Theme 3

Heat

Heat is closely related to human life. Topics in this theme discuss concepts and laws related to heat energy. We will investigate the aspects of changes in phases of matter, especially changes in the properties of gas. Three gas laws, Boyle's Law, Charles' Law and Gay-Lussac's (pressure) Law, will also be introduced.

°C

Why is water suitable to be used as a cooling agent?

What is the importance of specific heat capacity of a substance?

What influences the behaviour of gas molecules?

Kitchen is where a lot of the concepts related to heat energy can be applied. When we heat up water in a kettle, the rate of increase in water temperature depends on the quantity of water heated. When the water boils, its temperature will no longer increase. When the same quantity of oil and water are heated separately at the same time, oil will be hotter first. All these examples involve the relationship and interaction between physical properties of matter such as temperature, pressure, volume and heat. Applications of the concept of heat have greatly helped our daily life.

Video on application of physics concepts in the kitchen

http://bt.sasbadi.com/p4119a

Learning Standards and List of Formulae

Thermal Equilibrium

Observe Photograph 4.1. When a cold metal spoon is put into a cup of hot coffee, the spoon and the coffee are said to be in thermal contact because heat energy can be transferred between the two bodies. How can the metal spoon cool down the hot coffee? What is the final condition of the spoon and the coffee?

Photograph 4.1 A cold metal spoon in a cup of hot coffee
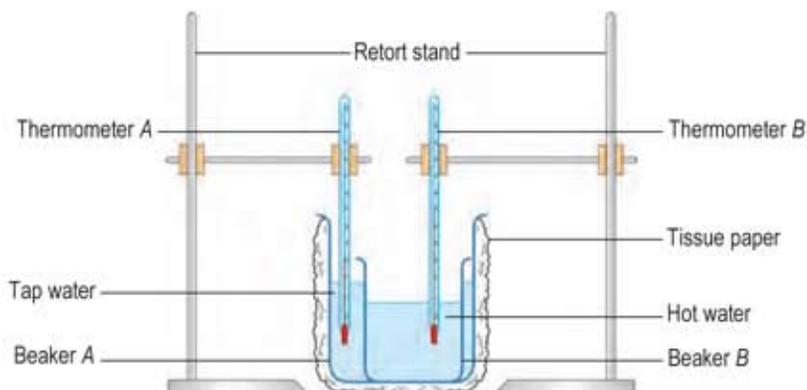
Activity 4.1

Aim: To show thermal equilibrium between two bodies in thermal contact

Apparatus: Two retort stands, two thermometers, 250 mℓ beaker labelled A, 50 mℓ beaker labelled B, measuring cylinder and stopwatch

Materials: 50°C hot water, tap water and tissue paper

Instructions:

1. Wrap beaker A with tissue and fill it with 150 mℓ of tap water.
2. Fill 40 mℓ of 50°C hot water into beaker B.
3. Place beaker B into beaker A. Then, place thermometer A and thermometer B into beaker A and beaker B respectively as shown in Figure 4.1.

Figure 4.1

4. Record the readings of thermometer A and thermometer B every 30 s until the readings of both thermometers are the same. (This activity can normally be carried out in five minutes)

Results:

Table 4.1

Time, t / s	Temperature of thermometer A / °C	Temperature of thermometer B / °C
0		
30.0		
60.0		

Discussion:
1. Why is beaker A wrapped with tissue paper?
2. Describe the changes in temperature of the hot water and tap water.
3. What causes the changes in temperature?

When two objects are **in thermal contact**, the temperature of the hot object will drop while the temperature of the cold object will rise until the **temperature** of both objects become the same. Net heat transfer between the two objects becomes zero. Both objects are said to be in **thermal equilibrium**. Figure 4.2 explains the flow of heat between two objects in thermal contact until thermal equilibrium is reached.
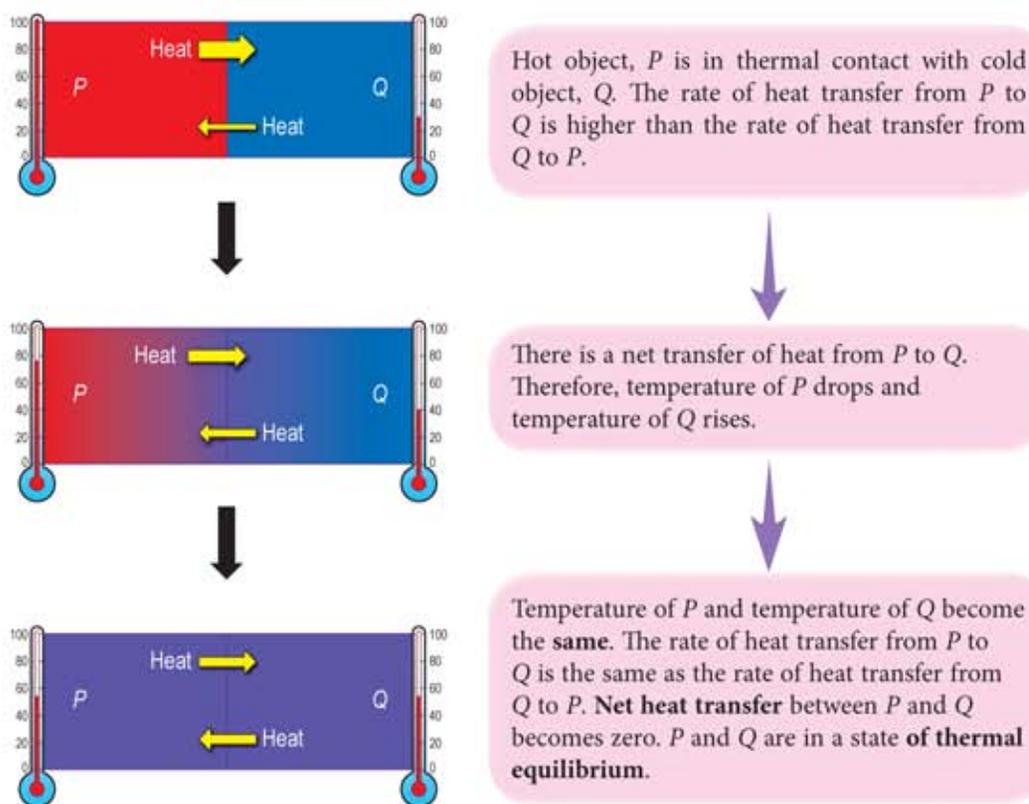

Hot object, P is in thermal contact with cold object, Q. The rate of heat transfer from P to Q is higher than the rate of heat transfer from Q to P.

There is a net transfer of heat from P to Q. Therefore, temperature of P drops and temperature of Q rises.

Temperature of P and temperature of Q become the **same**. The rate of heat transfer from P to Q is the same as the rate of heat transfer from Q to P. **Net heat transfer** between P and Q becomes zero. P and Q are in a state **of thermal equilibrium**.

Figure 4.2 Flow of heat energy and thermal equilibrium

4.1.1

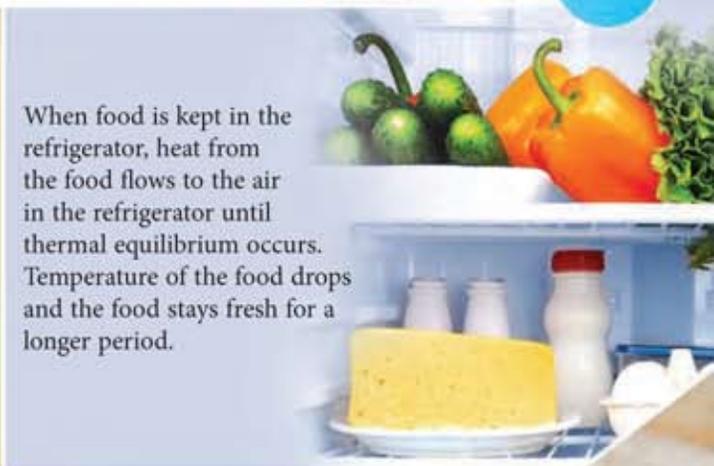## Thermal Equilibrium in Daily Life

Thermal equilibrium causes two objects in thermal contact to reach the same temperature. Figure 4.3 shows examples of thermal equilibrium in daily life.
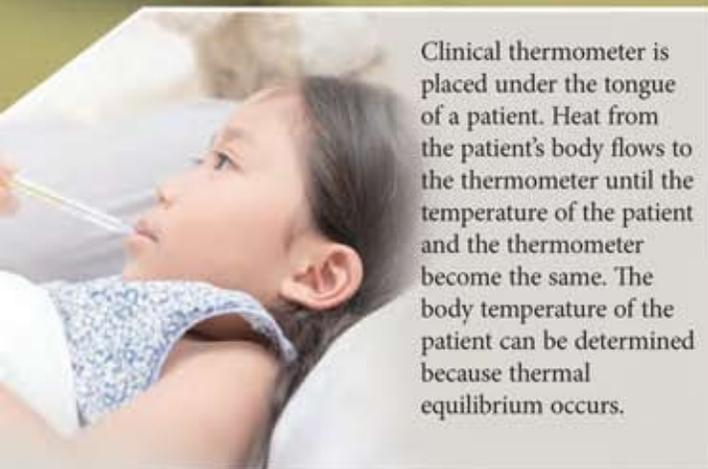
Heating Object

Hot air in oven is in thermal contact with cake batter. Heat from the hot air flows to the cake batter. This causes the cake batter to be heated until it is baked.

