

SECTION A

- A1.** (a) correct positioning of all 3 error bars;
correct length of error bars – at least 3 mm long, even if only two are shown; [2]
- (b) a smooth curve through the data points within 2 mm of each data point; [1]
Award [0] for points joined by straight-line segments.
- (c) line of best-fit must be a curve;
in order to pass through the error bars; [2]
Award [0] for plain “curve” without attempt at an explanation.
- (d) (i) $20(\pm 2)^\circ\text{C}$; [1]
- (ii) large enough triangle-hypotenuse 6 cm, from which to get slope;
correct calculation of slope at $x = 50\text{cm}$ to give $(-1.05 \pm 0.25)^\circ\text{C cm}^{-1}$;
for a more accurate calculation in the range $(-1.05 \pm 0.15)^\circ\text{C cm}^{-1}$; [3]
- (e) realization that $\frac{R_{50}}{\left(\frac{\Delta\theta}{\Delta x}\right)_{50}} = \frac{R_{10}}{\left(\frac{\Delta\theta}{\Delta x}\right)_{10}}$ if rate is proportional to temperature gradient;
substitution to get $R_{50} = \left(\frac{R_{10}}{\left(\frac{\Delta\theta}{\Delta x}\right)_{10}} \left(\frac{\Delta\theta}{\Delta x}\right)_{50} \right) = \frac{43}{1.81} \times 1.05 = 25 \text{ W}$;
with a comment about the agreement of the result with the given value of R_{50} ; [3]
- (f) a graph of $\ln\theta$ versus x would be a straight-line;
with $k =$ (negative) slope; [2]
Do not accept answers that use point(s) from the graph on page 4 and solve for k .
- A2.** (a) (i) initial momentum = $500 \times 6 = 3000 \text{ N s}$;
final momentum = $500 \times (-1) + 700 \times 5 = 3000 \text{ N s}$; [2]
(working must be shown to award marks)
Allow approach that shows equal and opposite momentum changes.
- (ii) initial kinetic energy = $\frac{1}{2} 500 \times 36 = 9000 \text{ J}$;
final kinetic energy = $\frac{1}{2} 500 \times 1 + \frac{1}{2} 700 \times 25 = 9000 \text{ J}$; [2]
(working must be shown to award marks)
- (b) impulse = change of momentum = $700 \times 5 = 3500 \text{ N s}$;
duration of collision = 2.0 s ;
to give $F = \frac{3500}{2.0} = 1800 \text{ N}$; [3]
Accept force in the range 1700 N to 1800 N even with three significant figures.

- A3.** (a) (i) **two** arrows directed towards the centre of the circular path, within ± 0.5 cm of the centre; [1]
- (b) (i) negative by stating any rule for the direction of the magnetic force; [1]
- (ii) the work done is zero; since the force is at all times normal to the velocity; [2]
- (c) a curved path starting at X and in the right direction i.e. counterclockwise; circular path of radius $\frac{R}{2}$; [2]
Allow diameter 3-4 cm and be generous with how round the circle is.
- A4.** (a) the kinetic energy of 3.8 MeV gets converted to electrical potential energy; equal therefore to $3.8 \times 10^6 \times 1.6 \times 10^{-19} = 6.1 \times 10^{-13}$ J; [2]
- (b) correct identification of charges of alpha and palladium nucleus; electrical potential energy = $9 \times 10^9 \times \frac{2 \times 46 \times (1.6 \times 10^{-19})^2}{d}$; $d = 3.5 \times 10^{-14}$ m; [3]
Award [1 max] for those who fail to square the elementary charge (answer 2.2×10^3 m) or those who square the d in the denominator (answer 1.9×10^{-7} m).
- (c) it will be greater since the gold nucleus has more protons/force of repulsion is greater/electrical potential energy between alpha and gold nucleus is larger at the same distance; [1]
- (d) (i) $m \approx Au$; [1]
- (ii) $\rho = \frac{m}{V}$
 $= \frac{A \times 1.66 \times 10^{-27} \text{ kg}}{\frac{4\pi}{3} A (1.2 \times 10^{-15})^3 \text{ m}^3}$;
 to give $\rho \approx 2 \times 10^{17} \text{ kg m}^{-3}$ (no mark for answer) [1]

