This mark scheme is published as an aid to teachers and candidates, to indicate the requirements of the examination. It shows the basis on which Examiners were instructed to award marks. It does not indicate the details of the discussions that took place at an Examiners’ meeting before marking began, which would have considered the acceptability of alternative answers.

Mark schemes should be read in conjunction with the question paper and the Principal Examiner Report for Teachers.

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1 (a) (gravitational) potential at infinity defined as/is zero

(gravitational) force attractive so work got out/done as object moves from infinity

so potential is negative

B1 [2]

(b) (i) \[ \Delta E = m \Delta \phi \]

\[ = 180 \times (14 - 10) \times 10^8 \]

\[ = 7.2 \times 10^{10} \text{ J} \]

increase

B1 [3]

(ii) energy required = 180 \times (10 - 4.4) \times 10^8

or

energy per unit mass = (10 - 4.4) \times 10^8

or

\[ \frac{1}{2} \times 180 \times v^2 = 180 \times (10 - 4.4) \times 10^8 \]

or

\[ \frac{1}{2} \times v^2 = (10 - 4.4) \times 10^8 \]

\[ v = 3.3 \times 10^4 \text{ m s}^{-1} \]

A1 [3]

2 (a) e.g. time of collisions negligible compared to time between collisions

no intermolecular forces (except during collisions)

random motion (of molecules)

large numbers of molecules

(total) volume of molecules negligible compared to volume of containing vessel

or

average/mean separation large compared with size of molecules

any two

B2 [2]

2 (b) (i) mass = \[ 4.0 / (6.02 \times 10^{-23}) = 6.6 \times 10^{-24} \text{ g} \]

or

mass = \[ 4.0 \times 1.66 \times 10^{-27} \times 10^3 = 6.6 \times 10^{-24} \text{ g} \]

B1 [1]

(ii) \[ \frac{3}{2} kT = \frac{1}{2} m \langle c^2 \rangle \]

\[ \frac{3}{2} \times 1.38 \times 10^{-23} \times 300 = \frac{1}{2} \times 6.6 \times 10^{-27} \times \langle c^2 \rangle \]

\[ \langle c^2 \rangle = 1.88 \times 10^6 \text{ (m}^2 \text{s}^{-2}) \]

C1

r.m.s. speed = \[ 1.4 \times 10^3 \text{ m s}^{-1} \]

A1 [3]
3 (a) acceleration/force proportional to displacement (from fixed point) M1
   acceleration/force and displacement in opposite directions A1 [2]

(b) maximum displacements/accelerations are different B1
   graph is curved/not a straight line B1 [2]

(c) (i) $\omega = \frac{2\pi}{T}$ and $T = 0.8$ s C1
   $\omega = 7.9$ rad s$^{-1}$ A1 [2]

(ii) $a = (-)\omega^2 x$
   $= 7.85^2 \times 1.5 \times 10^{-2}$ C1
   $= 0.93$ ms$^{-2}$ or $0.94$ ms$^{-2}$ A1 [2]

(iii) $\Delta E = \frac{1}{2} m\omega^2 (x_0^2 - x^2)$ C1
   $= \frac{1}{2} \times 120 \times 10^{-3} \times 7.85^2 \times \{(1.5 \times 10^{-2})^2 - (0.9 \times 10^{-2})^2\}$ C1
   $= 5.3 \times 10^{-4}$ J A1 [3]

4 (a) (i) product of speed and density M1
   reference to speed in medium (and density of medium) A1 [2]

(ii) $\alpha$: ratio of reflected intensity and/to incident intensity B1

   $Z_1$ and $Z_2$: (specific) acoustic impedances of media (on each side of boundary) B1 [2]

(b) in muscle: $I_M = I_0 e^{-\mu x}$
   $= I_0 \exp(-23 \times 3.4 \times 10^{-2})$ C1

$I_M / I_0 = 0.457$ C1

at boundary: $\alpha = (6.3 - 1.7)^2 / (6.3 + 1.7)^2$
   $= 0.33$ C1

$I_T / I_M = [(1 - \alpha) =] 0.67$ C1

$I_T / I_0 = 0.457 \times 0.67 = 0.31$ A1 [5]
5 (a) (i) \(1011\)  

(ii)

<table>
<thead>
<tr>
<th>(t) (ms)</th>
<th>(0)</th>
<th>0.25</th>
<th>0.50</th>
<th>0.75</th>
<th>1.00</th>
<th>1.25</th>
<th>1.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V)</td>
<td>1011</td>
<td>0110</td>
<td>1000</td>
<td>1110</td>
<td>0101</td>
<td>0011</td>
<td>0001</td>
</tr>
</tbody>
</table>

All 6 correct, 2 marks. 5 correct, 1 mark.

