A thermometer has a thermal capacity of 1.3 J K\(^{-1}\). The initial temperature of the thermometer is 20°C. When used to measure the temperature of 40 g of water, it measures 37°C.

(a) Determine the energy absorbed by the thermometer when it is placed in the water.

(b) Calculate the temperature change of the water as a result of introducing the thermometer.

\[ \text{specific heat capacity of water} = 4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1} \]

(Total 4 marks)

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(Total 4 marks)

(2)

(b) Explain why it is more effective to cool cans of drinks by placing them in a bucket full of melting ice rather than in a bucket of water at an initial temperature of 0 °C.

(Total 6 marks)
Molten lead at its melting temperature of 327°C is poured into an iron mould where it solidifies. The temperature of the iron mould rises from 27°C to 84°C, at which the mould is in thermal equilibrium with the now solid lead.

mass of lead = 1.20 kg
specific latent heat of fusion of lead = $2.5 \times 10^4$ J kg$^{-1}$
mass of iron mould = 3.00 kg
specific heat capacity of iron = 440 J kg$^{-1}$ K$^{-1}$

(a) Calculate the heat energy absorbed by the iron mould.

answer = ______________________ J

(2)

(b) Calculate the heat energy given out by the lead while it is changing state.

answer = ______________________ J

(1)

(c) Calculate the specific heat capacity of lead.

answer = ______________________ J kg$^{-1}$ K$^{-1}$

(3)
An electrical immersion heater supplies 8.5 kJ of energy every second. Water flows through the heater at a rate of 0.12 kg s\(^{-1}\) as shown in the figure below.

(a) Assuming all the energy is transferred to the water, calculate the rise in temperature of the water as it flows through the heater.

specific heat capacity of water = 4200 J kg\(^{-1}\) K\(^{-1}\)

\[
\text{answer} = \underline{____________________} \text{ K}
\]
(b) The water suddenly stops flowing at the instant when its average temperature is 26 °C. The mass of water trapped in the heater is 0.41 kg. Calculate the time taken for the water to reach 100 °C if the immersion heater continues supplying energy at the same rate.

\[
\text{answer} = \text{______________________________ s} \quad \text{(2)}
\]

(Total 4 marks)

5 The mass of a car and its passengers is 950 kg. When the brakes are applied the car decelerates uniformly from a speed of 25 m s\(^{-1}\) to a speed of 15 m s\(^{-1}\) in 2.5 s.

(a) Calculate the decelerating force developed by the brakes.

\[ \text{(2)} \]

(b) Calculate the work done in decelerating the car.

\[ \text{(3)} \]

(c) Calculate the rate of energy dissipation by the brakes.

\[ \text{(2)} \]

(d) There are four brake discs, each of mass 1.2 kg. The material from which the discs are made has a specific heat capacity of 510 J kg\(^{-1}\) K\(^{-1}\).

(i) Assuming that all the energy dissipated during braking is converted into internal energy of the brake discs equally, calculate the temperature rise of the discs.

\[ \text{(3)} \]

(ii) State and explain the effect on the temperature rise of one factor that has not been taken into account in the assumption in part (i).

\[ \text{____________________________________________________________} \]
\[ \text{____________________________________________________________} \]
\[ \text{____________________________________________________________} \]
\[ \text{____________________________________________________________} \]

\[ \text{(2)} \]

(Total 12 marks)

6 Use the following data to answer the question below.

specific latent heat of fusion of lead = 23 kJ kg\(^{-1}\)
molar mass of lead = 0.21 kg mol\(^{-1}\)
(a) Estimate the mass of a lead atom.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(b) Estimate the energy supplied to an atom of lead when solid lead melts.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(c) Calculate the speed of a lead atom with the same kinetic energy as the energy supplied in part (b).

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(Total 5 marks)

A female runner of mass 60 kg generates thermal energy at a rate of 800 W.

(a) Assuming that she loses no energy to the surroundings and that the average specific heat capacity of her body is 3900 J kg\(^{-1}\)K\(^{-1}\), calculate

(i) the thermal energy generated in one minute,

___________________________________________________________________
___________________________________________________________________

(ii) the temperature rise of her body in one minute.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(3)
(b) In practice it is desirable for a runner to maintain a constant temperature. This may be achieved partly by the evaporation of sweat. The runner in part (a) loses energy at a rate of 500 W by this process.