SECTION B

B1. Part 1 Motion of a ball

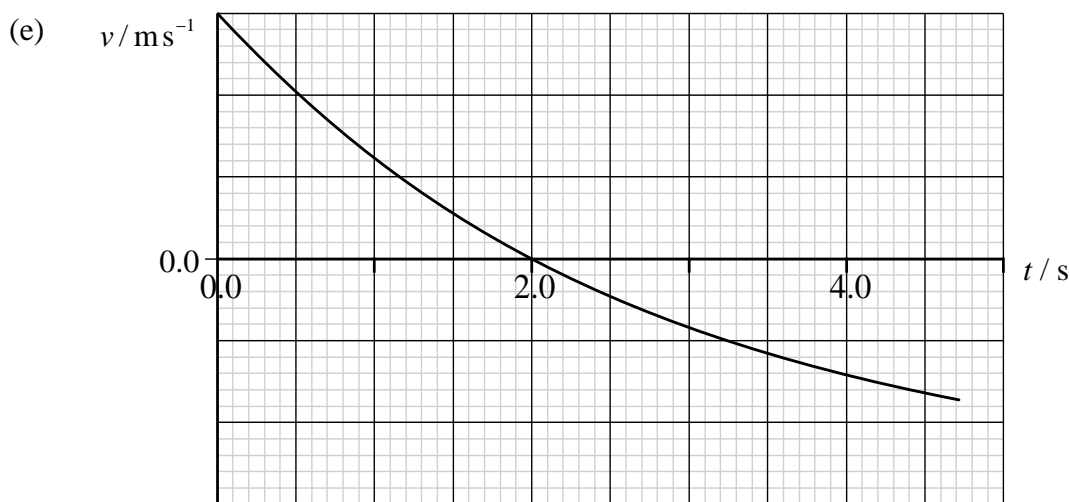
(a) the maximum height reached by the ball/the displacement in the first 2s/the distance travelled; [1]

(b) 30 m; [1]
Accept answers in the range 25 m to 30 m.

(c) (i) drawing tangent at $t = 1.0\text{s}$;
 using a sufficiently large triangle – at least 6 cm hypotenuse;
 to get $a = 15\text{ms}^{-2}$; [3]
Accept acceleration in the range 14.5–15.5 ms⁻² .

(ii) $R + mg = ma$;
 $R = 3.75 - 2.50 = 1.2\text{N}$; [2]
(Watch ECF from (i))

(d) slope of the graph is decreasing;
 the force of air resistance must decrease as well; [2]



smooth curve at $t = 2.0\text{ s}$;
 terminating between 4.25 s and 4.50 s ; [2]
(Award second marking point only if first is correct)

(f) it will be less;
 because mechanical energy/kinetic energy is being transformed into thermal energy (in the particle and air); [2]
Award [0] for an answer without justification.

(g) the areas under the graph for the upward and downward motion must be the same;
 from the way the curve slopes it follows that the time must be longer than 2.0s ; [2]

or

the average speed on the way down is less;
 and so the time taken is longer;

Part 2 Emission of electrons

- (a) energy required to leave the metal is $1.8 \times 1.6 \times 10^{-19} = 2.88 \times 10^{-19} \text{ J}$;
 area from which energy is collected is $\pi(5.0 \times 10^{-11})^2 = 7.85 \times 10^{-21} \text{ m}^2$;
 energy falling on area per second is $E = 1.6 \times 7.85 \times 10^{-21} = 1.26 \times 10^{-20} \text{ J}$;
 so time required is $\frac{2.88 \times 10^{-19} \text{ J}}{1.25 \times 10^{-20} \text{ J}}$;
 = 22.9s , approximately 23s (*no mark for answer*) [4]
- (b) the energy of light is carried in bundles/quanta/photons;
 so the electron will be ejected immediately after it absorbs one photon (of sufficient energy); [2]
- (c) (i) the minimum voltage for which the ammeter reads zero current;
 the recorded voltage is the kinetic energy of the electrons in electron volts; [2]
- (ii) straight-line with positive slope;
 with positive intercept on frequency axis; [2]
- (iii) since $E_k = hf - \phi$;
 slope is Planck's constant; [2]
Award [1] for a statement without explanation.
- (d) energy falling on one square meter of the metal per second is 1.6J ;
 realization that $N \frac{hc}{\lambda} = 1.6 \text{ J}$ (where photon energy is $\frac{hc}{\lambda} = 3.83 \times 10^{-19} \text{ J}$ and
 $N =$ number of photons per unit area per second is $4.18 \times 10^{18} \text{ m}^{-2} \text{ s}^{-1}$) ;
 number of electrons is $0.05 \times N = 2.1 \times 10^{17}$; [3]

