SL Paper 2

An ideal monatomic gas is kept in a container of volume 2.1×10^{-4} m^3, temperature 310 K and pressure 5.3×10^5 Pa.

The volume of the gas in (a) is increased to 6.8×10^{-4} m^3 at constant temperature.

a.i. State what is meant by an ideal gas. [1]

a.ii. Calculate the number of atoms in the gas. [1]

a.iii Calculate, in J, the internal energy of the gas. [2]

b.i. Calculate, in Pa, the new pressure of the gas. [1]

b.ii Explain, in terms of molecular motion, this change in pressure. [2]

Markscheme

a.i. a gas in which there are no intermolecular forces

OR

a gas that obeys the ideal gas law/all gas laws at all pressures, volumes and temperatures

OR

molecules have zero PE/only KE

Accept atoms/particles.

[1 mark]

a.ii. N = «$\frac{pV}{kT} = \frac{5.3\times10^{5}\times2.1\times10^{-4}}{1.38\times10^{-23}\times310}$» 2.6×10^{22}

[1 mark]

a.iii «For one atom $U = \frac{3}{2}kT$» $\frac{3}{2} \times 1.38 \times 10^{-23} \times 310$ / 6.4×10^{-21} «J»

U = «$2.6 \times 10^{22} \times \frac{3}{2} \times 1.38 \times 10^{-23} \times 310$» 170 «J»

Allow ECF from (a)(ii)

Award ***[2]*** *for a bald correct answer*

Allow use of $U = \frac{3}{2}pV$

[2 marks]

b.i. p_2 = «$5.3 \times 10^5 \times \frac{2.1\times10^{-4}}{6.8\times10^{-4}}$» 1.6×10^5 «Pa»

[1 mark]

b.ii.«volume has increased and» average velocity/KE remains unchanged

«so» molecules collide with the walls less frequently/longer time between collisions with the walls

«hence» rate of change of momentum at wall has decreased

«and so pressure has decreased»

The idea of average must be included

Decrease in number of collisions is not sufficient for MP2. Time must be included.

Accept atoms/particles.

[2 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
b.i. [N/A]
b.ii. [N/A]

A closed box of fixed volume 0.15 m^3 contains 3.0 mol of an ideal monatomic gas. The temperature of the gas is 290 K.

When the gas is supplied with 0.86 kJ of energy, its temperature increases by 23 K. The specific heat capacity of the gas is 3.1 kJ kg^{-1} K^{-1}.

a. Calculate the pressure of the gas. [1]

b.i. Calculate, in kg, the mass of the gas. [1]

b.ii. Calculate the average kinetic energy of the particles of the gas. [1]

c. Explain, with reference to the kinetic model of an ideal gas, how an increase in temperature of the gas leads to an increase in pressure. [3]

Markscheme

a. «$\frac{3.0\times8.31\times290}{0.15}$»

48 «kPa»

[1 mark]

b.i. mass = «$\frac{860}{3100\times23}$» 0.012 «kg»

*Award **[1]** for a bald correct answer.*

[1 mark]

b.ii. $\frac{3}{2}$ 1.38 × 10^{-23} × 313 = 6.5 × 10^{-21} «J»

[1 mark]

c. larger temperature implies larger (average) speed/larger (average) KE of molecules/particles/atoms

increased force/momentum transferred to walls (per collision) / more frequent collisions with walls

increased force leads to increased pressure because P = F/A (as area remains constant)

Ignore any mention of PV = nRT.

[3 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

This question is about thermal properties of matter.

a. Explain, in terms of the energy of its molecules, why the temperature of a pure substance does not change during melting. [3]

b. 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. [4]

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

a. energy supplied/bonds broken/heat absorbed;

increases potential energy;

no change in kinetic energy (so no change in temperature);

b. use of $M \times 4.2 \times 10^3 \times \Delta\theta$
$ml = 75 \times 10^{-3} \times 3.3 \times 10^5$ / 24750 J;
recognition that melted ice warms and water cools to common final temperature;
3.4°C;

Examiners report

a. [N/A]
b. [N/A]

This question is about internal energy.

(i) Mathilde raises the temperature of water in an electric kettle to boiling point. Once the water is boiling steadily, she measures the change in the mass of the kettle and its contents over a period of time.

The following data are available.

Initial mass of kettle and water = 1.880 kg
Final mass of kettle and water = 1.580 kg
Time between mass measurements = 300 s
Power dissipation in the kettle = 2.5 kW

Determine the specific latent heat of vaporization of water.

(ii) Outline why your answer to (b)(i) is an overestimate of the specific latent heat of vaporization of water.

Markscheme

(i) mass lost in 300 s=(1.880-1.580)=0.3 (kg);

(energy supplied=750 kJ) (do not award credit for this line)

L=2.5 MJ kg^{-1}; *(unit must appear correctly here)*

*Award **[2]** for a bald correct answer.*

(ii) energy will be transferred to surroundings; } *(accept energy is lost by/from kettle to surroundings)*
so calculated energy to water is too large / change in mass too large;
(hence overestimate)
*Award **[0]** for a bald correct answer.*
Treat references to energy gained by kettle as neutral; the kettle is at a constant temperature.

Examiners report

[N/A]

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.

a. 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]

b. Molten zinc cools in an iron mould. [4]

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 $= 12 \text{ kg}$
Mass of zinc $= 1.5 \text{ kg}$
Specific heat capacity of iron $= 440 \text{ J kg}^{-1}\text{K}^{-1}$
Specific latent heat of fusion of zinc $= 113 \text{ kJ kg}^{-1}$
Melting temperature of zinc $= 420 \text{ °C}$

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

Markscheme

a. 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)

b. energy lost by freezing zinc $= 1.5 \times 113000\ (= 170000\ \mathrm{J})$; } *(watch for power of ten error)*

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

energy lost by cooling solid zinc $= 195000\ (\mathrm{J})$;

specific heat capacity of zinc $\frac{195000}{1.5\times[420-89]} = 390\ (\mathrm{J\,kg^{-1}K^{-1}})$;

Award ***[3 max]*** *for an answer of 733 (kJ kg^{-1}K^{-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;

Examiners report

a. Many candidates scored at least two marks on this straightforward recall of material from the syllabus. In weak answers it was not always clear that the statements of energy referred to molecules, atoms or particles in the solid or liquid. There was also confusion as to whether the melting process involved an increase or decrease in potential energy.

b. The calculation was well done by many with substantial numbers of correct answers. A common error was a failure to read the units of specific latent heat of the zinc correctly and thus to incur a power of ten error. This lost some though not all of the marks. Solutions that incurred zero or a low score were characterised by ill-presented and unexplained numbers showing that the candidate had little idea of the correct approach to the problem. Examiners expected the answer to this question to begin with "Energy lost by zinc = energy gained by iron" and to proceed step by step from there.

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.

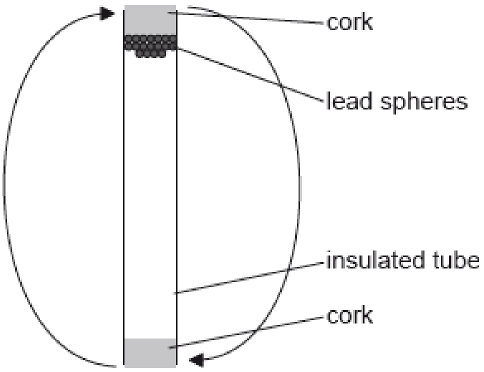
In a nuclear reactor, outline the purpose of the

Fission of one uranium-235 nucleus releases 203 MeV.

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

Part 2 Thermal physics

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.



a. Outline which of the three generation methods above is renewable. [2]

b.i. heat exchanger. [1]

b.ii. moderator. [2]

c.i. Determine the maximum amount of energy, in joule, released by 1.0 g of uranium-235 as a result of fission. [3]

d.i. Describe the main principles of the operation of a pump storage hydroelectric scheme. [3]

d.ii A hydroelectric scheme has an efficiency of 92%. Water stored in the dam falls through an average height of 57 m. Determine the rate of flow of water, in $\mathrm{kg\,s^{-1}}$, required to generate an electrical output power of 4.5 MW. [3]

e. Distinguish between specific heat capacity and specific latent heat. [2]

f.i. Discuss the changes to the energy of the lead spheres. [2]

f.ii. The specific heat capacity of lead is $1.3 \times 10^{2}\ \mathrm{J\,kg^{-1}K^{-1}}$. Deduce the number of times that the tube is turned upside down. [4]

Markscheme

a. pump storage;

renewable as can be replaced in short time scale / storage water can be pumped back up to fall again / source will not run out; } *(do not accept "because water is used")*

b.i. (allows coolant to) transfer thermal/heat (energy) from the reactor/(nuclear) reaction to the water/steam;

Must see reference to transfer – "cooling reactor/heating up water" is not enough.

b.ii. reduces speed/kinetic energy of neutrons; *(do not allow "particles")*

improves likelihood of fission occurring/U-235 capturing neutrons;

c.i. (203 MeV is equivalent to) 3.25×10^{-11} (J);

6.02×10^{23} nuclei have a mass of 235 (g) / evaluates number of nuclei;

$(2.56 \times 10^{21}$ nuclei produce) 8.32×10^{10} (J) / multiplies two previous answers;

*Award **[3]** for bald correct answer.*

*Award **[1]** for correct conversion from eV to J even if rest is incorrect.*

d.i. water flows between water masses/reservoirs at different levels;

flow of water drives turbine/generator to produce electricity;

at off peak times the electricity produced is used to raise water from lower to higher reservoir;

d.ii. use of $\frac{mgh}{t}$;

$\frac{m}{t} = \frac{4.5 \times 10^6}{0.92 \times 9.81 \times 57}$; *(t is usually ignored, assume 1 s if not seen)*

$8.7 \times 10^3\ (\mathrm{kg\,s^{-1}})$;

*Award **[3]** for a bald correct answer.*

e. specific heat capacity is/refers to energy required to change the temperature (without changing state);

specific latent heat is energy required to change the state/phase without changing the temperature;

If definitions are given they must include salient points given above.

f.i. gravitational potential energy → kinetic energy;

kinetic energy → internal energy/thermal energy/heat energy;

Do not allow heat.

Two separate energy changes must be explicit.

f.ii. use of $mc\Delta T$;

use of $n \times mg\Delta h$;

equating $(c\Delta T = ng\Delta h)$;

236 ***or*** 240;

or

use of $\Delta U = mc\Delta T$;

$(0.22 \times 1.3 \times 10^2 \times 8 =)\ 229\ (\mathrm{J})$;

$n \times mg\Delta h = 229\ (\mathrm{J})$;

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

*Award **[4]** for a bald correct answer.*

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
[N/A]

d.ii.[N/A]

e. The essential difference between specific heat capacity and specific latent heat is that the former refers to a change of temperature without changing state; whereas the latter refers to a change of state without changing temperature. Most candidates just wrote definitions which they had learnt by rote – and omitted the constant temperature for a substance changing state.