Calculate the mass of sweat evaporated in one minute.

specific latent heat of vaporisation of water = $2.3 \times 10^6$ J kg$^{-1}$

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(3)

(c) Explain why, when she stops running, her temperature is likely to fall.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(2)

(Total 8 marks)

In an experiment to measure the temperature of the flame of a Bunsen burner, a lump of copper of mass 0.12 kg is heated in the flame for several minutes. The copper is then transferred quickly to a beaker, of negligible heat capacity, containing 0.45 kg of water, and the temperature rise of the water measured.

specific heat capacity of water = $4200$ J kg$^{-1}$ K$^{-1}$
specific heat capacity of copper = $390$ J kg$^{-1}$ K$^{-1}$

(a) If the temperature of the water rises from 15 °C to 35 °C, calculate the thermal energy gained by the water.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(2)

(b) (i) State the thermal energy lost by the copper, assuming no heat is lost during its transfer.
(ii) Calculate the fall in temperature of the copper.

(iii) Hence calculate the temperature reached by the copper while in the flame.

A cola drink of mass 0.200 kg at a temperature of 3.0 °C is poured into a glass beaker. The beaker has a mass of 0.250 kg and is initially at a temperature of 30.0 °C.

specific heat capacity of glass = 840 J kg\(^{-1}\)K\(^{-1}\)

specific heat capacity of cola = 4190 J kg\(^{-1}\)K\(^{-1}\)

(i) Show that the final temperature, \(T_f\), of the cola drink is about 8 °C when it reaches thermal equilibrium with the beaker.
Assume no heat is gained from or lost to the surroundings.
(ii) The cola drink and beaker are cooled from $T_f$ to a temperature of 3.0 °C by adding ice at a temperature of 0 °C.
Calculate the mass of ice added.
Assume no heat is gained from or lost to the surroundings.

specific heat capacity of water $= 4190 \, \text{J kg}^{-1} \, \text{K}^{-1}$
specific latent heat of fusion of ice $= 3.34 \times 10^5 \, \text{J kg}^{-1}$

mass ____________________ kg

(Total 5 marks)

(a) Lead has a specific heat capacity of $130 \, \text{J kg}^{-1} \, \text{K}^{-1}$.

Explain what is meant by this statement.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(1)
(b) Lead of mass 0.75 kg is heated from 21 °C to its melting point and continues to be heated until it has all melted.

Calculate how much energy is supplied to the lead.
Give your answer to an appropriate number of significant figures.

melting point of lead = 327.5 °C  
specific latent heat of fusion of lead = 23 000 J kg$^{-1}$

energy supplied ____________________ J  
(3)  
(Total 4 marks)

(a) ‘The pressure of an ideal gas is inversely proportional to its volume’, is an incomplete statement of Boyle’s law. 

State two conditions necessary to complete the statement.

1. _________________________________________________________________

2. _________________________________________________________________

(2)
A volume of 0.0016 m$^3$ of air at a pressure of $1.0 \times 10^5$ Pa and a temperature of 290 K is trapped in a cylinder. Under these conditions the volume of air occupied by 1.0 mol is 0.024 m$^3$. The air in the cylinder is heated and at the same time compressed slowly by a piston. The initial condition and final condition of the trapped air are shown in the diagram.

In the following calculations treat air as an ideal gas having a molar mass of 0.029 kg mol$^{-1}$.

(i) Calculate the final volume of the air trapped in the cylinder.

$$\text{volume of air} = \text{________________________ } \text{ m}^3$$

(ii) Calculate the number of moles of air in the cylinder.

$$\text{number of moles} = \text{________________________}$$
(iii) Calculate the initial density of air trapped in the cylinder.

\[
density = \text{______________ kg m}^{-3}
\]

(c) State and explain what happens to the speed of molecules in a gas as the temperature increases.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(2)

12

(a) Which statement explains why energy is needed to melt ice at 0°C to water at 0°C?

Place a tick (✔) in the right-hand column to show the correct answer.

<table>
<thead>
<tr>
<th>Statement</th>
<th>✔ if correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>It provides the water with energy for its molecules to move faster.</td>
<td>✔ if correct</td>
</tr>
<tr>
<td>It breaks all the intermolecular bonds.</td>
<td>✔ if correct</td>
</tr>
<tr>
<td>It allows the molecules to vibrate with more kinetic energy.</td>
<td>✔ if correct</td>
</tr>
<tr>
<td>It breaks some intermolecular bonds.</td>
<td>✔ if correct</td>
</tr>
</tbody>
</table>

(1)
A student adds ice at a temperature of –25°C to water. The water is stirred continuously. Ice is added slowly until all the ice has melted and the temperature of the water decreases to 0°C. The mass of ice added during the experiment is 0.047 kg.

