3

Temperature Change and Heat Capacity

In this chapter, we will learn about

- energy transfer and power
- heat capacity of objects
- specific heat capacity of substances
- thermal equilibrium
- the importance of the high specific heat capacity of water

3.1 Power and measurement of energy transferred

In Chapter 2, we learned that the temperature of a body can be increased by heating it. We shall now study how the rise in temperature of a body is related to the amount of energy transferred to the body.

Flipped classroom

Watch a video and answer the questions.

1 Power

To describe how fast energy is transferred from a power source during heating, we can use the quantity **power**. It is the rate of energy transfer, i.e. the energy transferred per unit time.

The transfer of energy can be due to doing work or heating. In this book, we consider energy transfer due to heating only.

$$\underbrace{P}_{\textbf{power}\text{ (W)}} = \frac{\overbrace{Q}^{\textbf{energy}\text{ transferred (J)}}}{\underbrace{t}_{\textbf{time}\text{ (s)}}}$$

The unit of power is the **watt** (**W**), named after the famous scientist *James Watt*. 1 W = 1 J s^{-1}.

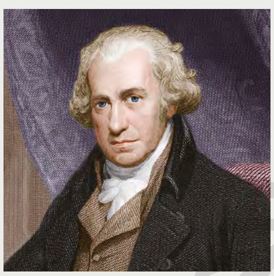
Larger units of power include the kilowatt (kW) and the megawatt (MW).

1 kW = 10^3 W = 1000 W

1 MW = 10^6 W = 1 000 000 W

Know more

James Watt (1736–1819)



James Watt was a Scottish mathematician and engineer. He introduced the concept of *horsepower* which is still commonly used in measuring the power of appliances like engines and boilers. The unit of power, the watt, is named after him.

OUP eResources

Example 1 Energy transferred

A 1.5-kW electric kettle is used to heat some tap water.

(a) How long does it take to transfer 600 kJ of energy to the water?

(b) If another electric kettle with a higher power is used to heat the same amount of tap water, how will the answer to (a) change? Explain briefly.

power 功率 watt (W) 瓦特 James Watt 瓦特 horsepower 馬力

Solution

(a) By $P = \dfrac{Q}{t}$,

$$t = \frac{Q}{P} = \frac{600\ 000}{1500} = 400 \text{ s}$$

It takes 400 s.

(b) The answer to (a) will become smaller. According to $Q = Pt$, using a **greater** power $\boldsymbol{P}$ to transfer the **same** amount of energy $\boldsymbol{Q}$ requires **less** time $\boldsymbol{t}$.

Tip
Rearranging $P = \dfrac{Q}{t}$ gives

$\mathbf{Q = Pt}$

unchanged decreases
increases

2 Measurement of energy transferred

✏ Ts may remind Ss that kilowatt-hour is a unit of energy, not power.

A joule is a very small amount of energy. It is just enough to heat up 1 g of water by about 0.25 °C. For daily use, energy is usually expressed in **kilowatt-hour** (**kW h**). This unit is actually used to calculate the cost of electrical energy.

Skill
Mathematics
Scientific notation
▸ p.192

One kilowatt-hour is equal to the amount of energy used by an electrical appliance with 1 kW of power in 1 hour, i.e.

$$\begin{aligned} 1 \text{ kW h} &= (1000 \text{ J s}^{-1})(3600 \text{ s}) \\ &= 3\ 600\ 000 \text{ J} \\ &= 3.6 \times 10^{6} \text{ J} \end{aligned}$$

The electrical energy supplied to an electrical appliance can be measured using a **joulemeter** or a **kilowatt-hour meter** (Fig 3.1a), depending on the amount of energy to be measured. In general, the joulemeter measures the electrical energy from a low-voltage power supply while the kilowatt-hour meter measures that supplied by the *mains*.

(i) (ii)

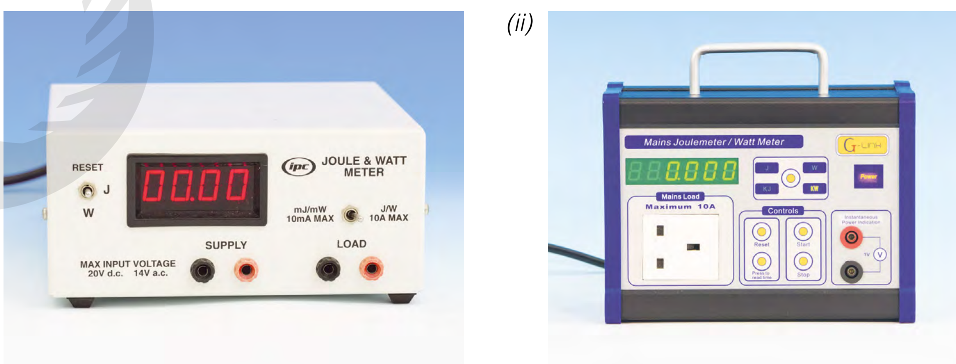


Fig 3.1a (i) A joulemeter and (ii) a kilowatt-hour meter.

kilowatt-hour (kW h) 千瓦小時 joulemter 焦耳計 kilowatt-hour meter 千瓦時計 mains 市電

Google Forms   Microsoft Forms

Quick check 1

→ E-version in OUP Exercise Platform is also available.

1 The information about some hair dryers is shown in the table below. Complete the table.

Hair dryer	Power	Energy consumed	Time taken
A	1200 W	4.2×10^5 J	
B		5.4×10^5 J	280 s
C	2 kW		3 min

2 A light bulb is connected to a power supply via a joulemeter. Which of the following quantities is measured by the joulemeter?

A Heat given off by the light bulb
B Internal energy of the light bulb
C Temperature of the light bulb
D Energy supplied to the light bulb

Exercise 3.1

★**1** Zoe puts a cup of tea on a cup warmer (Fig a).

Fig a

The power of the cup warmer is 5 W. Suppose 80% of the power is transferred to the tea. How much energy does the tea gain in 2 minutes?

A 8 J
B 10 J
C 480 J
D 600 J

2 It takes a kettle 5 minutes to transfer 540 000 J of energy to boil some water. What is the power of the kettle?

3 (a) Express 4.2 kW h in joules.

(b) Express 62 000 J in kilowatt-hours.

4 A 5-kW heater is completely immersed in a large tank of water. How much energy is transferred to the water if it is switched on for half an hour? Express your answer in joules.

★**5** (a) Express 1.2 kW h in joules.

(b) An induction heater (Fig b) has a power of 2100 W. How long does it take to transfer 1.2 kW h of energy to heat some water? Assume all the electrical energy is converted into the internal energy of the water.

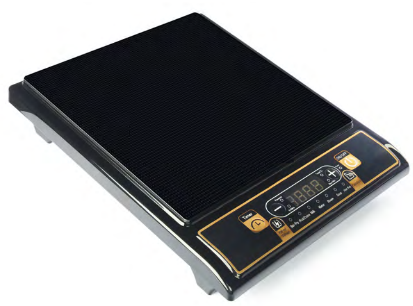


Fig b

★**6** An electric kettle transfers 600 kJ of energy to some water in 10 minutes. How long does it take to supply 1100 kJ of energy to heat the water?

3.2 Heat capacity and specific heat capacity

1 Energy transfer and temperature change

When we heat a certain amount of water with a heat source at a stable power, e.g. electric hot plate, it takes longer time to raise the water to a higher temperature. This suggests that a larger amount of energy transferred to the water causes a larger temperature change. We will quantify the relationship between the energy transferred to a substance and its temperature change in the experiment below.

Recall that $Q = Pt$.

→ This video demonstrates Expt 3a.

Video

Experiment 3a Relationship between energy transferred and temperature change

1 Set up the apparatus as shown (Fig a).

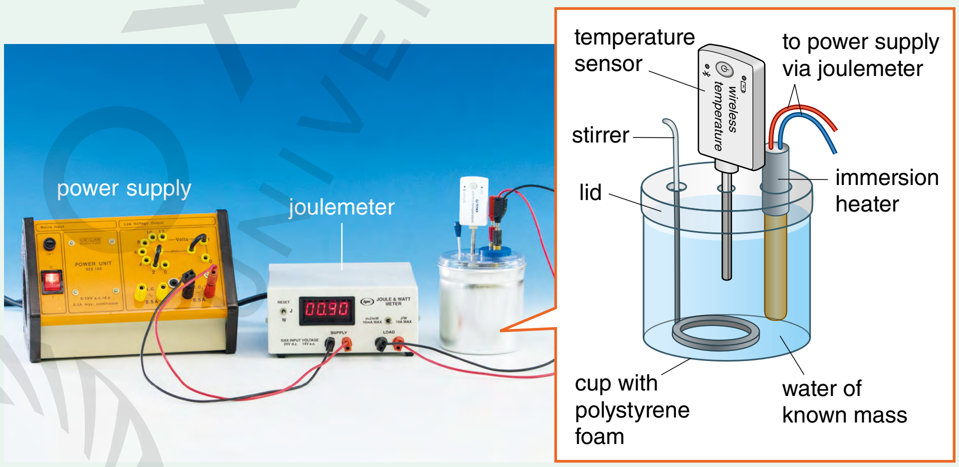


Fig a

2 Switch on the heater and start timing. After one minute, record the initial temperature T_0 of the water and the initial joulemeter reading J_0.

3 After every minute, record the temperature reading T and the joulemeter reading J. Then work out the temperature change ΔT (= $T - T_0$) and the total energy transferred to the water Q (= $J - J_0$). Repeat this step and continue for at least six minutes.

4 Plot a graph of Q against ΔT.

Polystyrene absorbs very little energy from the heater because its heat capacity is very low.
It reduces energy loss to the surroundings because it is a poor conductor.

Polystyrene foam is commonly used in experiments about heat because

1 it absorbs very little energy from a heater; and
2 its foam structure helps reduce energy loss to the surroundings.

The heater and water are hot during and after heating. Do not touch them.

Precaution

1. Immerse the heating part of the heater totally in water before switching it on. Otherwise, the heater may overheat.
2. Keep the heating part of the heater totally immersed in water throughout the experiment to maximize the transfer of energy to the water.
3. Keep stirring the water, especially before taking the temperature readings, to ensure a uniform temperature throughout the water.

Discussion

How is the energy transferred to the water related to its temperature change?

DSE goal

Define heat capacity.

Solve problems involving heat capacity.

2 Heat capacity of objects

In Experiment 3a, if the energy transferred Q is plotted against temperature change ΔT, a straight line through the origin is obtained (Fig 3.2a). This shows that Q is directly proportional to ΔT for a constant mass of water, i.e. $Q \propto \Delta T$.