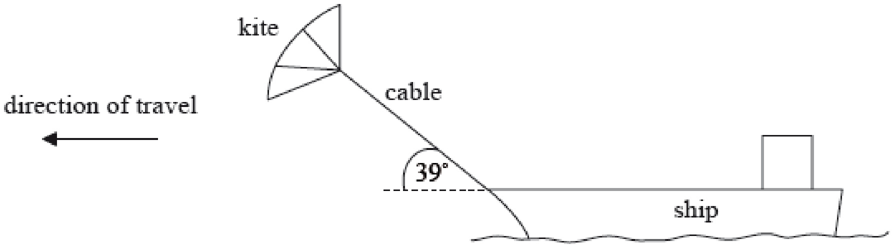
f.i. This is a question specifically about energy changes so candidates are expected to use accurate language and spell out the changes one by one. Common mistakes were omitting the “gravitational” in gravitational potential energy; referring to “heat” rather than thermal energy; and saying that gravitational potential energy changed to thermal and kinetic energy as if it were a single process.

f.ii. This was generally well done. There were four marks and the question asks the candidates to “deduce” so it is essential that the argument is transparent. The examiner cannot be expected to search through a mass of numbers in order to carry forward an error.

This question is in **two** parts. **Part 1** is about the motion of a ship. **Part 2** is about melting ice.

Part 1 Motion of a ship

Some cargo ships use kites working together with the ship’s engines to move the vessel.



The tension in the cable that connects the kite to the ship is 250 kN. The kite is pulling the ship at an angle of 39° to the horizontal. The ship travels at a steady speed of $8.5\ \mathrm{m\,s^{-1}}$ when the ship’s engines operate with a power output of 2.7 MW.

The ship’s engines are switched off and the ship comes to rest from a speed of $7\ \mathrm{m\,s^{-1}}$ in a time of 650 s.

Part 2 Melting ice

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.

a. Outline the meaning of work. [2]

b.i. Calculate the work done on the ship by the kite when the ship travels a distance of 1.0 km. [2]

b.ii. Show that, when the ship is travelling at a speed of $8.5\ \mathrm{m\,s^{-1}}$, the kite provides about 40% of the total power required by the ship. [4]

c. The kite is taken down and no longer produces a force on the ship. The resistive force F that opposes the motion of the ship is related to the speed v of the ship by [3]

$$F = kv^2$$

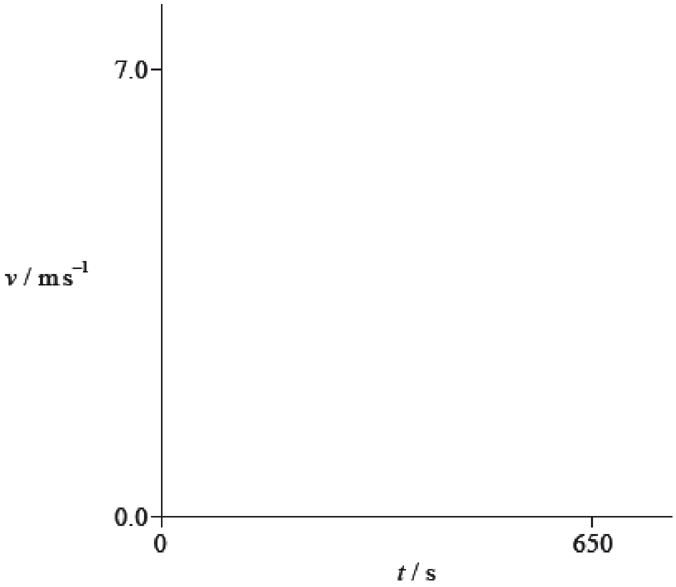
where k is a constant.

Show that, if the power output of the engines remains at 2.7 MW, the speed of the ship will decrease to about $7\ \mathrm{m\,s^{-1}}$. Assume that k is independent of whether the kite is in use or not.

d.i. Estimate the distance that the ship takes to stop. Assume that the acceleration is uniform. [2]

d.ii. It is unlikely that the acceleration of the ship will be uniform given that the resistive force acting on the ship depends on the speed of the ship. [2]

Using the axes, sketch a graph to show how the speed v varies with time t after the ship's engines are switched off.



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

f.i. 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]

f.ii. The following data are available. [3]

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

Specific latent heat of fusion of ice $= 3.30 \times 10^5\ \mathrm{J\,kg^{-1}}$

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

g. 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]

Markscheme

a. $\text{work done} = \text{force} \times \text{distance moved;}$

(distance moved) in direction of force;

or

energy transferred;

from one location to another;

or

work done $= Fs\cos\theta$;

with each symbol defined;

b.i. horizontal force $= 250\,000 \times \cos 39° \ (= 1.94 \times 10^5\ \text{N})$;

work done $= 1.9 \times 10^8\ \text{J}$;

b.ii. power provided by kite $= (1.94 \times 10^5 \times 8.5 =)\ 1.7 \times 10^6\ \text{W}$;

total power $= (2.7 + 1.7) \times 10^6\ \text{W}\ (= 4.4 \times 10^6\ \text{W})$;

fraction provided by kite $= \frac{1.7}{2.7+1.7}$;

38% ***or*** 0.38; *(must see answer to 2+ sig figs as answer is given)*

Allow answers in the range of 37 to 39% due to early rounding.

or

*Award **[3 max]** for a reverse argument such as:*

if 2.7 MW is 60%;

then kite power is $\frac{2}{3} \times 2.7\ \text{MW} = 1.8\ \text{MW}$;

shows that kite power is actually 1.7 MW; *(QED)*

c. $P = (kv^2) \times v = kv^3$;

$\frac{v_1}{v_2} = \left(\sqrt[3]{\left(\frac{P_1}{P_2}\right)} =\right) \sqrt[3]{\left(\frac{7.7}{4.4}\right)}$;

final speed of ship $= 7.2\ \text{m s}^{-1}$; *(at least 2 sig figs required).*

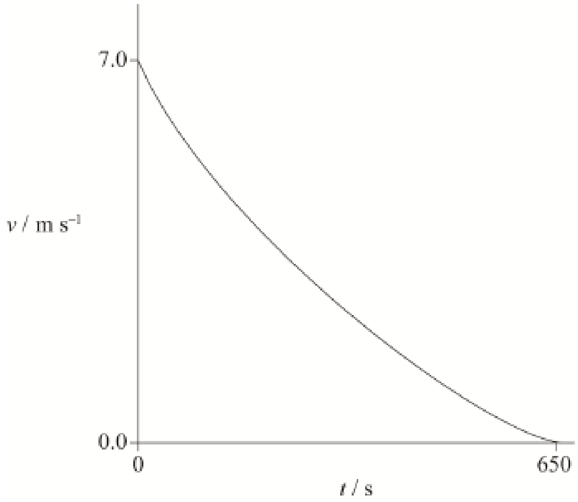
Approximate answer given, marks are for working only.

d.i. correct substitution of 7 or 7.2 into appropriate kinematic equation;

an answer in the range of 2200 to 2400 m;

d.ii. starts at $7.0/7.2\ \text{m s}^{-1}$; *(allow ECF from (d)(i))*

correct shape;



e. 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;

f.i. $(Q =)\ 45.0 \times 125\ (= 5625\ \mathrm{J})$;

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

f.ii. $\text{energy available} = 125 \times 600\ (= 75000\ \mathrm{J})$;

$\text{energy available to warm the water} = 75000 - [0.15 \times 3.3 \times 10^5]\ (= 25500\ \mathrm{J})$;

$\text{temperature} = \left(\frac{25500}{0.15 \times 4200} =\right) 40.5^\circ\mathrm{C}$;

g. 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;

Examiners report

a. [N/A]

b.i. [N/A]

b.ii. This is a “show that” question which means that the candidate is obliged to show their line of reasoning. Very few SL candidates did this.

c. This was easy using proportionality, but most candidates at SL attempted to calculate k unnecessarily. Even so there were many correct answers.

d.i. [N/A]

d.ii. [N/A]

e. A minority of candidates knew that molecules made a transition from being localised to being free to migrate, but had difficulty expressing their answers coherently. Candidates are so used to commenting on the energy transformations when ice melts, that many completely misread the question.

f.i. Many good answers, although those that did not get the correct answers presented their working in such a way that part marks (ECF) were not able to be given.

f.ii. Many good answers, although those that did not get the correct answers presented their working in such a way that part marks (ECF) were not able to be given.

g. The significance of the temperature of the surroundings was ignored by nearly all candidates, but most were able to obtain 2 marks for suggesting that thermal energy would be lost to the surroundings causing a lower final temperature.

This question is about the use of energy resources.

Electrical energy is obtained from tidal energy at La Rance in France.

Water flows into a river basin from the sea for six hours and then flows from the basin back to the sea for another six hours. The water flows through turbines and generates energy during both flows.

The following data are available.

Area of river basin $= 22\ \mathrm{km}^2$

Change in water level of basin over six hours $= 6.0\ \mathrm{m}$

Density of water $= 1000\ \mathrm{kg\,m^{-3}}$

Nuclear reactors are used to generate energy. In a particular nuclear reactor, neutrons collide elastically with carbon-12 nuclei $\left({}^{12}_{6}\mathrm{C}\right)$ that act as the moderator of the reactor. A neutron with an initial speed of $9.8 \times 10^6\ \mathrm{m\,s^{-1}}$ collides head-on with a stationary carbon-12 nucleus. Immediately after the collision the carbon-12 nucleus has a speed of $1.5 \times 10^6\ \mathrm{m\,s^{-1}}$.

a. State the difference between renewable and non-renewable energy sources. [1]

b. (i) The basin empties over a six hour period. Show that about $6000\ \mathrm{m}^3$ of water flows through the turbines every second. [10]

(ii) Show that the average power that the water can supply over the six hour period is about 0.2 GW.

(iii) La Rance tidal power station has an energy output of $5.4 \times 10^8\ \mathrm{kW\,h}$ per year. Calculate the overall efficiency of the power station. Assume that the water can supply 0.2 GW at all times.

Energy resources such as La Rance tidal power station could replace the use of

fossil fuels. This may result in an increase in the average albedo of Earth.

(iv) State **two** reasons why the albedo of Earth must be given as an average value.

d. (i) State the principle of conservation of momentum. [10]

(ii) Show that the speed of the neutron immediately after the collision is about $8.0 \times 10^6\ \mathrm{m\,s^{-1}}$.

(iii) Show that the fractional change in energy of the neutron as a result of the collision

is about 0.3.

(iv) Estimate the minimum number of collisions required for the neutron to reduce its initial energy by a factor of 10^6.

(v) Outline why the reduction in energy is necessary for this type of reactor to function.

Markscheme

a. only non-renewable is depleted/cannot re-generate whereas renewable can / consumption rate of non-renewables is greater than formation rate and consumption rate of renewables is less than formation rate;

Do not allow "cannot be used again".

b. (i) volume released = $(22 \times 10^6 \times 6 =)\ 1.32 \times 10^8\ (\mathrm{m}^3)$;

volume per second $\frac{1.32\times10^8}{6\times3600}\ (= 6111\ \mathrm{m}^3)$;

(ii) use of average depth for calculation (3 m);

gpe lost $6100 \times 1000 \times 9.81 \times 3$;

0.18 (GW);

Accept g = 10 m s^{–2}.

