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) force proportional to product of masses and inversely proportional to square of separation
   either point masses or particles or 'size' \( \ll \) separation

   \[ F \propto \frac{M_1 M_2}{x^2} \]

   A1 [2]

(b) gravitational force provides the centripetal force

   \[ \frac{GMm}{x^2} = m\omega^2 \]
   \[ \omega = \frac{2\pi}{T} \]

   A1 [3]

(c) either use of gradient of graph or line through origin so can use single point or line shown extrapolated to origin

   gradient = \( \frac{4.5 \times 10^{14}}{0.35} \)

   \[ 6.67 \times 10^{-11} \times M = 4\pi^2 \times (4.5 \times 10^{14} \times 10^9)/(0.35 \times 24 \times 3600)^2 \]

   correct conversion for km\(^3\) and power of 10

   correct conversion for day\(^2\)

   \[ M = 1.02 \times 10^{26} \text{ kg} \]


2 (a) total volume of molecules negligible compared to that of containing vessel no intermolecular forces molecules in random motion time of collision small compared with the time between collisions large number of molecules any two

   B2 [2]

(b) in a real gas there is a range of velocities or must take the average of \( v^2 \)

   B1 [1]

(c) (i) \( \rho \frac{1}{3} \rho <c^2> \)

   \[ 1.0 \times 10^5 = \frac{1}{3} \times 1.2 \times <c^2> \]

   \[ <c^2> = 2.5 \times 10^5 \]

   \[ c_{r.m.s.} = 500 \text{ m s}^{-1} \]

   C1

   A1 [3]

(ii) \( T \propto <c^2> \)

   \[ <c^2> = 2.5 \times 10^5 \times 480/300 \]

   \[ = 4.0 \times 10^5 \text{ m}^2 \text{ s}^{-2} \]

   allow ECF from (c)(i)

   A1 [2]

3 (a) same temperature no (net) transfer of thermal energy (between the bodies)

   B1 [2]

(b) (i) 41.3 K

   B1 [1]

(ii) 330.4 K

   B1 [1]
(c) $\Delta E_k = \frac{3}{2} \times 1.9 \times 60$

$= 171 \text{ J}$

work done $= p\Delta V$

$= 1.2 \times 10^5 \times 950 \times 10^{-6}$

$= 114 \text{ J}$

thermal energy $= 114 + 171$

$= 285 \text{ (290) J}$

4 (a) acceleration/force proportional to distance from a fixed point or displacement

either acceleration/force and displacement in opposite directions

or acceleration/force (always) directed towards a fixed point/mean position/equilibrium position

(b) $h \rho g = Mg/A$

$h \times 790 \times 4.9 \times 10^{-4} = 70 \times 10^{-3}$ leading to $h = 0.18 \text{ m or 18 cm}$

(c) (i) $\omega^2 = \frac{(790 \times 4.9 \times 10^{-4} \times 9.81)}{(70 \times 10^{-3})}$

$= 54.25$

$\omega = 7.37 \text{ (rad s}^{-1})$

period $(= 2\pi / \omega) = 0.85 \text{ s}$

$t_1 = 0.43 \text{ s}$

2. $t_3 = 1.28 \text{ s (allow 2 s.f.)}$

(ii) energy of peak $= \frac{1}{2}M\omega^2x_0^2$

change $= \frac{1}{2} \times 70 \times 10^{-3} \times 54.25 \{(2.2 \times 10^{-2})^2 - (1.0 \times 10^{-2})^2\}$

$= 7.3 \times 10^{-4} \text{ J}$
5 (a) charges in metal do not move
   no (resultant) force on charges so no (electric) field
   (allow 1/2 for "no field inside sphere")

(b) either average field strength
   \[ \frac{1}{2} (28 + 54) \text{ NC}^{-1} \]
   average force
   \[ 8.5 \times 10^{-9} \times \frac{1}{2} (28 + 54) \]
   \[ = 3.49 \times 10^{-7} \text{ N} \]
   change in potential energy
   \[ 3.49 \times 10^{-7} \times 2.0 \times 10^{-2} \]
   \[ = 7.0 \times 10^{-9} \text{ J} \]
   (allow range 54 ± 1)
   or (for a point charge) \( V = Ex \)
   \[ \Delta V = (54 \times 5.0 \times 10^{-2}) - (28 \times 7.0 \times 10^{-2}) \]
   change in potential energy
   \[ 8.5 \times 10^{-9} \times (2.70 - 1.96) \]
   \[ = 6.3 \times 10^{-9} \text{ J} \]
   (allow range 54 ± 1)
   or \( \Delta V \) is area under curve
   \[ \Delta V = 0.74 \text{ V} \]
   change in potential energy
   \[ 8.5 \times 10^{-9} \times 0.74 \]
   \[ = 6.3 \times 10^{-9} \text{ J} \]
   (allow range 0.70 to 0.84)

6 (a) magnetic fields are equal in magnitude/strength/flux density
   magnetic fields are opposite in direction
   fields superpose/add/cancel to give zero/negligible resultant field

(b) core causes increase in magnetic flux in the solenoid/induced poles in core
   or field induced in core
   changing flux threads/cuts the turns on the solenoid
   (by Faraday’s law) an e.m.f. is induced in the solenoid
   by Lenz’s law, this e.m.f. opposes the battery e.m.f.