Know more

Direct proportion $y \propto x$

Suppose the graph of y against x is **a straight line** and it **passes through the origin** (Fig a). We say that y is directly proportional to x, i.e. $y \propto x$. In this case, we can write:

$$y = kx$$

where k is a constant and equal to the slope of the graph.

Note that the graph in Figure b does **not** represent a direct proportional relationship. This is because the graph does not pass through the origin. In this case, m and n have a linear relationship only.

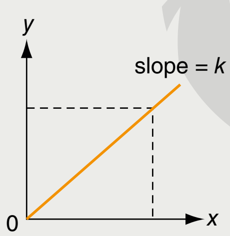


Fig a Graph of a direct proportional relationship.

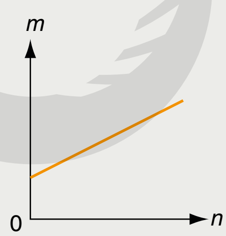


Fig b Graph of a linear relationship.

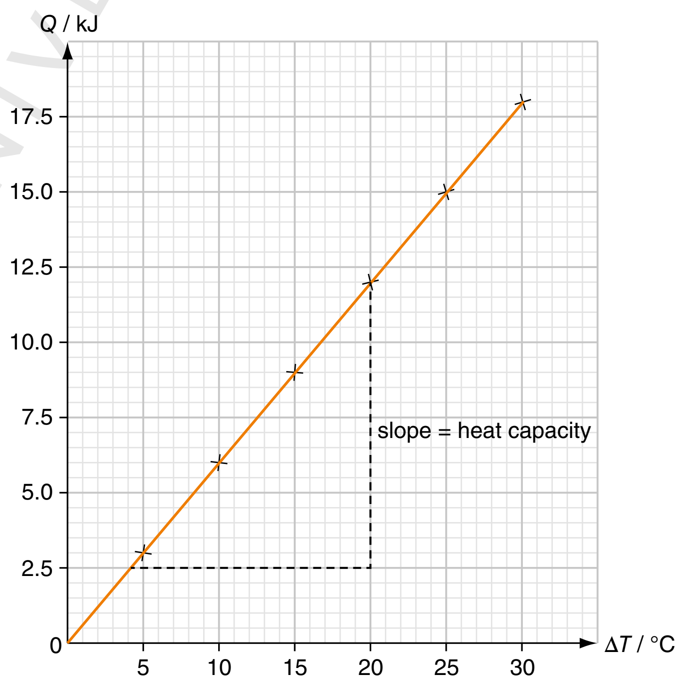


Fig 3.2a Graph of Q against ΔT. More energy is needed to produce a larger temperature change for the same mass.

The direct proportional relationship between Q and ΔT for a body of constant mass can be expressed as follows.

energy transferred from/to object (J) — heat capacity of object (J °C^{-1}) — temperature change (°C)

$$Q = C\Delta T$$

or

$$C = \frac{Q}{\Delta T}$$

The unit for heat capacity can be obtained from its defining equation.

$$\text{Unit of } C = \frac{\text{unit of } Q}{\text{unit of } \Delta T} = \frac{\text{J}}{°\text{C}} = \text{J °C}^{-1}$$

where C is the **heat capacity** of the body. Its unit is J °C^{-1}.

The heat capacity of a body is the energy needed to raise the temperature of that body by 1 °C.

Note that the slope of the Q–ΔT graph gives the heat capacity of the body.

Example 2 Heat capacity of water of different masses

The temperature of a glass of water rises from 15 °C to 20 °C when 4 kJ of energy is supplied to it. If the water in an entire swimming pool is heated to get the same temperature change, 5×10^{10} J of energy is required.

(a) What are the heat capacities of the two bodies?

(b) Suppose 4 kJ of energy is supplied to the glass of water. What is its final temperature if its initial temperature is 27 °C?

Solution

(a) For the glass of water,

$$C = \frac{Q}{\Delta T} = \frac{4000}{20 - 15} = 800 \text{ J °C}^{-1}$$

For the pool of water,

$$C = \frac{Q}{\Delta T} = \frac{5 \times 10^{10}}{5} = 1 \times 10^{10} \text{ J °C}^{-1}$$

(b) Final temperature = 27 + 5 = 32 °C

Tip
C of the glass of water is constant. According to $Q = C\Delta T$, the same Q always gives the same ΔT.

Think about...

Why are the heat capacities of the glass of water and the pool of water different?

heat capacity 熱容量

Ts may use Q1 for explanation. The gold brick has a higher heat capacity than the silver trophy. However, it **cannot** be concluded that more energy is needed to raise the temperature of the substance 'gold' by 1 °C than 'silver', since the gold brick has a larger mass than the silver trophy. Mass is also not the only factor affecting the energy required to heat up an object since more energy is needed to raise the temperature of the lighter plastic rod than the other two objects.

Quick check 2

→ E-version in OUP Exercise Platform is also available.

Google Forms   Microsoft Forms

1 In an experiment, three objects made of different materials are heated. The following table shows the results. Find the heat capacity of each object by completing the table.

	Gold brick	Silver trophy	Plastic rod
Mass / kg	2	1	0.5
Temperature rise / °C	10	25	1
Energy transferred / J	2600	6000	800
Heat capacity / J °C^{-1}			

DSE goal

Define specific heat capacity.
Solve problems involving specific heat capacity.

DSE exam

13(1B)Q1, 15(1A)Q2, 17(1B)Q1(b), 19(1A)Q1, 20(1B)Q1, 21(1B)Q1(b)–(d), 22(1A)Q1, etc.

3 Specific heat capacity of substances

→ This video demonstrates Expt 3b.

Video

Experiment 3b Relationship between energy transferred and mass

1 Use the same set-up as Experiment 3a on p.63. Put 0.10 kg of water into the cup.

2 Switch on the heater. After one minute, record the initial temperature T_0 of the water and the initial joulemeter reading J_0.

Follow the precautions stated in Experiment 3a.

3 Switch off the heater when the temperature has risen by about 5 °C. Record the energy Q transferred to the water and the temperature rise ΔT.

After the heater is switched off, wait and record the highest temperature reached as the final temperature.

4 Repeat the steps with different masses of water.

5 Plot a graph of Q against m.

The heater and water are hot during and after heating. Do not touch them.

Discussion

How is the energy transferred related to the mass of water?

The result of Experiment 3b shows that to produce the same temperature rise ΔT, the energy Q transferred is directly proportional to the mass m of the water (Fig 3.2b), i.e. $Q \propto m$. This relationship is also valid for other substances.

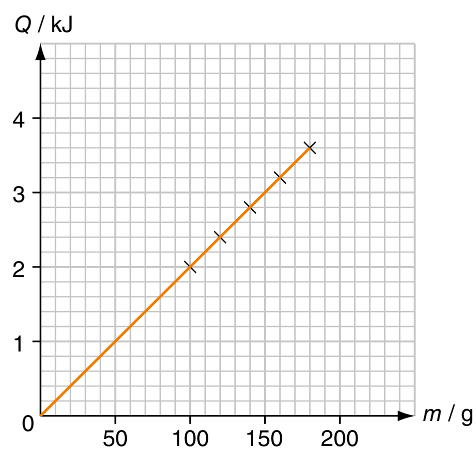


Fig 3.2b Graph of Q against m. More energy is needed to produce the same temperature rise in a larger mass.

Does gold need more energy to heat up than copper? This question cannot be solved by simply comparing the heat capacities of two randomly chosen pieces of gold and copper. This is because heat capacity does not solely depend on the type of substance but also on the mass of the object. The heat capacity for a unit mass of the substance should be considered; we call this the **specific heat capacity** of the substance.

A substance with a higher specific heat capacity requires more energy to increase its temperature by 1 °C for each kg of the substance.

The specific heat capacity of a substance is the energy needed to raise the temperature of 1 kg of the substance by 1 °C.

Note that **the heat capacity describes the thermal property of an object while the specific heat capacity describes the thermal property of a substance**. Now we are able to answer the question about gold and copper (Fig 3.2c).

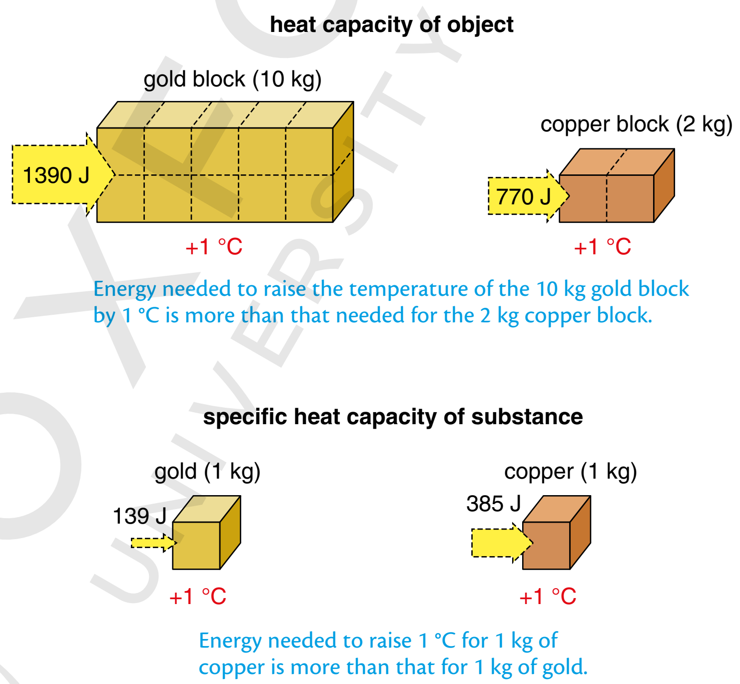


Fig 3.2c *The specific heat capacities of gold and copper tell us that copper needs more energy to heat up than gold.*

For an object made of only one substance, its heat capacity C is related to the specific heat capacity of the substance c as follow:

$$c = \frac{C}{m}$$

specific heat capacity of substance (J kg^{-1} °C^{-1})

heat capacity of object (J °C^{-1})

mass of object (kg)

The unit of specific heat capacity is J kg^{-1} °C^{-1}.

specific heat capacity 比熱容量

Substituting $C = mc$ into $Q = C\Delta T$, we have

We learned that Q is directly proportional to both ΔT and m from Experiments 3a and 3b.

energy transferred from/to object (J)

mass of object (kg)

specific heat capacity of substance (J kg^{-1} °C^{-1})

$$\boldsymbol{Q = mc\Delta T}$$

temperature change (°C)

or

$$\boldsymbol{c = \frac{Q}{m\Delta T}}$$

Example 3 | Energy needed to raise temperature

The aluminium pot as shown below is heated. Its mass is 2 kg. The specific heat capacity of aluminium is 900 J kg^{-1} °C^{-1}.