B2. Part 1 Waves on a string

- (a) (i) wavelength = 3.0 cm; [1]
- (ii) period = 0.25 ms;
hence frequency = 4000 Hz; [2]
(Bald answer 4000 Hz scores [2])
- (iii) $c = \left(\frac{0.03}{0.25 \times 10^{-3}} \right) = 0.03 \times 4000 = 120 \text{ ms}^{-1}$; [1]
Watch ECF from (i) and (ii).
- (b) (i) correct labelling of amplitude of 2.0 mm; [1]
Any line from equilibrium to crest or trough.
- (ii) cosine wave from $x = 0$; [2]
period constant throughout ;
- (c) (i) pulse of similar shape and size; [2]
and inverted;
Accept pulse that is of similar width but smaller amplitude.
- (ii) the string pulls on the wall and so the wall pulls in the opposite direction on the string by Newton's third law; [2]
the wall pushes on the string creating an inverted pulse;
- (d) (i) the oscillating left end creates a travelling wave to the right; [3]
which gets reflected by the fixed end;
at any one time there are two waves on the string travelling in opposite directions whose displacements/amplitudes are added (creating the standing wave);
- (ii) $c = f \lambda$
 $\lambda = \frac{4L}{3} = 4.0 \text{ m}$;
hence $f = \frac{120}{4.0} = 30 \text{ Hz}$; [2]
Use ECF for wave speed from (a)(iii).

- (e) (i) sources whose phase difference is constant; [1]
- (ii) the waves from the transmitters interfere;
 the path difference varies as the satellite moves and so the amplitude of the detected (superposed) signal varies as well; [2]
Accept references to path difference changing from being an integral or half integral multiple of the wavelength as the satellite moves.
- (iii) three fringe separations in 7.7 km ;
 hence $s = \frac{7.7}{3} = 2.57 \text{ km}$;
 using $s = \frac{\lambda D}{s} \Rightarrow D = \frac{2.57 \times 160}{1.2} = 342 \text{ km} = 340 \text{ km (2 s.d.)}$; [3]

Part 2 Electromagnetic induction

- (a) the induced e.m.f. (in a loop) is proportional to the rate of change of the magnetic flux linkage (in the loop); [1]
- (b) (i) as the loop is moved away the magnetic field through the loop is getting smaller;
 hence the magnetic flux through it is changing with time;
Accept also answers based on considerations of induced e.m.f. in each section of loop e.g.
 e.m.f. is induced in upper and lower section of loop;
 no e.m.f. induced in sides/e.m.f. of same sign;
 e.m.f. in upper section larger hence current in loop; [2 max]
- (ii) the direction of the current is clockwise;
 because in this way the magnetic field created by the induced current is in the same direction as the external magnetic field thus opposing the change in flux; [2]
Accept any other reasonable formulation based on Lenz's law but not bald answer without explanation or incorrect explanation.
- (iii) work is being performed on the loop by the agent pushing the loop;
 against the attractive magnetic force between the loop and the wire;
 so that the loop moves at constant speed; [3]

B3. Part 1 Electrical conduction

- (a) (delocalized/valence/free) electrons that are not bound to any one particular atom of the metal/electrons loosely bound to atoms; [1]
- (b) (i) the mass of 1.0m^3 is 8.93×10^3 kg ;
and therefore number of moles is $\frac{8.93 \times 10^6}{64}$;
 $= 1.4 \times 10^5$ mol (no marks for answer) [2]
- (ii) $1.4 \times 10^5 \times 6.02 \times 10^{23} = 8.4 \times 10^{28}$; [1]
- (c) there is no net transfer of electric charge to the right or left;
because on the average as much charge moves to the right as to the left;
or
random velocities means no net motion in any direction ;
hence no transfer of charge ; [2]
- (d) arrow to the right; [1]
- (e) (i) $\frac{0.50}{10^{-3}} = 5 \times 10^2$ s **or** ≈ 8 min; [1]
Accept answer in seconds or minutes up to 2 significant figures.
- (ii) all electrons in the wire start drifting at the same time/the electric field is established in the wire almost instantaneously;
the lamp will light as soon as the electrons already in the lamp filament begin to move; [2]
- (iii) the electrons gain kinetic energy as they are accelerated by the potential difference across the filament;
they collide with the filament atoms transferring energy to them;
the average kinetic energy of the filament atoms thus increases;
which implies that the temperature of the filament increases
(since temperature is a measure of the average kinetic energy of the molecules); [4]
- (f) ammeter in series with battery;
voltmeter in parallel with lamp; [2]
- (g) (i) from zero up to a maximum of 0.15 A ; [1]
- (ii) correct identification of current;
to get $R = \frac{V}{I} = \frac{0.80}{0.32} = 2.5 \Omega$; [2]