(i) Calculate the energy required to melt the ice at a temperature of 0°C. The specific latent heat of fusion of water is $3.3 \times 10^5$ J kg$^{-1}$.

\[
\text{energy} = \text{________________________ J}
\]

(1)

(ii) The water loses $1.8 \times 10^4$ J of energy to the ice during the experiment. Calculate the energy given to the ice to raise its temperature to 0°C. Assume that no energy is transferred to or from the surroundings and beaker.

\[
\text{energy} = \text{________________________ J}
\]

(1)

(iii) Calculate the specific heat capacity of the ice. State an appropriate unit for your answer.

specific heat capacity = ____________________ unit = __________

(2)

(Total 5 marks)
Mark schemes

1. (a) energy = heat capacity × temperature change
   
   $22 \text{ J}$
   
   (2)

   (b) $E = mc\theta$

   $0.13 \text{ K condone } ^\circ \text{C } / \frac{\text{their(i) }}{168}$ (allow e.c.f. from (i))
   
   (2)

2. (a) (use of $\Delta Q = mcT$ gives)

   $\Delta Q_1 = 1.5 \times 4200 \times 18$ (1)
   
   $= 1.134 \times 10^5$ (J) (1)

   $\Delta Q_2 = 1.5 \times 3.4 \times 10^5 = 5.1 \times 10^5$ (J) (1)

   total energy released ($= 1.134 \times 10^5 + 5.1 \times 10^5$)
   
   $= 6.2 \times 10^5$ (J) (1)

   (6.23 × 10^5 J)

   (4)

   (b) (ice) requires energy to melt [or mention of latent heat] (1)

   stays at 0 °C (for longer) (or cools for longer) (1)

   (or extracts more energy from the drink)

   (2)

   [6]

3. (a) using $Q = mc\Delta \theta$

   $= 3.00 \times 440 \times (84-27)$ (1)

   $7.5 \times 10^4$ (J) (1)

   (2)

   (b) using $Q = ml$

   $= 1.20 \times 2.5 \times 10^4$

   $= 3.0 \times 10^4$ (J) (1)
(c) (heat supplied by lead changing state + heat supplied by cooling lead = heat gained by iron)

\[ 3.0 \times 10^4 + \text{heat supplied by cooling lead} = 7.5 \times 10^4 \] (1)

heat supplied by cooling lead = \( 4.5 \times 10^4 = mc\Delta \theta \)

\[ c = \frac{4.5 \times 10^4}{1.2 \times (327 - 84)} \] (1)

\[ c = 154 \text{ (J kg}^{-1} \text{ K}^{-1}) \] (1)

(d) any one idea (1)

no allowance has been made for heat loss to the surroundings

or the specific heats may not be a constant over the range of temperatures calculated

4

(a) \[ \Delta T = \left( \frac{\Delta Q}{mc} \right) = \frac{8.5 \times 10^3}{4200 \times 0.12} \checkmark \]

\[ 17 \text{ K} \checkmark \]

(b) \[ \Delta T = \left( \frac{\Delta Q}{mc} \right) - \frac{100 - 26}{\Delta t} = \frac{8.5 \times 10^3}{0.41 \times 4200} \checkmark \]

\[ t = 15 \text{ s} \checkmark \]

5

(a) \[ Ft = \Delta(mv) \]

or \( F = ma \) and \( a = (v - u) / t \)

3800 N
(b) work done = change in KE

or
appropriate equation of motion for s
or
work done = Fs

Calculation of one KE correctly
or s calculated correctly (50 m)

\[ 1.9 \times 10^5 \text{ J (condone N m) e.c.f. for } F \]

(c) power = \{force from (a)} \times \text{any velocity}

or
power = change in KE / time

76 kW (kJ s\(^{-1}\))

ecf from (b) or ecf from (a) for use of \( P = Fv \) (their \( F \times 20 \))

(d) (i) (their (b)) = 4.8 (or 1.2) \times 510 \times \Delta \theta \) (allow use of 1.2 instead of 4.8 for this mark)

appreciation of 4 discs evident in the calculation

77.6 (78) K (or °C) or their (b) / 2450

(ii) temperature rise will be lower

there will be air resistance
some energy becomes internal energy of the air

OR
other components of the braking system (including answers involving friction of tyres with road)
these will use some of the energy to increase temperature

OR
heat / energy transfer to the surroundings
since surroundings at lower temperature or
temperature or internal energy of surroundings rises

[12]
6

(a) mass of one atom = \( \frac{0.21}{6.0 \times 10^{-23}} = 3.5 \times 10^{-25} \) kg (1)

(b) energy supplied = \( 23 \times 10^3 \times 3.5 \times 10^{-25} \) (1)

\[ = 8.1 \times 10^{-21} \text{ J} \] (8.05 \times 10^{-21} \text{ J}

(allow C.E. for value from (i))

