Chapter 10
Thermal physics

Worksheet

Worked examples

Practical: Estimating the temperature of a metal object heated in the flame of a Bunsen burner

End-of-chapter test

Marking scheme: Worksheet

Marking scheme: End-of-chapter test

Worksheet

specific heat capacity of water = $4200\,\mathrm{J\,kg^{-1}\,K^{-1}}$

Intermediate level

1 Describe the arrangement of atoms, the forces between the atoms and the motion of the atoms in:

a a solid; [3]

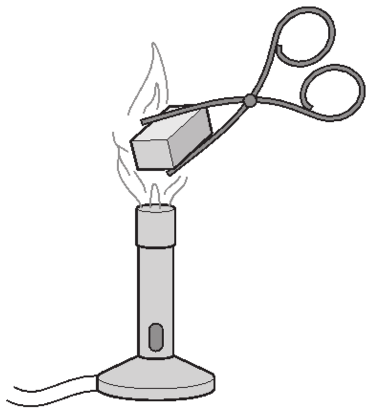
b a liquid; [3]

c a gas. [3]

2 A small amount of gas is trapped inside a container. Describe the motion of the gas atoms as the temperature of the gas within the container in increased. [3]

3 **a** Define the **internal energy** of a substance. [1]

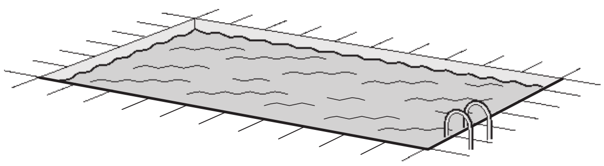
b The temperature of an aluminium block increases when it is placed in the flame of a Bunsen burner. Explain why this causes an increase in its internal energy. [3]



c An ice cube is melting at a temperature of 0 °C. Explain whether its internal energy is increasing or decreasing as it melts at 0°C. [4]

4 Write a word equation for the change in the thermal energy of a substance in terms of its mass, the specific heat capacity of the substance and its change of temperature. [1]

5 During a hot summer's day, the temperature of $6.0 \quad 10^5$ kg of water in a swimming pool increases from 21 °C to 24 °C. Calculate the change in the internal energy of the water. [3]



6 A 300 g block of iron cools from 300 °C to room temperature at 20 °C. The specific heat capacity of iron is $490\,\mathrm{kg^{-1}\,K^{-1}}$. Calculate the heat released by the block of iron. [3]

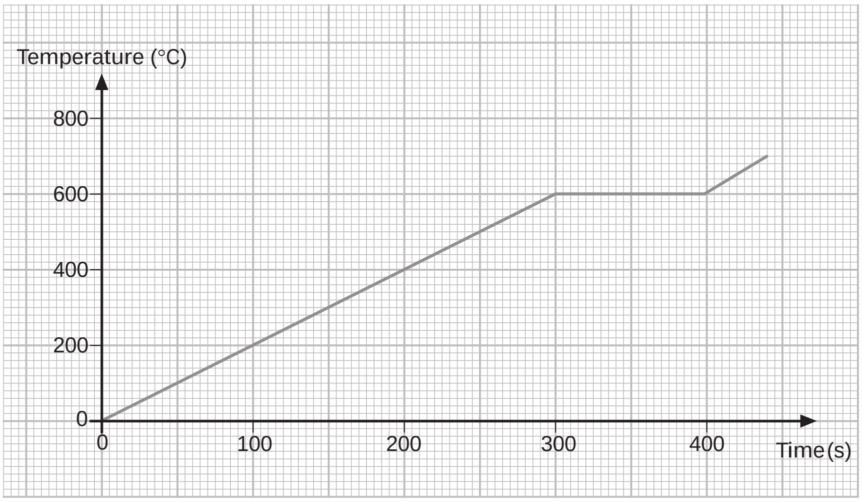
Higher level

7 An electrical heater is used to heat 100 g of water in a well-insulated container at a steady rate. The temperature of the water increases by 15 °C when the heater is operated for a period of 5.0 minutes. Determine the change of temperature of the water when the same heater and container are individually used to heat:

a 300 g of water for the same period of time; [3]

b 100 g of water for a time of 2.5 minutes. [3]

