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Section A

1 (a) work done moving unit mass
from infinity to the point
M1
A1 [2]

(b) (i) at \( R, \phi = 6.3 \times 10^7 \text{ J kg}^{-1} \) (allow \( \pm 0.1 \times 10^7 \)) \( \phi = GM/R \)
\[ \frac{6.3 \times 10^7}{R} = \frac{(6.67 \times 10^{-11} \times M)}{(6.4 \times 10^6)} \]
\[ M = 6.0 \times 10^{24} \text{ kg} \] (allow 5.95 \( \rightarrow \) 6.14)
A1 [3]
Maximum of 2/3 for any value chosen for \( \phi \) not at \( R \)

(ii) change in potential = \( 2.1 \times 10^7 \text{ J kg}^{-1} \) (allow \( \pm 0.1 \times 10^7 \))
loss in potential energy = gain in kinetic energy
\[ \frac{1}{2} mv^2 = \phi m \text{ or } \frac{1}{2} mv^2 = GM/3R \]
\[ \frac{1}{2} v^2 = 2.1 \times 10^7 \]
\[ v = 6.5 \times 10^3 \text{ m s}^{-1} \] (allow 6.3 \( \rightarrow \) 6.6)
(answer 7.9 \( \times \) 10\(^3\) m s\(^{-1}\), based on \( x = 2R \), allow max 3 marks)

(iii) e.g. speed / velocity / acceleration would be greater
deviates / bends from straight path
B1
(any sensible ideas, 1 each, max 2)

2 (a) (i) reduction in energy (of the oscillations)
reduction in amplitude / energy of oscillations
due to force (always) opposing motion / resistive forces
B1
any two of the above, max 2

(ii) amplitude is decreasing (very) gradually / oscillations would
continue (for a long time) / many oscillations
M1
light damping
A1 [2]

(b) (i) frequency = \( 1/0.3 \) = 3.3 Hz
allow points taken from time axis giving \( f = 3.45 \text{ Hz} \)
A1 [1]

(ii) energy = \( \frac{1}{2} mv^2 \) and \( v = \omega a \)
\[ = \frac{1}{2} \times 0.065 \times (2\pi/0.3)^2 \times (1.5 \times 10^{-2})^2 \]
\[ = 3.2 \text{ mJ} \]
M1
A0 [2]

(c) amplitude reduces exponentially / does not decrease linearly
so will be not be 0.7 cm
M1
A1 [2]
3 (a) (i) 1 \text{ deg C} \text{ corresponds to } \frac{(3840 - 190)}{100} \Omega \\
\text{ for resistance } 2300 \Omega, \text{ temperature is } 100 \times (2300 - 3840) / (190 - 3840) \text{ C1} \\
\text{ temperature is } 42 \text{°C} \text{ A1 [2]} \\
(ii) \text{ either } 286 \text{ K} = 13 \text{°C} \text{ or } 42 \text{°C} = 315 \text{ K} \text{ B1} \\
\text{ thermodynamic scale does not depend on the property of a substance} \text{ M1} \\
\text{ so change in resistance (of thermistor) with temperature is non-linear} \text{ A1 [3]} \\

(b) heat gained by ice in melting = 0.012 \times 3.3 \times 10^5 \text{ J} \\
\quad = 3960 \text{ J} \text{ C1} \\
heat lost by water = 0.095 \times 4.2 \times 10^3 \times (28 - \theta) \text{ C1} \\
3960 \times (0.012 \times 4.2 \times 10^3 \times \theta) = 0.095 \times 4.2 \times 10^3 \times (28 - \theta) \text{ C1} \\
\theta = 16 \text{°C} \text{ A1 [4]} \\
\text{ (answer } 18 \text{°C} \text{ – melted ice omitted – allow max 2 marks)} \\
\text{ (use of (\theta - T) then allow max 1 mark)} \\

4 (a) force = q_1 q_2 / 4 \pi \epsilon_0 \lambda^2 \\
\quad = (6.4 \times 10^{-19})^2 / (4 \pi \times 8.85 \times 10^{-12} \times (12 \times 10^{-6})^2) \text{ C1} \\
\quad = 2.56 \times 10^{-17} \text{ N} \text{ A1 [3]} \\

(b) potential at P is same as potential at Q \text{ B1} \\
\text{ work done } = q \Delta V \text{ M1} \\
\Delta V = 0 \text{ so zero work done} \text{ A0 [2]} \\

(c) at midpoint, potential is \textbf{2} \times (6.4 \times 10^{-19}) / (4 \pi \epsilon_0 \times 6 \times 10^{-6}) \text{ C1} \\
\text{ at P, potential is (6.4 \times 10^{-19}) / (4 \pi \epsilon_0 \times 3 \times 10^{-6}) + (6.4 \times 10^{-19}) / (4 \pi \epsilon_0 \times 9 \times 10^{-6}) \text{ C1} \\
\text{ change in potential } = (6.4 \times 10^{-19}) / (4 \pi \epsilon_0 \times 9 \times 10^{-6}) \text{ C1} \\
\text{ energy } = 1.6 \times 10^{-19} \times (6.4 \times 10^{-19}) / (4 \pi \epsilon_0 \times 9 \times 10^{-6}) \text{ C1} \\
\quad = 1.0 \times 10^{-22} \text{ J} \text{ A1 [4]} \\

