) The person is losing heat and as a result, temperature decreases.
Understanding the Gas Laws

Boyle's Law

\[ P \propto \frac{1}{V} \]

or

\[ PV = \text{Constant} \]

\[ P_1 V_1 = P_2 V_2 \]

Charles' Law

\[ V \propto T \]

or

\[ \frac{V}{T} = \text{Constant} \]

\[ \frac{V_1}{T_1} = \frac{V_2}{T_2} \]

The absolute temperature refers to 0 K or -273 °C, which measured on the absolute temperature scale (Kelvin temperature scale) and used in studies on gas laws.

Pressure Law

When a bottle containing hot air is put into basin of ice (temperature decrease), the hot air condenses and causes low pressure in the bottle. The atmospheric pressure outside is greater and presses the bottle inwards.

\[ P \propto T \]

or

\[ \frac{P}{T} = \text{Constant} \]

\[ \frac{P_1}{T_1} = \frac{P_2}{T_2} \]

Calculation:

\[ \frac{P_1}{T_1 + 273} = \frac{P_2}{T_2 + 273} \]
Experiment:

Aim:
To investigate the relationship between the temperature, T and the volume, V of a gas at constant pressure.

Problem Statement:
What is the relationship between the volume and temperature of a fixed mass of gas at constant?

Hypothesis:
Volume of a fixed mass of gas at constant increases when its temperature is increased.

Variables:
(a) Manipulated: Temperature of trapped air
(b) Responding: Length of air column
(c) Fixed: Atmospheric pressure and mass

Materials:
Capillary tube, tall beaker, thermometer, Bunsen Turner, tripod stand, wire gauze, retort stand, mercury, concentrated sulphuric acid, stirrer, ruler, and ice.

Procedures:

1. The air sample under investigation is trapped inside the capillary tube by a bead of concentrated sulphuric acid which acts as an index.
2. The capillary tube is mounted on a 30-cm ruler such that the bottom end of the column of air is aligned with the '0' mark on the ruler.
3. Water and ice are poured into the beaker until the column of air is fully immersed under water. The water is stirred until the water temperature falls to 0 °C. The length of the air column, x and the temperature, \( \theta \) is recorded.
4. The water is heated and continuously stirred. The values of x and \( \theta \) are recorded for each temperature increment of 10 °C until a temperature of 90 °C is reached.
5. A graph of length of air column, x against temperature, \( \theta \) is drawn.
Experimental Data:

<table>
<thead>
<tr>
<th>Temperature, $\theta$ ($^\circ$C)</th>
<th>Length of air column, $x$ (cm)</th>
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<tbody>
<tr>
<td>10</td>
<td></td>
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<tr>
<td>20</td>
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<td>90</td>
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A graph of $x$ against $\theta$ is shown in Figure 4.42.

Discussion:
The graph shows that the length of the air column (volume of gas) is proportional to the absolute temperature, $\theta$ (K).

Conclusion:
The volume of a fixed mass of gas of a pressure is directly proportional to that temperature (in Kelvin) of the gas. The hypothesis is valid.