A-Level Physics

Thermal Energy Transfer

Mark Scheme

Time available: 61 minutes
Marks available: 47 marks

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1. (a) Combining and making use of $Q = Pt$ and $Q = mc\Delta\theta$ equations without the need to make t the subject. ✓
= 27 (s) ✓

$t = (1.2 \times 450)\,\frac{(125-20)}{2100}$

No ecf for the second mark

2

(b) (The power supplied in time t raises the temperature of m kg of water and converts it to steam)

Mark for use of an equation where errors in the time or temperature change or powers of 10 are condoned. ✓$_1$

✓$_1$ $Pt = mc_w\Delta\theta + ml$ *OR* $P = \frac{mc_w\Delta\theta + ml}{t}$

Mark is for the correct evaluation of Δm or P. No ecf. ✓$_2$

✓$_2$ *in 1 minute 2100 × 60*

$= \Delta m \times 4200 \times (100 - 20) + \Delta m \times 2.3 \times 10^6$

$\Delta m = 0.048$ *kg min*$^{-1}$

OR

in one second 2100

$= \Delta m \times 4200 \times (100 - 20) + \Delta m \times 2.3 \times 10^6$

$\Delta m = 0.00080$ *kg s*$^{-1}$

OR

$$P = = \frac{0.060 \times 4200 \times (100 - 20) + 0.060 \times 2.3 \times 10^6}{60}$$

Mark is for the deduction about the claim, which may be an ecf provided an attempt at the calculation is made with a clear answer. ✓$_3$

$P = 2.6(4) \times 10^3$ *W*

✓$_3$ *So claim is not true.*

0.048 kg min^{-1} *is smaller than 60 g min*$^{-1}$

OR

0.00080 kg s^{-1} *= 48 g min*$^{-1}$ *is smaller than 60 g min*$^{-1}$

OR

2.6×10^3 *W is greater than 2.1 kW* ✓$_3$

(The most common ecf will be to leave out the raising of the water temperature before changing the water to steam giving calculated values of $\Delta m = 0.055$ *kg min*$^{-1}$*, or*

$\Delta m = 0.00091$ *kg s*$^{-1}$ *or* $P = 2.3 \times 10^3$ *W)*

3

[5]

2. (a) 28 (°C) ✓

1

(b) The energy transferred reduces the number of nearest atomic neighbours

First alternative must not imply total loss of intermolecular forces or neighbours.

A reference to 'breaking <u>*the*</u> *bonds' implies all the bonds and does not gain the mark.*

No mark for saying bonds weaken.

However these errors in discussing the bonds does not prevent a mark coming from another point

OR

allows atoms to move their centre of vibration

Last alternative might be expressed as 'atoms change from fixed positions to them being able to slide around each other'.

Ignore any references to changes in separation.

OR

breaks some of the (atomic) bonds

OR

crystalline to amorphous ✓ (owtte)

An explanation that involves increasing the kinetic energy will lose the mark.

So will any description that implies it becomes a gas.

1

(c) The (total or mean) kinetic energy remains constant. ✓

The (total or mean) potential energy increases. ✓

2

(d) The <u>mean</u> speed/<u>mean</u> kinetic energy increases ✓

Ignore references to larger separation (because it's not always true): collisions (as it is not a gas) or measures of randomness (which are usually too vague).

Condone use of average for mean.

Don't allow velocity instead of speed.

During this time interval the atoms are all in the liquid form so no credit for references that indicate a change of state.

1

(e) Using both $\Delta Q = mc\Delta\theta$ **and** $\Delta Q = P\Delta t$ ✓

$$\left(c = \frac{P\Delta t}{m\Delta\theta} = \frac{35 \times (14.8 - 11.2) \times 60}{0.25 \times (110 - 28)} = 369\right)$$

c = 370 ✓ (allow 365–375)

J kg^{-1} K^{-1} ✓ (or J kg^{-1} C^{-1})

First mark can be given by seeing the substitution which may have some errors for example not using exactly 28. These will be penalised in the second mark.

Correct answer gains first two marks NB 400 J kg^{-1} K^{-1} shows candidate has wrongly made calculations for the solid. No mark for the unit if a solidus is used because of the uncertainty of whether the K is on the top or bottom line. (which is correct J / kg / K or J / kg K ?)
However allow a prefix if kilojoules are used for example.

3

(f) (Using both $\Delta Q = ml$ and $\Delta Q = P\Delta t$)

$$l\left(=\frac{P\Delta t}{m}\right) = \frac{35 \times ((11.2-1.8) \times 60)}{0.25} = 79 \text{ kJ kg}^{-1}$$ ✓

hence M = gallium ✓ (condone an ecf consistent with the calculation provided a comment is made if the value falls outside the range of the table)

The calculation yields1.3 kJ kg^{-1} if the 60 seconds is omitted.

Interim stage heat supplied = 19.7 kJ

A valid calculation must be shown to gain this second mark.

2

[10]

3. (a) Specific latent heat of fusion is the <u>energy</u> (required) to change 1 kg / unit mass of material from the solid state to the liquid state or melt/fuse ✓

Without a change of temperature or at the freezing/melting temperature/point ✓

The direction of energy transfer must be consistent with the direction of the change of state (If energy to change… is given then required or needed is implied)

2nd mark stands alone.