Clinical thermometer is placed under the tongue of a patient. Heat from the patient's body flows to the thermometer until the temperature of the patient and the thermometer become the same. The body temperature of the patient can be determined because thermal equilibrium occurs.

Cooling Object

When food is kept in the refrigerator, heat from the food flows to the air in the refrigerator until thermal equilibrium occurs. Temperature of the food drops and the food stays fresh for a longer period.
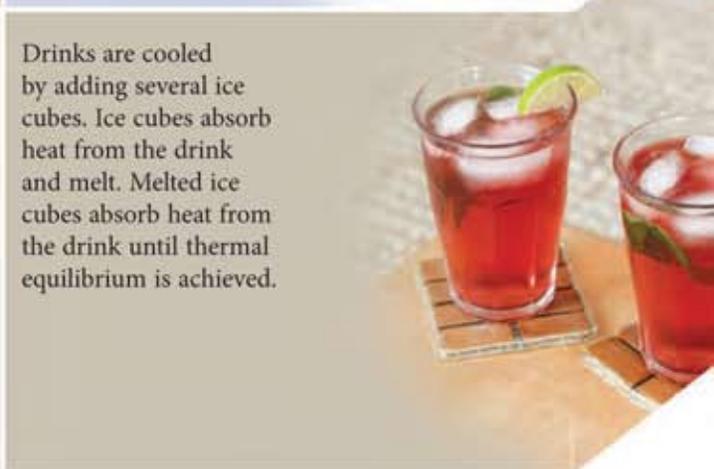
Drinks are cooled by adding several ice cubes. Ice cubes absorb heat from the drink and melt. Melted ice cubes absorb heat from the drink until thermal equilibrium is achieved.

Figure 4.3 Thermal equilibrium in daily life

Activity 4.2 ISS ICS

Aim: To discuss situations and applications of thermal equilibrium in daily life
Instructions:

1. Carry out this activity in groups.
2. Gather information on situations and other applications of thermal equilibrium in daily life. The information can be obtained from reading resources or websites.
3. Discuss the flow of heat energy until thermal equilibrium is achieved.
4. Draw a mind map based on your findings.

4.1.1

To Calibrate a Liquid-in-glass Thermometer Using Two Fixed Points

This thermometer does not have a clear scale. We need another thermometer.

This thermometer can still be used. We just need to calibrate the thermometer.

Info File

The process of calibrating uses the thermometric property of liquids in glass. Thermometric property means a physical property which can be measured (such as length of column of liquid) which changes with temperature.

A thermometer that does not have a scale can be calibrated using two fixed temperature points. Two fixed points used for distilled water are melting point of ice, 0°C and boiling point of water, 100°C.

Gateway to SCIENCE, TECHNOLOGY and SOCIETY

Cooking thermometer is used to measure the temperature of food during and after food preparation. Poor control of time and temperature can cause food poisoning. As such, periodic calibration of the thermometer is very important.

Activity 4.3

Aim: To calibrate a liquid-in-glass thermometer using boiling point of distilled water and melting point of ice

Apparatus: Thermometer, ruler, 250 mℓ beaker, immersion heater, power supply and retort stand

Materials: Ice, distilled water and masking tape

Instructions:

1. Cover the scale of the thermometer with masking tape so that the scale cannot be seen.
2. Prepare two beakers. Fill beaker A with ice and a small amount of distilled water. Fill beaker B with distilled water and put in an immersion heater.
3. Put a thermometer into beaker A. Wait until there is no more change in the level of liquid column. Then, mark the level of liquid column on the stem of the thermometer. Label this level as 0°C (Figure 4.4).
4. Remove the thermometer from beaker A and switch on the immersion heater in beaker B.
5. When the distilled water in beaker B is boiling, put the thermometer into beaker B. Wait until there is no more change in the level of liquid column. Then, mark the level of liquid column on the stem of the thermometer. Label this level as 100°C (Figure 4.4). Switch off the immersion heater.
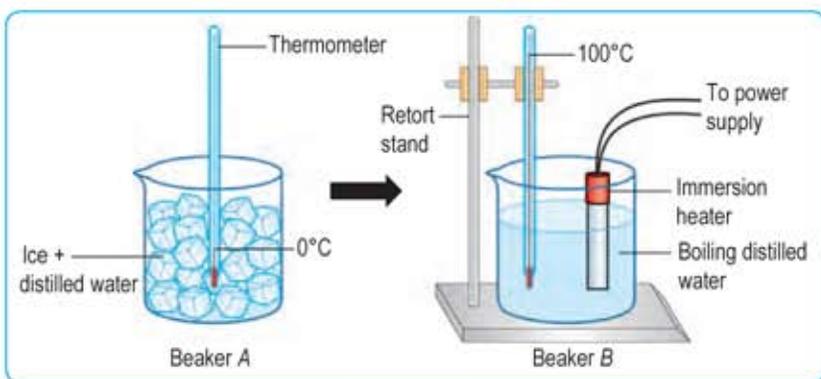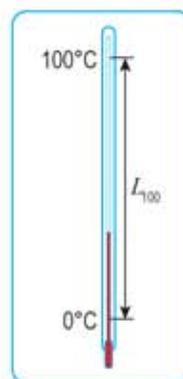
4.1.2

Figure 4.4

Figure 4.5

6. Measure the length from the 0°C mark to the 100°C mark as L_{100} (Figure 4.5).
7. Prepare beaker C and fill it with tap water.
8. Put the calibrated thermometer into beaker C. Wait until there is no more change in the level of the liquid column. Then, mark the level of the liquid column on the stem of the thermometer. Label this level as θ°C.
9. Measure the length from the 0°C mark to the θ°C mark as L_θ.
10. Calculate the temperature of tap water using the formula, $\theta = \dfrac{L_\theta}{L_{100}} \times 100°C$

Discussion:
1. The bulb of the thermometer should not touch the base or side wall of the beaker while taking measurement. Explain.
2. Why should you wait until there is no more change in the level of the liquid column before making a mark on the stem of the thermometer?

Calibration is a process of making a scale of reading on a thermometer. 0°C is the fixed lower limit and 100°C is the fixed upper limit. The length of liquid column between the fixed lower limit and the fixed upper limit is divided into 100 equal divisions. The thermometer is then calibrated and can be used to measure temperature between 0°C and 100°C.

Formative Practice 4.1

1. State what happens to two objects in thermal equilibrium.

2. Is our body in thermal equilibrium with the environment? Explain your answer.

3. Aisyah uses an uncalibrated laboratory thermometer to determine the temperature of a liquid, θ°C. She finds that the length of the liquid column when the thermometer is put into the liquid is as shown in Figure 4.6. Calculate the temperature of the liquid, θ°C.
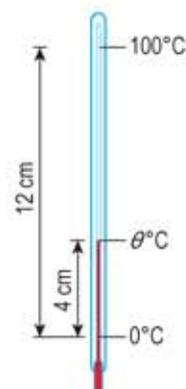

