This question is about thermal energy transfer.

A hot piece of iron is placed into a container of cold water. After a time the iron and water reach thermal equilibrium. The heat capacity of the container is negligible.

1a. Define specific heat capacity. [2 marks]

**Markscheme**

-the energy required to change the temperature (of a substance) by 1K/°C/unit degree; of mass 1 kg / per unit mass;

1b. The following data are available. [5 marks]

- Mass of water = 0.35 kg
- Mass of iron = 0.58 kg
- Specific heat capacity of water = 4200 J kg⁻¹ K⁻¹
- Initial temperature of water = 20°C
- Final temperature of water = 44°C
- Initial temperature of iron = 180°C

(i) Determine the specific heat capacity of iron.

(ii) Explain why the value calculated in (b)(i) is likely to be different from the accepted value.

**Markscheme**

(i) use of \( mc \Delta T \);

- \( 0.58 \times c \times [180-44] = 0.35 \times 4200 \times [44-20] \);
- \( c \approx 447 \text{ J kg}^{-1} \text{ K}^{-1} \);

(ii) energy would be given off to surroundings/environment / energy would be absorbed by container / energy would be given off through vaporization of water;

- hence final temperature would be less;
- hence measured value of (specific) heat capacity (of iron) would be higher;

This question is in two parts. Part 1 is about ideal gases and specific heat capacity. Part 2 is about simple harmonic motion and waves.

**Part 1** Ideal gases and specific heat capacity

2a. State two assumptions of the kinetic model of an ideal gas. [2 marks]

**Markscheme**

-point molecules / negligible volume;
-no forces between molecules except during contact;
-motion/distribution is random;
-elastic collisions / no energy lost;
-obey Newton’s laws of motion;
-collision in zero time;
-gravity is ignored;
Argon behaves as an ideal gas for a large range of temperatures and pressures. One mole of argon is confined in a cylinder by a freely moving piston.

(i) Define what is meant by the term one mole of argon.

(ii) The temperature of the argon is 300 K. The piston is fixed and the argon is heated at constant volume such that its internal energy increases by 620 J. The temperature of the argon is now 350 K. Determine the specific heat capacity of argon in J kg$^{-1}$ K$^{-1}$ under the condition of constant volume. (The molecular weight of argon is 40)

**Markscheme**

(i) the molecular weight of argon in grams / 6.02×10$^{23}$ argon atoms / same number of particles as in 12 g of C-12; (allow atoms or molecules for particles)

(ii) mass of gas = 0.040 kg; specific heat = $\frac{Q}{m\Delta T}$ or $620 = 0.040 \times c \times 50$; (i.e. correctly aligns substitution with equation)

$\left(\frac{620}{0.040 \times 50}\right) = 310$ J kg$^{-1}$ K$^{-1}$;

At the temperature of 350 K, the piston in (b) is now freed and the argon expands until its temperature reaches 300 K. Explain, in terms of the molecular model of an ideal gas, why the temperature of argon decreases on expansion.

**Markscheme**

temperature is a measure of the average kinetic energy of the molecules; (must see “average kinetic” for the mark)

energy/momentum to move piston is provided by energy/momentum of molecules that collide with it; the (average) kinetic energy of the gas therefore decreases;

Do not allow arguments in terms of loss of speed as a result of collision with a moving piston.

### Part 2 Change of phase

Water at constant pressure boils at constant temperature. Outline, in terms of the energy of the molecules, the reason for this.

**Markscheme**

temperature is a measure of the (average) kinetic energy of the molecules; at the boiling point, energy supplied (does not increase the kinetic energy) but (only) increases the potential energy of the molecules/goes into increasing the separation of the molecules/breaking one molecule from another / OWTE;

In an experiment to measure the specific latent heat of vaporization of water, steam at 100°C was passed into water in an insulated container. The following data are available.

- Initial mass of water in container = 0.300 kg
- Final mass of water in container = 0.312 kg
- Initial temperature of water in container = 15.2°C
- Final temperature of water in container = 34.6°C
- Specific heat capacity of water = 4.18×10$^{3}$ J kg$^{-1}$ K$^{-1}$

Show that the data give a value of about 1.8×10$^{5}$ J kg$^{-1}$ for the specific latent heat of vaporization L of water.
3c. Explain why, other than measurement or calculation error, the accepted value of $L$ is greater than that given in (h).