(a) Calculate the energy required to raise its temperature from 10 °C to 30 °C.

(b) Find the heat capacity of the pot.

Solution

(a) Energy required = $mc\Delta T$ = 2 × 900 × (30 – 10) = 36 000 J

(b) Heat capacity of the pot = mc = 2 × 900 = 1800 J °C^{-1}

The energy change of the pot in Example 3 can be illustrated by a simple diagram as shown in Figure 3.2d. The red arrow represents the energy gained by the pot.

Such a diagram will be used in the later part of this book.

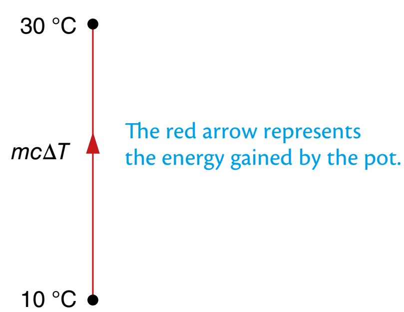


Fig 3.2d *Simple diagram illustrating the energy change of the pot.*

Google Forms Microsoft Forms

Quick check 3

→ E-version in OUP Exercise Platform is also available.

1 A heater transfers energy to the objects listed in the table below. Complete the table.

Object	Mass / kg	Energy transferred / J	Specific heat capacity / J kg^{-1} °C^{-1}	Temperature increase / °C
A	4.8	900		2
B	2.4	4800	120	
C		5000	600	5.5
D	3.0		4200	0.7

2 Solid *X* absorbs more energy than solid *Y* when their temperatures increase by 1 °C. *X* must have a greater

A heat capacity.

B specific heat capacity.

Learn by practice 1

1 (a) Object *X* of mass 12 kg has a heat capacity of 1680 J °C^{-1}. Find its specific heat capacity.

(b) Object *Y* of mass 0.6 kg has a specific heat capacity of 2720 J kg^{-1} °C^{-1}.

(i) Find its heat capacity.

(ii) Compare its heat capacity with *X*. Which object has a greater heat capacity?

2 A metal block has a specific heat capacity of 370 J kg^{-1} °C^{-1}. When it absorbs an energy of 60 000 J, its temperature increases from 28 °C to 52 °C. Find the mass of the block.

DSE goal

Determine the specific heat capacity of a substance.

DSE exam

14(1B)Q1, 16(1B)Q1

4 Measuring specific heat capacity

Experiment 3c / Measuring the specific heat capacity of water

Use the same set-up as Experiment 3a on p.63. Find the energy required to raise the temperature of 0.2 kg of water by about 10 °C. Calculate the specific heat capacity of water.

Discussion

What are the possible sources of error in this experiment? How is the result affected by these errors?

Follow the precautions stated in Experiment 3a. Moreover, after the heater is switched off, wait and record the highest temperature reached as the final temperature.

The heater and water are hot during and after heating. Do not touch them.

Simulation Video

→ This simulation is a 'virtual expt' on the measurement of the specific heat capacity of water.

→ This video demonstrates Expt 3c.

Skill
Mathematics

Significant figures and rounding

Depending on the accuracy required, we can round the calculation result to different *significant figures* (sig. fig.).

Typically, answers are expressed in 3 significant figures in this series of books.

▸ p.193

Example 4 Measuring the specific heat capacity of water

In Experiment 3c, the following results were obtained:

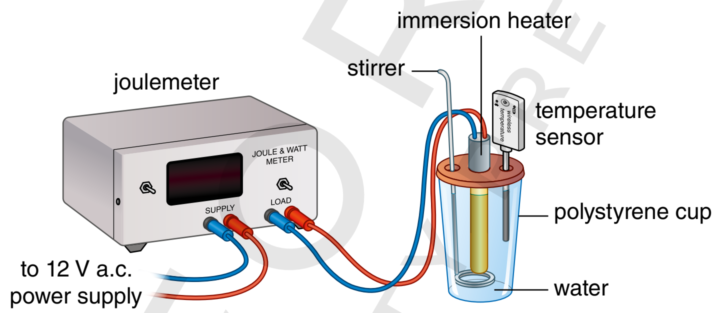
Mass of water = 0.2 kg

Initial joulemeter reading = 0

Initial temperature = 20 °C

Final joulemeter reading = 15 000 J

Final temperature = 37 °C



(a) Write the equation used to calculate the specific heat capacity of water in the experiment.

(b) Calculate the specific heat capacity of water using the above data.

(c) The standard value of the specific heat capacity of water is 4200 J kg^{-1} °C^{-1}. Find the percentage error of the result in (b).

(d) State two possible sources of error.

(e) How could you improve the accuracy of the experiment?

→ Teaching notes and exercises are available on OUP web.

Solution

(a) $c = \dfrac{Q}{m\Delta T}$

(b) Specific heat capacity of water $= \dfrac{Q}{m\Delta T} = \dfrac{15\ 000}{0.2 \times (37 - 20)} = 4410$ J kg^{-1} °C^{-1}

(c) Percentage error $= \dfrac{4410 - 4200}{4200} \times 100\% = 5\%$

(d) Some energy is lost to the surrounding air.

Some energy is absorbed by the cup, the stirrer and the thermometer.

(e) Wrap the polystyrene cup with cotton wool to reduce energy loss to the surroundings.

Skill
Experiment

Percentage error

All measurements contain errors. If the measured value of a quantity is *M* while the standard value of this quantity is *S*, the error *E* in this measurement is the difference between *M* and *S*, i.e. $E = |M - S|$. Then, percentage error

$= \dfrac{|M - S|}{S} \times 100\%$

The smaller the percentage error, the more precise the measurement.

How do the sources of error affect the measured value of the specific heat capacity *c* of water? To answer this, we shall first find out how the error affects the quantities used to calculate *c*.

significant figure 有效數字

Writing practice

Question

Explain why the measured value of the specific heat capacity of water in Experiment 3c is higher than the actual value. (3 marks)

Answer

As some energy is lost to the surroundings, 1A

the energy supplied by the immersion heater is greater than the energy absorbed by the water. / The temperature rise of water in the cup is lower than that it should be. 1A

By $c = \dfrac{Q}{m\Delta T}$, the measured value of c is higher than the actual value. 1A

Practise yourself

1 When doing Experiment 3c, a student wrongly uses the total mass of the cup and the water to calculate the specific heat capacity of water. Explain why the calculated value of c is lower than the actual value. (2 marks)

Simulation
Video

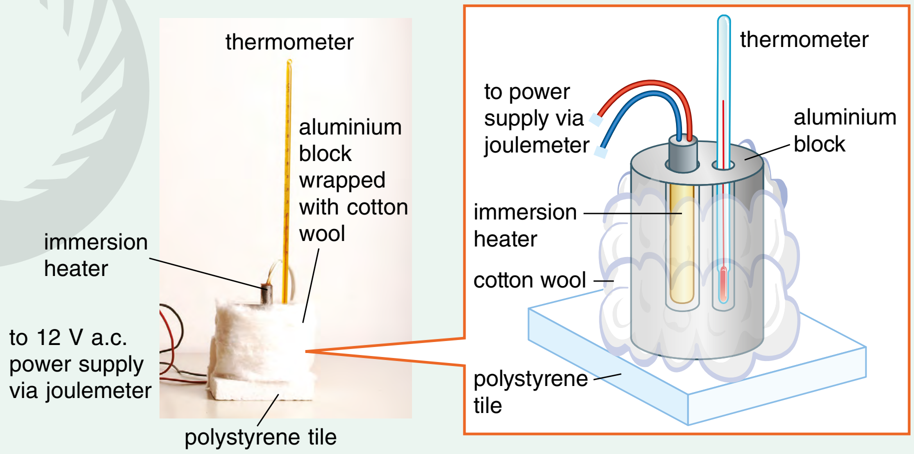
→ This simulation is a 'virtual expt' on the measurement of the specific heat capacity of aluminium. Ss can repeat the vitual expt using different metals.

→ This video demonstrates Expt 3d.

The heater and aluminium block are hot during and after heating. Do not touch them.

Experiment 3d Measuring the specific heat capacity of aluminium

Set up the apparatus as shown. Find the energy required to raise the temperature of a 1-kg cylindrical aluminium block by about 10 °C. Calculate the specific heat capacity of aluminium.



Precaution

1 Add a few drops of oil to the holes in the aluminium block to ensure good thermal contact between the heater and the block and between the thermometer and the block.

2 Insert the heating part of the heater entirely into the block before switching it on. Otherwise, the heater may overheat.

3 After the heater has been switched off, wait and record the highest temperature reached as the final temperature.

Discussion

1 Why is the aluminium block wrapped in cotton wool and placed on a polystyrene tile?

2 What are the possible sources of error in this experiment?

As in Experiment 3c, some energy is lost to the surroundings in Experiment 3d. Therefore, the measured value of the specific heat capacity of aluminium is greater than the actual value.

The high specific heat capacity of water is a result of the hydrogen bonding between its molecules. The applications of the high specific heat capacity of water will be discussed on p.78–79.

Table 3.2a shows the specific heat capacities c of some common substances. Note that water has a much higher specific heat capacity than the others.

Substance	c / J kg^{-1} °C^{-1}	Substance	c / J kg^{-1} °C^{-1}
Water	4200	Steel	466
Aluminium	900	Copper	370
Glass	600	Lead	130
Iron	480	Gold	129

Table 3.2a Specific heat capacities c of some common substances.

Learn by practice 2

1 In an experiment, an aluminium block is heated by a heater (Fig a).

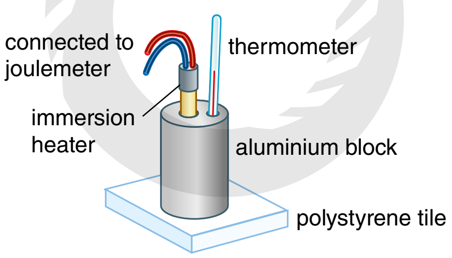


Fig a

(a) Write the equation used to calculate the specific heat capacity of aluminium in the experiment.

(b) Table a shows the data recorded in the experiment.

	Temperature / °C	Joulemeter reading / J
Initial	23	34 000
Final	47	61 000

Table a

The mass of the block is measured to be 1.2 kg. Calculate the specific heat capacity of aluminium.