Figure 4.6
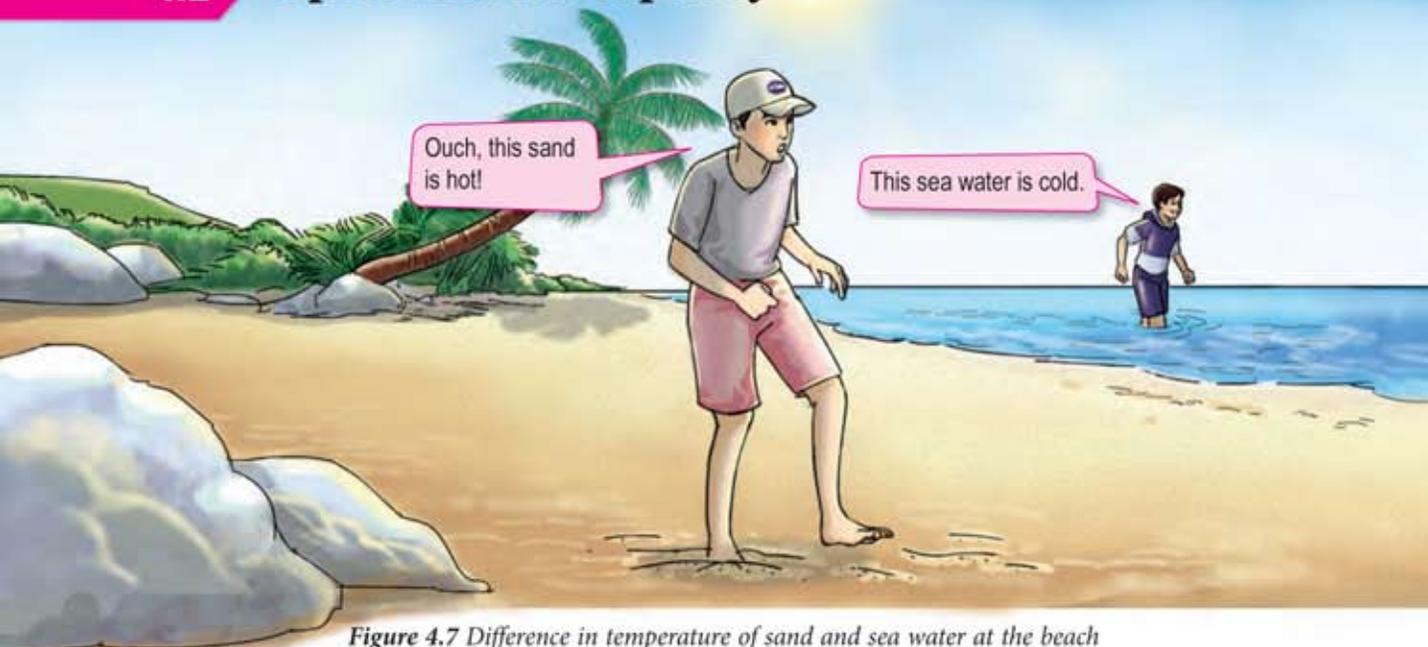
4.1.2

4.2 Specific Heat Capacity

Figure 4.7 *Difference in temperature of sand and sea water at the beach*

Figure 4.7 shows two different situations. The sun heats up the sand and sea water at the same period of time. However, sand gets hot quickly and sea water gets hot slowly.

This can be explained based on the concept of **heat capacity**. Different objects have different heat capacity. Sand has a low heat capacity and gets hot quickly while sea water has a high heat capacity and gets hot slowly.

> **Heat capacity, C** of an object is the quantity of heat needed to raise the temperature of the object by 1°C.
>
> $C = \dfrac{Q}{\Delta\theta}$, that is Q = quantity of heat supplied
> $\Delta\theta$ = change in temperature
>
> Unit for $C = $ J °C^{-1}

When 100 J of heat is supplied to objects X and Y, object X experiences a rise in temperature of 1°C and object Y 2°C. What are the respective heat capacity of objects X and Y?

> Heat capacity for object X, $C_X = \dfrac{100 \text{ J}}{1°C}$
> $= 100$ J °C^{-1}
>
> Heat capacity for object Y, $C_Y = \dfrac{100 \text{ J}}{2°C}$
> $= 50$ J °C^{-1}
>
> Object X has a higher heat capacity than object Y.
> Therefore, the increase in temperature of object X is less than object Y.

4.2.1

Heat capacity of an object increases when the mass of the object increases. For example, the water in a full kettle takes a longer time to boil compared to the water in a half-filled kettle. This shows that water of bigger mass has a higher heat capacity compared to water of smaller mass. Figure 4.8 shows several daily situations involving heat capacity.

After being left to cool for some time, the soup in a large bowl is hotter compared to the same soup in a small bowl.

The dashboard of a car has a lower heat capacity compared to the cushion. Absorption of heat energy from the Sun causes the dashboard to experience a higher rise in temperature compared to the cushion.

Dashboard

Cushion

Daily Situations Involving Heat Capacity

At noon, there is a significant difference in temperature between cement court and grass.

Figure 4.8 Daily situations which involve heat capacity

4.2.1

Specific Heat Capacity of Substance

Figure 4.9 shows a material engineer tries to choose a suitable metal as building material. He needs a material that does not heat up easily. Since the heat capacity of a material differs with its mass, he needs to make his choice based on **specific heat capacity** instead – which means he has to choose the material based on the heat capacity of every 1 kg of each material.

Specific Heat Capacity

http://bt.sasbadi.com/p4127

Figure 4.9 A material engineer is comparing specific heat capacity between different metals

Specific heat capacity, c of a substance is the quantity of heat needed to raise the temperature of 1 kg mass of the substance by 1°C.

$$c = \frac{Q}{m\Delta\theta}, \text{ where } \quad Q = \text{quantity of heat supplied (J)}$$
$$m = \text{mass (kg)}$$
$$\Delta\theta = \text{change of temperature (°C or K)}$$

Unit for c = J kg^{-1} °C^{-1} or J kg^{-1} K^{-1}

Quantity of heat, Q that is absorbed or released by an object can be determined using the formula $Q = mc\Delta\theta$.

For example, the specific heat capacity of the metal aluminium is 900 J kg^{-1} °C^{-1}. This means 1 kg of aluminium requires 900 J of heat to raise its temperature by 1°C.

SMART INFO

Heat capacity, $C = \frac{Q}{\Delta\theta}$

Specific heat capacity, $c = \frac{Q}{m\Delta\theta}$

Every substance has its own value of specific heat capacity. Table 4.2 shows examples of substances and their specific heat capacity.

Table 4.2 Specific heat capacity of different substances

Type of substance	Substance	Specific heat capacity, c / J kg^{-1} °C^{-1}	Type of substance	Substance	Specific heat capacity, c / J kg^{-1} °C^{-1}
Liquid	Water	4 200	Metal	Aluminium	900
	Sea water	3 900		Iron	450
	Ethanol	2 500		Copper	390
	Paraffin	2 100		Gold	300
	Cooking oil	1 850		Mercury	140
	Olive oil	1 890		Lead	130
Gas	Methane	2 200	Non-metal	Polycarbonate	1 250
	Steam (at 100°C)	2 020		Wood	1 700
				Concrete	850
	Neon	1 030		Sand	800
	Air	1 000		Glass	670

Water is a substance which has high specific heat capacity. Water needs to absorb a large amount of heat to have a small rise in temperature. This makes water a good cooling agent. Metal on the other hand has lower specific heat capacity compared to non-metal. Therefore, objects made from metal get hot quickly when supplied with an amount of heat.

Based on Table 4.2, the specific heat capacity for water is higher compared to metals such as aluminium.

How can these values be determined?

4.2.2

Experiment 4.1

Aim: To determine the specific heat capacity of water

Apparatus: Power supply, immersion heater, beaker, stopwatch, thermometer, retort stand and electronic balance

Materials: Water and tissue paper

Procedure:

1. Wrap a beaker with tissue paper.
2. Place the beaker on top of an electronic balance and reset the reading of the balance to zero.
3. Fill the beaker with water until it is three-quarter full.
4. Record the reading of the mass of the water, m shown on the electronic balance.
5. Set up the apparatus as shown in Figure 4.10.

Retort stand
Thermometer
Water
Beaker
Tissue paper
Immersion heater
Power supply
POWER SUPPLY
CURRENT A   VOLTAGE V

Figure 4.10

6. Record the initial temperature of the water, θ_1.
7. Switch on the immersion heater and start the stopwatch at the same time.
8. Observe the change in the thermometer reading.
9. After five minutes, switch off the immersion heater. Record the highest thermometer reading as the final water temperature, θ_2.

SMART INFO

Immersion heater converts **electrical energy** to **heat energy**. The heat energy supplied by the immersion heater is
$Q = Pt$, where
P = power of heater and
t = period of time heater is switched on

Change in water temperature,
$\Delta\theta = \theta_2 - \theta_1$.
For this experiment, the equation
$Q = mc\Delta\theta$ is expressed as
$Pt = mc\ (\theta_2 - \theta_1)$.

Results:

Table 4.3

Power of immersion heater, P / W	
Heating time, t / s	
Mass of water, m / kg	
Initial temperature of water, θ_1 / °C	
Final temperature of water, θ_2 / °C	

Analysis of data:

Calculate the specific heat capacity of water using the formula, $c = \dfrac{Pt}{m(\theta_2 - \theta_1)}$.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:

1. Why does the beaker need to be wrapped with tissue paper?
2. Why is the final water temperature, θ_2 not taken as soon as the five-minute heating time ends?
3. Given specific heat capacity of water is 4 200 J kg⁻¹ °C⁻¹, compare the value of specific heat capacity of water obtained from the experiment with the value given. Explain the difference between the two values (if any).
4. Suggest methods to increase the accuracy of the result of this experiment.