*Award **[1 max]** if 6 m is used and an "average" is used at end of solution without mention of average depth.*

(iii) converts/states output with units; } *(allow values quoted from question without unit)* converts/states input with units; } *(allow values quoted from question without unit)*

calculates efficiency from $\frac{\text{output}}{\text{input}}$ as 0.31;

*Award **[3]** for bald correct answer.*

eg:

power output $\frac{5.4\times10^8}{365\times24\times3600}$ $(= 17\ \text{kW h s}^{-1})$;

$= 17 \times 3600000 = 6.16 \times 10^7\ (\text{W})$;

efficiency = $\left(\frac{6.16\times10^7}{2.0\times10^8} =\right)$ 31% ***or*** 0.31;

or

0.2 GW is $1.752 \times 10^9\ (\text{kW h year}^{-1})$;

$\frac{5.4\times10^8}{1.752\times10^9}$;

efficiency $= 0.31$;

(iv) cloud cover / weather conditions;

latitude;

time of year / season;

nature/colour of surface;

d. (i) (total) momentum unchanged before and after collision / momentum of a system is constant; } *(allow symbols if explained)*

no external forces / isolated system / closed system;

Do not accept "conserved".

(ii) final momentum of neutron $=$ neutron mass $\times 9.8 \times 10^6 - 1\text{u} \times 12 \times 1.5 \times 10^6$; } *(allow any appropriate and consistent mass unit)*

final speed of neutron $= 8.0$ ***or*** $8.2 \times 10^6\ (\text{m s}^{-1})$;

$(\approx 8.0 \times 10^6\ (\text{m s}^{-1}))$

Allow use of 1 u for both masses giving an answer of 8.2 × 10^6 *(m s*$^{-1}$*).*

(iii) initial energy of neutron $= 8.04 \times 10^{-14}\ (\text{J})$ and final energy of neutron $= 5.36 \times 10^{-14}\ (\text{J})$; } *(both needed)*

fractional change in energy $= \left(\frac{(8.04-5.36)}{8.04} =\right)$ 0.33;

or

fractional change $= \left(\frac{\frac{1}{2}mv_i^2-\frac{1}{2}mu_f^2}{\frac{1}{2}mv_i^2}\right)$; }*(allow any algebra that shows a subtraction of initial term from final term divided by initial value)*

$\left(= \frac{(9.8\times10^6)^2-(8.0\times10^6)^2}{(9.8\times10^6)^2}\right)$ *(allow omission of 10*^{6}*)*

$= 0.33$; *(allow 0.30 if 8.2 used)*

Do not allow ECF if there is no subtraction of energies in first marking point.

(iv) $(0.33)^n = 10^{-6}$;

$n = 13$; *(allow n = 12 if 0.3 is used)*

(v) neutrons produced in fission have large energies;

greatest probability of (further) fission/absorption (when incident neutrons have thermal energy or low energy);

Do not accept "reaction" for "fission reaction".

Examiners report

a. Many candidates continue to give weak responses to questions in which they are asked to compare renewable and non-renewable resources. Although the “it cannot be used again” answer has largely disappeared, many candidates still fail to appreciate that the issue is about the rate at which the resource can be replaced.

b. (i) This was often well done, although occasional recourse was made to inappropriate physics (see bii). Candidates should note that in questions where the final answer is quoted (typically “Show that …..” questions) candidates are strongly advised to quote answers to one more significant figure than in the question.

(ii) The rare candidate who understood the physics here was able to give a clear account of the solution. Many failed to spot the factor of a half in the water level change and introduced a factor of two later and arbitrarily. Others completely misunderstood the (simple) nature of the problem and used a random equation from the data booklet (usually $1/3\rho Av^3$). This of course gained no marks. A simple initial diagram would have helped many to avoid errors.

(iii) As in question 1 there were far too many candidates who clearly do not understand and have not practised the problem of converting between energy units. Effective use of units would have made this an easy calculation. Explanations were few and candidates were clearly struggling with this aspect of energy.

(iv) Many candidates were able to give one coherent reason but two distinct answers were rare.

d. (i) As is often the case with this question, candidates state that “momentum is conserved” and fail to explain what this means. There was much confusion with energy conservation rules.

(ii) Calculations of the final speed of the neutron were confused with little or no explanation of the equations. It was often not clear what mass values (if any) were being used in the solution.

(iii) There were few clear solutions to this problem. Some candidates did not appreciate the meaning of fractional energy change and others were still travelling along the momentum route from an earlier part, scoring few, if any, marks.

(iv) Candidates had evidently not considered the mechanical issues of moderation in their learning. There was little recognition that the change in fractional energy is 0.33n where n is the number of collisions. The most frequent answer was that the change is 0.33n.

(v) There was more clarity about the reasons for moderation but even so, answers were poorly expressed. Only a minority recognised that the probability of absorption is greatest at low neutron incident energy.

This question is in **two** parts. **Part 1** is about a lightning discharge. **Part 2** is about fuel for heating.

Part 1 Lightning discharge

The magnitude of the electric field strength E between two infinite charged parallel plates is given by the expression

$$E = \frac{\sigma}{\varepsilon_0}$$

where σ is the charge per unit area on one of the plates.

A thundercloud carries a charge of magnitude 35 C spread over its base. The area of the base is $1.2 \times 10^7\ \mathrm{m}^2$.

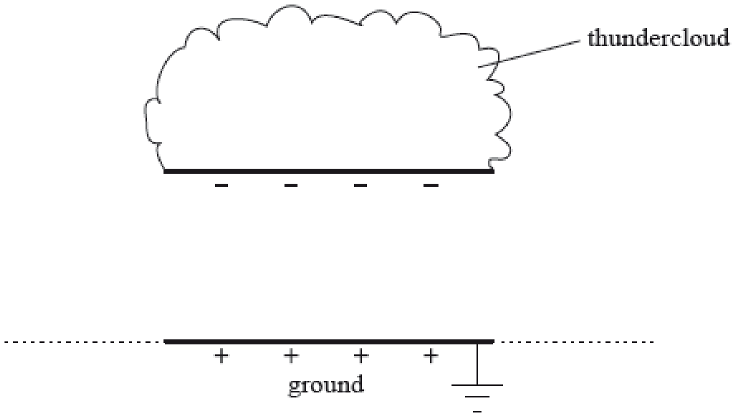
Part 2 Fuel for heating

A room heater burns liquid fuel and the following data are available.

Density of liquid fuel	$= 8.0 \times 10^2\ \mathrm{kg\,m^{-3}}$
Energy produced by $1\ \mathrm{m^3}$ of liquid fuel	$= 2.7 \times 10^{10}\ \mathrm{J}$
Rate at which fuel is consumed	$= 0.13\ \mathrm{g\,s^{-1}}$
Latent heat of vaporization of the fuel	$= 290\ \mathrm{kJ\,kg^{-1}}$

Part 1.a. Define *electric field strength*. [2]

Part 1.b. A thundercloud can be modelled as a negatively charged plate that is parallel to the ground. [3]



The magnitude of the charge on the plate increases due to processes in the atmosphere. Eventually a current discharges from the thundercloud to the ground.

On the diagram, draw the electric field pattern between the thundercloud base and the ground.

Part 1.c. (i) Determine the magnitude of the electric field between the base of the thundercloud and the ground. [12]

(ii) State **two** assumptions made in (c)(i).

1.

2.

(iii) When the thundercloud discharges, the average discharge current is 1.8 kA. Estimate the discharge time.

(iv) The potential difference between the thundercloud and the ground before discharge is $2.5 \times 10^8\ \mathrm{V}$. Determine the energy released in the discharge.

Part 2.a. Define the *energy density* of a fuel. [1]

Part 2.b. (i) Use the data to calculate the power output of the room heater, ignoring the power required to convert the liquid fuel into a gas. [5]

(ii) Show why, in your calculation in (b)(i), the power required to convert the liquid fuel into a gas at its boiling point can be ignored.

Part 2.c. State, in terms of molecular structure and their motion, **two** differences between a liquid and a gas. [2]

1.

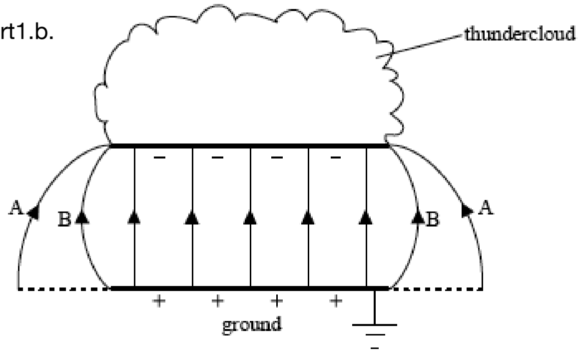
2.

Markscheme

Part 1.a. force acting per unit charge;

on positive test / point charge;

Part1.b.



lines connecting plate and ground equally spaced in the central region of thundercloud <u>and</u> touching both plates; *(judge by eye)*

edge effects shown; *(accept either edge effect A or B shown on diagram)*

field direction correct;

Part1.c. (i) $\sigma = \left(\frac{35}{1.2\times10^{7}} =\right)\ 2.917\times10^{-6}\ (\mathrm{C\,m^{-2}})$;

$E = \frac{2.917\times10^{-6}}{8.85\times10^{-12}}$;

$= 3.3\times10^{5}\ \mathrm{N\,C^{-1}}$ ***or*** $\mathrm{V\,m^{-1}}$;

*Award **[3]** for bald correct answer.*

(ii) edge of thundercloud parallel to ground;

thundercloud and ground effectively of infinite length;

permittivity of air same as vacuum;

(iii) $t = \frac{Q}{I}$;

$t = \frac{35}{1800}$;

$= 20\ \mathrm{m\,s}$;

(iv) use of energy $=$ p.d. $\times$ charge;

average p.d. $= 1.25\times10^{8}\ (\mathrm{V})$;

energy released $= 1.25\times10^{8}\times35$;

$= 4.4\times10^{9}\ \mathrm{J}$;

*Award **[3 max]** for 8.8 GJ if average p.d. point omitted.*

Accept solution which uses average current $\left(from\frac{charge}{time}\right)$.

Allow ecf from (c)(ii).

Part2.a. energy (released) per unit mass;

Accept per unit volume or per kg or per m^3.

Do not accept per unit density.

Part2.b. (i) volume of fuel used per second $= \frac{\text{rate}}{\text{density}}\ \left(= 1.63\times10^{-7}\ (\mathrm{m^3})\right)$;

energy $= 2.7\times10^{10}\times1.63\times10^{-7}$;

$= (4.3875 =)\ 4.4\ \mathrm{kW}$;

*Award **[3]** for bald correct answer.*

(ii) power required $= (2.9\times10^{5}\times0.13\times10^{-3} =)\ 38\ \mathrm{W}$;

small fraction/less than 1% of overall power output / *OWTTE*;

Part2.c. sensible comment comparing molecular structure;

e.g. liquid molecular structure (more) ordered than that of a gas.

in gas molecules far apart/about 10 molecular spacings apart / in liquid molecules close/touching.

sensible comment comparing motion of molecules;

e.g. in liquid: molecules interchange places with neighbouring molecules / no long distance motion.
in gases: no long-range order / long distance motion.

Examiners report

Part 1.a. Many omitted the reference to a test charge that is positive.

Part 1.b. Common errors were to draw the field lines in the wrong direction, to omit edge effects, and to fail to draw field lines that touch the plates.

Part 1.c. (i) This part was well done.

(ii) Most candidates could only identify one assumption made in the calculation.

(iii) The estimation of discharge time was well done.

(iv) There was a general failure to recognise that the average pd during the discharge is half the maximum (starting) value and this lost a mark.