8 The diagram below shows the variation of the temperature of 200 g of lead as it is heated at a steady rate.



a Use the graph to state the melting point of lead. [1]

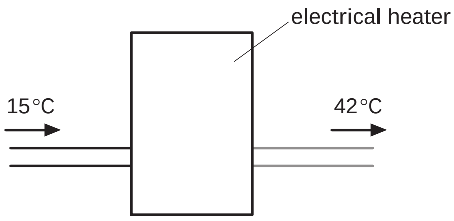
b Explain why the graph is a straight line at the start. [1]

c Explain what happens to the energy supplied to the lead as it melts at a constant temperature. [1]

d The initial temperature of the lead is 0 °C. Use the graph to determine the total energy supplied to the lead before it starts to melts. [3]
(The specific heat capacity of lead is $130\,\mathrm{J\,kg^{-1}\,K^{-1}}$.)

e Use your answer to **d** to determine the rate of heating of the lead. [2]

9 The diagram shows piped water being heated by an electrical heater.

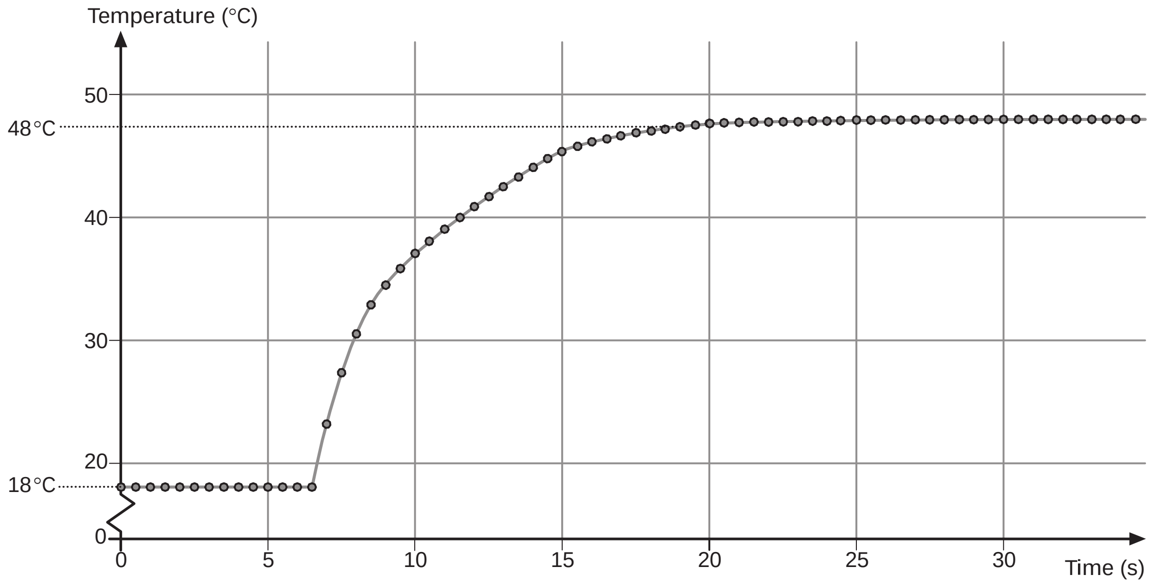


The water flows through the heater at a rate of $0.015\,\mathrm{kg\,s^{-1}}$. The heater warms the water from 15 °C to 42 °C. Assuming that all the energy from the heater is transferred to heating the water, calculate the power of the heater. [5]

Extension

10 Hot water of mass 300 g and at a temperature of 90 °C is added to 200 g of cold water at 10 °C. What is the final temperature of the mixture? You may assume there are no losses to the environment and all heat transfer takes place between the hot water and the cold water. [5]

11 A metal cube of mass 75 g is heated in a naked flame until it is red hot. The metal block is quickly transferred to 200 g of cold water. The water is well stirred. The graph shows the variation of the temperature of the water recorded by a datalogger during the experiment.



