RAFFLES INSTITUTION
YEAR 5-6 PHYSICS DEPARTMENT

9749 H2 Physics
2023 GCE A-Level Suggested Solutions

Paper 1

1 **C** The varying reaction time of a person will cause him/her to start and stop the stop-watch either early or late giving rise to random error.

2 **D** Displacement is the area under the $v - t$ graph $= \frac{1}{2}(p+q)r$

3 **A**

$$E = \frac{1}{2}mv^2 = \frac{1}{2}\frac{(mv)^2}{m} = \frac{1}{2}\frac{p^2}{m}$$
$$p = \sqrt{2mE}$$

Average force,

$$F = \frac{\Delta p}{\Delta t}$$
$$F = \frac{0-(-p)}{t}$$
$$Ft = p$$
$$Ft = \sqrt{2mE}$$
$$\Rightarrow Ft \propto \sqrt{E}$$

4 **C** Since collision is elastic,
Relative speed of approach = relative speed of separation

$$u_1 - (-u_2) = v_2 - v_1$$
$$u_1 + u_2 = v_2 - v_1$$

5 **B** Let the CG be a distance x below the centre of the upper square. Treating the sheet as horizontal and take moments about the CG.

$$mgx = 0.5mg(4-x)$$
$$2x = 4 - x$$
$$x = 1.33$$

Hence, it is 6.0 – 1.33 = 4.7 cm

Or:

$$x_{cm} = \frac{m_1x_1 + m_2x_2}{m_1 + m_2}$$
$$= \frac{0.5m(2.0) + m(6.0)}{1.5m}$$
$$= 4.67 \text{ cm}$$

6 **B** $P = 0.6 \times \left(\frac{1}{2}\frac{m}{t}u^2 - \frac{1}{2}\frac{m}{t}v^2 \right) = 0.6 \times \frac{1}{2}(9.7)\left(4.0^2 - 1.5^2\right)$

$= 40.0125 \text{ W}$

Option A: $P = 12 \times 1.5 = 18$ W
Option B: $P = 12 \times 3.3 = 39.6$ W
Option C: $P = 24 \times 0.60 = 14.4$ W
Option D: $P = 24 \times 2.8 = 67.2$ W

7 **C** In half a year, Earth will complete half a circle around the Sun. Hence angular displacement is π rad.

8 **B** Gravitational field strength is gravitational force exerted per unit mass.

9 **C** For path C, the spacecraft will constantly experience gravitational force due to Earth. Hence it will tend to curve towards the Earth unless the spacecraft fires its rockets to maintain its straight path.

10 **A** Time duration t for each molecule to hit the same shaded wall again $= \frac{2p}{v}$

$$F = \frac{\Delta p}{t} = \frac{N\left(mv - (-mv)\right)}{t}$$
$$= \frac{2Nmv}{\frac{2p}{v}} = \frac{mNv^2}{p}$$

11 **B** $U \propto T$

$$\therefore \frac{U_{0°C}}{U_{273°C}} = \frac{273}{(273 + 273)}$$

$U_{273°C} = 2U$

12 **C** $P = mc\frac{\theta}{t}$

For the same P supplied, gradient of temperature-time graph of P (i.e. $\frac{\theta}{t}$) is steeper than that of Q. Hence, c of P will be smaller than that of Q.

$Pt = mL$. Since P took a longer time t, L of P is larger than that of Q.

13 **B** $\frac{1}{2}m\omega^2 x_0{}^2 = \frac{1}{2}\left(\frac{2.9 \times 10^{-2}}{6.02 \times 10^{23}}\right)\left(\frac{2\pi}{3.0 \times 10^{-3}}\right)^2 \left(2.0 \times 10^{-6}\right)^2$

$= 4.2 \times 10^{-31}$ J

14 **D** Phase difference $= \frac{1}{3} \times 360° = 120°$

$I \propto A^2$

$$\frac{I_X}{I_Y} = \frac{3^2}{2^2} = 2.25$$

15 **B** After 1st filter $= I_0$

After 2nd filter $= I_0 \cos^2 45°$

After 3rd filter $= I_0 \cos^2 45° \cos^2 45° = 0.25 I_0$

16 **D** $b \sin\theta = \lambda$

Using small angle approximation,

$b \tan\theta \approx \lambda$

$$b\left(\frac{x/2}{D}\right) \approx \lambda$$

$$b \approx \frac{2\lambda D}{x} = \frac{2cD}{fx}$$

17 **A**

$$\sin\theta = \frac{n\lambda}{d}$$

$$d = \frac{2\left(500 \times 10^{-9}\right)}{\sin\left(\frac{60°}{2}\right)} = 2.0 \times 10^{-6} \text{ m} = 2.0 \times 10^{-3} \text{ mm}$$