Experiment 4.2

Aim: To determine the specific heat capacity of aluminium

Apparatus: Power supply, immersion heater, 1 kg aluminium block, stopwatch, thermometer and retort stand

Material: Tissue paper

Procedure:

1. Set up the apparatus as shown in Figure 4.11.
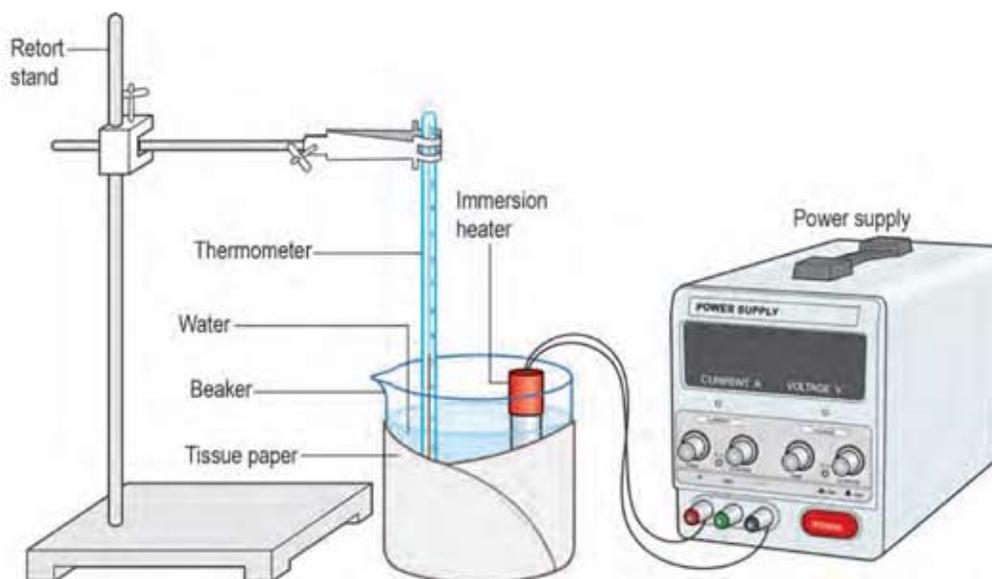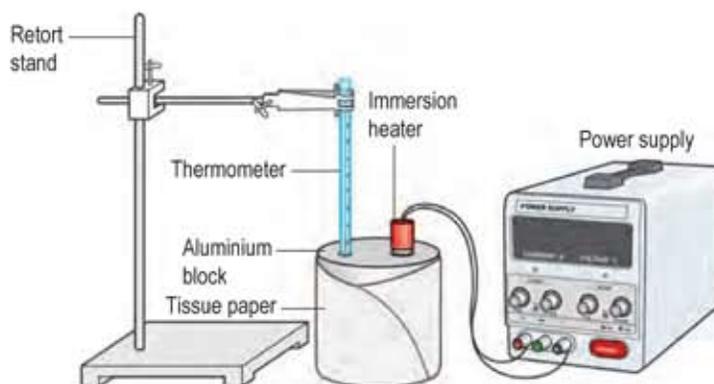

Figure 4.11

4.2.3

2. Record the initial temperature of the aluminium block, θ_1.
3. Switch on the immersion heater and start the stopwatch at the same time.
4. After five minutes, switch off the immersion heater. Record the highest thermometer reading as the final temperature of the aluminium block, θ_2.

Results:

Table 4.4

Power of immersion heater, P / W	
Heating time, t / s	
Mass of aluminium, m / kg	
Initial temperature of aluminium, θ_1 / °C	
Final temperature of aluminium, θ_2 / °C	

Analysis of data:

Calculate the specific heat capacity of aluminium using the formula, $c = \dfrac{Pt}{m(\theta_2 - \theta_1)}$.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. What can be done to obtain a better thermal contact between the bulb of the thermometer and the aluminium block?
2. Given specific heat capacity of aluminium is 900 J kg^{-1} °C^{-1}, compare the value of specific heat capacity of aluminium obtained from the experiment with the value given. Explain the difference between the two values (if any).

Applications of Specific Heat Capacity

Knowledge on specific heat capacity is very important in daily life, material engineering and also understanding several natural phenomena.

Selection building materials of traditional houses in various climate zones

Wood has a high specific heat capacity and gets hot slowly. In warm weather regions, traditional houses are built from wood which functions as an insulator of heat from the scorching sun. In cold weather regions, traditional houses are also built from wood. Heat from fires lit in the wooden houses cannot flow out because wood functions as a good heat insulator.

Warm climate

Cold climate

Cooking utensils
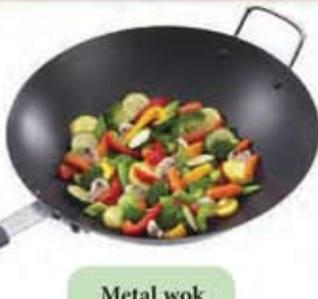
Metal wok

Clay pot

Woks are made of metal with low specific heat capacity. As such, food can be fried at high temperature in a short time. Clay pots on the other hand are made of clay which has a high specific heat capacity. As such, food can stay hot for a long time.

Car radiator system

Burning of fuel in car engines produces large amounts of heat. This heat needs to be released to avoid overheating the engine. Water has a high specific heat capacity and is used as a cooling agent. A pump will pump water into the engine block. Water will flow through the engine block to absorb heat produced. Hot water flows to the radiator. Cold air is sucked in by fans so that heat in the hot water can be released quickly through cooling fins.
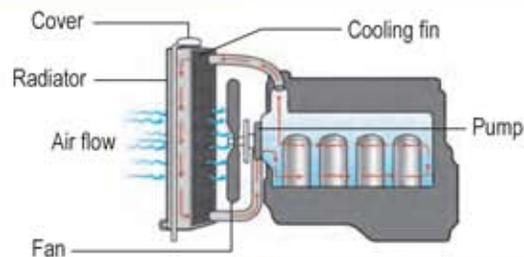
Video on car radiator system

http://bt.sasbadi.com/p4132

4.2.4

Outer layer of space capsule

Space capsule on its journey back to Earth encounters air resistance when entering the atmosphere. This friction increases the temperature and causes the space capsule to burn. Therefore, the outer layer of a space capsule is made from substance with a high specific heat capacity and melting point.

Production of latest materials in the construction of green buildings

Cement layer — Cement layer
Styrofoam insulating board
Concrete sheet
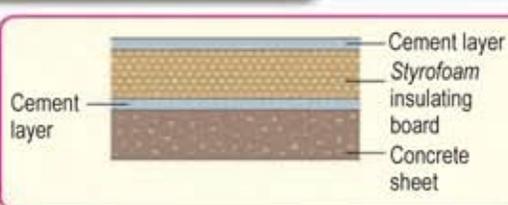
The Diamond Building, Energy Commission is built with an insulating concrete roof, that is a roof fitted with insulators using *styrofoam* boards. *Styrofoam* has a high specific heat capacity and can reduce the absorption of heat from the surroundings to reduce the temperature inside the building.

The Diamond Building

http://bt.sasbadi.com/p4133

Cooking utensils

The body of a pot is made of aluminium which has a low specific heat capacity. This enables the pot to heat up quickly. However, the handle of the pot is made from plastic which has a high specific heat capacity. This ensures that the handle of the pot gets hot slowly and is safe to handle.

Handle of pot

Body of pot

4.2.4

Sea breeze

Land has a lower specific heat capacity than the sea. Therefore, temperature on land rises more quickly than temperature in the sea during daytime. The air on land becomes hot and rises upwards. Cold air from the sea moves towards land as sea breeze.

Land breeze

Sea has a higher specific heat capacity than land. So, temperature in the sea drops more slowly than temperature on land at night. Hot air above the sea rises upwards. Cold air above the land moves towards the sea as land breeze.

![Activity icon] **Activity** 4.4   ISS ICS

Aim: To search for information on applications of specific heat capacity

Instructions:
1. Carry out a Round Table activity.
2. Gather information on applications of specific heat capacity related to:
    (a) Daily life
    (b) Material engineering
    (c) Natural phenomena
3. The information can be obtained from reading materials in the library or on the Internet.
4. One group member writes the information on a piece of paper. The paper is then passed clockwise so other group members can add their information.
5. Present your group findings in your class.

Solving Problems Involving Specific Heat Capacity

Example 1

A 0.5 kg metal block is heated by a 50 W electric heater for 90 s. The temperature of the block rises from 20°C to 45°C. Calculate the specific heat capacity of the metal.

Solution:

Step 1
List the given information in symbols.

Temperature rise, $\Delta\theta = 45 - 20$
$\qquad = 25°C$
Mass of block, $m = 0.5$ kg
Power of heater, $P = 50$ W
Heating time, $t = 90$ s

Step 2
Identify and write down the formula used.

$c = \dfrac{Q}{m\Delta\theta}$
$= \dfrac{Pt}{m\Delta\theta}$

Step 3
Substitute numerical values into the formula and perform the calculations.