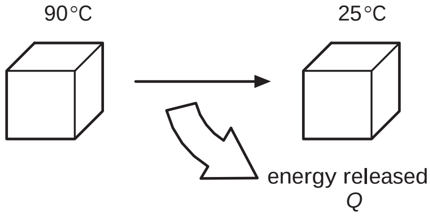
The metal has a specific heat capacity of 500 J kg^{-1} K^{-1}. Use the additional information provided in the graph to determine the initial temperature of the metal cube. You may assume there are no losses to the environment and all heat transfer takes place between the metal block and the water. [5]

Total: $\frac{\quad}{56}$ Score: %

Worked examples

Example 1

A piece of brass of mass 80 g cools from 90 °C to 25 °C over a period of 5 minutes. Calculate the energy released by the metal and the average power it dissipates. The specific heat capacity of brass is 380 J kg^{-1} K^{-1}.



The energy released, Q, is given by:

$Q = mc$

where m is the mass, c is the specific heat capacity and is the change in the temperature. In our case, we have:

$m = 0.080$ kg $\quad c = 380$ J kg^{-1} K^{-1} $\quad = 25 - 90 = -65$ °C

The temperature of the metal decreases, therefore it releases energy.

energy released $= -mc \quad = 0.080 \quad 380 \quad 65$

energy released $= -1.98 \quad 10^3$ J $\quad -2.0$ kJ

The average power dissipated by the metal is given by:

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

Hence:

$$P = \frac{1.98 \quad 10^3}{5.0 \quad 60} \quad 6.6\ \text{W}$$

Example 2

A small electrical heater is used to heat water. The heater has a power rating of 30 W and the water passes through the heater at a rate of 1.5 10^{-3} kg s^{-1}. The temperature of the water entering the heater is 20 °C. Determine the temperature of the water leaving the heater. You may assume that all the energy of the heater is used to warm the water. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

In a period of 1.0 s, 30 J of energy is supplied to water of mass 1.5 10^{-3} kg.

A power of 30 W means 30 J of energy is released every second.

Therefore for a period of 1.0 s, we have:

$Q = 30$ J $\quad m = 1.5 \quad 10^{-3}$ kg $\quad c = 4200$ J kg^{-1} K^{-1} $\quad = ?$

$Q = mc$

$$= \frac{Q}{mc} = \frac{30}{1.5 \quad 10^{-3} \quad 4200} \quad 4.8\ °\text{C}$$

The change in the temperature of the water is 4.8 °C. Therefore the final temperature of the water emerging from the heater is:

final temperature $= 20 + 4.8 = 24.8$ °C

Tip

Since power P is equal to the rate of change of energy, we have:

$$P = \frac{mc}{t} = \left(\frac{m}{t}\right) c$$

You can use this equation to determine the change in temperature of the water directly, rather than considering a time interval of 1.0 s.

Practical

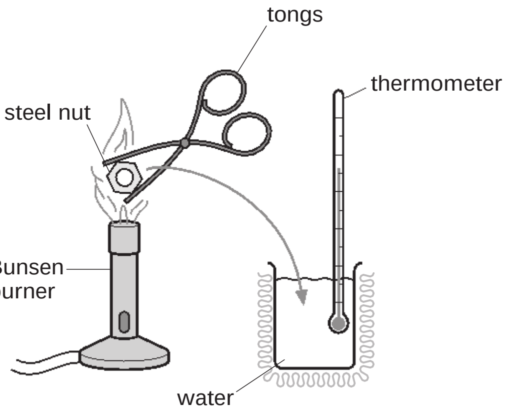
Estimating the temperature of a metal object heated in the flame of a Bunsen burner

Safety

Transfer the hot steel nut carefully into the cold water. It is advisable to have some eye protection in order to minimise the hazards from any hot splashing water or hot steam when the steel nut is transferred to the water. Teachers and technicians should follow their school and departmental safety policies and should ensure that the employer's risk assessment has been carried out before undertaking any practical work.

Apparatus

- Bunsen burner
- tongs
- large steel nut
- 100 ml beaker (insulated)
- thermometer
- digital scales
- eye protection
- computer with temperature sensor (optional)



Introduction

Specific heat capacity is discussed on page 106 of *Physics 2*. In this experiment you will estimate the temperature of a piece of metal heated in the flame of a Bunsen burner.