(c) (use of \( \frac{1}{2} m v^2 = E_K \) gives) \( \frac{1}{2} \times 3.5 \times 10^{-25} \times v^2 = 8.1 \times 10^{-21} \)

\[ v = \left( \frac{2.0 \times 8.1 \times 10^{-21}}{3.5 \times 10^{-25}} \right)^{1/2} = 220 \text{ m s}^{-1} \] (215 m s\(^{-1}\))

(\( E_K = 8.05 \times 10^{-21} \) gives \( v = 214 \text{ m s}^{-1} \)) (allow C.E. for value of \( E_K \) from (ii))

7

(a) (i) energy = \( 800 \times 60 = 48 \times 10^3 \) J (1)

(ii) (use of \( \Delta Q = mc \Delta \theta \) gives) \( 48 \times 10^3 = 60 \times 3900 \times \Delta \theta \) (1)

\( \Delta \theta = 0.21 \text{ K} \) (1) (0.205 K)

(allow C.E. for value of energy from (i))

(b) \( \Delta Q = ml \) gives \( 500 \times 60 = m \times 2.3 \times 10^6 \) (1)

\( m = 0.013 \) kg (1)

(c) not generating as much heat internally (1)

still losing heat (at the same rate)

[or still sweating] (1)

hence temperature will drop (1)

\( \text{Imax } 2 \)

8

(a) (use of \( \Delta Q = mc \Delta T \) gives) \( \Delta Q = 0.45 \times 4200 \times (35 - 15) \) (1)

\[ = 3.8 \times 10^4 \text{ J} \] (3.78 \times 10^4 \text{ J}) (1)

(b) (i) \( 3.8 \times 10^4 \) J (1)

(allow C.E. for incorrect value of \( \Delta Q \) from (a))

(ii) \( (mc \Delta T = \Delta Q \) gives) \( 0.12 \times 390 \times \Delta T = 3.8 \times 10^4 \) (1)

\( \Delta T = 812 \text{ K} \) (1)

(allow C.E. for incorrect value of \( \Delta Q \) from (i))

(iii) \( 812 + 35 = 847 \) °C (1)

(allow C.E. from (ii))

\[ \text{Imax } 2 \]
9 (heat supplied by glass = heat gained by cola)
(usage of $m_g \Delta T_g = m_c \Delta T_c$)

1st mark for RHS or LHS of substituted equation

$$0.250 \times 840 \times (30.0 - T_f) = 0.200 \times 4190 \times (T_f - 3.0) \checkmark$$

2nd mark for 8.4°C

$$ (210 \times 30 - 210 T_f = 838 T_f - 838 \times 3)$$

$T_f = 8.4(1) \degree C \checkmark$

Alternatives:

8°C is substituted into equation (on either side shown will get mark)

✓

resulting in 4620J~4190J ✓

or

8°C substituted into LHS ✓ (produces $\Delta T = 5.5\degree C$ and hence)

$= 8.5\degree C \sim 8\degree C \checkmark$

8°C substituted into RHS ✓

(produces $\Delta T = 20\degree C$ and hence)

$= 10\degree C \sim 8\degree C \checkmark$
(ii) (heat gained by ice = heat lost by glass + heat lost by cola)

*NB correct answer does not necessarily get full marks*

(heat gained by ice = \(mc \Delta T + ml\))

\[
\text{heat gained by ice} = m \times 4190 \times 3.0 + m \times 3.34 \times 10^5
\]

(heat gained by ice = \(m \times 346600\))

\[3^{rd} \text{ mark is only given if the previous 2 marks are awarded}\]

heat lost by glass + heat lost by cola

\[
= 0.250 \times 840 \times (8.41 - 3.0) + 0.200 \times 4190 \times (8.41 - 3.0)
\]

(= 5670 J)

*(especially look for \(m \times 4190 \times 3.0\))

the first two marks are given for the formation of the substituted equation not the calculated values

\[
m (=5670 / 346600) = 0.016 \text{ (kg)}
\]

*if 8°C is used the final answer is 0.015 kg*

or (using cola returning to its original temperature)

(heat supplied by glass = heat gained by ice)

(heat gained by glass = \(0.250 \times 840 \times (30.0 - 3.0)\))

heat gained by glass = 5670 (J)

(heat used by ice = \(mc \Delta T + ml\))

heat used by ice = \(m(4190 \times 3.0 + 3.34 \times 10^5)\) (\(= m(346600)\))

\[
m (=5670 / 346600) = 0.016 \text{ (kg)}
\]

10

10

(a) (it takes) 130 J / this energy to raise (the temperature of) a mass of 1 kg (of lead) by 1 K / 1 °C (without changing its state)

1 kg can be replaced with unit mass.