$c = \dfrac{(50)(90)}{(0.5)(25)}$
$= 360$ J kg^{-1} °C^{-1}

Assumption: All heat supplied by the electric heater is absorbed by the metal block. No heat is lost to the surroundings.

Example 2

20 g of boiling water at 100°C is poured into a glass containing 200 g of water at 28°C. Calculate the final temperature of the mixture of water.

Solution:

20 g water, 100°C → Heat is released Q_1 → Temperature of mixture, y ← Heat is absorbed Q_2 ← 200 g water, 28°C

Let y = final temperature of mixture
For boiling water:
Mass, $m_1 = 20$ g
$= 0.02$ kg
Temperature change, $\Delta\theta_1 = (100 - y)°C$
For water at 28°C:
Mass, $m_2 = 200$ g
$= 0.20$ kg
Temperature change, $\Delta\theta_2 = (y - 28)°C$
Specific heat capacity of water, $c = 4\,200$ J kg^{-1} °C^{-1}

$Q_1 = Q_2$
$m_1 c\Delta\theta_1 = m_2 c\Delta\theta_2$
$0.02\,(4\,200)(100 - y) = 0.20\,(4\,200)(y - 28)$
$8\,400 - 84y = 840y - 23\,520$
$924y = 31\,920$
$y = 34.55°C$

Therefore, the final temperature of the mixture of water is 34.55°C.

Assumption: No heat is absorbed or released to the surrounding. Heat transfer only occurs between the boiling water and the water at 28°C. Therefore, heat released by the boiling water is the same as the heat absorbed by the water at 28°C.

Aim: To build a model of a cluster home which can overcome the problem of extreme temperatures

Instructions:

1. Work in groups.
2. Read and understand the following information.

Cluster homes are homes which resemble terrace houses. However, three walls of the house are shared with the houses behind and beside it (Figure 4.12).

Photograph 4.2 shows an example of a cluster home which has only one door for exit and entrance, while windows are only in the front part of the home. The shape of the home can minimize the use of land. However, when our country experienced the El Nino phenomenon with extreme rise in temperature, residents of terrace cluster homes experienced extreme heat.

Figure 4.12 Plan of cluster home

Photograph 4.2 Example of cluster home

3. Based on the above information, analyse the situation by listing the facts and problems related to the condition of extreme temperature in cluster homes.
4. Brainstorm several solutions to the problems. Sketch a model based on your solutions.
5. Build the model based on the sketch.
6. Display and present the model.

Formative Practice 4.2

1. What is the difference between heat capacity and specific heat capacity?

2. How much heat energy is needed to increase the temperature of a 0.2 kg mass of gold by 10°C?
   [Given the value of specific heat capacity of gold is 300 J kg^{-1} °C^{-1}]

3. A container contains 200 g of water at initial temperature of 30°C. An iron nail of mass 200 g at temperature of 50°C is immersed in the water. What is the final water temperature? State the assumptions you need to make in your calculations.
   [Given the value of specific heat capacity of water is 4 200 J kg^{-1} °C^{-1} and that of iron is 450 J kg^{-1} °C^{-1}]

4.3 Specific Latent Heat

Latent Heat

Elements can exist in three states: solid, liquid and gas. The difference in the arrangement and movement of molecules among the three states of matter shows that there are stronger molecular bonds in solid than in liquid and gas. As gas molecules move freely at random, the bond between gas molecules is the weakest.

Figure 4.13 shows the changes in phase of matter. During the changes in the phase of matter such as melting and boiling, the temperature remains constant even though heat is being supplied continually. Heat that is absorbed during melting and boiling without change in temperature is known as **latent heat**. During condensation and freezing, latent heat is released without temperature change.
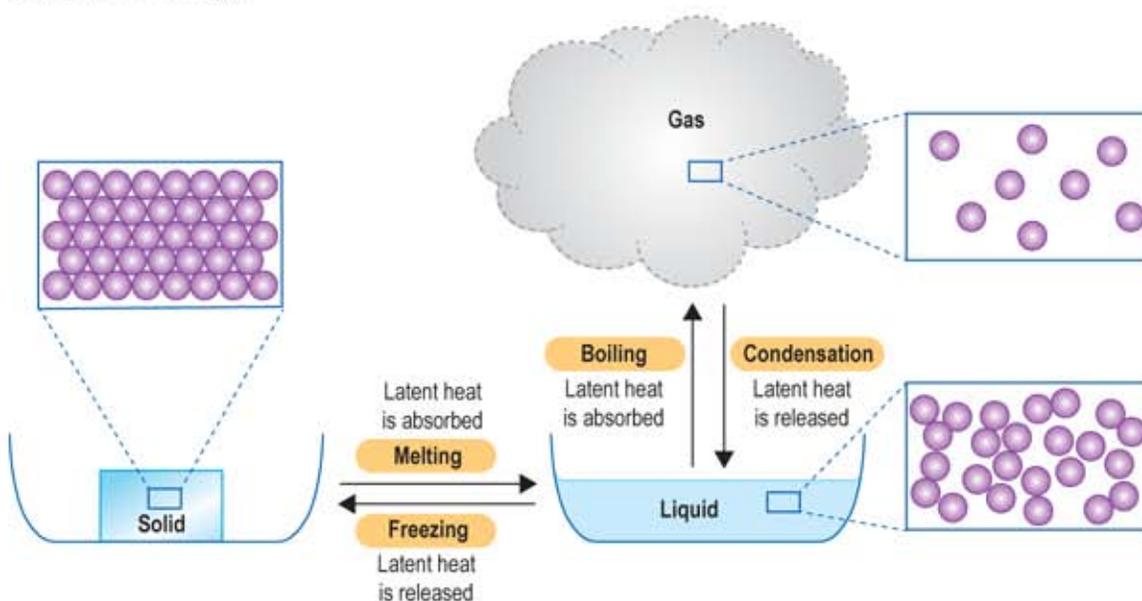
Figure 4.13 *Changes in phases of matter*

Specific Latent Heat

The quantity of heat needed to change the state of matter of an object depends on the mass of the object and its material. **Specific latent heat**, *l* of a substance is the quantity of heat, *Q* that is absorbed or released during a change of phase of 1 kg of the substance without any change in its temperature.

Latent Heat

http://bt.sasbadi.com/p4137

> An object of mass, *m* absorbs a quantity of heat, *Q* during a change of phase. Therefore, specific latent heat of the substance of the object is
>
> $$l = \frac{Q}{m}$$
>
> S.I. unit for specific latent heat is $J\ kg^{-1}$.

4.3.1 4.3.2

Specific latent heat of fusion, l_f of a substance is the quantity of heat, Q that is absorbed during melting or the quantity of heat released during freezing of 1 kg of the substance without any change in temperature.

Specific latent heat of vaporisation, l_v of a substance is the quantity of heat, Q that is absorbed during boiling or the quantity of heat released during condensation of 1 kg of the substance without any change in temperature.

Figure 4.14 shows the heating curve when an object changes its state from solid to gas.

TU – Gas is heated
• Heat is absorbed
• Temperature increases
• Kinetic energy of molecules increases

RS – Liquid is heated until boiling point
• Heat is absorbed
• Temperature increases
• Kinetic energy of molecules increases

PQ – Solid is heated until melting point
• Heat is absorbed
• Temperature increases
• Kinetic energy of molecules increases

Melting
Solid → Liquid
Q – Solid starts to melt
QR – Solid is melting
R – The whole solid has melted
• Latent heat is absorbed to weaken the bond between molecules
• Molecules are released from their fixed position and move throughout the liquid
• Kinetic energy of molecules does not increase
• Constant temperature

Boiling
Liquid → Gas
S – Liquid starts to boil
ST – Liquid is boiling
T – The whole liquid has boiled
• Latent heat is absorbed to break the bond between molecules
• Molecules are separated far from one another
• Kinetic energy of molecules does not increase
• Constant temperature

Figure 4.14 *Heating curve*

Figure 4.15 shows the cooling curve when an object changes its state from gas to solid.