$$\text{lines per mm } = \frac{1}{2.0 \times 10^{-3}} = 500$$

18 **A**

$$x = \frac{\lambda D}{a}$$

$x \propto D$

$\therefore$ x increase linearly with t since D is increased at a constant rate

19 **D** The beam of protons will be attracted to plate Y (negative plate) and move in a parabolic path as the electric force on them is constant (always downwards).

20 **B**

$$V = \frac{Q}{4\pi\varepsilon_0 r} \quad \Rightarrow \quad V \propto \frac{1}{r}$$

$$\therefore \frac{V_P}{636} = \frac{2\sqrt{2}}{3}$$

$V_P = 600$ V

21 **B** Definition of e.m.f.

22 **D** For balance point to be reached, both the positive polarity of the cells must be facing the same side i.e., to the left based on the potentiometer circuit. Either X or Y must be on point P so that it can be moved to find the balance length. Option D is the only possible option.

23 **C** When intensity is zero, the resistance of LDR is maximum. The combined resistance will be maximum. As intensity increases, the resistance of the LDR decreases. Hence the combined resistance will decrease.

24 **A** The magnetic field lines can be imagined as produced by a North pole on the left of the field lines. The bar magnet will be attracted to the North pole and move along the horizontal field line.

25 **D** The final position of the beam is upwards and rightwards compared to the position with no fields.

For the electrons to be deflected upwards, either the magnetic field must be pointing rightwards or the electric field must be pointing downwards.

For the electrons to be deflected rightwards, either the magnetic field must be pointing downwards or the electric field must be pointing leftwards.

From the options given, magnetic field must be pointing rightwards and electric field leftwards.

26 **C** Unit of magnetic flux density is tesla.

Since magnetic flux is the product of magnetic flux density and area, its unit is tesla metre^2.

27 **D** The graph shows a half-wave rectification wave. It can only be produced by having a sinusoidal source and diodes pointing in the same direction.

28 **A** $E = hf$

$$\left(-30.6 - \left(-122.4\right)\right) \times 1.60 \times 10^{-19} = \left(6.63 \times 10^{-34}\right) \frac{3.00 \times 10^{8}}{\lambda}$$

$\lambda = 1.35 \times 10^{-8}$ m

29 **A**

$$p = \frac{h}{\lambda}$$

$\lambda p = h$

30 **C**

$$V_{rms} = \sqrt{\frac{V_0^{\,2} \times T}{T}} = V_0$$

Paper 2

1 **(a)** The pressure at different depths *h* in the water is given by ρgh + atmospheric pressure, where ρ is the density of water. <u>Hence the pressure at the lower surface is higher than the pressure at the upper surface.</u> [1]
Therefore, <u>the upward force acting on the lower surface is larger than the downward force acting on the upper surface</u>, resulting in a <u>net upward force</u> which is the uprhrust. [1]

(b) **(i)** By Archimedes' principle, upthrust = weight of water displaced. [1]
Also, volume of water displaced = volume of block.

$$\begin{aligned}\text{Upthrust} &= \rho Vg \\ &= 1000\times\left(27.8\times10^{-6}\right)\times9.81 \\ &= 0.2727 \\ &\approx \mathbf{0.27\ N}\ \text{(shown)}\end{aligned}$$ [1]

(ii) Applying principle of moments to

<u>Fig. 1.1:</u>

$$8.3\times W = 18.0\times F \qquad (1)$$ [1]

<u>Fig. 1.2:</u>

$$7.8\times W = 19.0\times\left(F-0.27\right) \qquad (2)$$ [1]

(2) ÷ (1):
$$\begin{aligned}\frac{78}{83} &= \frac{19}{18}\frac{F-0.27}{F} \\ 78F &= 87.6F - 23.7 \\ F &= \mathbf{2.5\ N}\end{aligned}$$ [1]

2 **(a)** Minimum kinetic energy occurs at the highest point where the velocity is $v\cos42^\circ = 0.743v$. [1]

Hence,

$$\frac{1}{2}m\left(0.743v\right)^2 = 65$$

$$v = \sqrt{\frac{65\times2}{0.55\times0.743^2}} = 20.7\ \text{m s}^{-1}$$ [1]