Marks for 130J or energy.

+1 kg or unit mass.

+1 K or 1 °C.

Condone the use of 1 °K

(b) (using \(Q = mc \Delta T + ml\))

\[
= 0.75 \times 130 \times (327.5 - 21) + 0.75 \times 23000
\]

(= 29884 + 17250)

= 47134

= \(4.7 \times 10^4\) (J)

*For the first mark the two terms may appear separately i.e. they do not have to be added.*

Marks for substitution + answer + 2 sig figs (that can stand alone).
(a)  1. fixed mass or fixed number of molecules / moles ✔
2. constant temperature ✔
   
   Allow alternatives to fixed mass such as 'sealed vessel' or 'closed system'.
   
   Not amount of gas as this is ambiguous.
   
   The temperature must not be specific.

(b)  (i) \[ V_2 = \frac{P_1 \times V_1 \times T_2}{P_1 \times T_1} \]

\[ V_2 = \frac{1.0 \times 10^5}{4.4 \times 10^5} \times 0.0016 \times \frac{350}{290} \]

or \( V = \frac{nRT}{P} \)

\[ V = 0.067 \times 8.31 \times 350 / (4.4 \times 10^{-4}) ✔ \]
\[ = 0.00044 \text{ m}^3 ✔ (4.39 \times 10^{-4} \text{ m}^3) \]

1st mark comes from use of valid equation with substitutions.
In the alternative look out for \( 0.067 = 1/15 = (0.0016 / 0.024) \)
And \( R = N_A k \)
Correct answer gains full marks
If no other answer is seen then 1 sig fig is wrong.

(ii) (proportion of a mole of trapped air
   = volume of cylinder / volume of mole)
   = 0.0016 / 0.024 = 0.067 (mol) ✔ (0.0667)
   or
   (use of \( n = pV/RT \))
   = 1.0 \times 10^5 \times 0.0016 / (8.31 \times 290) = 0.066 (mol) ✔ (0.0664)
   or
   = 4.4 \times 10^5 \times 0.00044 / (8.31 \times 350) = 0.067 (mol) ✔ (0.0666)

   Answers range between 0.066 - 0.067 mol depending on the volume carried forward.

   (answer alone gains mark)
   Working must be shown for a CE
   Ans = \( V_2 \times 151 \)
(iii) (mass = molar mass × number of moles)
mass = 0.029 × 0.0667 ✔ (0.00193 kg)
(density = mass / volume)
density = 0.00193 / 0.0016 = 1.2(1) kg m⁻³ ✔
(no continuation errors within this question but allow simple powers of 10 arithmetic errors which will lose one mark)

\[
CE \text{ mass} = 0.029 \times (b)(ii) \\
CE \text{ density} = (0.029 \times (b)(ii)) / 0.0016 \\
or \ (18.1 \times (b)(ii))
\]

(c) the (average / mean / mean-square) speed of molecules increases (with absolute temperature) ✔
as the mean kinetic energy is proportional to the (absolute) temperature
Or
Reference to KE_{mean} = \frac{3}{2} kT ✔ but mean or rms must feature in the answer somewhere.

(a) Tick in 4th box

(b) (i) (using heat energy = ml)
energy = 0.047 × 3.3 × 10⁵ = 1.6 × 10⁴ (J) ✔ (1.55 × 10⁴ J)

answer alone gains mark

(ii) (heat in from water = heat supplied to melt and raise ice temperature)
1.8 × 10⁴ = 1.6 × 10⁴ + (energy to raise temp of ice)
energy to raise temp of ice = 2 × 10³ (J) ✔

answer alone gains mark allow 2, 2.5 or 3 × 10³ J
allow CE if substitution is shown
1.8 × 10⁴ − (b)(i)

(iii) (using heat energy = mCΔT)
c = 2 × 10³ / 0.047 × 25
= 2 × 10³ ✔ (1.7 × 10³) (note there is a large range of correct answers)
J kg⁻¹ K⁻¹ or J kg⁻¹ °C⁻¹ ✔ (allow use of dividing line but don’t allow °K and °C⁻¹ is not the same as C⁻¹)

only allow CE if substitutions are seen

\[
c = (b)(ii) / 0.047 \times 25 \\
= b(ii) \times 0.851
\]

allow 1 sig fig.

common answers:
for 2.5 × 10³ J gives 2.1 × 10³ or 2 × 10³
for 3 × 10³ J gives 2.6 × 10³ or 3 × 10³