PQ – Gas cools to boiling point
• Heat is released
• Temperature decreases
• Kinetic energy of molecules decreases

RS – Liquid cools to freezing point
• Heat is released
• Temperature decreases
• Kinetic energy of molecules decreases

TU – Solid cools
• Heat is released
• Temperature decreases
• Kinetic energy of molecules decreases

Temperature

P

Gas

Gas and liquid

Q

R

Boiling point

Liquid

S   Liquid and solid

T

Freezing point

Solid

U

0

Time

Condensation
Gas → Liquid
Q   – Gas starts to condense
QR – Gas is condensing
R   – The whole of the gas has condensed
• Latent heat is released and molecular bond is formed
• Molecules move throughout the liquid
• Kinetic energy of molecules does not decrease
• Constant temperature

Freezing
Liquid → Solid
S   – Liquid starts to freeze
ST – Liquid is freezing
T   – The whole liquid has frozen
• Latent heat is released so that bond between molecules is strengthened
• Molecules vibrate around a fixed position
• Kinetic energy of molecules does not decrease
• Constant temperature

Figure 4.15 *Cooling curve*

4.3.2

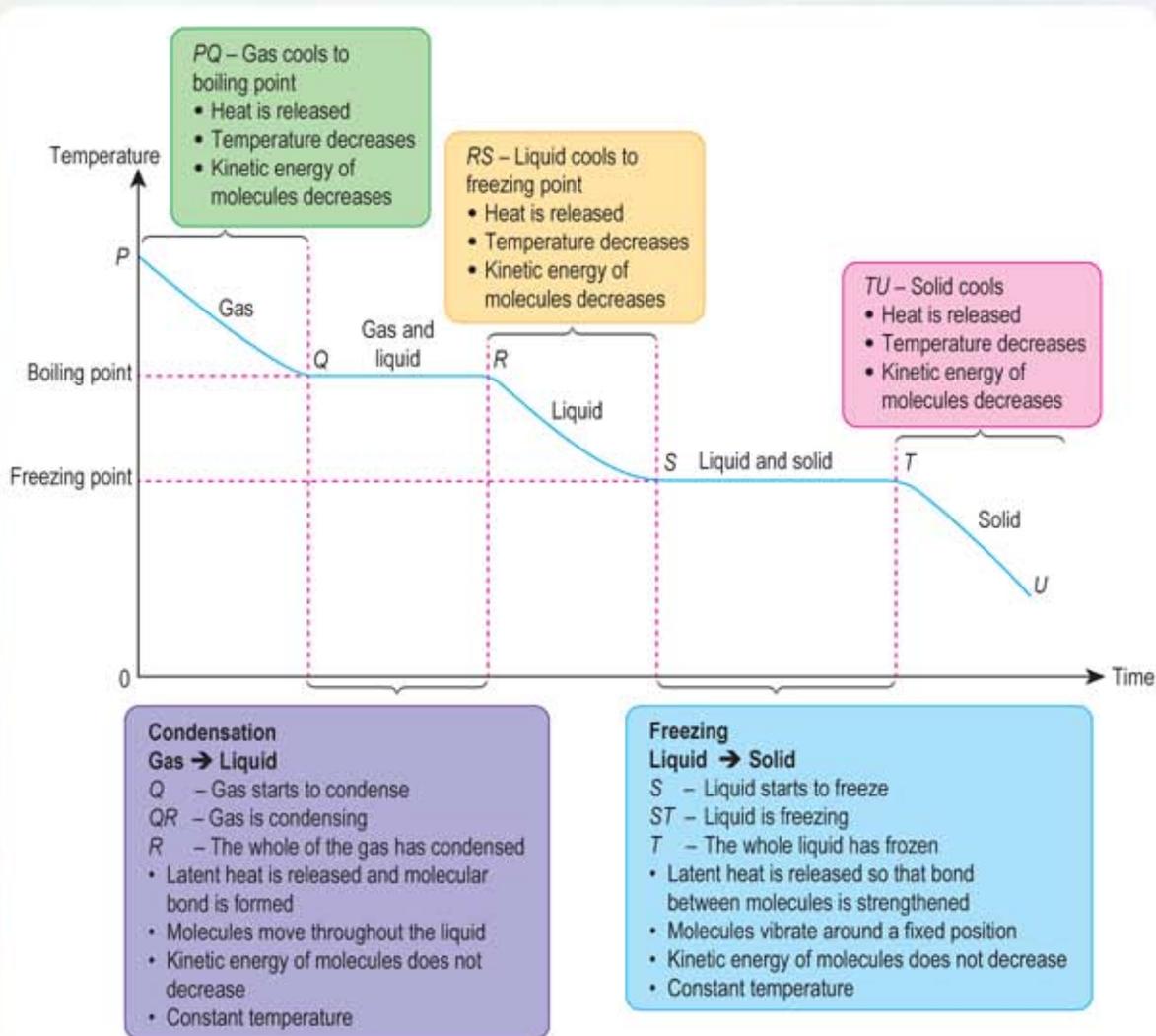**Aim:** To compare and discuss:
- specific latent heat of fusion of ice and wax
- specific latent heat of vaporisation of water and oil

Instructions:

1. Carry out a Think-Pair-Share activity.
2. Study the information given in Table 4.5.

Table 4.5

Substance	Phase at room temperature	Melting point / °C	Specific latent heat of fusion, l_f / J kg^{-1}	Boiling point / °C	Specific latent heat of vaporisation, l_v / J kg^{-1}
Wax	Solid	46 to 68	1.45×10^5 to 2.10×10^5	–	–
Lead	Solid	327	0.25×10^5	1 750	8.59×10^5
Copper	Solid	1 083	2.07×10^5	2 566	47.3×10^5
Ice	Solid	0	3.34×10^5	–	–
Water	Liquid	–	–	100	22.6×10^5
Petrol	Liquid	–	–	35 to 200	3.49×10^5
Diesel	Liquid	–	–	180 to 360	2.56×10^5
Olive oil	Liquid	6	2.67×10^5	–	–
Ethanol	Liquid	–114	1.04×10^5	78	8.55×10^5
Oxygen	Gas	–219	0.14×10^5	–183	2.13×10^5
Nitrogen	Gas	–210	0.26×10^5	–196	2.00×10^5

3. Based on the information above, discuss the following questions:
   (a) Compare the specific latent heat of fusion for ice and wax. Then, state the difference between ice and wax in terms of strength of bond between molecules.
   (b) Compare the specific latent heat of vaporisation for water and petrol. Then, state the difference between water and petrol in terms of strength of bond between molecules and distance of separation between molecules in gaseous phase.
   (c) For a specific substance, why is specific latent heat of vaporisation larger than specific latent heat of fusion?
4. Present the results of your discussion in a graphic form.

Note:
- Petrol and diesel are different types of hydrocarbons and have different boiling points.

Based on Activity 4.6, each substance has a different specific latent heat. How is the value of specific latent heat determined?

Experiment 4.3

Aim: (i) To determine specific latent heat of fusion of ice, l_f
(ii) To determine specific latent heat of vaporisation of water, l_v

(A) Specific latent heat of fusion of ice, l_f

Apparatus: Immersion heater, filter funnel, beaker, electronic balance, power supply, stopwatch and retort stand

Material: Crushed ice

Procedure:

1. Place the beaker for the experiment set and the control set on the electronic balance respectively. Reset the readings of both electronic balances to zero.

2. Set up the apparatus as shown in Figure 4.16. Initially, both beakers and electronic balances are not below their respective filter funnels.
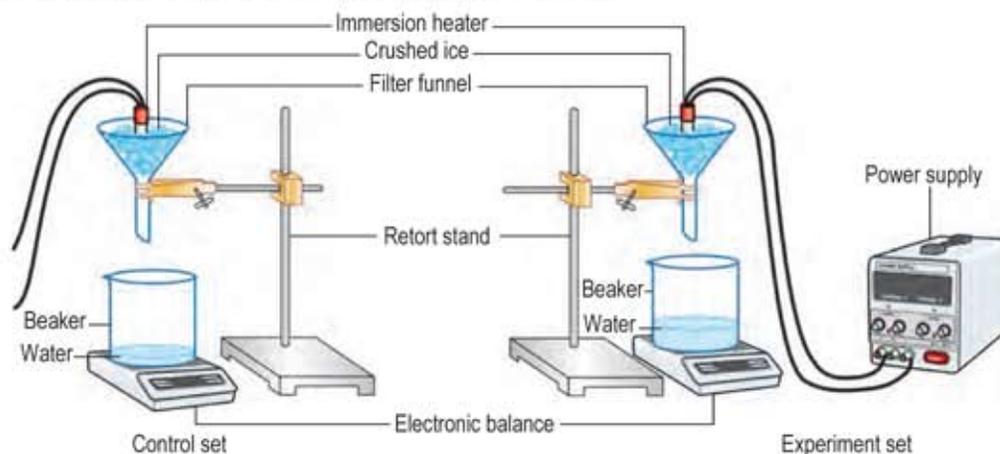

Figure 4.16

3. Switch on the immersion heater for the experiment set only. When water is dripping out of the filter funnel at a fixed rate, place the beakers and electronic balances respectively below the filter funnels. Start the stopwatch.

4. After time, t = 10 minutes, record the reading of the mass of water collected in the beaker of experiment set, m_1 and control set, m_2.

5. Switch off the immersion heater and record the power of the heater, P.

Results:

Table 4.6

Mass of water collected in beaker of experiment set, m_1 / kg	
Mass of water collected in beaker of control set, m_2 / kg	
Power of heater, P / W	
Heating time, t / s	

Analysis of data:

Calculate the specific latent heat of fusion of ice using the formula, $l = \dfrac{Pt}{(m_1 - m_2)}$.