Part 2.a. A handful of candidates defined energy density as energy converted per unit density, but most gave energy released per unit mass with a minority quoting energy released per unit volume.

Part 2.b. (i) Again, this was done well by the majority with the usual smattering of significant figure penalties and mistakes in handling powers of ten.

(ii) Arguments were weak and poorly supported by calculation.

Part 2.c. Candidates found great difficulty in stating the differences between liquids and gases. They often focused on either molecular structure or motion, but not both as required in the question.

Part 2 Melting of the Pobeda ice island

a. The Pobeda ice island forms regularly when icebergs run aground near the Antarctic ice shelf. The “island”, which consists of a slab of pure ice, breaks apart and melts over a period of decades. The following data are available. [8]

Typical dimensions of surface of island = 70 km × 35 km
Typical height of island = 240 m
Average temperature of the island = –35°C
Density of sea ice = 920 kg m^{-3}
Specific latent heat of fusion of ice = 3.3×10^{5}J kg^{-1}
Specific heat capacity of ice = 2.1×10^{3}J $kg^{-1}K^{-1}$

(i) Distinguish, with reference to molecular motion and energy, between solid ice and liquid water.

(ii) Show that the energy required to melt the island to form water at 0°C is about 2×10^{20}J. Assume that the top and bottom surfaces of the island are flat and that it has vertical sides.

(iii) The Sun supplies thermal energy at an average rate of 450 W m^{-2} to the surface of the island. The albedo of melting ice is 0.80. Determine an estimate of the time taken to melt the island assuming that the melted water is removed immediately and that no heat is lost to the surroundings.

b. Suggest the likely effect on the average albedo of the region in which the island was floating as a result of the melting of the Pobeda ice island. [2]

Markscheme

a. (i) in water, molecules are able to move relative to other molecules, less movement possible in ice / in water, vibration and translation of molecules possible, in ice only vibration;

in liquid there is sufficient energy/vibration (from latent heat) to break and re-form inter-molecular bonds;

(ii) mass of ice=70000×35000×240×920(=5.4×10^{14}kg);
energy to raise ice temperature to 0°C=$5.4\times10^{14}\times2.1\times10^{3}\times35$(= 3.98×10^{19}J);
energy to melt ice=$5.4\times10^{14}\times3.3\times10^{5}$(=$1.8\times10^{20}$J);
total= 2.2×10^{20}J

(iii) energy incident=450×70000×35000(=1.1×10^{12}Js^{-1}m^{-2});
energy available for melting=$1.1\times10^{12}\times0.2$(=$2.2\times10^{11}$J);
time $=\left(\frac{2.2\times10^{20}}{2.2\times10^{11}}=\right)9.9\times10^{8}\mathrm{s}$ ***or*** 32 years;

b. average albedo of ocean much smaller than (snow and) ice;

so average albedo (of Earth) is reduced;

Examiners report

a. [N/A]
b. [N/A]

In an experiment to determine the specific latent heat of fusion of ice, an ice cube is dropped into water that is contained in a well-insulated calorimeter of negligible specific heat capacity. The following data are available.

Mass of ice cube = 25g
Mass of water = 350g
Initial temperature of ice cube = 0°C
Initial temperature of water = 18°C
Final temperature of water = 12°C
Specific heat capacity of water = 4200Jkg^{-1}K^{-1}

a. Using the data, estimate the specific latent heat of fusion of ice. [4]

b. The experiment is repeated using the same mass of crushed ice. [2]

Suggest the effect, if any, of crushing the ice on

(i) the final temperature of the water.

(ii) the time it takes the water to reach its final temperature.

Markscheme

a. use of $m\times c\times\theta$ with correct substitution for either original water or water from melted ice

energy available to melt ice = «8820 – 1260 =» 7560 J

equates 7560 to mL

3.02×10^{5}Jkg^{-1}

FOR EXAMPLE
0.35 × 4200 × (18 – 12) ***OR*** 0.025 × 4200 × 12
7560 J
$L=\frac{7560}{0.025}$
3.02×10^5 Jkg^{-1}

*Award **[3 max]** if energy to warm melted ice as water is ignored (350kJkg^{-1}).*

Allow ECF in MP3.

b. (i)

no change in temperature/no effect, the energies exchanged are the same

(ii)

the time will be less/ice melts faster, because surface area is greater ***or*** crushed ice has more contact with water

Examiners report

a. [N/A]
b. [N/A]

Part 2 Internal energy

Humans generate internal energy when moving, while their core temperature remains approximately constant.

a. Distinguish between the concepts of internal energy and temperature. [3]

c. An athlete loses 1.8 kg of water from her body through sweating during a training session that lasts one hour. [2]

Estimate the rate of energy loss by the athlete due to sweating. The specific latent heat of evaporation of water is 2.3×10^6 J kg^{-1}.

Markscheme

a. *internal energy:*

total energy of component particles (in the human);

comprises potential energy + (random) kinetic energy;

temperature:
measure of average kinetic energy of particles;
indicates direction of (natural) flow of thermal energy;
internal energy measured in J and temperature measured
in K/°C ; *(both needed)*
(accept alternative suitable units)

c. total energy lost$=2.3\times10^6\times1.8(=4.14\times10^6\text{J})$;

1.2 kW;

Examiners report

[N/A]

a. [N/A]

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

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

b. 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. [4]

(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)

c. At the temperature of 350 K, the piston in (b) is now freed and the argon expands until its temperature reaches 300 K. [3]

Explain, in terms of the molecular model of an ideal gas, why the temperature of argon decreases on expansion.

Markscheme

a. 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;

b. (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 = 0.040kg ;
specific heat = $\frac{Q}{m\Delta T}$ ***or*** 620 = 0.04×c×50;
(i.e. correctly aligns substitution with equation)
$= \left(\frac{620}{0.040\times 50} =\right) 310\text{Jkg}^{-1}\text{K}^{-1};$

c. 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.

Examiners report

a. Many could only give one sensible assumption of the ideal gas kinetic model. It was very common to see the bald statement that there are no interatomic forces between the molecules. Candidates failed to give the proviso that this is not true during the collisions between molecules and with the walls of the container. Some candidates tried unsuccessfully to convince examiners that the empirical gas laws are in themselves assumptions.

b. (i) Many could either define the mole of argon in terms of 12 g of carbon-12 or in terms of a correctly stated Avogadro number. Either was acceptable if clear.

(ii) Although almost all were able to identify the starting point for the calculation of the specific heat capacity of argon, a very common error was to forget that the molar mass is quoted in grams not kilograms. It was therefore common to see answers that were 1000 times too small.

c. Explanations for the decrease in temperature of the gas on expansion were weak. The key to the explanation is that, at the molecular level, temperature is a measure of the average kinetic energy of the particles. This was often missing from the answers..

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.

a. Define *specific heat capacity.* [2]

b. The following data are available. [5]

Mass of water = 0.35 kg
Mass of iron = 0.58 kg
Specific heat capacity of water = 4200 J $\text{kg}^{-1}\text{K}^{-1}$
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

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

of mass 1 kg / per unit mass;

b. (i) use of $mc\Delta T$;

$0.58 \times c \times [180-44] = 0.35 \times 4200 \times [44-20]$;

$c = 447 \text{Jkg}^{-1}\text{K}^{-1} \approx 450 \text{Jkg}^{-1}\text{K}^{-1}$;

(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;

Examiners report

a. [N/A]
b. [N/A]

---

a. Define *internal energy.* [2]

b. 0.46 mole of an ideal monatomic gas is trapped in a cylinder. The gas has a volume of 21 m^3 and a pressure of 1.4 Pa. [4]

(i) State how the internal energy of an ideal gas differs from that of a real gas.

(ii) Determine, in kelvin, the temperature of the gas in the cylinder.

(iii) The kinetic theory of ideal gases is one example of a scientific model. Identify **one** reason why scientists find such models useful.

Markscheme

a. mention of atoms/molecules/particles

sum/total of kinetic energy and «mutual/intermolecular» potential energy

Do not allow "kinetic energy and potential energy" bald.
Do not allow "sum of average ke and pe" unless clearly referring to total ensemble.

b. i

«intermolecular» potential energy/PE of an ideal gas is zero/negligible

ii
THIS IS FOR USE WITH AN ENGLISH SCRIPT ONLY
use of $T = \frac{PV}{nR}$ ***or*** $T = \frac{1.4 \times 21}{0.46 \times 8.31}$

Award mark for correct re-arrangement as shown here not for quotation of Data Booklet version.
*Award **[2]** for a bald correct answer in K.*
*Award **[2 max]** if correct 7.7 K seen followed by –265°C and mark BOD. However, if only –265°C seen, award **[1 max]**.*

7.7 K
Do not penalise use of "°K"

ii
THIS IS FOR USE WITH A SPANISH SCRIPT ONLY
$T = \frac{PV}{nR}$

$T = \frac{1.4 \times 2.1 \times 10^{-6}}{0.46 \times 8.31}$

T = 7.7 $\times 10^{-6}$ K
Award mark for correct re-arrangement as shown here not for quotation of Data Booklet version.
Uses correct unit conversion for volume
*Award **[2]** for a bald correct answer in K. Finds solution. Allow an ECF from MP2 if unit not converted, ie candidate uses 21 m3 and obtains 7.7 K*
Do not penalise use of "°K"

iii
models used to predict/hypothesize

explain

simulate

simplify/approximate

Allow similar responses which have equivalent meanings. Response needs to identify ***one*** *reason.*

Examiners report

a. [N/A]
b. [N/A]

This question is about internal energy and thermal energy (heat).

a. Distinguish between internal energy and thermal energy. [3]

b. Describe, with reference to the energy of the molecules, the difference in internal energy of a piece of iron and the internal energy of an ideal gas. [2]

c. A piece of iron is placed in a kiln until it reaches the temperature θ of the kiln. The iron is then quickly transferred to water held in a thermally insulated container. The water is stirred until it reaches a steady temperature. The following data are available. [4]

Thermal capacity of the piece of iron = 60JK^{-1}
Thermal capacity of the water = $2.0\times10^3 \text{JK}^{-1}$
Initial temperature of the water = 16°C
Final temperature of the water = 45°C

The thermal capacity of the container and insulation is negligible.

(i) State an expression, in terms of θ and the above data, for the energy transfer of the iron in cooling from the temperature of the kiln to the final temperature of the water.

(ii) Calculate the increase in internal energy of the water as the iron cools in the water.

(iii) Use your answers to (c)(i) and (c)(ii) to determine θ.

Markscheme

a. internal energy is the total kinetic and potential energy <u>of the molecules</u> of a body;

thermal energy is a (net) amount of energy transferred between two bodies;

at different temperatures;

b. the internal energy of the iron is equal to the total KE plus PE of the molecules; the molecules of an ideal gas have only KE so internal energy is the total KE of the molecules;

c. (i) $60\times[\theta-45]$;

(ii) $(2.0\times10^3\times29)=5.8\times10^4$J;

(iii) $60\times[\theta-45]=5.8\times10^4$;
$\theta=1000$°C; (*allow 1010°C to 3 sig fig*)

Examiners report

a. Few could repeat the Subject Guide definition of internal energy and relate it to that of the molecules or atoms of the substance under discussion. Understanding of thermal energy was very limited with a widespread failure to describe it in terms of transferred energy. Candidates evidently struggle with this concept.

b. The distinction between internal energy of a solid and an ideal gas is not well understood by candidates. The emphasis is on the word “ideal” where no potential energy issues arise. Candidates were poor in their descriptions and explanations.

c. The three sub-sections of this question led towards a determination of the final energy when iron at high temperature is added to cold water in a container. There was confusion over both units and ideas. In (i) both K and °C appeared, in (ii) many answers of 29°C were presented for the increase in the internal energy of the water, and in (iii) there were further errors in temperature units and significant errors. Only about half the candidates were able to work towards a full answer in (iii).