Simulation

→ This simulation simulates the situation when two bodies of different temperatures are put in contact. Ss can vary the initial temperatures of the two bodies and find out the final temperatures. It is available on OUP web in PC version (.exe) only.

The internal energies of the two bodies may or may not be the same after they reach thermal equilibrium.

5 Law of conservation of energy

In chapter 2, we learned that when two bodies of different temperatures are put into contact, energy is transferred from the hotter body to the colder body. This transfer process stops when they are in thermal equilibrium, i.e. when they reach the same temperature (Fig 3.2e).

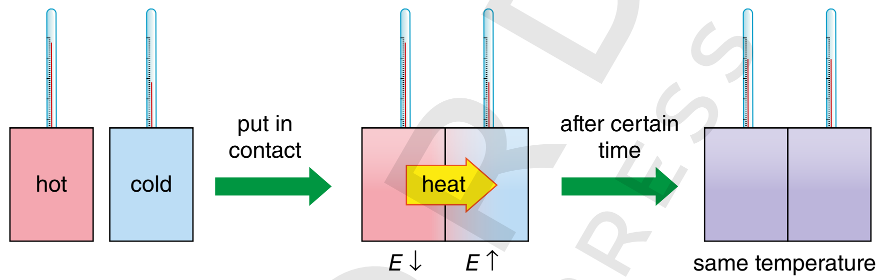


Fig 3.2e *Transfer of energy stops when the two bodies reach thermal equilibrium.*

If there is no energy transfer to/from other bodies,

energy lost by the hotter body = energy gained by the colder body

Although the energy in each body is changing during the transfer process, the total energy of the two bodies as a whole (a system) remains constant at any time. This agrees with the **law of conservation of energy**, which states that:

This law is very important and you will learn more about it in later chapters.

The total amount of energy in a closed system is conserved, i.e. always kept constant. Energy cannot be created or destroyed.

Video

→ This video demonstrates Expt 3e.

Beware of the hot water.

Experiment 3e 'Mixture'

Measure the mass and the temperature of a cup of hot water and a cup of water at room temperature. Quickly mix the two cups of water and measure the temperature of the 'mixture'. Calculate the energy lost by the hot water and the energy gained by the water at room temperature.

Discussion

1. Why should the experiment be carried out quickly?
2. Is the energy gained by the water at room temperature exactly the same as the energy lost by the hot water? Why?

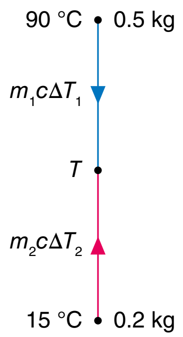
→ This is a Video Quiz about this experiment.

law of conservation of energy 能量守恆定律

We shall solve some problems using the law of conservation of energy.

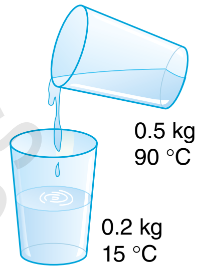
Tip

Drawing a simple diagram may help you see the energy change in the process more easily. The red arrow represents the energy gained by the cooler water and the blue arrow represents the energy lost by the hotter water.



Example 5 | Final temperature of a mixture

Water of mass 0.5 kg at 90 °C is added to water of mass 0.2 kg at 15 °C.



(a) Estimate the final temperature T of the mixture. Take the specific heat capacity of water to be 4200 J kg^{-1} °C^{-1}.

(b) The final temperature is measured to be 65 °C. Compare this value to your answer in (a) and explain the difference.

Solution

(a) Energy lost by hotter water = energy gained by cooler water

$$0.5 \times 4200 \times (90 - T) = 0.2 \times 4200 \times (T - 15)$$

$$0.5 \times (90 - T) = 0.2 \times (T - 15)$$

$$T = 68.6 \text{ °C}$$

(b) The value is lower than the answer in (a). This is because some energy is lost to the surroundings.

Google Forms | Microsoft Forms

Quick check 4

→ E-version in OUP Exercise Platform is also available.

1 *True or false:* When a metal block at temperature T_1 is put in contact with another metal block at temperature T_2, the final temperature of the blocks must be $\dfrac{T_1 + T_2}{2}$. (T/F)

2 Solid X is in contact with solid Y. They reach thermal equilibrium after a while. Assume that the energy loss to the surroundings is negligible. Which of the following must be correct? Put a tick in the corresponding box(es).

- ☐ They have the same final temperature.
- ☐ They have the same final internal energy.
- ☐ The energy lost by one solid is equal to the energy gained by the other.

Learn by practice 3

1 Some stainless steel ice cubes with a total mass of 200 g at −15 °C are put into some wine at 20 °C. The temperature of the wine becomes 9 °C when the ice cubes and the wine reach thermal equilibrium.

Estimate the mass of the wine. The specific heat capacities of stainless steel and the wine are 490 J kg^{-1} °C^{-1} and 3400 J kg^{-1} °C^{-1} respectively. Assume that there is no energy exchange with the surroundings.

By applying the law of conservation of energy, we can estimate the specific heat capacity of a metal by adding a hot metal block into some water. This is shown in the following experiment.

Video

→ This video demonstrates Expt 3f.

The set-up and the copper block are hot during and after heating. Do not touch them.

Experiment 3f Estimating the specific heat capacity of copper

1 Put a copper block with a known mass in a beaker of water. Heat the water and let it boil for at least one minute (Fig a).

2 Put 200 g of water at room temperature in a polystyrene cup. Measure the temperature of the water.

3 Transfer the hot copper block to the polystyrene cup. Stir the water well and measure the highest temperature reached by the water (Fig b).

4 By taking the specific heat capacity of water as 4200 J kg^{-1} $°C^{-1}$, calculate the specific heat capacity of copper.

Fig a

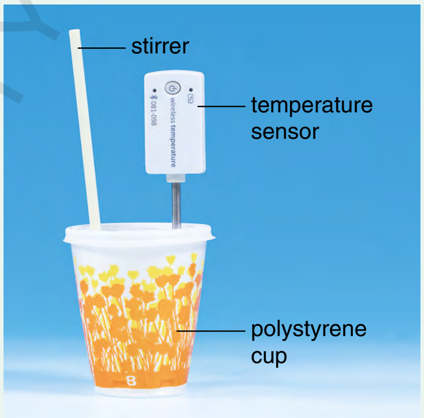


Fig b

Discussion

1 What is the temperature of the copper block when it is transferred from the beaker to the cup?

2 What are the possible sources of error in this experiment?

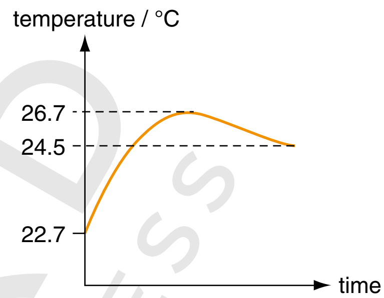
Know more

Hot stone bath

The hot stone bath in Bhutan is an example of energy transfer in a solid-liquid mixture. Hot stones are added on one side of a wooden chamber filled with water. As the stones heat up the water, people on the other side can enjoy a hot bath.

Example 6 | Estimating the specific heat capacity of copper

Jim performs Experiment 3f. After the hot copper block is transferred to the water in the polystyrene cup, he measures the water temperature every minute and obtains the graph as shown.



(a) Explain the increase in water temperature from 22.7 °C to 26.7 °C in the graph.

(b) Why does the water temperature no longer rise after reaching 26.7 °C?

(c) The mass of the copper block and the water are 132 g and 200 g respectively. By taking the specific heat capacity of water as 4200 J kg^{-1} °C^{-1}, calculate the specific heat capacity c of copper.

(d) State one possible source of error. Explain how this error affects the value of c obtained in (c).

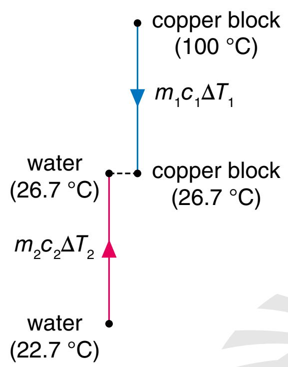
Solution

(a) The copper block has a higher temperature than the water in the cup. Energy is transferred from the block to the water, causing the water temperature to rise.

(b) When the temperature reaches 26.7 °C, the water and the block are in thermal equilibrium.

Tip

Simple diagram:



(c) Energy lost by copper block = energy gained by water

$$0.132 \times c \times (100 - 26.7) = 0.2 \times 4200 \times (26.7 - 22.7)$$
$$c = 347 \text{ J kg}^{-1} \text{ °C}^{-1}$$

(d) Some energy is lost to the surroundings after the copper block is transferred to the water in the cup. The highest temperature T reached by the water is lower than it should be.

As $c = \dfrac{0.2 \times 4200 \times (T - 22.7)}{0.132 \times (100 - T)}$, the calculated value of c becomes lower than the actual value.

Tip

A lower T would result in a lower value of $(T - 22.7)$ and a higher value of $(100 - T)$. Both would cause c to become lower in value.

✎ Ts may point out that Ss can also solve (d) by considering how the energy gained by water is different from the energy lost by copper block (energy lost by copper block = energy gained by water + energy loss to surroundings).

Think about...

1 Energy is also lost to the surroundings when the beaker of water is heated. Is this a source of error to the experiment?

2 Why does the water temperature drop after reaching the maximum value?

The law of conservation of energy can also be applied to solve problems involving heating with a fixed power.

Example 7 Heating with a fixed power

A 2200-W kettle heats 1.5 kg of water for two minutes. The initial temperature of the water is 25 °C. Find the final temperature T of the water if 10% of the energy is lost to the surroundings. Take the specific heat capacity of water to be 4200 J kg^{-1} °C^{-1}.

Solution

Energy supplied by kettle × (1 − 10%) = energy gained by water

$$Pt \times (1 - 10\%) = mc\Delta T$$

$$2200 \times (2 \times 60) \times 0.9 = 1.5 \times 4200 \times (T - 25)$$

$$T = 62.7\ °\text{C}$$

Learn by practice 4

Assume that there is no energy exchange with the surroundings.

1 A 5-kg metal block is heated by a heater of power 1500 W for 30 s and its temperature increases by 33 °C. Find the specific heat capacity of the metal.

2 Find the time required to raise the temperature of 2 kg of olive oil from 25 °C to 90 °C using a 1200-W heater. The specific heat capacity of the olive oil is 1970 J kg^{-1} °C^{-1}.