Procedure

1. Measure the mass of the empty beaker.
2. Fill the beaker with about 90 ml of water and measure its mass.
3. Determine the mass m_w of the water in the beaker.
4. Measure the mass m_s of the steel nut.
5. Measure the initial temperature of the water in the beaker.
6. Carefully heat the steel nut in the flame of the Bunsen burner by holding it with a pair of tongs.
7. Keep heating the steel nut until it starts to glow orange-red.
8. Quickly, but carefully, transfer the hot steel nut into the water.
9. Stir the water and measure the maximum final temperature of the water.
10. The specific heat capacity c_w of water is $4200\,\mathrm{J\,kg^{-1}\,K^{-1}}$. Using $Q = m_w c_w$, determine Q, the heat gained by the water.
11. Assuming all the thermal energy from the heated steel nut is transferred to the water, determine the change in temperature of the steel nut using the equation:

$$= \frac{Q}{m_s c_s}$$

The specific heat capacity c_s of steel is $420\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

12 Determine the initial temperature of the steel nut when it was transferred to the water.

13 What are the sources of errors in this experiment?

14 Use the Internet to find the typical temperature of a flame from a Bunsen burner. How reliable is your value for the initial temperature of the block?

Guidance for teachers

This experiment may be done as a teacher demonstration or a class experiment. If done as a demonstration, the temperature of the water may be monitored on a computer using a temperature sensor. The initial and final temperatures of the water may be read off the graph produced by the computer.

End-of-chapter test

Answer all questions.

1 **a** A glass of water is placed in direct sunlight during a hot summer's day. The temperature of the water increases.

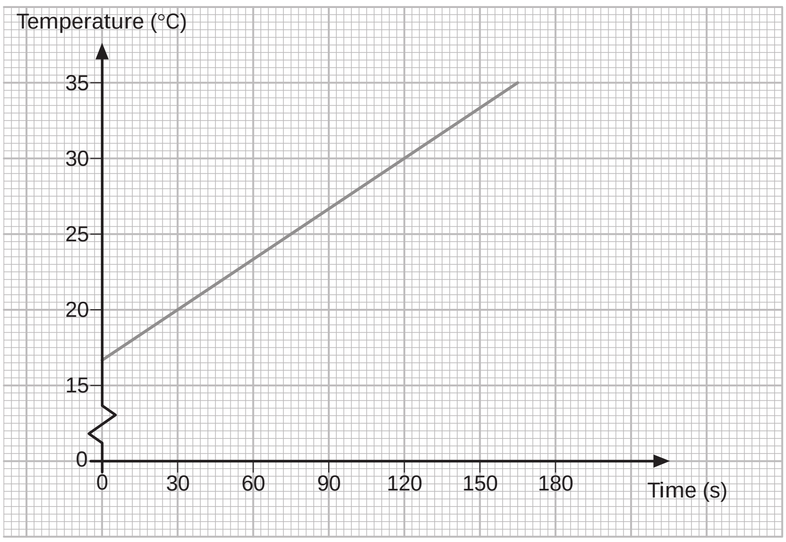
i Describe the change in the motion of the molecules of water. [1]

ii Explain whether or not there is a change in the internal energy of the water. [3]

b Complete the table below for each of the processes shown. Use the symbol '+' for an increase, the symbol '–' for a decrease and '0' for no change, as appropriate. [3]

	Kinetic energy of the particles	**Potential energy of the particles**	**Internal energy**
An aluminium block increasing its temperature from room temperature to 300 °C.			
Water boiling at 100 °C and changing into steam at 100 °C.			
Water at 0 °C changing into ice at –15 °C.			

2 The graph shows the variation of temperature of a metal block of mass 800 g when heated by an electrical heater.

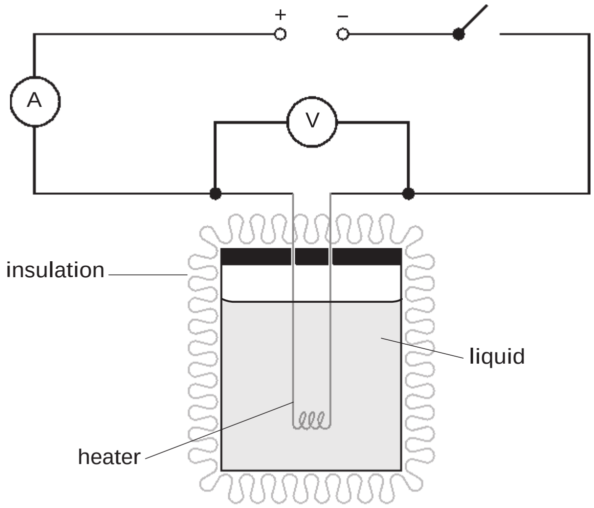


a Explain how the graph confirms that the metal block is being heated at a constant rate. [1]