**Markscheme**

some of the energy (of the condensing steam) is lost to the surroundings; so less energy available to be absorbed by water / rise in temperature of the water would be greater if no energy lost;

This question is about an ideal gas.

4a. Describe how the ideal gas constant $R$ is defined.

**Markscheme**

defined from the equation of state of an ideal gas $PV=nRT$; all symbols ($PVnT$) correctly identified;

4b. Calculate the temperature of 0.100 mol of an ideal gas kept in a cylinder of volume $1.40 \times 10^{-3}$ m³ at a pressure of $2.32 \times 10^{5}$ Pa.

**Markscheme**

$390/391$ K;

4c. The gas in (b) is kept in the cylinder by a freely moving piston. The gas is now heated at constant pressure until the volume occupied by the gas is $3.60 \times 10^{-3}$ m³. The increase in internal energy of the gas is $760$ J. Determine the thermal energy given to the gas.

**Markscheme**

work done $= (P\Delta V = 2.32 \times 10^{5} \times 2.20 \times 10^{-3} =) 510$ J; thermal energy $= (760 + 510 =) 1.27 \times 10^{3}$ J; Award [1 max] if volume is taken as $3.6 \times 10^{-3}$, giving an answer of $1600$ J.

4d. After heating, the gas is compressed rapidly to its original volume in (b). Outline why this compression approximates to an adiabatic change of state of the gas.

**Markscheme**

an adiabatic change is one in which no (thermal/heat) energy is transferred between system and surroundings / no energy enters/leaves system; a rapid compression means that there is insufficient time (for energy transfer) / OWTTE;
Part 2 Thermal concepts

5a. Distinguish between internal energy and thermal energy (heat).

Internal energy:

Thermal energy:

**Markscheme**

*internal energy:*

the sum of the potential and the (random) kinetic energy of the molecules/particles of a substance;

Allow “potential and kinetic” for “sum”.

*thermal energy:*

the (non-mechanical) transfer of energy between two different bodies as a result of a temperature difference between them;

---

5b. A 300 W immersion heater is placed in a beaker containing 0.25 kg of water at a temperature of 18°C. The heater is switched on for 120 s, after which time the temperature of the water is 45°C. The thermal capacity of the beaker is negligible and the specific heat capacity of water is $4.2 \times 10^3 \text{ J kg}^{-1} \text{K}^{-1}$.

(i) Estimate the change in internal energy of the water.

(ii) Determine the rate at which thermal energy is transferred from the water to the surroundings during the time that the heater is switched on.

**Markscheme**

(i) $\Delta U = 0.25 \times 4.2 \times 10^3 \times 27 = 2.835 \times 10^4 \text{ J}$; $= 2.8 \times 10^4 \text{ J}$; Award [2] for a bald correct final answer of 28 (kJ)

Award [1 max] if correct energy calculated but the answer goes on to work out a further quantity, for example power.

(ii) energy transfer = $[300 \times 120] - [2.835 \times 10^4] = 7.65 \times 10^3 \text{ J}$;

rate of transfer = $\frac{7.65 \times 10^3}{120} = 64 \text{ (W)}$;

Accept rounded value from (b)(i) to give 67 (W).

---

Part 2 Properties of a gas

6a. With respect to a gas, explain the meaning of the terms thermal energy and internal energy.

**Markscheme**

*(Q) energy transferred between two objects (at different temperatures);*(

*(U) (total) potential energy and (random) kinetic energy of the molecules/particles (of the gas);*
The graph shows how the pressure $P$ of a sample of a fixed mass of an ideal gas varies with volume $V$. The gas is taken through a cycle ABCD.

(i) Estimate the net work done during the cycle.

(ii) Explain whether the net work is done on the gas or by the gas.

(iii) Deduce, using the data from the graph, that the change C is isothermal.

(iv) Isothermal change A occurs at a temperature of 450 K. Calculate the temperature at which isothermal change C occurs.

(v) Describe the changes B and D.

Markscheme

(i) use of area within cycle; each large square has work value of 250 (J); estimate (16 x 250= )4000 (J); (allow 3600 − 4100)
Award [3] for same outcome with small squares of area 10 (J).