3 A bowl of soup is warmed by a 200-W heater. The mass of the soup is 0.5 kg. If the initial temperature of the soup is 3 °C, what is its temperature after 5 minutes? The specific heat capacity of the soup is 3500 J kg^{-1} °C^{-1}. Assume that the heat capacity of the bowl is negligible.

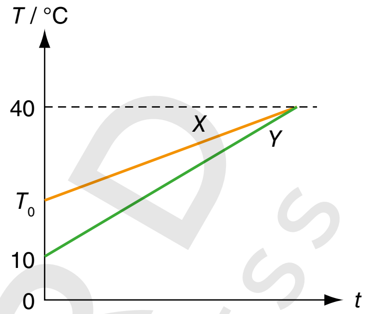
☆ HKDSE 2015 Paper 1A Q2

→ This video demonstrates how this question is solved.

Video

DSE practice 1 | Temperature–time graph

In an experiment, objects X and Y are heated by a heater with the same constant power. They are made of the same material but the mass of X is two times that of Y. The figure shows how the temperature T of each object changes with time t. Find T_0.



A 15　　　B 20

C 25　　　D 30

Solution

By $Q = Pt$ and $Q = mc\Delta T$,

$$\Delta T = \frac{Q}{mc} = \frac{Pt}{mc}$$

Common mistake ⚠
Students may not realize the relationship between energy and power. Therefore, they may not be able to derive the relationship between m, t and ΔT.

Note that P and c are the same for both objects.

For the same time duration t,

$$\frac{\Delta T_X}{\Delta T_Y} = \frac{\dfrac{Pt}{m_X c}}{\dfrac{Pt}{m_Y c}} = \frac{m_Y}{m_X} = \frac{1}{2}$$

$$\Delta T_X = \frac{1}{2}\Delta T_Y$$

$$40 - T_0 = \frac{1}{2} \times (40 - 10)$$

$$T_0 = 25$$

∴ The answer is C.

Revision 3 Q9 (p.86)

DSE goal

Discuss the practical importance of the high specific heat capacity of water.

Video

→ This video demonstrates another example showing the high specific heat capacity of water.

6 Importance of the high specific heat capacity of water

Paper burns when it is put over a flame. If paper is made into a pot for hot pot cooking, as shown in Figure 3.2f, and the paper pot is placed directly on flame, it does not burn.

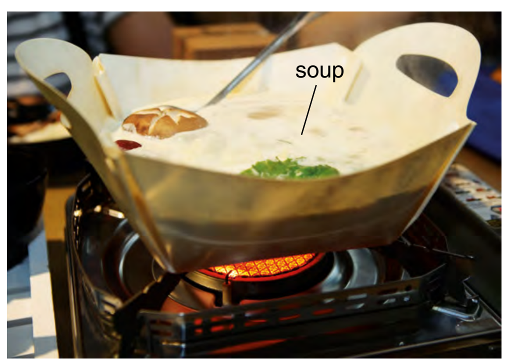


Fig 3.2f *A paper hot pot.*

The paper pot used for hot pot cooking does not burn because the soup held in it contains a lot of water. The water absorbs a large amount of energy from the flame without a sharp increase in temperature. This prevents the paper pot from overheating and thus burning. In fact, compared with other substances, water has a very high specific heat capacity (4200 J kg^{-1} $°C^{-1}$). This means **water can absorb or release a large amount of energy without a great change in temperature**.

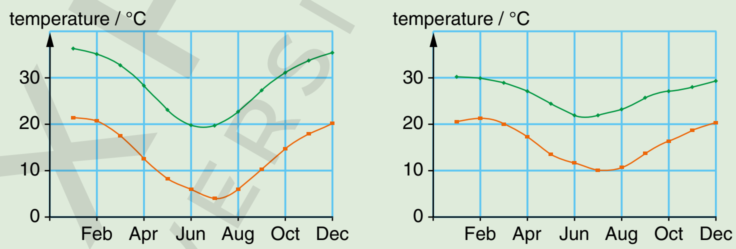
The following are some examples of how this thermal property of water is applied and observed in different areas (Fig 3.2g).

Regulating body temperature

About 60–70% of the mass of a person is made up of water. This helps **keep our body temperature stable** when the temperature of our surroundings changes.

Climate difference between coastal and inland areas

Coastal areas usually have cooler summers and milder winters as well as a much smaller daily temperature difference than inland areas at the same latitude. This is because the temperature of water rises and falls more slowly than that of sand. See Experiment 3g and its result on p.80.

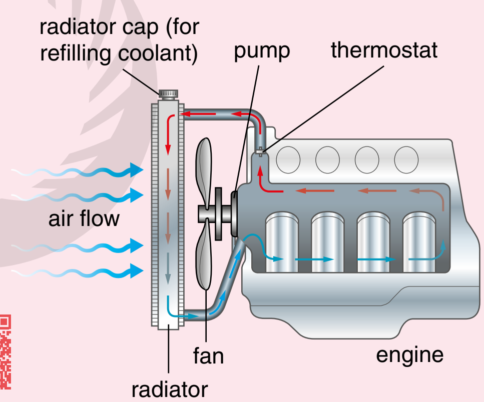


Average monthly highest and lowest temperatures in Alice Springs and Brisbane, an inland city and a coastal city in Australia

Coolant

Water is usually used as a coolant to reduce or regulate the temperature of a system.

In motor cars, water is used to take away energy from a hot engine and carry the energy to the radiator where the energy is released into the air.



An animation about the car engine cooling system:

The water circulated in a water cooling system is used as a coolant to take away energy from the processors of a computer.

reservoir of coolant (water)

Fig 3.2g *Importance of the high specific heat capacity of water.*

Video

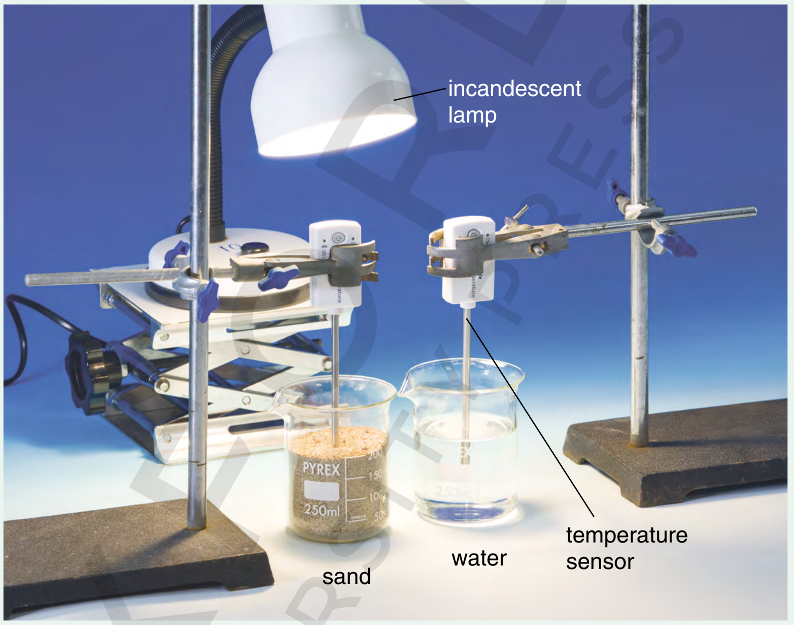
→ This video demonstrates Expt 3g.

Do not touch the hot incandescent lamp.

→ This is a Video Quiz about this experiment.

Experiment 3g The rate of change of water temperature

1 Prepare a beaker of water and a beaker of sand of the same mass, both at room temperature. Place an incandescent lamp directly above the beakers. Record the temperatures of the water and the sand with thermometers or temperature sensors.



2 Remove the lamp. Record how temperatures decrease using water and sand at 40 °C.

Discussion

In which beaker does the temperature change at a higher rate?

According to $Q = mc\Delta T$, for the same amount of energy Q absorbed or released by a certain mass of substance, the change in temperature ΔT is smaller if the specific heat capacity c is larger.

From Experiment 3g, we can see that the temperature of the water rises and falls more slowly than that of the sand (Fig 3.2h).

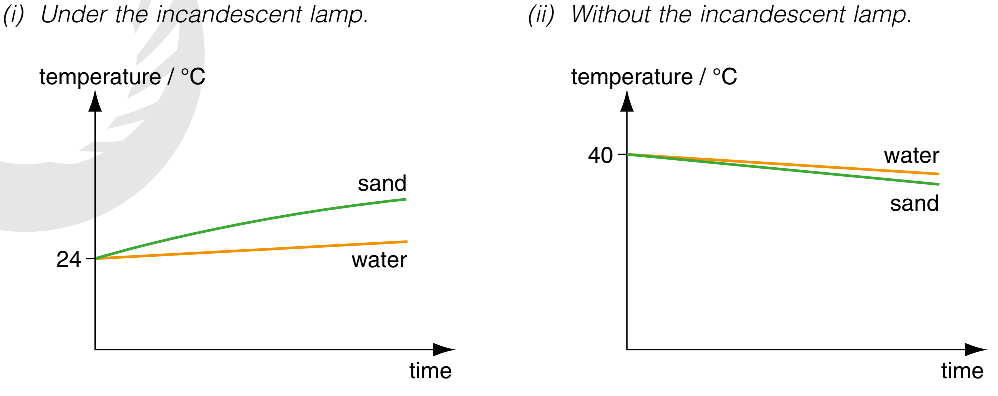


Fig 3.2h The temperature of water changes more slowly than that of sand.

Google Forms

Microsoft Forms

Quick check 5

→ E-version in OUP Exercise Platform is also available.

1 Which of the following is related to the high specific heat capacity of water? Put a tick in the corresponding box(es).

- ☐ In summer, the sand of a beach is much hotter than the seawater during daytime.
- ☐ Dry noodles usually cool faster than soup noodles in a cold winter day (Fig a).

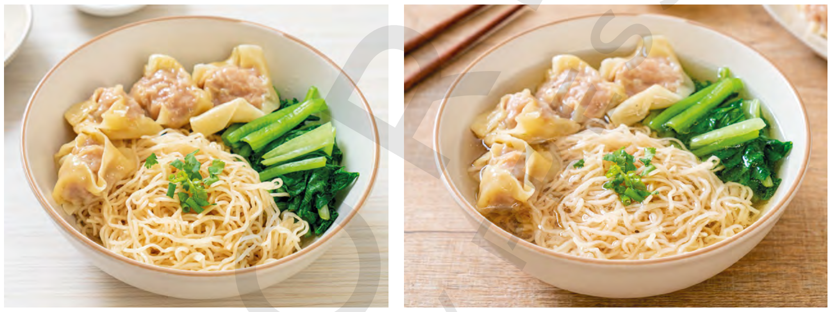


Fig a

2 A map is shown in Figure b. The blue area denotes the sea and the green area denotes the land. P, Q, R and S are four cities of the same latitude and altitude. Which city is most likely to have the largest variation in temperature over a day?