b Determine the energy supplied by the heater to increase the temperature of the metal block from 20 °C to 30 °C. [3]
(The specific heat capacity of the metal is 600 J kg^{-1} K^{-1}.)

c Use the graph to determine the power rating of the electrical heater. [3]

3 A student sets up an experiment to determine the specific heat capacity of a liquid held in a well-insulated container.



The mass of the liquid is 240 g and its initial temperature is 23 °C. When the switch is closed, the current recorded by the ammeter is 5.2 A and the voltmeter reading is 9.5 V. After a time of 5.0 minutes, the temperature of the liquid increases to 54 °C. Use this information to determine the specific heat capacity of the liquid. [5]

Total: $\overline{19}$ Score: %

Marking scheme

Worksheet

1 **a** The atoms in a solid are arranged in a three-dimensional structure. [1]

There are strong attractive forces between the atoms. [1]

The atoms vibrate about their equilibrium positions. [1]

b The atoms in a liquid are more disordered than those in a solid. [1]

There are still attractive electrical forces between the atoms but these are weaker than those for similar atoms in a solid. [1]

The atoms in a liquid are free to move around and have kinetic energy. [1]

c The atoms in a gas move around randomly. [1]

There are virtually no forces between the atoms because they are further apart than similar atoms in a liquid. [1]

The atoms of a gas move at high speeds (but no faster than those in a liquid at the same temperature). [1]

2 The atoms move faster [1]

because their kinetic energy increases as the temperature is increased. [1]

The atoms still have a random motion. [1]

3 **a** The internal energy of a substance is the sum (of the random distribution) of the kinetic and potential energies of its particles (atoms or molecules). [1]

b There is an increase in the average kinetic energy of the aluminium atoms as they vibrate with larger amplitudes about their equilibrium positions. [1]

The potential energy remains the same because the mean separation between the atoms does not change significantly. [1]

Hence, the internal energy increases because there is an increase in the kinetic energy of the atoms. [1]

c As the ice melts, the mean separation between the atoms increases. [1]

The increase in separation between the molecules increases the potential energy of the molecules. [1]

There is no change in the kinetic energy of the molecules because the temperature remains the same. [1]

The internal energy of the molecules increases because there is an increase in the potential energy of the molecules. [1]

4 Change in thermal energy
= mass   specific heat capacity   change in temperature [1]

5 $Q = mc$ [1]

$Q = 6.0 \quad 10^{5} \quad 4200 \quad (24 - 21)$ [1]

$Q = 7.56 \quad 10^{9}$ J $7.6 \quad 10^{9}$ J [1]

6 $Q = mc$ [1]

$Q = 300 \quad 10^{-3} \quad 490 \quad (20 - 300)$ [1]

$Q = -4.1 \quad 10^{4}$ J (The minus sign implies energy is released by the cooling metal.) [1]

7 **a** The thermal energy supplied Q and the specific heat capacity c remain constant. The mass m is larger by a factor of 3. [1]

Since $Q = mc$, we have:

$$= \frac{Q}{mc}; \qquad \propto = \frac{1}{m} \quad [1]$$

Increasing the mass by a factor of 3 decreases the change in temperature by a factor of 3.

Therefore $= \frac{15}{3} = 5.0\,°\text{C}$ [1]

b The thermal energy supplied Q is halved but the specific heat capacity c and the mass m remain constant. [1]

Since $Q = mc$, we have:

$$= \frac{Q}{mc}; \qquad \propto \quad Q \quad [1]$$

The change in temperature will halve because the energy supplied is halved.