Part 2 Thermodynamics

- (a) change in which the temperature stays constant; [1]
- (b) state X is at a lower temperature;
because $p_X V_X < p_Y V_Y$ / other argument e.g. comparing two points on the two curves that have the same volume or pressure ; [2]
Do not award first point if explanation is missing or incorrect.
- (c) (i) work is done on the gas and hence $W < 0$;
 using $Q = \Delta U + W$ and $Q = 0$ it follows that $\Delta U > 0$;
 thus the temperature increases; [3]
- (ii) curve starting at point p_Y, V_Y in direction of decreasing volume ;
 steeper than the isothermal through point p_Y, V_Y ;
 ending at a pressure equal to p_X ; [3]
- (d) the area under the isothermal curve of gas X;
 from the initial to the final volume; [2]

B4. Part 1 Plutonium as a power source



*Award [1] for correct numbers on alpha, and [1] for correct numbers on uranium.
No ECF on uranium if alpha wrong and other way around.*

- (b) (i) mass difference is $237.9979539 - (233.9904441 + 4.0015050) = 6.00 \times 10^{-3} \text{ u}$;
so energy released is $6.00 \times 10^{-3} \times 931.5 = 5.59 \text{ MeV}$;
conversion to Joules through $5.59 \times 10^6 \times 1.6 \times 10^{-19} \text{ J}$;
to get $8.9 \times 10^{-13} \text{ J}$ [3]

Accept alternative paths for example converting masses into kg etc.

Notice that using $E = mc^2$ gives

$$E = 6.00 \times 10^{-3} \times 1.661 \times 10^{-27} \times 9 \times 10^{16} = 8.96 \times 10^{-13} \approx 9 \times 10^{-13} \text{ J}.$$

- (ii) the alpha and the uranium nucleus have the same momentum;
and hence the alpha being of smaller mass than uranium carries most of the energy; [2]

- (c) (i) six months is short compared to the half-life and so the number of plutonium nuclei does not change appreciably ;
activity is proportional to the number of plutonium nuclei present/OWTTE ; [2]

- (ii) rate of energy released = $8.9 \times 10^{-13} \times 4.1 \times 10^{13}$;
= 37 W ; [2]

- (iii) $37 = 0.065 \times 150 \times \frac{\Delta\theta}{\Delta t}$;
to get $\frac{\Delta\theta}{\Delta t} = 3.8 \text{ K s}^{-1}$; [2]

- (d) (i) the alpha particles transfer kinetic energy to the plutonium atoms;
thus increasing the average kinetic/vibrational energy of the atoms;
and hence the temperature since temperature is a measure of the average kinetic energy of the atoms; [3]

- (ii) the transfer of energy increases the (interatomic) potential energy of the plutonium atoms;
at constant temperature;
while keeping the kinetic energy of the atoms constant; [3]

Part 2 Motion of a satellite

- (a) the work done per unit mass;
in bringing a small/point mass from infinity to a point (in the gravitational field); [2]
Ratio idea essential for first mark.

- (b) (i) equating gravitational force to centripetal $\frac{GMm}{r^2} = \frac{mv^2}{r}$;
to get the speed $v^2 = \frac{GM}{r}$;
and hence $E_K = \frac{1}{2} \frac{GMm}{r} = \frac{1}{2} \frac{GMm}{2R} = \frac{GMm}{4R}$; [3]

- (ii) potential energy in orbit is $E_p = -\frac{GMm}{r} = -\frac{GMm}{2R}$;
total energy is then $E = \frac{GMm}{4R} - \frac{GMm}{2R} = -\frac{GMm}{4R}$;
i.e. $E = -1.5 \times 10^{10}$ J; [3]
Award [1 max] for bare answer without explanation.

- (iii) at infinity the potential energy is zero and hence if satellite gets there its total energy will be $E \geq 0$;
but the satellite has negative energy and hence it cannot escape to infinity/the satellite is bound to the Earth forever;
the minimum energy that must be supplied } *the value must agree with the*
is $E = 1.5 \times 10^{10}$ J; (or ECF from (b) (ii)) } *candidate's answer to (b) (ii).* [3]
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