5 (a) e.g. ‘storage of charge’ / storage of energy \\
\text{ blocking of direct current} \\
\text{ producing of electrical oscillations} \\
\text{ smoothing} \\
\text{ (any two, 1 mark each)} \text{ B2 [2]} \\

(b) (i) capacitance of parallel combination = 60 \mu F \text{ C1} \\
\text{ total capacitance } = 20 \mu F \text{ A1 [2]} \\
(ii) p.d. across parallel combination = \frac{1}{2} \times p.d. \text{ across single capacitor} \text{ C1} \\
\text{ maximum is } 9 \text{V} \text{ A1 [2]} \\

(c) \text{ either energy } = \frac{1}{2} CV^2 \text{ or energy } = \frac{1}{2} QV \text{ and } Q = CV \text{ C1} \\
\text{ energy } = \frac{1}{2} \times 4700 \times 10^{-6} \times (18^2 - 12^2) \quad \text{ C1} \\
\quad = 0.42 \text{ J} \text{ A1 [3]}
6 (a) (i) straight line with positive gradient through origin M1 A1 [2]

(ii) maximum force shown at $\theta = 90^\circ$ zero force shown at $\theta = 0^\circ$ M1 M1 reasonable curve with $F$ about $\frac{1}{2}$ max at $30^\circ$ A1 [3]

(b) (i) force on electron due to magnetic field force on electron normal to magnetic field and direction of electron B1 B1 [2]

(ii) quote / mention of (Fleming’s) left hand rule M1 electron moves towards QR A1 [2]

7 (a) either the value of steady / constant voltage that produces same power (in a resistor) as the alternating voltage A1 [2]
or if alternating voltage is squared and averaged (M1) the r.m.s. value is the square root of this averaged value (A1)

(b) (i) 220 V A1 [1]

(ii) 156 V A1 [1]

(iii) 60 Hz A1 [1]

(c) power $= V_{rms}^2 / R$

$R = \frac{156^2}{1500} = 16 \, \Omega$ A1 [2]

8 (a) (i) number $= \frac{(5.1 \times 10^{-6} \times 6.02 \times 10^{23})}{241} = 1.27 \times 10^{16}$ C1 A1 [2]

(ii) $A = \frac{\lambda N}{5.9 \times 10^5} = \frac{\lambda}{1.27 \times 10^{16}}$ C1

$\lambda = 4.65 \times 10^{-11} \, \text{s}^{-1}$ A1 [2]

(iii) $4.65 \times 10^{-11} \times t_{\frac{1}{2}} = \ln 2$

$t_{\frac{1}{2}} = 1.49 \times 10^{10} \, \text{s}$ C1

$= 470 \, \text{years}$ A1 [2]

(b) sample / activity would decay appreciably whilst measurements are being made B1 [1]
Section B

9 (a) (i) fraction of the output (signal) is added to the input (signal) out of phase by $180^\circ / \pi \text{ rad} / \text{ to inverting input}$ \hspace{1cm} M1

   (ii) e.g. reduces gain
         increases bandwidth
         greater stability
         reduces distortion
         (any two, 1 mark each) \hspace{1cm} B2 \hspace{1cm} [2]

(b) (i) gain $= \frac{4.4}{0.062}$
         $= 71$ \hspace{1cm} A1 \hspace{1cm} [1]

   (ii) $71 = 1 + \frac{120}{R}$
        $R = 1.7 \times 10^3 \Omega$ \hspace{1cm} C1 \hspace{1cm} A1 \hspace{1cm} [2]

(c) for the amplifier not to saturate
    maximum output is $(71 \times 95 \times 10^{-3} =) \approx 6.7 \text{ V}$ \hspace{1cm} B1 \hspace{1cm} [3]
    supply should be +/- 9 V \hspace{1cm} A1

10 (a) (i) strain gauge \hspace{1cm} B1 \hspace{1cm} [1]

   (ii) piezo-electric / quartz crystal / transducer \hspace{1cm} B1 \hspace{1cm} [1]

(b) circuit: coil of relay connected between sensing circuit output and earth
    switch across terminals of external circuit
    diode in series with coil with correct polarity for diode
    second diode with correct polarity \hspace{1cm} B1 \hspace{1cm} [4]

11 either quartz or piezo-electric crystal
    opposite faces / two sides coated (with silver) to act as electrodes
    either molecular structure indicated
    or centres of (+) and (–) charge not coincident
    potential difference across crystal causes crystal to change shape
    alternating voltage (in US frequency range) applied across crystal
    causes crystal to oscillate / vibrate
    (crystal cut) so that it vibrates at resonant frequency
    (max 6) \hspace{1cm} B1 \hspace{1cm} [6]
12 (a) signal becomes distorted / noisy
    signal loses power / energy / intensity / is attenuated
    B1

(b)  (i) either numbers involved are smaller / more manageable / cover wider range
    or calculations involve addition & subtraction rather than multiplication and division
    B1 [1]

(ii) \[ 25 = 10 \log \left( \frac{P_{\text{min}}}{(6.1 \times 10^{-19})} \right) \]
    minimum signal power = \( 1.93 \times 10^{-16} \) W
    signal loss = \( 10 \log \left( \frac{6.5 \times 10^{-3}}{1.93 \times 10^{-16}} \right) \)
    = 135 dB
    maximum cable length = 135 / 1.6
    = 85 km so no repeaters necessary
    C1 C1 C1 C1 A1 [5]