Therefore $= \frac{15}{2} = 7.5\,°\text{C}$ [1]

8 **a** Melting point = 600 °C [1] (There is no change in temperature during change of state.)

b The lead is being heated at a steady rate and therefore the temperature also increases at a steady rate. [1]

c The energy supplied to the lead is used to break the atomic bonds and increase the separation between the atoms of lead (and hence their potential energy increases). [1]

d $Q = mc$ [1]; $Q = 200 \quad 10^{-3} \quad 130 \quad (600 - 0)$ [1]

$Q = 1.56 \quad 10^{4}\,\text{J} \quad 1.6 \quad 10^{4}\,\text{J}$ [1]

e In a time of 300 s, $1.56 \quad 10^{4}$ J of energy is supplied to the lead.

Rate of heating = power

$$\text{power} = \frac{1.56 \quad 10^{4}}{300} \quad [1]; \qquad \text{power} = 52\,\text{W} \quad [1]$$

9 The energy supplied per second is equal to the power of the heater.

In a time of 1 s, water of mass 0.015 kg has its temperature changed from 15 °C to 42 °C. [1]

$Q = mc$ (where Q is the energy supplied in 1 s) [1]

$Q = 0.015 \quad 4200 \quad (42 - 15)$ [1]

$Q = 1.7 \quad 10^{3}\,\text{J}$ [1]

The power of the heater is therefore 1.7 kW. [1]

(You may use $P = \left(\frac{m}{t}\right)c$ – see Worked example 2 on page 117.)

10 Heat ‘lost’ by hot water = heat ‘gained’ by cold water [1]

$0.3 \quad c \quad (90 - \quad) = 0.2 \quad c \quad (\quad - 10)$ [1]

where c is the specific heat capacity of the water and is the final temperature.

The actual value of c is not required, since it cancels on both sides of the equation.

Hence:

$0.3 \quad (90 - \quad) = 0.2 \quad (\quad - 10)$ [1]

$27 - 0.3 \quad = 0.2 \quad - 2.0$ [1]

$0.5 \quad = 29$ so $\quad = 58\,°\mathrm{C}$ [1]

11 Heat ‘lost’ by metal = heat ‘gained’ by cold water [1]

$0.075 \quad 500 \quad (\quad - 48) = 0.2 \quad 4200 \quad (48 - 18)$ [1]

(is the initial temperature of the metal.)

$$- 48 = \frac{0.2 \quad 4200 \quad 30}{0.075 \quad 500}$$ [1]

$- 48 = 672$ [1]; $\quad = 720\,°\mathrm{C}$ [1]

Marking scheme

End-of-chapter test

1 **a** **i** The molecules of water move faster. [1]

ii Internal energy = kinetic energy + potential energy

The kinetic energy of the molecules increases because they move faster. [1]

The potential energy remains constant because the separation between the molecules remains the same. [1]

Hence, the internal energy increases due to increase in the kinetic energy of the molecules. [1]

b

	Kinetic energy of the particles	**Potential energy of the particles**	**Internal energy**
An aluminium block increasing its temperature from room temperature to 300 °C.	+	0	+
Water boiling at 100 °C and changing into steam at 100 °C.	0	+	+
Water at 0 °C changing into ice at –15 °C.	–	–	–

One mark for each correct row. [3]

2 **a** The temperature of the metal increases at a steady rate, therefore it must be heated at a steady rate. [1]

b $Q = mc$ [1]

$Q = 800 \quad 10^{-3} \quad 600 \quad (30 - 20)$ [1]

$Q = 4.8 \quad 10^{3}\,\text{J}$ [1]

c From the graph it takes 90 s for the temperature to change from 20 °C to 30 °C. [1]

$$\text{power} = \frac{4.8 \quad 10^{3}}{90}$$ [1]

power = 53.3 W   53 W [1]

3 $Q = (VI)t$ [1]

$Q = 9.5 \quad 5.2 \quad (5.0 \quad 60) = 1.48 \quad 10^{4}\,\text{J}$ [1]

$Q = mc$ [1]

$$c = \frac{Q}{m} = \frac{1.48 \quad 10^{4}}{0.240 \quad (54 - 23)}$$ [1]

$c \quad 2.0 \quad 10^{3}\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$ [1]