A P B Q

C R D S

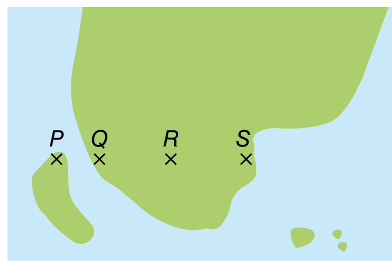


Fig b

STSE

Heat capacity, global warming and the rise of the sea levels

Global warming refers to the continuing trend of rising in the average temperatures of the Earth's surface as the atmosphere traps more and more energy from the Sun. Since the oceans have a much higher heat capacity, they store much more of the trapped energy than land.

Due to their high heat capacity, the temperatures of oceans change slowly. As the oceans heat up, they expand. It may take centuries for the oceans to reach a stable temperature and stop expanding. It is estimated that the expansion of oceans contributes about 42% of the whole contribution to the rise of sea levels.

What will happen to coastal cities if the sea level keeps rising for centuries? How does the warming of oceans impact marine habitats?

Bangladesh is a low-lying country frequently affected by flooding. What are the consequences for the country if the sea level rises significantly due to global warming?

Exercise 3.2

Take c (water) = 4200 J kg^{-1} °C^{-1}

(For Q1–2). In an experiment, four different substances are heated. The following table shows the results (Table a):

	P	***Q***	***R***	***S***
Mass / kg	1	5	3	2
Temperature rise / °C	5	5	10	10
Energy required / J	645	5850	11 540	10 460

Table a

1 Which substance has the highest specific heat capacity?

A *P* B *Q*
C *R* D *S*

2 The four substances are heated for the same period of time using different heaters. Which substance is heated by the heater with the highest power?

A *P* B *Q*
C *R* D *S*

3 Which of the following is/are related to the high specific heat capacity of water?

(1) The filing of a freshly baked apple pie easily burns your tongue but the crust seldom does.
(2) The water in a swimming pool feels warmer in daytime than in night-time.
(3) Water is used in a spacesuit to regulate an astronaut's body temperature.

A (2) only
B (3) only
C (1) and (3) only
D (1), (2) and (3)

★**4** Suppose a 1-kg copper block at 80 °C is put into 1-kg water at 20 °C. Which of the following is most likely the final temperature of the mixture?

A 16 °C B 24 °C
C 50 °C D 75 °C

★**5** A student carries out an experiment to find the specific heat capacity of water. Figure a shows his set-up.

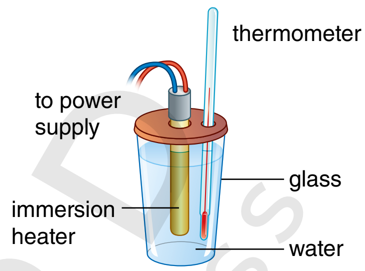


Fig a

Which of the following modifications can increase the accuracy of the experiment?

(1) Stir the water throughout the experiment.
(2) Record the temperature immediately after the heater is switched off.
(3) Add more water into the glass so that the heating part of the heater is totally immersed in water.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

6 Linda makes a cup of milk tea. She pours 50 g of milk at 5 °C into 150 g of tea at 95 °C (Fig b).

Fig b

Assume no energy is lost to the surroundings. What is the final temperature of the milk tea? The specific heat capacities of milk and tea are 3770 J kg^{-1} °C^{-1} and 4200 J kg^{-1} °C^{-1} respectively.

7 In an insulated room, there is 130 kg of air and the specific heat capacity of air is 1000 J kg^{-1} °C^{-1}. A heater in the room heats the air with a power of 1500 W. How long does it take to heat up the air from 20 °C to 28 °C?

★**8** The same amount of energy is transferred to an equal mass of water and copper. Which one has a higher temperature rise, the water or the copper? Explain your answer.

★**9** On a cold day, Ben orders congee and fried bread sticks (Fig c) for his breakfast. Explain whether the congee or the fried bread sticks get cold faster.

Fig c

★**10** A bucket of 5-kg water at 0 °C is mixed with 4-kg flour which is originally at 30 °C in a bakery factory. The mixture was mildly stirred for a few minutes before reaching a stable final temperature at 4 °C.

(a) Calculate the specific heat capacity of the flour. State the assumption in your calculation.

(b) Would the calculated value of the specific heat capacity of the flour be higher or lower than the actual value? Explain your answer.

★**11** A solid is heated in an electric oven. The graph below shows the relationship between the energy transferred Q and the temperature change ΔT of the solid (Fig d).

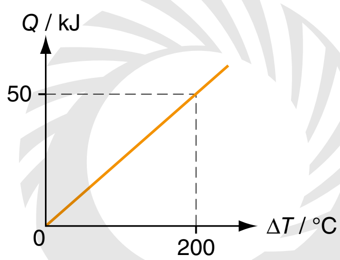


Fig d

(a) Find the heat capacity of this solid.

(b) How will the slope of the graph change if

(i) the mass of the solid decreases?

(ii) the power of the electric oven is set higher?

★**12** A kettle heats up 600 g of water from 10 °C to 70 °C in 1.5 minutes.

(a) Estimate the power of the kettle.

(b) Is the actual power of the kettle higher than, equal to or lower than the answer in (a)? Explain briefly.

★**13** Kim measures the specific heat capacity of copper using the following experiment set-up (Fig e).

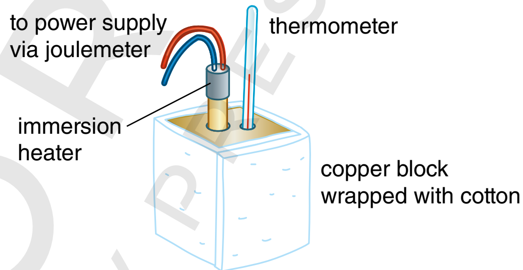


Fig e

The graph below shows the variation in the temperature T of the copper block with the joulemeter reading R (Fig f).

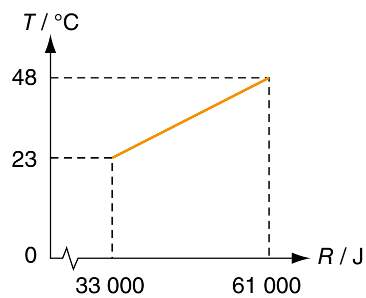


Fig f

(a) The mass of the copper block is 3 kg. Calculate the specific heat capacity of copper.

(b) Kim repeats the experiment by adding a few drops of oil to the holes in the copper block to insert the heater and the thermometer. Explain how this modification affects the result.

Q19 Exam Report: This question was in general well answered.

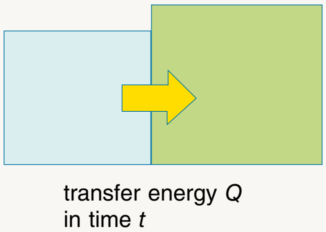
(a) Most candidates were able to calculate the energy released by the water using the equation $E = mc\Delta T$, but less able candidates failed to include the 15% energy lost during the transfer of water.

(b) Most candidates were able to work out the time needed for the water temperature to drop to 60 °C although some did not give their answers in hours as required.

(c) Only the more able candidates gave a satisfactory explanation on why the rate of heat released by the system gradually dropped.

Key concepts 3

1 Power P



- Rate of energy transfer
- $P = \dfrac{Q}{t}$
- Unit: watt (W)

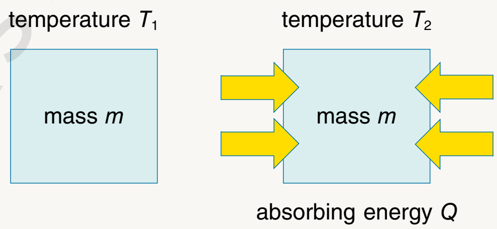
Q20 Exam Report:

(a) Many candidates failed to figure out how to raise the temperature of the sphere to 80 °C by using the water bath given. Some mistook the towel for insulation of the polystyrene cup rather than drying the sphere.

(b) Candidates' performance was satisfactory though some of them failed to point out that the temperature rise of water is lower than it should be.

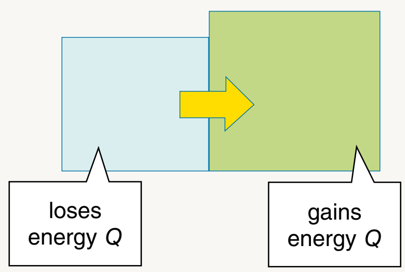
2 Heat capacity and specific heat capacity

- Heat capacity C
  - Energy needed to raise the temperature of a body by 1 °C
  - Unit: J °C^{-1}
- Specific heat capacity c
  - Energy needed to raise the temperature of 1 kg of a substance by 1 °C
  - Unit: J kg^{-1} °C^{-1}
- $Q = C(T_2 - T_1) = C\Delta T = mc\Delta T$
- $c = \dfrac{C}{m}$
- Water has a high specific heat capacity. It is useful in many areas.
  - It helps regulate body temperature.
  - It can be used as a coolant.



3 Conservation of energy

- The total energy in a closed system is conserved. Energy cannot be created or destroyed.



Key terms

Revision 3

Take c (water) = 4200 J kg^{-1} °C^{-1}

Multiple-choice questions

★**1** 3.2 Energy is removed from two hot liquids P and Q at the same rate. The two liquids have the same mass and initial temperature. Figure a shows how their temperatures θ vary with time.

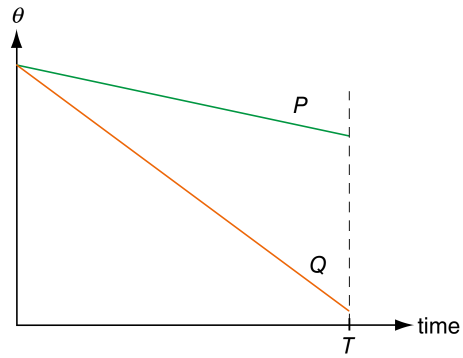


Fig a

Which of the following statements are correct?

(1) The heat capacity of P is larger than that of Q.

(2) The specific heat capacity of P is larger than that of Q.