Part 2 Thermal concepts

a. Distinguish between internal energy and thermal energy (heat). [2]

Internal energy:

Thermal energy:

b. 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 4.2×10^3J $\text{kg}^{-1}\text{K}^{-1}$. [4]

(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.

c. The water in (b) is further heated until it starts to boil at constant temperature. It is boiled for 500s measured from the time that it first starts to boil. The mass of water remaining after this time is 0.20kg. [5]

(i) Estimate, using the answer to (b)(ii), the specific latent heat of vaporization of the water.

(ii) Explain, in terms of the energy of the molecules of the water, why the water boils at constant temperature.

Markscheme

a. *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;

b. (i) $(\Delta U)=0.25\times4.2\times10^3\times27(=2.835\times10^4\text{J})$;

$=2.8\times10^4$(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=[300×120] – [2.835×10^4]=7.65×10^3 (J);

rate of transfer=$\frac{7.650\times10^3}{120} = 64\,(\mathrm{W})$;

Allow ECF from (b)(i).

*Award **[1 max]** for* $\frac{(b)(i)answer}{120}$ *where answer omits 300×120 term, however only allow this if 120 is seen. Award **[0]** for other numerators and denominators.*

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

c. (i) total energy supplied to water=(500×300–500×64=)1.18×10^5(J) ;

specific latent heat= $\left(\frac{Q}{m} = \frac{1.18\times10^5}{0.05} =\right) 2.4\times10^6\mathrm{Jkg}^{-1}$;

*Award **[1 max]** for* $\frac{500\times \mathrm{answerto(b)(ii)}}{0.05}$.

(ii) all the thermal energy is used to separate the molecules/break the bonds between molecules; and not to increase their (average) kinetic energy; average kinetic energy is a measure of the temperature (of the water);

Examiners report

a. There was a widespread failure to respond to the command term. “Distinguish” implies some type of comparison but often candidates simply gave definitions (which could in this mark scheme attract full credit). However, only a few received two marks. Explanations of the meaning for thermal energy were weak and usually failed to make clear the need for a temperature difference in the transfer of the energy.

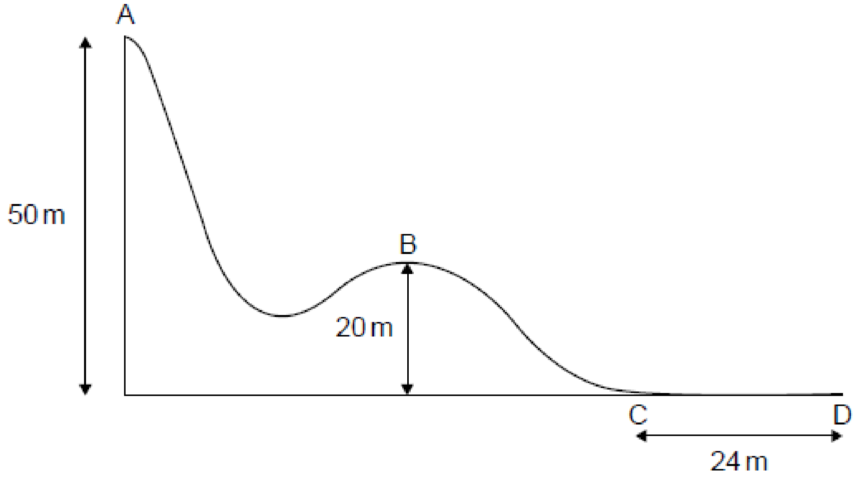
b. (i) Many were able to access both marks, but some lost credit by then inserting an extra final step and going part way to the solution to (ii). As these candidates did not fully understand what was meant by “change in internal energy” they could not achieve full marks for this part question.

(ii) This part question was more poorly done than (i). Incorrect solutions included: failures to subtract the 28 kJ arrived at in (b)(i), and incorrect arithmetic.

c. (i) This was poorly done with most candidates unable to calculate the mass of water that had been vaporized.

(ii) The part question invites the candidates to consider the energy of the molecules and to link this to the constant temperature of the boiling water. Responses were mostly unfocussed with few candidates able to put forward a logical or clearly articulated explanation.

The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

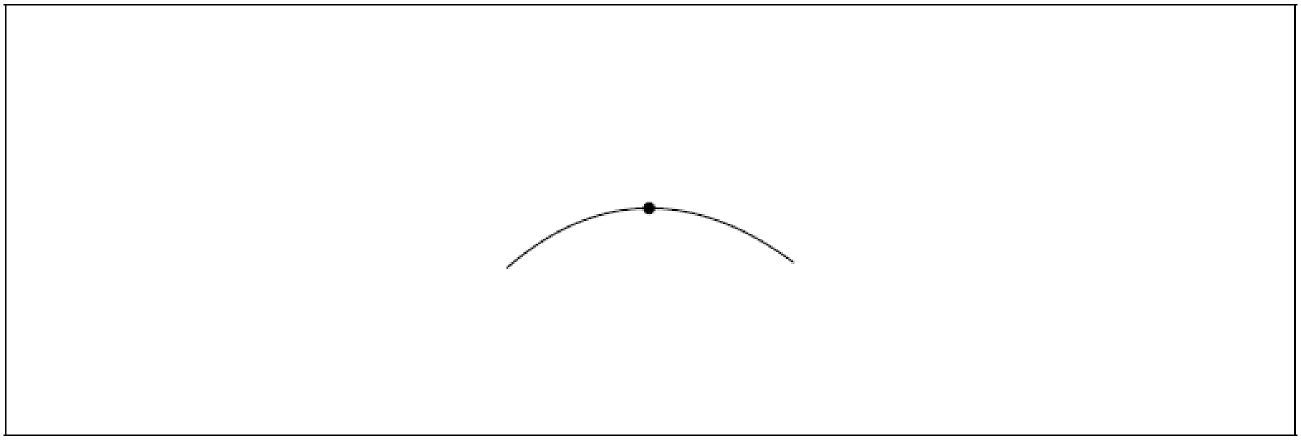
At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 m s^{-1}.

a.i. From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 m s^{-1}. [2]

a.ii. Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature. [2]

b.i. The dot on the following diagram represents the skier as she passes point B. [2]

Draw and label the vertical forces acting on the skier.



b.ii. The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B. [3]

c. The skier reaches point C with a speed of 8.2 m s^{-1}. She stops after a distance of 24 m at point D. [3]

Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

d.i. Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. [2]

d.ii. Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier. [2]

Markscheme

a.i. $\frac{1}{2}v^2 = 0.24\,\mathrm{gh}$

$v = 11.9$ «m s^{-1}»

Award GPE lost = 65 × 9.81 × 30 = «19130 J»

Must see the 11.9 value for MP2, not simply 12.

Allow g = 9.8 ms^{-2}.

a.ii. internal energy is the total KE «and PE» of the molecules/particles/atoms in an object

temperature is a measure of the average KE of the molecules/particles/atoms

*Award **[1 max]** if there is no mention of molecules/particles/atoms.*

b.i. arrow vertically downwards from dot labelled weight/W/mg/gravitational force/F_g/$F_{gravitational}$ ***AND*** arrow vertically upwards from dot labelled reaction force/R/normal contact force/N/F_N

W > R

Do not allow gravity.
Do not award MP1 if additional 'centripetal' force arrow is added.
Arrows must connect to dot.
Ignore any horizontal arrow labelled friction.
Judge by eye for MP2. Arrows do not have to be correctly labelled or connect to dot for MP2.

b.ii ***ALTERNATIVE 1***

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen

= 468 «N»

W/640 N (weight) is larger than the centripetal force required, so the skier does not lose contact with the ground

ALTERNATIVE 2

recognition that centripetal acceleration is required / $\frac{v^2}{r}$ seen

$a = 7.2$ «ms^{-2}»

g is larger than the centripetal acceleration required, so the skier does not lose contact with the ground

ALTERNATIVE 3

recognition that to lose contact with the ground centripetal force ≥ weight

calculation that $v \geq 14$ «ms^{-1}»

comment that 12 «ms^{-1}» is less than 14 «ms^{-1}» so the skier does not lose contact with the ground

ALTERNATIVE 4

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen

calculation that reaction force = 172 «N»

reaction force > 0 so the skier does not lose contact with the ground

Do not award a mark for the bald statement that the skier does not lose contact with the ground.

c. ***ALTERNATIVE 1***

$0 = 8.2^2 + 2 \times a \times 24$ therefore $a =$ «–»1.40 «m s^{-2}»

friction force = $ma = 65 \times 1.4 = 91$ «N»

coefficient of friction = $\frac{91}{65 \times 9.81} = 0.14$

ALTERNATIVE 2

$KE = \frac{1}{2}mv^2 = 0.5 \times 65 \times 8.2^2 = 2185$ «J»

friction force = KE/distance = 2185/24 = 91 «N»

coefficient of friction = $\frac{91}{65 \times 9.81} = 0.14$

Allow ECF from MP1.

d.i. «76 × 9.6»= 730

Ns ***OR*** kg ms^{-1}

d.ii. safety net extends stopping time

$F = \frac{\Delta p}{\Delta t}$ therefore *F* is smaller «with safety net»

OR

force is proportional to rate of change of momentum therefore *F* is smaller «with safety net»

Accept reverse argument.

Examiners report

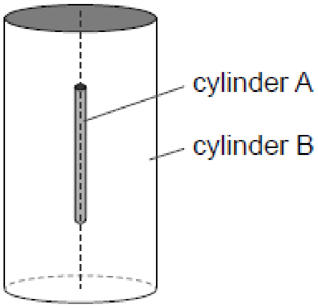
a.i. [N/A]
a.ii. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]
d.i. [N/A]
d.ii. [N/A]

The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 (${}^{226}_{86}\mathrm{Ra}$) decays by alpha emission to form a nuclide known as radon (Rn).

a. Write down the missing values in the nuclear equation for this decay. [1]

$${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{\cdots\cdots}_{86}\mathrm{Rn} + {}^{\cdots\cdots}_{2}\alpha$$

b. Rutherford and Royds put some pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B. [1]



At the start of the experiment all the air was removed from cylinder B. The alpha particles combined with electrons as they moved through the wall of cylinder A to form helium gas in cylinder B.