Conclusion:

What conclusion can be made from this experiment?

B **Specific latent heat of vaporisation of water, l_v**

Apparatus: High power immersion heater (500 W), power supply, beaker, electronic balance and stopwatch

Materials: Water and tissue paper

Procedure:

1. Set up the apparatus as shown in Figure 4.17.
2. Switch on the immersion heater and wait until the water boils.
3. When the water boils, start the stopwatch and at the same time, record the reading on the electronic balance, m_1.
4. After time, $t = 5$ minutes, record the reading on the electronic balance, m_2.
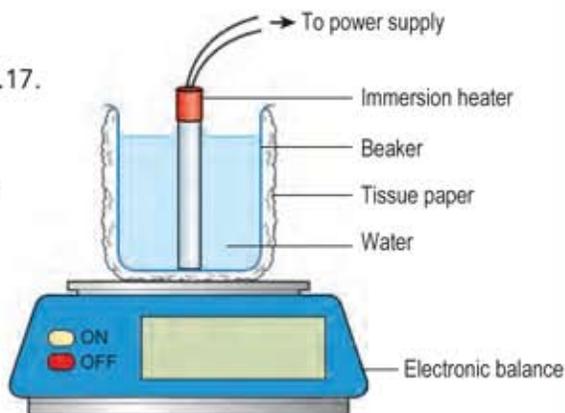5. Switch off the immersion heater and record the power of the heater, P.

To power supply
Immersion heater
Beaker
Tissue paper
Water
ON
OFF
Electronic balance

Figure 4.17

Results:

Table 4.7

Initial reading of electronic balance, m_1 / kg	
Final reading of electronic balance, m_2 / kg	
Time taken, t / s	
Power of heater, P / W	

Analysis of data:

Calculate the specific latent heat of vaporisation of water using the formula, $l = \dfrac{Pt}{(m_1 - m_2)}$.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. Why does a control set need to be prepared for experiment A but not for experiment B?
2. Given specific latent heat of fusion of ice = 3.34×10^5 J kg^{-1}, compare the value of specific latent heat of fusion of ice obtained from experiment A with the value given. Explain the difference between the two values (if any).
3. Given specific latent heat of vaporisation of water = 2.26×10^6 J kg^{-1}, compare the value of specific latent heat of vaporisation of water obtained from experiment B with the value given. Explain the difference between the two values (if any).
4. Suggest ways to increase the accuracy of the results of this experiment.

4.3.3

Observe Figure 4.18 which shows the changes of phase of water when latent heat is absorbed and released.

When ice melts, the ice molecules absorb latent heat of fusion causing ice to change from solid to liquid.

When water boils, the water molecules absorb latent heat of vaporisation causing water to change from liquid to gas.

When water vapour condenses, the water vapour molecules release latent heat of vaporisation causing water vapour to change from gas to liquid.

Figure 4.18 *Changes in phase of water*

Absorption of latent heat during melting and evaporation can be used to give the effect of cooling. Latent heat released during condensation however is used for the purpose of heating.

Activity 4.7

Aim: To show that evaporation causes cooling

Apparatus: 250 mℓ beaker, drinking straw and white tile

Materials: Alcohol and water

Instructions:

1. Set up the apparatus as shown in Figure 4.19.
2. Pour 100 mℓ alcohol into a beaker.
3. Touch the outside of the beaker and the water around the base of the beaker. Record your observations.
4. Blow air repeatedly into the alcohol.
5. Touch the outside of the beaker. Record your observations.

Figure 4.19

Discussion:

1. What happens to the alcohol when air is blown into it?
2. Compare the level of coldness of the beaker before and after air is blown into the alcohol. Explain your answer.
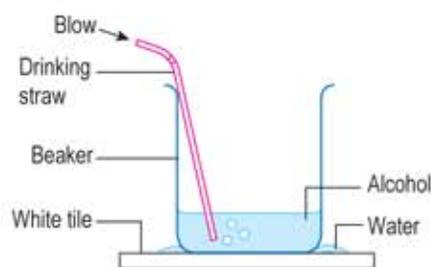3. State the effect of evaporation.

Specific latent heat of vaporisation is required in the change of phase from liquid to gas. This heat is absorbed from the surrounding. When a liquid evaporates, the liquid molecules absorb this heat to break the bond between molecules. The surrounding loses heat. Therefore, evaporation causes cooling to the surrounding.

4.3.4

Figure 4.20 shows examples of phase change of matter that involve specific latent heat.

Specific Latent Heat

- **Melting**
  - Cooling drinks and food with ice cubes

- **Evaporation**
  - Cooling body on hot day
  - Cooling system of refrigerator
  - Cooling system of air conditioner

- **Boiling**
  - Cooling as liquid nitrogen boils

- **Condensation**
  - Process of steaming food
  - Heating espresso coffee

Video on cooling with liquid nitrogen

http://bt.sasbadi.com/p4144a

Video on heating espresso coffee

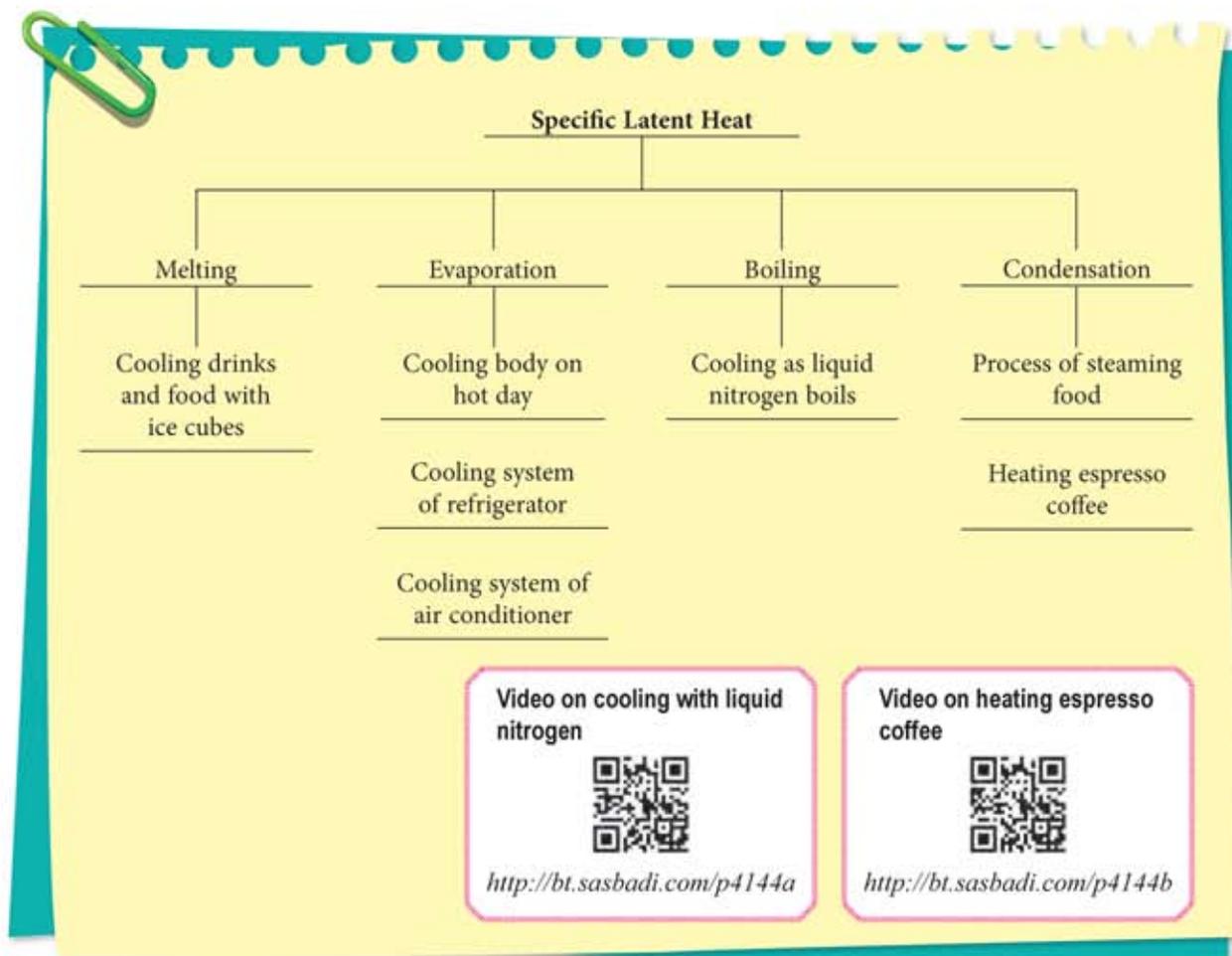*http://bt.sasbadi.com/p4144b*

Figure 4.20 *Examples involving specific latent heat*

Activity 4.8 ISS ICS

Aim: To discuss applications of specific latent heat in daily life

Instructions:

1. Work in groups.
2. Gather information on applications of specific latent heat in daily life:
   (a) Evaporation of sweat
   (b) Steaming food
3. Discuss how specific latent heat is applied in each situation.
4. Present the findings in the form of a mind map.