(3) The average KE of the molecules in P is higher than that in Q at time T.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

★**2** 3.2 The following two glasses of water (Fig b) absorb the same amount of energy. The ratio of the mass of water in glass X to that in glass Y is 3 : 2.

Fig b

What is the ratio of the temperature change of water in glass X to that in glass Y?

A 2 : 3 B 3 : 2
C 1 : 2 D 3 : 1

★**3** 3.2 Karen pours water of mass m_1 at 90 °C into a cup of water of mass m_2 at 20 °C (Fig c). The final temperature of the water is 50 °C. Find $m_1 : m_2$.

Fig c

A 3 : 4 B 4 : 3
C 2 : 9 D 9 : 2

★**4** 3.2 The set-up below is used to measure the specific heat capacity of a liquid (Fig d).

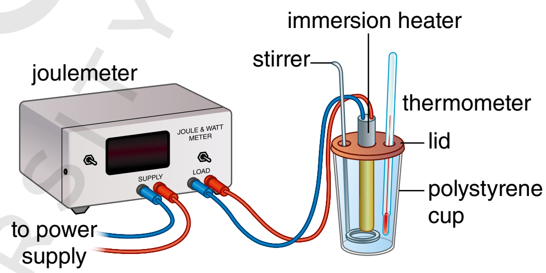


Fig d

Which of the following statements correctly describe(s) the function of the apparatus?

(1) The stirrer is used to make the temperature uniform throughout the liquid.

(2) The lid reduces energy loss to the surroundings.

(3) The joulemeter measures the energy supplied to the liquid.

A (1) only B (1) and (2) only
C (2) and (3) only D (1), (2) and (3)

★**5** 3.2 In an experiment, a hot body of material X is cooled by a fan. Figure e shows how its temperature T changes with time t.

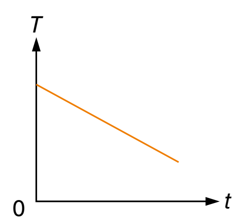
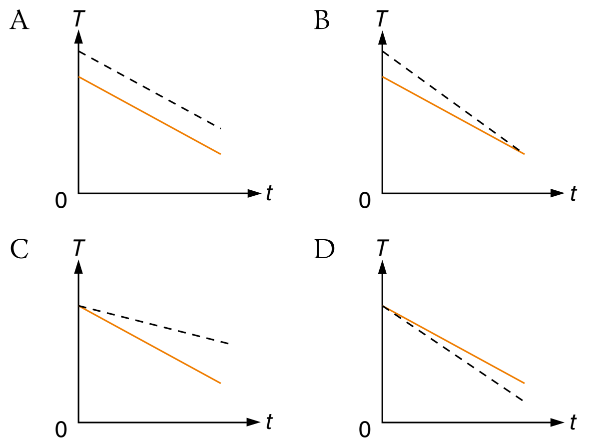


Fig e

Suppose a larger mass of X is cooled so that its energy is lost at the same rate as before. Which of the following graphs denoted by a dotted line best shows the new relationship between T and t?



★**6** 3.2 Figure f shows the variation of the temperature of a liquid with time when the liquid is heated by a 400-W heater. The mass of the liquid is 2 kg. Find the heat capacity of the liquid. Assume all the energy given out by the heater is absorbed by the liquid.

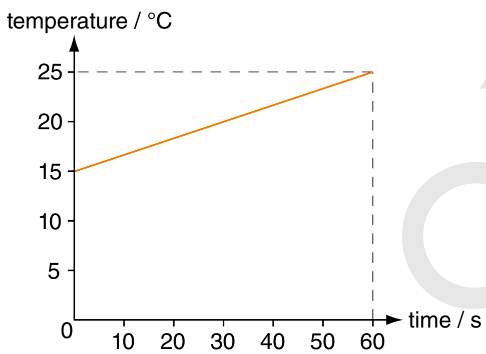


Fig f

A 600 J °C^{-1} B 800 J °C^{-1}
C 1200 J °C^{-1} D 2400 J °C^{-1}

★**7** 3.2 When a metal sphere at a temperature of 100 °C is put into a liquid at a temperature of 20 °C, the final temperature of the liquid is higher than 60 °C. Which of the following must be correct?

A The metal has a higher specific heat capacity than the liquid.

B The sphere has a higher heat capacity than the liquid.

C The sphere has a larger mass than the liquid.

D The energy gained by the liquid is greater than the energy lost by the sphere.

★★**8** 3.2 The specific heat capacity of aluminium is measured using the following set-up (Fig g).

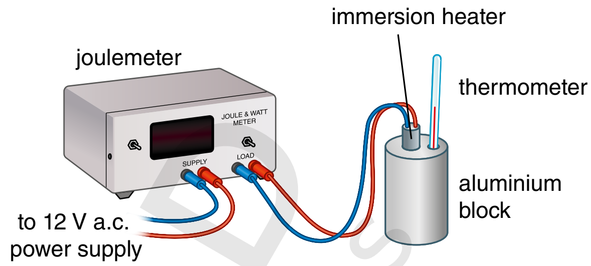


Fig g

The mass and temperature change of the block are m and ΔT respectively. The energy supplied to the heater as measured by the joulemeter is J. Which of the following is true about the actual specific heat capacity c of the aluminium block? (The energy loss to the surroundings **cannot** be ignored.)

A $c > mJ\Delta T$

B $c < \dfrac{J}{m\Delta T}$

C $c > \dfrac{J}{m\Delta T}$

D $c > \dfrac{mJ}{\Delta T}$

Refer p.72

3.2 **9** **HKDSE 2015 Paper 1A Q2**

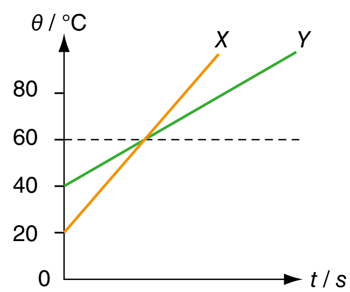


Fig h

Two objects X and Y are made of the same material. They are heated separately by heaters of the same power. The graph shows the variation of temperature θ of X and Y with time t (Fig h). What is the ratio of mass of X to that of Y?

A 3 : 1

B 2 : 1

C 1 : 2 (65%)

D 2 : 3

Conventional questions

★ **10** 3.2 A 3-kg metal block at 100 °C is put into a 5-kg water bath. The temperature of the water bath rises from 27 °C to 31.7 °C.

(a) State the direction of energy flow. (1 mark)

(b) How does the internal energy of the metal block change? (1 mark)

(c) Find the heat capacity of the metal block. (2 marks)

★ **11** 3.2 A 1.2-kg hot iron sphere with a heat capacity of 576 J °C^{-1} is cooled by immersing it fully in a tank of water (Fig i). The mass of the water is 3 kg and its initial temperature is 12 °C. After 5 minutes, both the iron sphere and the water reach a final temperature of 15 °C.

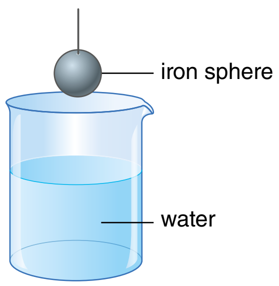


Fig i

(a) Find the energy gained by the water. (2 marks)

(b) Find the average rate of energy transfer from the iron sphere to the water. (2 marks)

(c) Find the initial temperature of the iron sphere. (2 marks)

★ **12** 3.2 (a) State the law of conservation of energy. (1 mark)

(b) A 2-kg steel block at 90 °C and a 5-kg copper block at 70 °C are fully immersed into 9 kg of water at 10 °C. Find the final temperature of the mixture using the law of conservation of energy. Given:

specific heat capacity of steel = 450 J kg^{-1} °C^{-1}

specific heat capacity of copper = 385 J kg^{-1} °C^{-1}

(2 marks)

★ **13** 3.2 Water with initial temperatures of 20 °C and 30 °C flows along water pipe segments *X* and *Y* respectively. The water then mixes together in segment *Z*. The flow rates in *X* and *Y* are 5 kg s^{-1} and 7 kg s^{-1} respectively (Fig j).

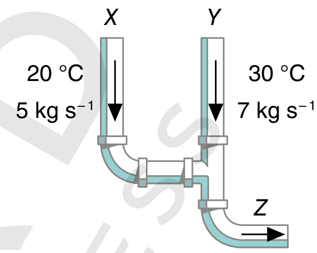


Fig j

(a) Find the temperature of the water in *Z*. (2 marks)

(b) With the initial temperatures and flow rates unchanged, the water in the pipe system is replaced by liquid *W* that has a specific heat capacity of 2500 J kg^{-1} °C^{-1}. How is the result in (a) affected? (1 mark)

★ **14** 3.2 An aluminium block of mass 1.6 kg is placed into a well-insulated container (Fig k). An immersion heater and a thermometer are inserted into the holes in the block. A few drops of oil are added to the holes. An energy of 6000 J is supplied to the aluninium block so that its temperature rises from 25 °C to 29 °C.

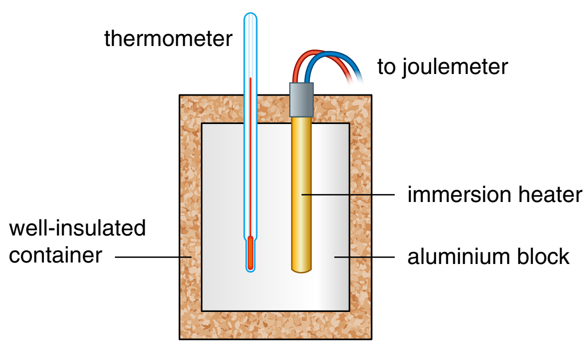


Fig k

(a) Calculate the specific heat capacity of aluminium. (2 marks)

(b) After the heater is switched off, the temperature of the block is not recorded immediately. Explain why. (1 mark)

(c) State a source of error in this experiment. Hence, deduce whether the actual value of the specific heat capacity of aluminium would be the same as, higher than, or lower than the experiment result. (3 marks)

★ **15** Jane uses the experiment set-up in Figure l to measure the specific heat capacity of oil.
3.2

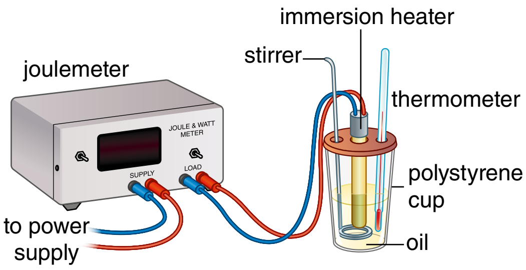


Fig l

She obtains the following results.