The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin.

c. Rutherford and Royds expected 2.7×10^{15} alpha particles to be emitted during the experiment. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3×10^{-5} m^3 and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B. [3]

d. Rutherford and Royds identified the helium gas in cylinder B by observing its emission spectrum. Outline, with reference to atomic energy levels, how an emission spectrum is formed. [3]

e. The work was first reported in a peer-reviewed scientific journal. Outline why Rutherford and Royds chose to publish their work in this way. [1]

Markscheme

a. 222 ***AND*** 4

Both needed.

b. alpha particles highly ionizing

OR

alpha particles have a low penetration power

OR

thin glass increases probability of alpha crossing glass

OR

decreases probability of alpha striking atom/nucleus/molecule

c. conversion of temperature to 291 K

$p = 4.5 \times 10^{-9} \times 8.31 \times$ «$\frac{2.91}{1.3\times10^{-5}}$»

OR

$p = 2.7 \times 10^{15} \times 1.38 \times 10^{-23} \times$ «$\frac{2.91}{1.3\times10^{-5}}$»

0.83 or 0.84 «Pa»

d. electron/atom drops from high energy state/level to low state

energy levels are discrete

wavelength/frequency of photon is related to energy change ***or*** quotes $E = hf$ ***or*** $E = \frac{hc}{\lambda}$

and is therefore also discrete

e. peer review guarantees the validity of the work

OR

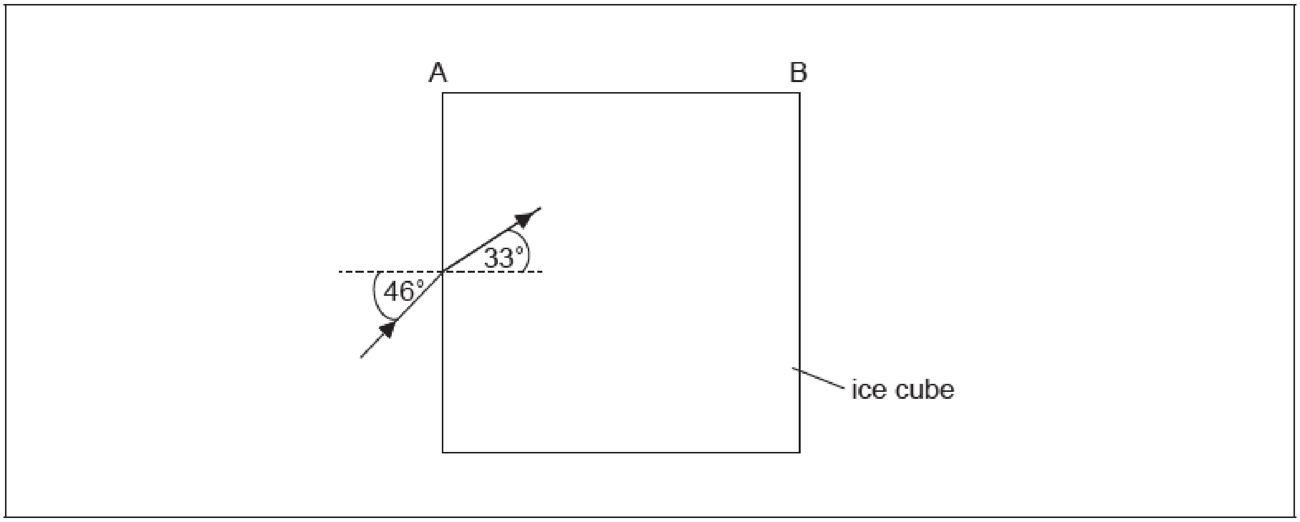
means that readers have confidence in the validity of work

OWTTE

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

A large cube is formed from ice. A light ray is incident from a vacuum at an angle of 46° to the normal on one surface of the cube. The light ray is parallel to the plane of one of the sides of the cube. The angle of refraction inside the cube is 33°.



Each side of the ice cube is 0.75 m in length. The initial temperature of the ice cube is –20 °C.

a.i. Calculate the speed of light inside the ice cube. [2]

a.ii. Show that no light emerges from side AB. [3]

a.iii. Sketch, on the diagram, the subsequent path of the light ray. [2]

b.i. Determine the energy required to melt all of the ice from –20 °C to water at a temperature of 0 °C. [4]

Specific latent heat of fusion of ice = 330 kJ kg^{-1}
Specific heat capacity of ice = 2.1 kJ kg^{-1} k^{-1}
Density of ice = 920 kg m^{-3}

b.ii. Outline the difference between the molecular structure of a solid and a liquid. [1]

Markscheme

a.i. «$v = c\frac{\sin i}{\sin r}$ =» $\frac{3\times10^{8}\times\sin(33)}{\sin(46)}$

2.3 x 10^{8} «m s^{-1}»

a.ii. light strikes AB at an angle of 57°

critical angle is «$\sin^{-1}\left(\frac{2.3}{3}\right)$ =» 50.1°

49.2° from unrounded value

angle of incidence is greater than critical angle so total internal reflection

OR

light strikes AB at an angle of 57°

calculation showing sin of “refracted angle” = 1.1

statement that since 1.1>1 the angle does not exist and the light does not emerge

[Max 3 marks]

a.iii.total internal reflection shown

ray emerges at opposite face to incidence

Judge angle of incidence=angle of reflection by eye or accept correctly labelled angles

With sensible refraction in correct direction

b.i.mass = «*volume* x *density*» $(0.75)^3$ x 920 «= 388 kg»

energy required to raise temperature = 388 x 2100 x 20 «= 1.63 x 10^7 J»

energy required to melt = 388 x 330 x 10^3 «= 1.28 x 10^8 J»

1.4 x 10^8 «J» ***OR*** 1.4 x 10^5 «kJ»

Accept any consistent units

*Award **[3 max]** for answer which uses density as 1000 kg^{-3} (1.5× 10^8 «J»)*

b.ii.in solid state, nearest neighbour molecules cannot exchange places/have fixed positions/are closer to each other/have regular pattern/have stronger forces of attraction

in liquid, bonds between molecules can be broken and re-form

OWTTE

Accept converse argument for liquids

[Max 1 Mark]

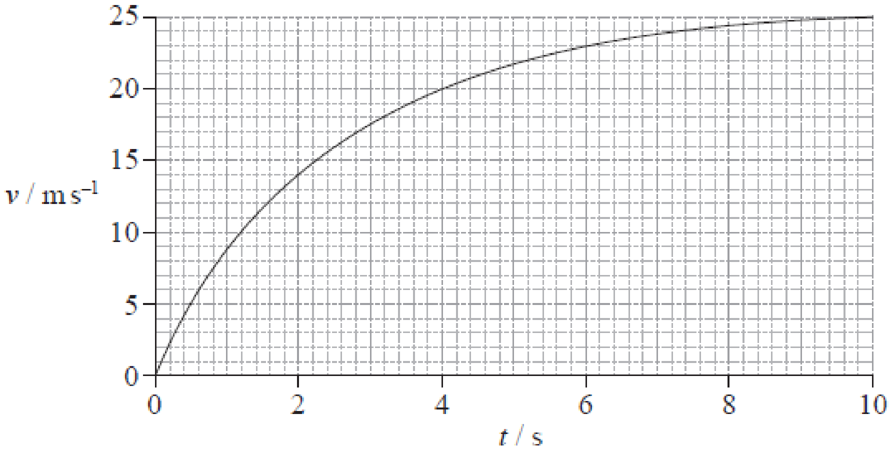
Examiners report

a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
b.i. [N/A]
b.ii. [N/A]

This question is in **two** parts. **Part 1** is about mechanics and thermal physics. **Part 2** is about nuclear physics.

Part 1 Mechanics and thermal physics

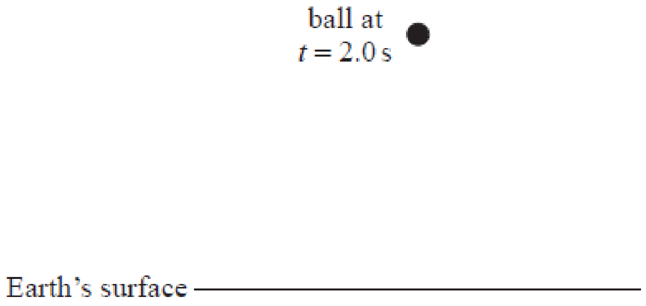
The graph shows the variation with time *t* of the speed *v* of a ball of mass 0.50 kg, that has been released from rest above the Earth’s surface.



The force of air resistance is **not** negligible. Assume that the acceleration of free fall is $g = 9.81 \text{ms}^{-2}$.

a. State, without any calculations, how the graph could be used to determine the distance fallen. [1]

b. (i) In the space below, draw and label arrows to represent the forces on the ball at 2.0 s. [7]



(ii) Use the graph opposite to show that the acceleration of the ball at 2.0 s is approximately 4 ms^{-2}.

(iii) Calculate the magnitude of the force of air resistance on the ball at 2.0 s.

(iv) State and explain whether the air resistance on the ball at $t = 5.0$ s is smaller than, equal to **or** greater than the air resistance at $t = 2.0$ s.

c. After 10 s the ball has fallen 190 m. [6]

(i) Show that the sum of the potential and kinetic energies of the ball has decreased by 780 J.

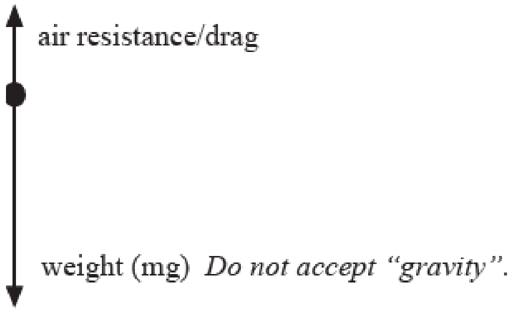
(ii) The specific heat capacity of the ball is 480 J kg^{-1} K^{-1}. Estimate the increase in the temperature of the ball.

(iii) State an assumption made in the estimate in (c)(ii).

Markscheme

a. the area under the curve;

b. (i) arrows as shown, with up arrow shorter;



(ii) drawing of tangent to curve at t = 2.0 s;
calculation of slope of tangent in range 3.6 – 4.4ms^{-2} ;
*Award **[0]** for calculations without a tangent but do not be particular about size of triangle.*

(iii) calculation of F = ma = 0.50 × 4 = 2N
R(= mg −ma = 0.50×9.81− 0.50× 4) ≈ 3N;

(iv) the acceleration is decreasing;
and so R is greater;
or
air resistance forces increase with speed;
since speed at 5.0 s is greater so is resistance force;

c. (i) loss of potential energy is $mg\Delta h$=0.50×9.81×190=932J;

gain in kinetic energy is $\frac{1}{2}mv^2 = \frac{1}{2}0.50 \times 25^2 = 156\text{J}$;

loss of mechanical energy is 932–156;

≈780J

(ii) $mc\Delta\theta$=780J;
$\Delta\theta = \left(\frac{780}{0.5\times480}\right) \approx 3\text{K}/3^{\circ}\text{C}$;

(iii) all the lost energy went into heating just the ball / no energy transferred to surroundings / the ball was heated uniformly;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about change of phase.