7 (a) (i) \( V_0 (= 14 \sqrt{2} ) = 19.8 \) (20) V

(ii) \( \omega (= 2\pi \times 750) = 4700 \text{ rad s}^{-1} \)

(b) large amount of charge required to charge capacitor
   capacitor would charge and discharge rapidly/in a very short time
   or capacitor would charge and discharge 750/1500 times per second
   \[ I = \frac{Q}{t}, \text{ so large current} \]
8 (a) \( \frac{hc}{\lambda} = \phi + E_{\text{MAX}} \)
\( h = \) Planck constant, \( c = \) speed of light / e.m. radiation

(b) (i) gradient of line is \( hc \)
\( h \) and \( c \) are both constants

(ii) \( \phi = 2.28 \times 1.6 \times 10^{-19} \)
\( = 3.65 \times 10^{-19} \) (J)

\( \frac{hc}{\lambda_0} = 3.65 \times 10^{-19} \)
\( \lambda_0 = \frac{(6.63 \times 10^{-34} \times 3.0 \times 10^8)}{(3.65 \times 10^{-19})} \)
\( = 5.45 \times 10^{-7} \) m

9 (a) energy required to separate the nucleons (in a nucleus)
or energy required to separate the protons and neutrons in a nucleus
(or energy released when nucleons combine (to form a nucleus)/energy released when protons and neutrons combine to form a nucleus)
either completely or to infinity
(either free protons and neutrons or from infinity)

(b) (i) either different forms of same element or nuclei having same number of protons with different numbers of neutrons

(ii) 1784 MeV (accept min. 3 s.f.)
7.57 MeV

(c) (i) \( \lambda = \ln 2 / (7.1 \times 10^8 \times 365 \times 24 \times 3600) = 3.1 \times 10^{-17} \) s\(^{-1} \)

(ii) \( A = \lambda N \)
\( 5000 = 3.1 \times 10^{-17} \times N \)
\( N = 1.61 \times 10^{20} \)

mass \( = 235 \times (1.61 \times 10^{20}) / (6.02 \times 10^{23}) \)
\( = 0.063 \) g (accept min. 2 s.f.)
Section B

10 (a) correct LED symbol B1
separately connected between $V_{OUT}$ and earth with opposite polarities M1
diode B 'pointing' from $V_{OUT}$ to earth A1 [3]

(b) diode in $V_{OUT}$ line M1
diode 'pointing' towards $V_{OUT}$ from earth A1
relay coil connected between $V_{OUT}$ and earth M1

(if a diode is placed across the relay it must point down otherwise max. 2/4;
one diode but wrong direction max. 3/4)

11 (a) e.g. scattering (in metal)
non-parallel beam (not just “A closer than B”)
reflection (from metal)
diffraction in the metal/lattice

any two B2 [2]

(b) (i) 1. ratio $= e^{ix}$
$= \exp(0.27 \times 4.0)$
$= 2.94 (2.9)$ A1 [2]

2. ratio $= \exp(0.27 \times 2.5) \times \exp(3.0 \times 1.5)$
$= 1.96 \times 90$
$= 177 (180)$ A1 [2]

(do not penalise unit error more than once)

(ii) each ratio gives measure of transmission ratios (in (i)) very different so good contrast B1 [2]

12 (a) (i) serial-to-parallel converter B1 [1]

(ii) digital-to-analogue converter or DAC B1 [1]

(iii) (audio) amplifier or AF amplifier B1 [1]

(b) (i) 4 A1 [1]

(ii) 1011 A1 [1]

(c) correct levels at 0.25 ms intervals
0, 8, 11, 10, 15 A1
and 7, 4 A1
series of steps, each of depth 0.25 ms M1
voltage levels shown in correct intervals A1 [4]
13 (a) advantage: e.g. shorter time delay
greater coverage over a long time

 disadvantage: e.g. satellite needs to be tracked
more satellites for (continuous) coverage/communication
(any sensible suggestions)

(b) (i) frequencies linking Earth with satellite

6 GHz is uplink frequency
4 GHz is downlink frequency (allow vice versa)

(ii) either signal from Earth to satellite is attenuated greatly
or downlink must be amplified greatly before transmission
downlink would swamp uplink unless frequencies are different