Mass of oil = 0.80 kg

Initial joulemeter reading = 0

Final joulemeter reading = 8400 J

Initial temperature = 24.5 °C

Final temperature = 30.5 °C

(a) Calculate the specific heat capacity of oil. (2 marks)

(b) The standard value of the specific heat capacity of oil is 1670 J kg^{-1} $°C^{-1}$.

(i) Explain why the value in (a) is higher than the standard value. (2 marks)

(ii) What is the percentage error of the value in (a)? (2 marks)

(c) State the importance of using a polystyrene cup in the experiment. (1 mark)

(d) Suggest one modification to improve the accuracy of the experiment. (1 mark)

★ **16** Mike puts some fish balls into 800 g of water. The fish-ball-and-water mixture is 20 °C and Mike puts it on a stove to heat it up (Fig m). Take the heat capacity of the fish balls to be 192 J $°C^{-1}$.
3.2

Fig m

(a) If it takes 5 minutes to heat the mixture up to 90 °C, what is the power of the stove? (3 marks)

(b) He then puts some noodles with a temperature of 15 °C into the water. It takes another 1 minute to heat the mixture up to 90 °C using the same setting. What is the heat capacity of the noodles? (2 marks)

★ **17** Janice is given the following apparatus to measure the specific heat capacity of water *c* (Fig n). Describe how Janice should conduct the experiment. Write down how she can obtain the value of *c* by plotting a straight-line graph using data obtained in the experiment. (5 marks)
3.2

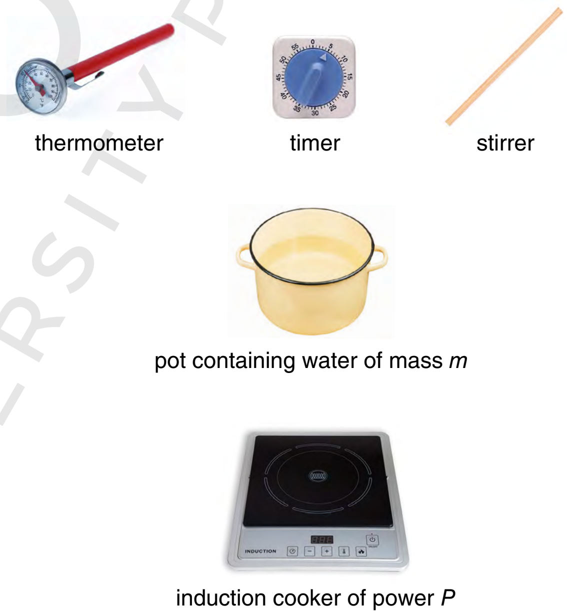


Fig n

★★ **18** Suppose 1 kg of water and 1 kg of iron at the same temperature of 20 °C are put in a refrigerator at 4 °C.
3.2

(a) Describe and explain the change in the average kinetic energy of the water molecules. (2 marks)

(b) Compare the changes in the internal energy of the water and the iron. (2 marks)

(c) 'When there is a power failure, the more water inside the refrigerator, the slower the temperature will increase inside the refrigerator.' Comment on this statement. (3 marks)

▶ Refer p.79

3.2 19 HKDSE 2013 Paper 1B Q1

See p.84 for the Exam Report.

Fig o

A solar water heater (Fig o) is installed on the rooftop of a house. During the day, the heater heats up 1.5 m^3 of water to 80 °C. At night, the hot water in the storage tank is circulated to the radiators (Fig p) in different rooms of the house to keep the rooms warm.

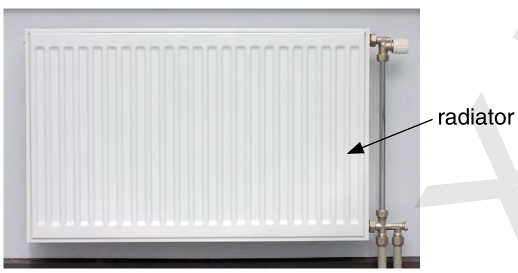


Fig p

Given: density of water = 1000 kg m^{-3},

specific hear capacity of water = 4200 J kg^{-1} °C^{-1}

(a) Given that 15% of the energy is lost during the transfer of water, how much heat can be released from the system to the rooms when the water temperature drops to 60 °C? (3 marks)

(b) Given that during night time the radiators maintain an average output power of 4.5 kW, how long can the radiators maintain this average power until the water temperature in the system drops to 60 °C? Give your answer in hours. (2 marks)

(c) The rate of heat released by the solar water heating system during the time period calculated in (b) is in fact not constant and gradually drops. Explain why this is so. (1 mark)

3.2 20 HKDSE 2016 Paper 1B Q1

See p.84 for the Exam Report.

The following experimental items are provided for estimating the specific heat capacity of bronze c_b:

- a bronze sphere of mass 0.80 kg hung with a thread at room temperature T_0
- a polystyrene cup containing 0.50 kg of water at room temperature T_0
- a water bath maintained at 80 °C
- a thermometer
- a stirrer
- a towel

(a) Describe the procedures of the experiment and state **two** experimental precautions to be taken. Write down an equation for finding c_b. (6 marks)

(b) The value of c_b found in the experiment in (a) is lower than the actual value. Explain. (2 marks)

21 Misc HKDSE 2017 Paper 1B Q1

See p.90 for the Exam Report.

Read the following passage about **soil thermometer** and answer the questions that follow.

> The temperature of soil changes with depth, and this information is important to farmers and scientists. To measure soil temperatures at depths close to the ground surface, the bulb of a thermometer is buried in the soil. The stem of the thermometer is bent 90° for easy reading. Figure q(i) is a schematic diagram and Figure q(ii) shows a photo of a soil thermometer.

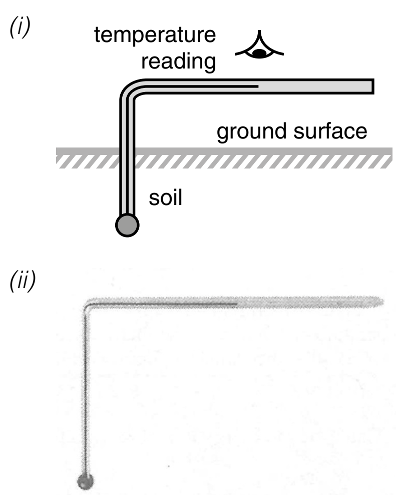


Fig q

For depths greater than 30 cm, a steel pipe is driven into the soil (Fig r(i)); and a liquid-in-glass thermometer with a protective glass case is lowered into the steel pipe (Fig r(ii)). The bulb of the thermometer is embedded in paraffin wax (Fig r(iii)). To read the temperature, the thermometer is lifted out of the steel pipe by pulling the chain.

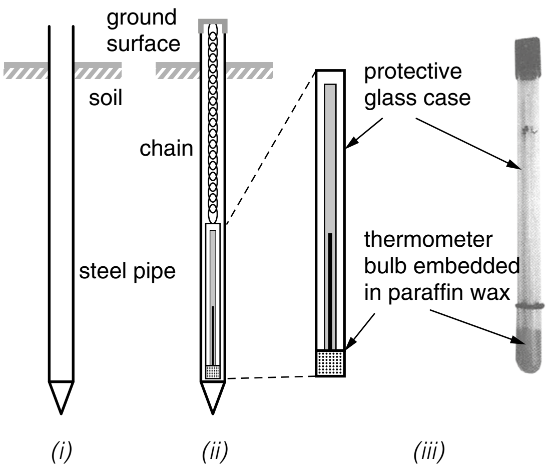


Fig r

(a) As shown in Figure q(ii), the bulb of the soil thermometer is very large compared to those of common thermometers. Suggest a reason for this design. (1 mark)

(b) On a certain morning, the air temperature is 15 °C. An observer takes a measurement of the soil temperature at 1 m deep. The thermometer reading is 20 °C. It is given that the mass of the paraffin wax enclosing the thermometer bulb is 0.015 kg, and the specific heat capacity of paraffin wax is 2.9×10^3 J kg^{-1} °C^{-1}.

(i) Calculate the energy loss of the paraffin wax as it cools down to the air temperature. (2 marks)

(ii) It is known that the paraffin wax enclosing the bulb of the thermometer gains or loses energy at a constant rate of 0.5 J s^{-1}, estimate the time taken for the paraffin wax to reach the air temperature after the thermometer is lifted out of the soil. (2 marks)

(iii) If there is no paraffin wax enclosing the bulb of the thermometer, explain how the thermometer reading as recorded by the observer is affected. (2 marks)

Q21 Exam Report: This question was based on a passage describing the use of soil thermometers. The situation was unfamiliar to most candidates and the general performance was unsatisfactory.

(a) Few were able to state that a larger bulb of such a thermometer would improve its sensitivity.

(b) Most candidates did well in parts (i) and (ii). However, very few gave a concise explanation of the function of paraffin was in (iii).

3.2 **22 HKDSE 2020 Paper 1B Q1**

In a restaurant, 'wontons in soup' is prepared by putting 5 pieces of cooked wonton at 4 °C into a bowl with 0.06 kg of soup at temperature 96 °C.

Given:

average mass of each piece of wonton = 0.02 kg

specific heat capacity of wonton = 3300 J kg^{-1} °C^{-1}

specific heat capacity of soup = 4200 J kg^{-1} °C^{-1}

(a) Find the final temperature of the mixture. Assume that the heat capacity of the bowl and the heat loss to the surroundings are negligible. (2 marks)

(b) The soup in (a) is taken from a metallic container of heat capacity 2000 J °C^{-1} containing 16 kg of soup maintained at 96 °C by an immersion heater.

(i) Why does that energy have to be supplied by the heater to keep the soup at 96 °C? (1 mark)

(ii) A student used the following method to find the heater's operating power P: remove the heater from the container and record the temperature of the 16 kg of soup after 10 minutes. It is found that the temperature has dropped 9 °C. Estimate P. (3 marks)

(iii) If the student repeats the measurement after another 10 minutes, would the corresponding temperature drop be larger than, equal to or smaller than 9 °C? Explain. (2 marks)

Q22 Exam Report: This question examined candidates' knowledge and understanding of heat transfer. It was generally well answered.

(a) Most candidates obtained the correct answer.

(b) (i) Candidates' performance was good though a few misunderstood the question and tried to explain 'why the soup should be kept at 96 °C'.

(ii) Many omitted the contribution of the container in the calculation. Some candidates mistook the temperature drop (9 °C) as the final temperature.

(iii) Most candidates did well. A few wrongly assumed that the temperature drop would remain the same despite the temperature difference becoming smaller.