2

(b) (Dividing both sides of the equation $\Delta Q = m\,c\,\Delta\theta$ by Δt gives $\Delta Q/\Delta t = m\,c\,\Delta\theta/\Delta t$ or

$\Delta\theta = (\Delta Q/\Delta t) \times \Delta t/m\,c$ where $m = \rho V$)

$\Delta\theta = 2700 \times (60 \times 60) / (4.5 \times 1000 \times 4200)$ ✓

Full substitution correct ✓

Temperature rise = $\Delta\theta$ = 0.51 (K) ✓ (= 0.514 K)

Working <u>must be seen</u> as there is a self-cancelling error with two 1000 factors.

So answer alone gains the 3rd mark only.

First mark can be gained if (60 × 60) is absent even if not re-arranged.

The change of temperature may be written as a difference between 28 °C and an unknown temperature (allow in kelvin written either way round ie with incorrect sign)

*1 sig fig is **not** acceptable.*

Useful numbers:

$4.5 \times 1000 \times 4200 = 1.89 \times 10^{7}$

$2700/(4500\times4200) = 1.4 \times 10^{-4}$

Max 2 if:

Omits (60 × 60) giving 1.43×10^{-4} K

Omits 60 giving 8.57×10^{-3}

3

(c) (When the pump is working at speed) the pump is <u>doing work</u> (on the water) ✓

Work (and heat both) can raise the temperature of a body (as stated in the 1st Law of thermodynamics) (this may be expressed as work is converted to thermal energy) OWTTE

OR

The pump increases the randomness / turbulence of the water/molecules

OR

The <u>mean</u> square speed/*mean* kinetic energy is proportional to the (absolute) temperature ✓

(this may be given in the form on an equation) OWTTE

(Lenient mark – a reference to random motion or more collisions may gain this mark but a simple increase in kinetic energy is not enough).

Do not penalise answers that go nowhere unless they directly contradict a marked answer.

2

[7]

4. (a) Tick in 4th box **1**

(b) (i) (using heat energy = *ml*)

energy = $0.047 \times 3.3 \times 10^5 = 1.6 \times 10^4$ (J) ✓ (1.55×10^4 J)

answer alone gains mark

1

(ii) (heat in from water = heat supplied to melt and raise ice temperature)

$1.8 \times 10^4 = 1.6 \times 10^4$ + (energy to raise temp of ice)

energy to raise temp of ice = 2×10^3 (J) ✓

answer alone gains mark allow 2, 2.5 or 3 × 10^3 J

allow CE if substitution is shown

1.8×10^4 – (b)(i)

1

(iii) (using heat energy = $mc\Delta T$)

c = 2×10^3 / 0.047 × 25

= 2×10^3 ✓ (1.7×10^3) (note there is a large range of correct answers)

J kg^{-1} K^{-1} or J kg^{-1} $^oC^{-1}$ ✓ (allow use of dividing line but don't allow ^oK and $^oC^{-1}$ is not the same as C^{-1})

only allow CE if substitutions are seen

c = (b)(ii) / 0.047 × 25

= b(ii) × 0.851

allow 1 sig fig.

common answers:

for 2.5 × 10^3 J gives 2.1 × 10^3 or 2 × 10^3

for 3 × 10^3 J gives 2.6 × 10^3 or 3 × 10^3

2

[5]

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

1 kg can be replaced with unit mass.

Marks for 130J or energy.

+1 kg or unit mass.

+1 K or 1 °C.

Condone the use of 1 °K

1

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

= 0.75 × 130 × (327.5 – 21) + 0.75 × 23000 ✓

(= 29884 + 17250)

= 47134 ✓

= 4.7×10^4 (J) ✓

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

Marks for substitution + answer + 2 sig figs (that can stand alone).

3

[4]

6.

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

17 K ✓

2

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

t = 15 s ✓

2

[4]

7.

(a) (i) heat water to 100 °C, energy (= 190 × 4200 × 79) = 63 (MJ) **(1)**
vapourise water, energy
(=190 × 2.3 × l0^6) = 440(MJ) **(1)**
(437MJ)

energy transferred (per sec) = (437 + 63) MJ **(1)**
(= 500 MJ)

(ii) mass of rocks (= $4.0 \times 10^6 \times 3200$)

= 1.3×10^{10}(kg) **(1)**

(1.28×10^{10})

temperature fall of ΔT in one day, energy removed
(= $1.28 \times 10^{10} \times 850 \times \Delta T$) = $1.1 \times 10^{13}\ \Delta T$ **(1)**

(1.09×10^{13} AT)
(allow C.E. for value of mass of rocks)

energy transfer in one day (= $500 \times 10^6 \times 3600 \times 24$)
= 4.3×10^{13} (J) **(1)**

in one day $\Delta T\left(= \frac{4.3 \times 10^{13}}{1.1 \times 10^{13}}\right) = 3.9(1)$ K **(1)**

7

(b) number of nuclei in 1 kg of ^{238}U $= \left(\frac{6.02 \times 10^{23}}{0.238}\right) = 2.5(3) \times 10^{24}$ **(1)**

activity of lkg of ^{238}U = $\frac{\ln 2}{T_{1/2}} \times 2.53 \times 10^{24}$ **(1)**

$\left(= \frac{\ln 2}{4.5 \times 10^{9} \times 3.1 \times 10^{7}} \times 2.53 \times 10^{24}\right) = 1.2(6) \times 10^{7}\,(s^{-1})$ **(1)**

energy released per sec per kg of ^{238}U

$= 1.2(6) \times 10^{7} \times 4.2 \times 1.6 \times 10^{-13}$(J) **(1)**

$(8.47 \times 10^{-6}$(J))

mass of ^{238}Uneeded = $\frac{500 \times 10^{6}}{8.47 \times 10^{-6}} = 5.9(0) \times 10^{13}$kg **(1)**

5

[12]