(ii) (work is done by the gas because) area under expansion is greater than that under compression/pressure during expansion is greater than during compression;

(iii) clear attempt to compare two $PV$ values; evaluate two $PV$ values correctly eg 75 x 80= 6000 and 200 x 30= 6000;

(iv) use of $PV=nRT$ or equivalent; 1350/1330 (K);

(v) both changes are isochoric/isovolumetric/constant volume changes; B: temperature/internal energy increases, D: temperature/internal energy decreases; B: thermal energy/heat input (to system), D: thermal energy/heat output (from system); B: pressure increases, D: pressure decreases;
Part 2 Melting ice

7a. Describe, with reference to molecular behaviour, the process of melting ice. [2 marks]

**Markscheme**

In ice, molecules vibrate about a fixed point; as their total energy increases, the molecules (partly) overcome the attractive force between them; in liquid water the molecules are able to migrate/change position;

A container of negligible mass, isolated from its surroundings, contains 0.150 kg of ice at a temperature of −18.7 °C. An electric heater supplies energy at a rate of 125 W.

7b. After a time interval of 45.0 s all of the ice has reached a temperature of 0 °C without any melting. Calculate the specific heat capacity of ice. [2 marks]

**Markscheme**

\[
Q = 45.0 \times 125 = 5625 \text{ J;}
\]

\[
c = \left(\frac{Q}{m \Delta \theta}\right) = 2.01 \times 10^3 \text{ J kg}^{-1}\text{K}^{-1};
\]

7c. The following data are available. [3 marks]

- Specific heat capacity of water = 4200 J kg\(^{-1}\)K\(^{-1}\)
- Specific latent heat of fusion of ice = 3.30 \times 10^5 J kg\(^{-1}\)

Determine the final temperature of the water when the heater supplies energy for a further 600 s.

**Markscheme**

Energy available = 125 \times 600 = 75000 J;

Energy available to warm the water = 75000 − [0.15 \times 3.3 \times 10^5] = 25500 J;

Temperature = \left(\frac{25500}{0.15 \times 4200}\right) = 40.5^\circ C;

7d. The whole of the experiment in (f)(i) and (f)(ii) is repeated with a container of negligible mass that is not isolated from the surroundings. The temperature of the surroundings is 18 °C. Comment on the final temperature of the water in (f)(ii). [3 marks]

**Markscheme**

Ice/water spends more time below 18 °C; so net energy transfer is in to the system; so final water temperature is higher;

or

Ice/water spends less time below 18 °C; so net energy transfer is out of the system; so final water temperature is lower;
Part 2 Thermal Energy Transfer

8a. [5 marks]

(i) Define the specific latent heat of fusion of a substance.

(ii) Explain, in terms of the molecular model of matter, the relative magnitudes of the specific latent heat of vaporization of water and the specific latent heat of fusion of water.

**Markscheme**

(i) the energy (absorbed/released) when a unit mass/one kg; of liquid freezes (to become solid) at constant temperature / of solid melts (to become liquid) at constant temperature;

(ii) potential energy changes during changes of state / bonds are weakened/broken during changes of state; potential energy change is greater for vaporization than fusion / more energy is required to break bonds than to weaken them; SLH vaporization is greater than SLH fusion;

*Only award third marking point if first marking point or second marking point is awarded.*

8b. [5 marks]

A piece of ice is placed into a beaker of water and melts completely.

The following data are available.

- Initial mass of ice = 0.020 kg
- Initial mass of water = 0.25 kg
- Initial temperature of ice = 0°C
- Initial temperature of water = 80°C
- Specific latent heat of fusion of ice = 3.3×10^5 J kg\(^{-1}\)
- Specific heat capacity of water = 4200 J kg\(^{-1}\)K\(^{-1}\)

(i) Determine the final temperature of the water.

(ii) State two assumptions that you made in your answer to part (f)(i).

**Markscheme**

(i) use of \(\Delta Q = mc\Delta T\) and mL;

\[
0.020 \times 3.3 \times 10^5 + 0.020 \times 4200 \times (T - 0) = 0.25 \times 4200 \times (80 - T);
\]

\(T=68(°C);


*Award [2] for an answer of \(T=74(°C)\) (missed melted ice changing temperature).*

(ii) no energy given off to the surroundings/environment;
no energy absorbed by beaker;
no evaporation of water;

9a. This question is about energy.

At its melting temperature, molten zinc is poured into an iron mould. The molten zinc becomes a solid without changing temperature.

