Thermal Energy Transfers

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Course	HL IB Physics
Section	The Particulate Nature of Matter
Topic	Thermal Energy Transfers
Difficulty	Medium

To be used by all students preparing for HL IB Physics
Students of other boards may also find this useful

1

The correct answer is **C** because:

- Power of heater = 150*m*
- By looking at the horizontal line section of the graph we can calculate the time, *t*, taken for the substance to turn from a solid to a liquid:
  - $t = 400 - 120 = 280$ seconds
- Use the specific latent heat equation to calculate the energy required to melt the substance:
  - $Q = mL$
  - $Pt = mL$
- Substitute $P = 150m$ and $t = 280$ s into $Pt = mL$:
  - $150m \times 280 = mL$
  - $L = 150 \times 280 = 42\,000$
  - Hence $L = 4.2 \times 10^4$ J kg^{-1}

2

The correct answer is **D** because:

- Temperature is directly proportional to the average kinetic energy of the molecules
  - Since the temperature has remained constant, the kinetic energy will stay the same
  - This eliminates options **B** & **C**
- As particles move further apart from each other, the higher the potential energy becomes
- In a liquid, the molecules are further apart than in a solid
- When a liquid turns into a solid, the molecules become closer together
  - Therefore, the potential energy decreases

A is incorrect as the potential energy depends on how far apart the molecules are, so for a phase change, this will always increase or decrease

B & **C** are incorrect as the kinetic energy depends on the temperature, so if the temperature stays the same then so will the kinetic energy

3

The correct answer is **C** because:

- The question says the liquid is initially at its boiling point and heated until it all evaporates into a gas
  - This means it is undergoing a phase change
- When a substance is in the process of changing state no temperature change occurs
  - This is shown by graph **C**

A, B & **D** are incorrect as these graphs all show a temperature rise associated with the addition of energy which is only the case once all of the material has changed state. The graph of temperature vs energy changes following a complete change of state to gas depends on whether it is contained at a constant volume or pressure and so is determined by a greater number of factors

It is a common misconception that temperature rises during a phase change. In fact, there is no temperature change because the energy being supplied to the liquid is used in breaking the intermolecular bonds.

As the molecules move further apart from one another, the potential energy increases, which does not affect the temperature of the substance. Once the phase change is complete, energy supplied to the molecules begins to increase the kinetic energy of the molecules, which does affect the temperature.

4

The correct answer is **A** because:

- Energy will be released by the water due to the temperature decreasing and the change of state from liquid to solid
- Energy is released due to the change in temperature, ΔQ_T:
  - From the data booklet: $Q = mc\Delta T$
  - $\Delta Q_T = 2 \times 4200 \times (30 - 0)$
  - $\Delta Q_T = 252\,000 = 2.52 \times 10^5$ J

- Energy is released due to change in state from solid to liquid, ΔQ_2:
  - From the data booklet: $Q = mL$
  - $\Delta Q_2 = 2 \times (3.4 \times 10^5)$
  - $\Delta Q_2 = 6.8 \times 10^5$ J
- Total energy released, ΔQ_T:
  - $\Delta Q_T = \Delta Q_1 + \Delta Q_2$
  - $\Delta Q_T = (2.52 \times 10^5) + (6.8 \times 10^5)$
  - $\Delta Q_T = 9.32 \times 10^5$ J
- Calculate the power, P required by the refrigerator:
- Recall the equation for power, energy and time:
  - Power = $\frac{\text{Energy}}{\text{Time}}$
  - $P = \frac{9.32 \times 10^5}{4000} = 233$ W

5

The correct answer is **C** because:

- The energy, Q, required to raise the temperature of the water to 100 °C is
  - $Q = mc\Delta T$
  - $Q = 1 \times 4000 \times (100 - 20) = 320\,000$ J
- The time required to provide this much energy is:
  - time = $\frac{energy}{power}$
  - time = $\frac{320\,000}{2000}$ = 160 s

If you do this in one step it is easier mathematically as you can divide 4000 by 2000 which gives 2:

$$\text{time} = \frac{1 \times 4000 \times 80}{2000} = 160 \text{ s}$$

6

The correct answer is **B** because:

- The graph shows the time over which the substance changes state from liquid to solid
- The period of time over which the temperature does not change (the flat section of the graph) is when the liquid is freezing
- The gradient of the graph on either side of this tells us about the specific heat capacity
- A steeper gradient = a lower specific heat capacity
    - This is because less energy is required to change the temperature
- The gradient of the graph, while the substance is liquid, is **steeper**
    - This, therefore, represents a **lower** specific heat capacity
- The gradient of the graph once the substance is **solid** is **less steep**
    - This, therefore, represents a **greater** specific heat capacity
- Hence, the specific heat capacity of the liquid is lower than the specific heat capacity of the solid
    - This is statement **B**

A & **C** are incorrect as we cannot deduce anything about the latent heat of vaporization (liquid ↔ gas) or fusion (liquid ↔ solid) from the graph as we would need to know some values for energy supplied and mass of the substance. In general, the latent heat of fusion of a substance is always less than its latent heat of vaporisation. This is because more energy is required to separate the liquid molecules to convert the liquid into a gaseous state (vaporization process) than to bring the liquid molecules together (fusion process) to form a solid. However, this cannot be deduced from the graph given in the question

D is incorrect as this would be true if the initial drop in temperature was less steep and if the second drop in temperature was steeper

7

The correct answer is **A** because:

- This energy transfer can be split into 3 parts
  - Raising the temperature of solid aluminium from 645°C to 660°C
  - Changing the aluminium from solid to liquid at 660°C
  - Raising the temperature of liquid aluminium from 660°C to 720°C
- When raising the temperature of a substance we use the equation
  - $\Delta Q = mc\Delta T$
  - Where ΔQ is the energy supplied, m is the mass, c is the specific heat capacity and ΔT is the change in temperature
- When changing the state of a substance we use the equation
  - $\Delta Q = mL$
  - Where L is the latent heat (in this case, of fusion, since its liquid ↔ solid)
- The amount of energy required to heat the solid aluminium, Q_s, from 645°C to 660°C is given by
  - $Q_s = mc_s(660 - 645) = 15mc_s$
- The amount of energy required to change the aluminium from a solid to a liquid, Q_f, is given by
  - $Q_f = mL_f$
- The amount of energy required to heat the liquid aluminium, Q_L, from 660°C to 720°C is given by
  - $Q_L = mc_L(720 - 660) = 60mc_L$
- The total energy required, ΔQ, is therefore
  - $\Delta Q = Q_s + Q_f + Q_L$
  - $\Delta Q = 15mc_S + mL_f + 60mc_L$
  - $\Delta Q = m(15c_S + L_f + 60c_L)$

8

The correct answer is **B** because:

- The gradient, z, is equal to the change in the y-component, ΔT, over the x-component, ΔQ:
  - $z = \frac{\Delta T}{\Delta Q}$

- Specific heat capacity is given by $\Delta Q = mc\Delta T$
- Substituting this into the first equation:
  - $z = \dfrac{\Delta T}{mc\Delta T} = \dfrac{1}{mc}$
- Rearranging for *m*:
  - $m = \dfrac{1}{zc}$

9

The correct answer is **D** because:

- In this process, heat energy can be transferred from the hotter substance (water) to the cooler substance (ice)
- The system is thermally isolated from the surroundings and so no energy can enter or leave the system
  - Therefore, the total internal energy must remain **constant**

A & **B** are incorrect as the internal energy of a substance is the sum of the potential and kinetic energies of the molecules. Overall, these will individually increase and decrease during a temperature / phase change but the total internal does not change if no external energy is being added or if any internal energy is removed

C is incorrect as this would be correct if the question asked about the change in potential energy of the molecules. This is because potential energy will increase during the phase change (from solid to liquid) as the molecules become further away from one another. It then stays constant as the temperature increases as temperature affects the kinetic energy of the molecules but not the potential energy

10

The correct answer is **D** because:

- Both experiments can be described using $Q = mc\Delta T$
  - For the first experiment, $Q_1 = mc\Delta T$
  - For the second experiment, $Q_2 = 2mc\Delta T$

- The mass can be determined by taking the difference between these two equations:
  - $Q_2 - Q_1 = 2mc\Delta T - mc\Delta T$
  - $Q_2 - Q_1 = mc\Delta T$
- Using this expression, we can substitute and rearrange to obtain the mass, *m*:
  - $4500 - 2000 = m \times 5000 \times 10$
  - $2500 = m \times 5000 \times 10$
  - $m = \frac{2500}{5000 \times 10} = \frac{0.5}{10}$
  - $m = 0.05$ kg = 50 g

11

The correct answer is **B** because:

- Convection occurs when particles are in motion, creating convection currents in a fluid;
  - Mars does not have an atmosphere so convection currents cannot form – options **C** and **D** are incorrect.
- Conduction occurs in solids as vibrating particles oscillate;
  - Conduction can happen between the materials of the equipment and the ground of either Mars or Earth – option **A** is incorrect, leaving option **B** as the correct answer.
- As a final check, radiation occurs without the need for an elastic medium
  - Radiation would occur on Earth and Mars, which fits with option

12

The correct answer is **A** because:

- The Stefan-Boltzmann Law states that, $P = e\sigma AT^4$
- Removing the constants shows that $P \propto T^4$ since the surface area is a constant for each planet

- Energy per second is equivalent to power, so use the Stefan-Boltzmann Law.
- The ratio of the temperature of Venus to Earth, $\frac{T_{Venus}}{T_{Earth}}$ = 90% = 0.9
  - So, the ratio of radiated power, $\frac{P_{Venus}}{P_{Earth}}$ = 0.7 to 1 significant figure

B is incorrect as it is 0.9 rather than 0.9^4

C is incorrect as the answer is $\sqrt[4]{0.9}$ rather than 0.9^4

D is incorrect as the answer is $\left(\frac{10}{9}\right)^4$ rather than $\left(\frac{9}{10}\right)^4$

13

The correct answer is **C** because:

- The Stefan-Boltzmann Law states that power $P = e\sigma AT^4$
- Removing the constants shows that $P \propto AT^4$
- The new area $A' = \frac{1}{3}A$ and the new temperature $T' = 3T$
  - Therefore the new power $P' \propto A'(T')^4 = (\frac{1}{3}A)(3T)^4 = \frac{1}{3} \times A \times 81 \times T^4$
  - Therefore $P' = \frac{81}{3} \times AT^4 = 27P$

14

The correct answer is **D** because:

- Wien's Law states the most common wavelength emitted by a black body is given by $\lambda_{max} = \frac{2.90 \times 10^{-3}}{T}$ where T is its absolute temperature

- $\lambda_{max} \propto \frac{1}{T}$ therefore:
  - The intensity peak occurs at lower wavelengths for higher temperatures
  - This eliminates options **A** and **C** since the dotted line peaks at a smaller wavelength than the solid line peaks
- The intensity has a higher maximum value for the hotter object
  - This means that **D** is the correct graph