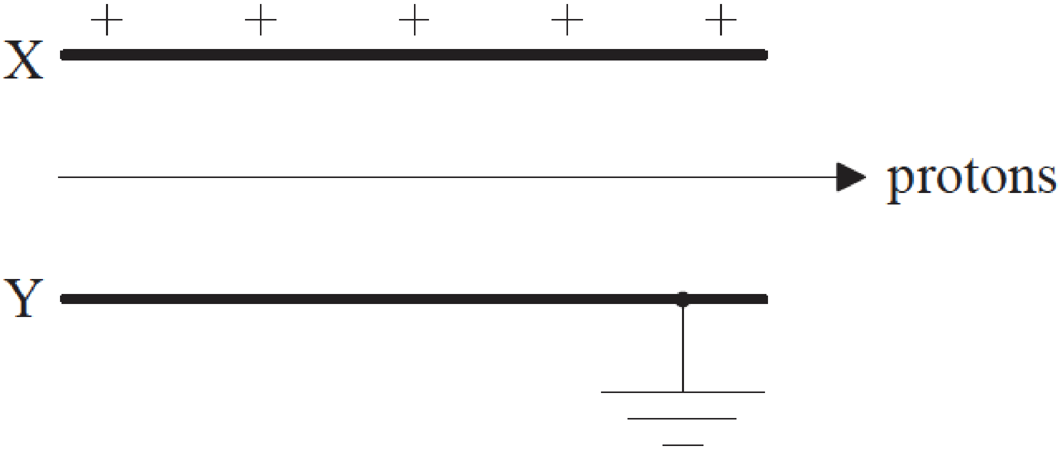
Part 1 Electric fields and radioactive decay

Part 2 Change of phase

a. Define *electric field strength*. [2]

b. A simple model of the proton is that of a sphere of radius 1.0×10^{-15}m with charge concentrated at the centre of the sphere. Estimate the magnitude of the field strength at the surface of the proton. [2]

c. Protons travelling with a speed of $3.9\times10^{6}\text{ms}^{-1}$ enter the region between two charged parallel plates X and Y. Plate X is positively charged and plate Y is connected to earth. [4]



A uniform magnetic field also exists in the region between the plates. The direction of the field is such that the protons pass between the plates without deflection.

(i) State the direction of the magnetic field.

(ii) The magnitude of the magnetic field strength is 2.3×10^{-4}T. Determine the magnitude of the electric field strength between the plates, stating an appropriate unit for your answer.

d. Protons can be produced by the bombardment of nitrogen-14 nuclei with alpha particles. The nuclear reaction equation for this process is given below. [1]

$$^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow \mathrm{X} + {}^{1}_{1}\mathrm{H}$$

Identify the proton number and nucleon number for the nucleus X.

e. The following data are available for the reaction in (d). [3]

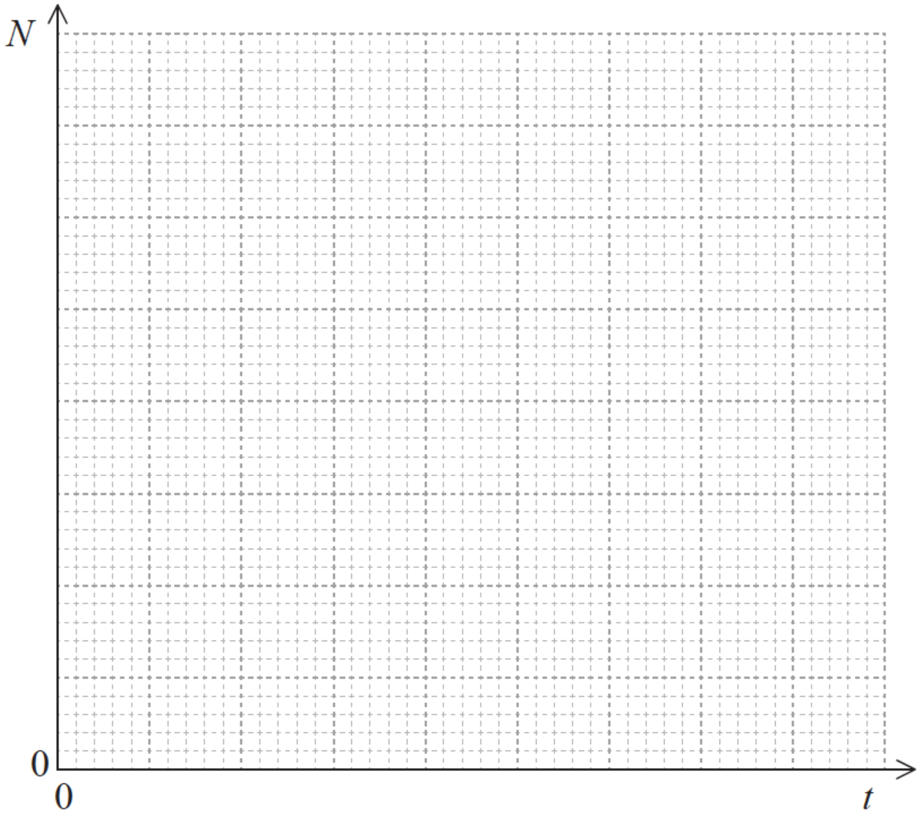
Rest mass of nitrogen-14 nucleus =14.0031 u
Rest mass of alpha particle =4.0026 u
Rest mass of X nucleus =16.9991 u
Rest mass of proton =1.0073 u

Show that the minimum kinetic energy that the alpha particle must have in order for the reaction to take place is about 0.7 Me V.

f. A nucleus of another isotope of the element X in (d) decays with a half-life $T_{\frac{1}{2}}$ to a nucleus of an isotope of fluorine-19 (F-19). [5]

(i) Define the terms *isotope* and *half-life*.

(ii) Using the axes below, sketch a graph to show how the number of atoms *N* in a sample of X varies with time *t*, from *t*=0 to $t = 3T_{\frac{1}{2}}$. There are N_0 atoms in the sample at *t*=0.



g. Water at constant pressure boils at constant temperature. Outline, in terms of the energy of the molecules, the reason for this. [2]

h. 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. [4]

The following data are available.

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

Show that the data give a value of about $1.8 \times 10^6 \text{Jkg}^{-1}$ for the specific latent heat of vaporization *L* of water.

i. Explain why, other than measurement or calculation error, the accepted value of *L* is greater than that given in (h). [2]

Markscheme

a. the force exerted per unit charge;

on a positive small/test charge;

b. $E = \frac{ke}{r^2} = \frac{9 \times 10^9 \times 1.6 \times 10^{-19}}{10^{-30}}$;

$= 1.4 \times 10^{21} \text{NC}^{-1}$ ***or*** Vm^{-1};

c. (i) into the (plane of the) paper;

(ii) *Ee*=*Bev* ***or*** *E*=*Bv*;

=($2.3\times10^{-4}\times3.9\times10^{6}$=)900/897;

NC^{-1} ***or*** Vm^{-1};

d. *proton number*: 8

nucleon number: 17

(both needed)

e. 16.9991u+1.0073u-[14.0031u+4.0026u];

$=-7.00\times10^{-4}$;

$7.000\times10^{-4}\times931.5=0.6521$MeV;

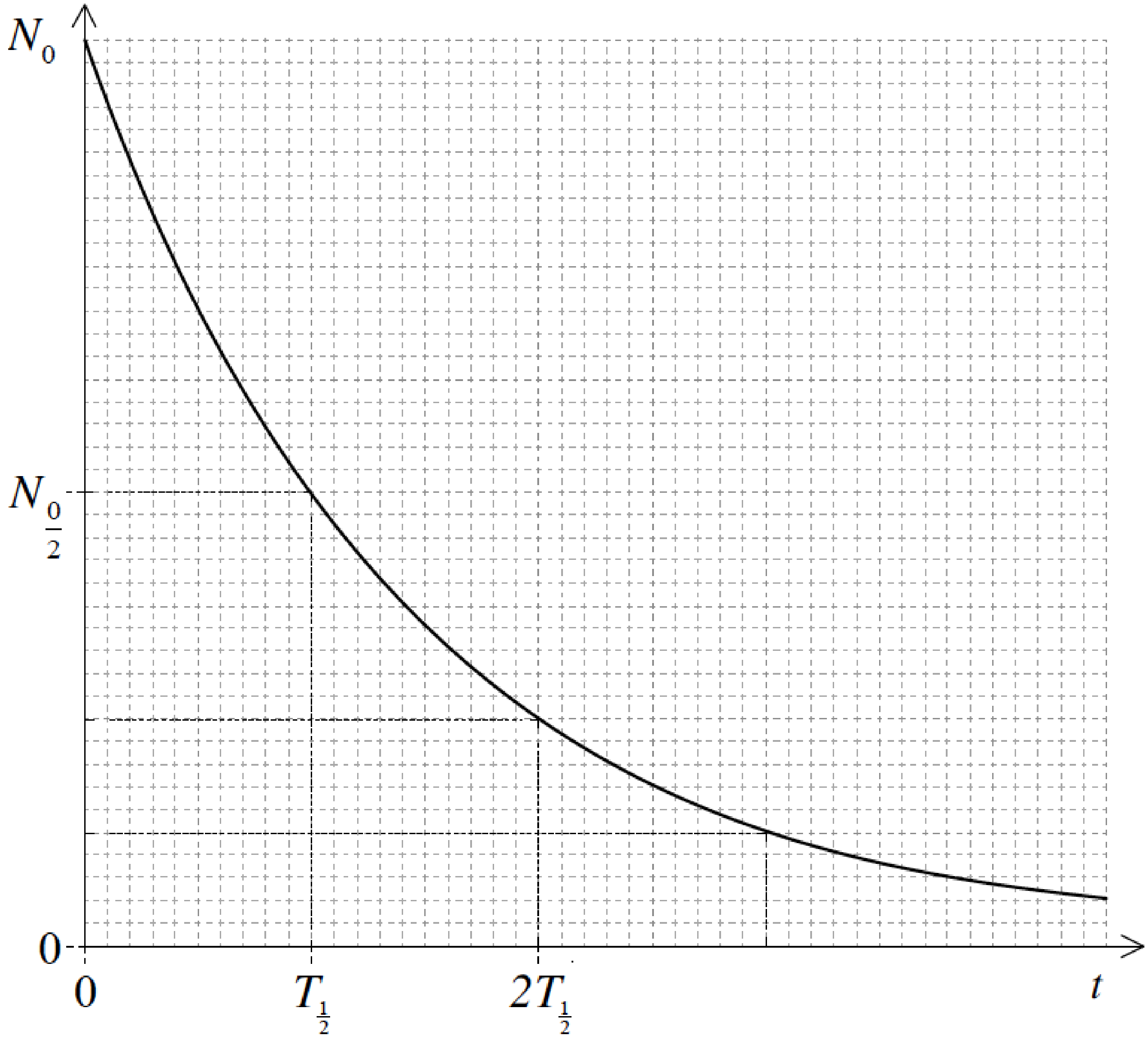
(~0.7MeV)

f. (i) *isotope:*

same proton number/element/number of protons ***and*** different number of neutrons/nucleon number/neutron number; } *(both needed)*

half-life:
time for the activity (of a radioactive sample) to fall by half its original value / time for half the radioactive/unstable nuclei/atoms (in a sample) to decay;

(ii)



(approximately) exponential shape;
minimum of three half lives shown;
graph correct at $\left[T_{\frac{1}{2}}, \frac{N_0}{2}\right]$, $\left[2T_{\frac{1}{2}}, \frac{N_0}{4}\right]$, $\left[3T_{\frac{1}{2}}, \frac{N_0}{8}\right]$;

g. 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 / *OWTTE*;

h. (energy gained by cold water is) 0.300×4180×[34.6-15.2] / 24327;

(energy lost by cooling water is) 0.012×4180×[100-34.6] / 3280;

(energy lost by condensing steam is) 0.012*L*;

$1.75 \times 10^6 (\text{Jkg}^{-1})/$

$\frac{[\text{theirenergygainedbycoldwater} - \text{theirenergylostbycoolingwater}]}{0.012}$;

Award ***[4]*** *for* $1.75 \times 10^6 (\text{Jkg}^{-1})$.
Award ***[2 max]*** *for an answer that ignores cooling of condensed steam.*

i. 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;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]
g. [N/A]
h. [N/A]
i. [N/A]

This question is in **two** parts. **Part 1** is about nuclear reactions. **Part 2** is about thermal energy transfer.