4.3.4

Applications of Specific Latent Heat in Daily Life

Cooling system in refrigerator

A refrigerator uses the cooling effect from evaporation. During circulation of the cooling agent, heat is absorbed from inside the refrigerator and released outside.
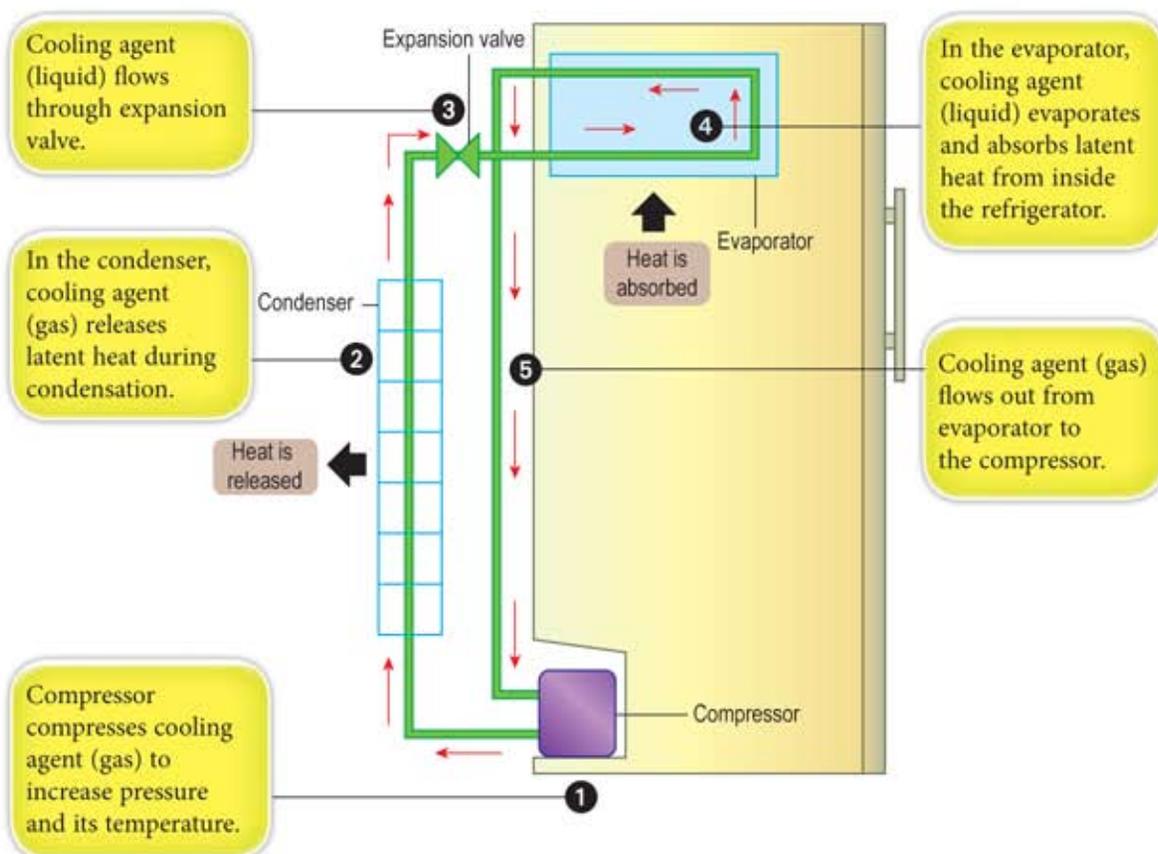
Cooling agent (liquid) flows through expansion valve.

In the evaporator, cooling agent (liquid) evaporates and absorbs latent heat from inside the refrigerator.

In the condenser, cooling agent (gas) releases latent heat during condensation.

Cooling agent (gas) flows out from evaporator to the compressor.

Compressor compresses cooling agent (gas) to increase pressure and its temperature.

Expansion valve

Heat is absorbed

Evaporator

Condenser

Heat is released

Compressor

Figure 4.21 *Cooling system in a refrigerator*

Evaporation of sweat

We sweat on hot days or while doing heavy work. When sweat evaporates, heat is absorbed from the body causing a cooling effect. The rate of evaporation will increase when there is air circulation.

DIY

Wet your right hand. Put your right hand which is wet and your left hand which is dry in front of a table fan. What difference can you feel on your right and left hands?

4.3.4

Solving Problems Involving Latent Heat

Example 1

Figure 4.22 shows a 480 W immersion heater used to melt ice in a container. In 120 s, the reading of the electronic balance decreases by 0.172 kg.

(a) What is the mass of ice that has melted during the heating period?

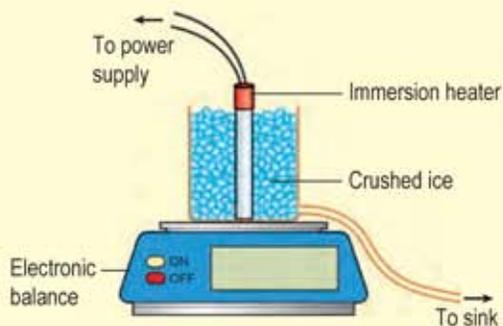(b) Calculate the specific latent heat of fusion of ice, l_f.

Figure 4.22

Solution:

(a) Make assumptions:
  (i) Ice is melted by heat from the immersion heater only.
  (ii) All water from the melting ice flows out of the container.

Relate the change in the readings of the electronic balance to the mass of ice which has melted:

Mass of ice melted = Decrease in the reading of the electronic balance
$$m = 0.172 \text{ kg}$$

(b) Make assumptions:
  (i) All heat supplied by the immersion heater is absorbed by the melting ice.
  (ii) No transfer of heat from the surrounding into the apparatus.

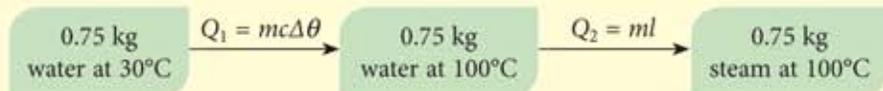|	
Step ❶ List the given information in symbols.	$m = 0.172 \text{ kg}$ $P = 480 \text{ W}$ $t = 120 \text{ s}$
Step ❷ Identify and write down the formula used.	$Pt = ml_f$
Step ❸ Substitute numerical values into the formula and perform the calculations.	$480 \times 120 = 0.172 \times l_f$ $l_f = \dfrac{480 \times 120}{0.172}$ $= 3.35 \times 10^5 \text{ J kg}^{-1}$

4.3.5

Example 2

What is the amount of heat supplied by a water heater to change 0.75 kg of water at 30°C to steam at 100°C? State the assumptions you make in your calculations.
[Specific heat capacity of water, $c_{water} = 4.20 \times 10^3$ J kg^{-1} °C^{-1}, specific latent heat of vaporisation of water, $l_v = 2.26 \times 10^6$ J kg^{-1}]

Solution:

$$\boxed{\begin{array}{c} 0.75 \text{ kg} \\ \text{water at } 30°C \end{array}} \xrightarrow{Q_1 = mc\Delta\theta} \boxed{\begin{array}{c} 0.75 \text{ kg} \\ \text{water at } 100°C \end{array}} \xrightarrow{Q_2 = ml} \boxed{\begin{array}{c} 0.75 \text{ kg} \\ \text{steam at } 100°C \end{array}}$$

Make assumptions:
(i) All heat supplied by the heater is absorbed by the water.
(ii) No loss of heat to the surrounding during heating and change of phase.

There are two stages of change:
(i) increase in water temperature from 30°C to its boiling point of 100°C
(ii) change of phase from water to steam without change in temperature.

Amount of heat supplied, $Q = Q_1 + Q_2$
$$= mc\Delta\theta + ml$$
$$= [0.75 \times 4.2 \times 10^3 \times (100 - 30)] + (0.75 \times 2.26 \times 10^6)$$
$$= 1.92 \times 10^6 \text{ J}$$

Formative Practice 4.3

1. Figure 4.23 shows an electric steamer. Explain how the fish is heated.

2. What is the amount of heat released when 0.8 kg of water at 25°C cools until it becomes ice at −6°C? State the assumptions you make in your calculations.

   [Specific heat capacity of water, $c_{water} = 4.2 \times 10^3$ J kg^{-1} °C^{-1}, specific heat capacity of ice, $c_{ice} = 2.0 \times 10^3$ J kg^{-1} °C^{-1} and specific latent heat of fusion of ice, $l_f = 3.34 \times 10^5$ J kg^{-1}]

Fish

Contain water

Figure 4.23

4.3.5