(b) sketch: 6 horizontal steps of width 0.25 ms shown  
steps at correct heights and all steps shown  
steps shown in correct time intervals

(c) increase sampling frequency/rate  
so that step width/depth is reduced  
increase number of bits (in each number)  
so that step height is reduced

6 (a) sketch: from \(x = 0\) to \(x = R\), potential is constant at \(V_s\)  
smooth curve through \((R, V_s)\) and \((2R, 0.5V_s)\)  
smooth curve continues to \((3R, 0.33V_s)\)

(b) sketch: from \(x = 0\) to \(x = R\), field strength is zero  
smooth curve through \((R, E)\) and \((2R, 0.25E)\)  
smooth curve continues to \((3R, 0.11E)\)

7 (a) line has non-zero intercept/line does not pass through origin  
charge is/should be proportional to potential (difference)  
or charge is/should be zero when p.d. is zero  
therefore there is a systematic error
(b) reasonable attempt at line of best fit
   use of gradient of line of best fit clear
   \[ C = 2800 \, \mu F \text{ (allow } \pm 200 \, \mu F) \]  
   A1 [3]

(c) energy = \( \frac{1}{2} CV^2 \) or energy = \( \frac{1}{2} QV \) and \( C = Q / V \)
   \[ \Delta \text{ energy} = \frac{1}{2} \times 2800 \times 10^{-6} \times (9.0^2 - 6.0^2) \]
   \[ = 6.3 \times 10^{-2} \text{ J} \]  
   A1 [3]

8 (a) op-amp has infinite/(very) large gain
   op-amp saturates if \( V^+ \neq V^- \)
   \( V^+ \) is at earth potential so P (or \( V^- \)) must be at earth
   A1 [3]

(b) input resistance to op-amp is very large
   or
   current in \( R_2 = \) current in \( R_1 \)
   \[ V_{IN} (-0) = IR_2 \text{ and } (0) - V_{OUT} = IR_1 \]  
   M1
   \[ V_{OUT} / V_{IN} = -R_1 / R_2 \]  
   A1 [3]

(c) relay coil connected between \( V_{OUT} \) and earth
   correct diode symbol connected between \( V_{OUT} \) and coil or between coil and earth
   correct polarity for diode ('clockwise')
   M1
   A1 [3]

9 (a) 0.10 mm
   B1 [1]

(b) \[ V_H = (0.13 \times 3.8) / (6.0 \times 10^{28} \times 0.10 \times 10^{-3} \times 1.60 \times 10^{-19}) \]
   \[ = 5.1 \times 10^{-7} \text{ V} \]  
   A1 [2]

10 (a) (non-uniform) magnetic flux in core is changing
   induces (different) e.m.f. in (different parts of) the core
   (eddy) currents form in the core
   which give rise to heating
   M1
(b) as magnet falls, tube cuts magnetic flux \( M_1 \)
e.m.f./(eddy) currents induced in metal/aluminium (tube) \( A_1 \)
(eddy) current heating of tube \( M_1 \)
with energy taken from falling magnet \( A_1 \)
or
(eddy) currents produce magnetic field \( \text{(M1)} \)
that opposes motion of magnet \( \text{(A1)} \)
so magnet B has acceleration < \( g \)
or
magnet B has smaller acceleration/reaches terminal speed \( A_1 \) [5]

11 (a) period = 15 ms \( C_1 \)

frequency \( (= 1 / T) = 67 \text{ Hz} \) \( A_1 \) [2]

(b) zero \( A_1 \) [1]

(c) \( I_{\text{r.m.s.}} = I_0 / \sqrt{2} \) \( C_1 \)

\( = 0.53 \text{ A} \) \( A_1 \) [2]

(d) energy = \( I_{\text{r.m.s.}}^2 \times R \times t \) or \( \frac{1}{2} I_0^2 \times R \times t \)

or

power = \( I_{\text{r.m.s.}}^2 \times R \) and energy = power \( \times t \) \( C_1 \)

energy = \( 0.53^2 \times 450 \times 30 \times 10^{-3} \)

\( = 3.8 \text{ J} \) \( A_1 \) [2]

12 (a) (in a solid electrons in) neighbouring atoms are close together \( \text{(M1)} \)
(this changes their electron energy levels \( \text{M1} \)
(many atoms in lattice) cause a spread of energy levels into a band \( A_1 \) [3]
(b) photons of light give energy to electrons in valence band  
   electrons move into the conduction band  
   leaving holes in the valence band  
   these electrons and holes are charge carriers  
   increased number/increased current, hence reduced resistance  

13 (a) e.g. background count (rate)/radiation  
   multiple possible counts from each decay  
   radiation emitted in all directions  
   dead-time of counter  
   (daughter) product unstable/also emits radiation  
   self-absorption of radiation in sample or absorption in air/detector window  
   three sensible suggestions, 1 each  

(b) \[ A = A_0 \exp(-\ln 2 \times t / T_{1/2}) \]  
   \[ 1.21 \times 10^2 = 3.62 \times 10^4 \exp(-\ln 2 \times 42.0 / T_{1/2}) \]  
   \or\  
   \[ 1.21 \times 10^2 = 3.62 \times 10^4 \exp(-\lambda \times 42.0) \]  
   \[ T_{1/2} = 5.1 \text{ minutes (306 s)} \]  

(c) discrete energy levels (in nuclei)