Part 1 Nuclear reactions

Part 2 Thermal energy transfer

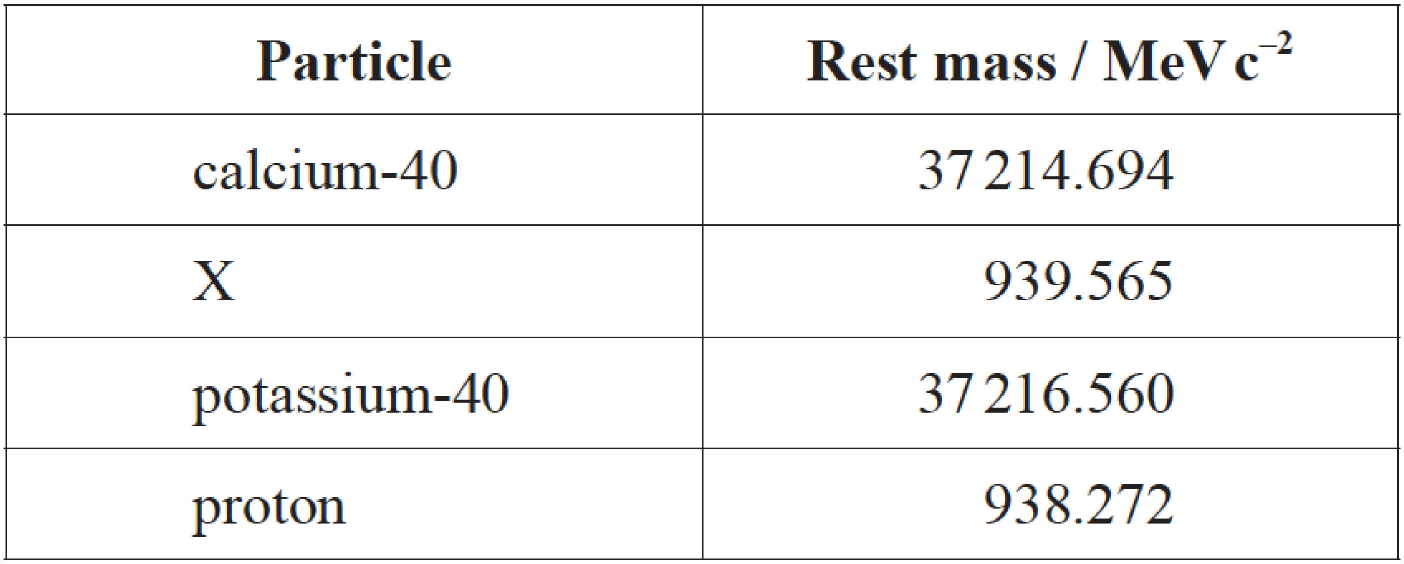
a. (i) Define the term *unified atomic mass unit.* [2]

(ii) The mass of a nucleus of einsteinium-255 is 255.09 u. Calculate the mass in MeVc^{-2}.

c. When particle X collides with a stationary nucleus of calcium-40 (Ca-40), a nucleus of potassium (K-40) and a proton are produced. [6]

$$^{40}_{20}\mathrm{Ca} + \mathrm{X} \rightarrow {}^{40}_{19}\mathrm{K} + {}^{1}_{1}\mathrm{p}$$

The following data are available for the reaction.



Particle	Rest mass / MeV c^{-2}
calcium-40	37 214.694
X	939.565
potassium-40	37 216.560
proton	938.272

(i) Identify particle X.

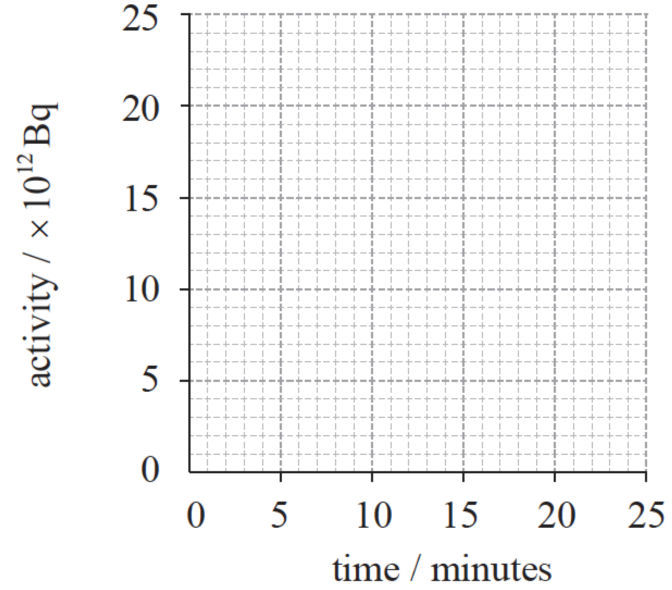
(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(iii) Before the reaction occurs, particle X has kinetic energy 8.326 MeV. Determine the total combined kinetic energy of the potassium nucleus and the proton.

d. Potassium-38 decays with a half-life of eight minutes. [5]

(i) Define the term *radioactive half-life*.

(ii) A sample of potassium-38 has an initial activity of 24×10^{12}Bq. On the axes below, draw a graph to show the variation with time of the activity of the sample.



(iii) Determine the activity of the sample after 2 hours.

e. (i) Define the *specific latent heat* of fusion of a substance. [5]

(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.

f. A piece of ice is placed into a beaker of water and melts completely. [5]

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 = 3.3×10^5J 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

a. one twelfth of the mass of a carbon-12 atom/ $^{12}_{6}\mathrm{C}$;

Do not allow nucleus.

$255.09\times931.5 = 237600(\mathrm{MeVc^{-2}})$;
*Award **[1]** for a bald correct answer.*

c. (i) neutron/$^{1}_{0}\mathrm{n}$;

(ii) the (rest) mass of the products is greater than that of the reactants;
energy must be given to supply this extra mass;

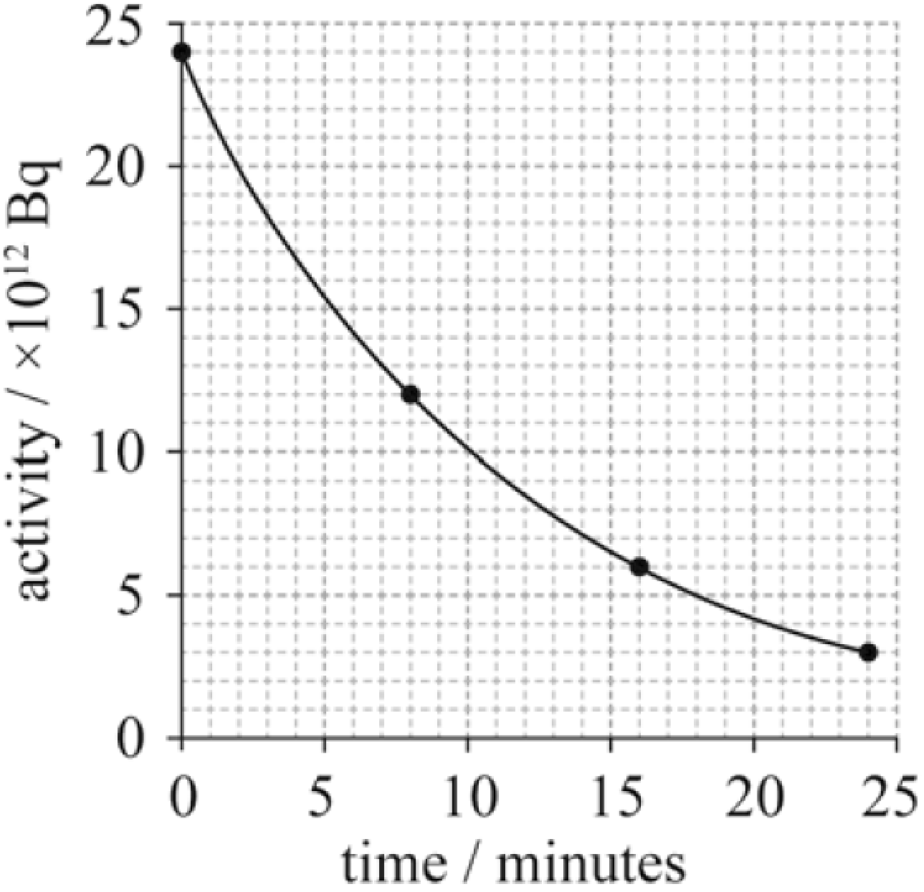
(iii) $\Delta m = [37216.560 + 938.272] - [37214.694 + 939.565] = 0.573\ (\mathrm{MeVc^{-2}})$;
energy required for reaction=0.573(MeV);

kinetic energy=(8.326-0.573=)7.753(MeV);

*Award **[3]** for a bald correct answer.*

d. (i) time for the activity of a sample to halve / time for half the radioactive nuclei to decay;

(ii) four data points (0, 24) (8, 12) (16, 6) (24, 3) correct;
smooth curve through points;



(iii) 2 hours (=120 minutes)=15 half-lives;
activity=$\frac{24\times10^{12}}{2^{15}} = 7.3 \times 10^8\,(\text{Bq})$;

or

$\lambda = \frac{\ln 2}{8}$; $\left(A = A_0 e^{-\lambda t}\text{method}\right)$;
=7.3×10^8(Bq)

*Award **[2]** for a bald correct answer.*

e. (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.

f. (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);
*Allow **[3]** for a bald correct answer.*
*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;

Examiners report

a. i) The definition of the unified atomic mass unit relates to the mass of the carbon 12 atom. Few candidates made this reference.

   ii) Almost all were able to convert the mass unit into MeVc^{-2}.

c. i) This was well answered with the majority of candidates identifying the neutron.

   ii) Few could relate the mass defect to the energy required to initiate the reaction.

   iii) Many were able to calculate the mass defect but did not realize that in this reaction it is the energy needed to initiate the reaction. This is why the products have more combined mass than the reactants.

d. i) The definition of radioactive half-life was often poorly done with few appreciating that half the radioactive nuclei decay into a more stable form. Those that explained that the activity of the sample would halve were more successful.

   ii) Almost all were able to draw the decay curve.

   iii) This was well answered with responses split between those that successfully found the number of half-lives elapsed in 2 hours and going on to find the activity of the sample and those that took the decay constant route. At SL, most successfully found the number of half lives elapsed in 2 hours and were able to find the corresponding activity of the sample.

e. i) The majority related the latent heat to the energy required for a change of state but few successfully completed the definition by explaining that fusion is the change of state between a solid and liquid at constant temperature.

   ii) This explanation was poorly done with few gaining full marks. Few could relate the change in potential energy during a change of state to fusion and vaporization.

f. i) Of those candidates that established a relevant energy transfer equation, many did not include the heat gained by the ice once it had melted.

   ii) Few could state two sources of energy loss that were not included in their energy equation.