Outline why a given mass of molten zinc has a greater internal energy than the same mass of solid zinc at the same temperature. [3 marks]

**Markscheme**

same temperature so (average) kinetic energy (of atoms/molecules) the same;

(interatomic) potential energy of atoms is greater for liquid / energy is needed to separate the atoms; ) (do not allow “forces are weaker” arguments)

internal energy = potential energy + kinetic energy; (allow BOD for clear algebra)

(so internal energy is greater)
Molten zinc cools in an iron mould.

The temperature of the iron mould was 20° C before the molten zinc, at its melting temperature, was poured into it. The final temperature of the iron mould and the solidified zinc is 89° C.

The following data are available.

- Mass of iron mould = 12 kg
- Mass of zinc = 1.5 kg
- Specific heat capacity of iron = 440 J kg⁻¹K⁻¹
- Specific latent heat of fusion of zinc = 113 kJ kg⁻¹
- Melting temperature of zinc = 420 °C

Using the data, determine the specific heat capacity of zinc.

**Markscheme**

energy lost by freezing zinc = \(1.5 \times 113000\) (= 170000 J); (watch for power of ten error)

energy gained by iron = \(12 \times 440 \times [89 - 20]\) (= 364000 J);

energy lost by cooling solid zinc = 195000 (J);

specific heat capacity of zinc = \(\frac{195000}{\frac{1.5 \times 113}{10^3}}\) = 390 (J kg⁻¹K⁻¹);

Award [3 max] for an answer of 733 (kJ kg⁻¹K⁻¹) (\(1.5 \times 113\) was used).

or

thermal energy lost by zinc = thermal energy gained by iron;

indication that thermal energy lost by zinc has a latent heat contribution and a specific heat contribution expressed algebraically or numerically;

substitution correct;

answer;

---

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

**Part 1 Energy resources**

Electricity can be generated using nuclear fission, by burning fossil fuels or using pump storage hydroelectric schemes.

A hydroelectric scheme has an efficiency of 92%. Water stored in the dam falls through an average height of 57 m. Determine the **[3 marks]** rate of flow of water, in kg s⁻¹, required to generate an electrical output power of 4.5 MW.

**Markscheme**

use of \(\frac{mgh}{T}\):

\[
\frac{mgh}{T} = \frac{4.5 \times 10^6}{0.92 \times 9.81 \times 57}; \quad (t \text{ is usually ignored, assume } 1 \text{ if not seen})
\]

\(8.7 \times 10^3\) kg s⁻¹);

Award [3] for a bald correct answer.

---

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

**Part 2 Thermal physics**

Distinguish between specific heat capacity and specific latent heat. **[2 marks]**
A mass of 0.22 kg of lead spheres is placed in a well-insulated tube. The tube is turned upside down several times so that the spheres fall through an average height of 0.45 m each time the tube is turned. The temperature of the spheres is found to increase by 8 °C.

**Markscheme**

gravitational potential energy → kinetic energy;
kinetic energy → internal energy/thermal energy/heat energy;
Do not allow heat.
Two separate energy changes must be explicit.

**Gravitational Potential Energy**

\[ m \cdot g \cdot \Delta h \]

\[ n \times m \cdot g \cdot \Delta h = 229 \text{ (J)} \]

\[ n = \frac{229}{0.22 \times 9.81 \times 0.45} = 236 \text{ or } 240; \] (allow if answer is rounded up to give complete number of inversions)

Award [4] for a bald correct answer.

This question is about thermal properties of matter.

**11a.** Explain, in terms of the energy of its molecules, why the temperature of a pure substance does not change during melting. [3 marks]
Markscheme
energy supplied/bonds broken/heat absorbed;
increases potential energy;
no change in kinetic energy (so no change in temperature);

11b. Three ice cubes at a temperature of 0°C are dropped into a container of water at a temperature of 22°C. The mass of each ice cube is 25 g and the mass of the water is 330 g. The ice melts, so that the temperature of the water decreases. The thermal capacity of the container is negligible.

The following data are available.

Specific latent heat of fusion of ice = $3.3 \times 10^5$ J kg$^{-1}$

Specific heat capacity of water = $4.2 \times 10^3$ J kg$^{-1}$ K$^{-1}$

Calculate the final temperature of the water when all of the ice has melted. Assume that no thermal energy is exchanged between the water and the surroundings.

Markscheme
use of $M \times 4.2 \times 10^3 \times \Delta \theta$

$m_f = 75 \times 10^{-3} \times 3.3 \times 10^5 / 24750$ J;

recognition that melted ice warms and water cools to common final temperature;
3.4°C;