Hence, vertical component is $20.7\sin42^\circ = 13.8\ \approx 14\ \text{m s}^{-1}\ \left(\text{shown}\right)$ [1]

(b) Let the time of flight be *t*. Applying $v = u + at$ to the vertical motion,

$$\begin{aligned}-14 &= 14 - 9.81t \\ t &= 2.85\ \text{s}\end{aligned}$$ [1]

Horizontal velocity $= 20.7\times0.743 = 15.4\ \text{m s}^{-1}$ [1]

Horizontal displacement $= 15.4\times2.85 = \mathbf{44\ m}$ [1]

(c) The net force and the average deceleration in the upward motion is larger in magnitude than the net force and average acceleration in the downward motion. Hence, the time taken to reach the maximum height will be shorter. [1]

OR:
As energy is lost continuously due to air resistance, the average speed in the upward motion is higher than the average speed in the downward motion. Since the distance travelled is the same, the time taken to reach the maximum height will be shorter.

3 **(a)** **(i)** Distance of the satellite from the centre of Earth = 36000 + 6400 = 42400 km. [1]

$$F = \frac{GMm}{r^2} = \frac{6.67\times10^{-11}\times6.0\times10^{24}\times6800}{\left(42400\times10^{3}\right)^2} = \mathbf{1510\ N}$$ [1]

(ii) All geostationary satellites should have the same period T.

$$\frac{GMm}{r^2} = mr\omega^2$$ [1]

$$= mr\left(\frac{2\pi}{T}\right)^2$$

$$T^2 = \frac{4\pi^2}{GM}r^3$$

Hence, T is independent of the mass m of the satellite.

(b) **(i)** Magnetic force provides the centripetal force:

$$Bev = \frac{mv^2}{r}$$ [1]

$$r = \frac{mv}{Be} = \frac{3.4\times10^{-23}}{0.0018\times1.6\times10^{-19}} = \mathbf{0.118\ m}$$ [1]

(ii) From $r = \frac{mv}{Be}$, the radius depends on the momentum of the particle too. Hence, ions with the same charge but different momentum will travel in circular path of different radii. [1]

4 **(a)** **(i)** The sound wave produced by the loudspeaker travels to the metal plate and is reflected.
The reflected wave travels toward the loudspeaker and superpose with the incident wave. [1]
Since the incident wave and the reflected wave have the same amplitude, wavelength and frequency and travel in opposite directions, the resultant disturbance is a stationary wave. [1]

(ii) From Fig. 4.2,

$$2T = 10\times0.50\times10^{-3}$$ [1]

$$T = 2.5\times10^{-3}\ \text{s}$$

$$f = \frac{1}{T} = \frac{1}{2.5\times10^{-3}} = 400\ \text{Hz}\ (\textit{shown})$$ [1]

(iii) Wavelength $\lambda = \frac{340}{400} = 0.85$ m [1]

Distance between adjacent nodes $= \frac{\lambda}{2} = \mathbf{0.425\ m}$ [1]

(b) **(i)** Path difference = 0.4 m = 2λ. [1]
Hence, the waves arrive at P in phase and interfere constructively to give a maximum intensity. [1]

(ii) Since $I \propto \frac{1}{r^2}$ [1]

$\frac{I_X}{I_Y} = \left(\frac{1.8}{1.4}\right)^2$ [1]

$I_Y = 4.5 \times 10^{-6} \times 0.605$
$= \mathbf{2.72 \times 10^{-6}\ W\ m^{-2}}$

(iii) Since $I \propto A^2$, hence $A \propto \frac{1}{r}$ [1]

$\frac{A_x}{A_y} = \frac{1.8}{1.4}$ [1]
$= \mathbf{1.3}$

5 **(a)** Resistance is the ratio $\frac{V}{I}$.

At low p.d., the resistance is constant as p.d. increases because the graph is a straight line passing through the origin, implying that current and p.d. is increasing at the same rate. [1]

At high p.d., the graph curves upward implying that current is increasing at a faster rate than the p.d. Hence the ratio $\frac{V}{I}$ which is equal to the resistance decreases. [1]

(b) **(i)** The current in the two resistors are identical. Hence, [1]

Ratio $= \frac{I^2(220)}{I^2(640)} = 0.344 \approx 0.34$ $(\textit{shown})$ [1]

(ii) Since the current in the two resistors are still identical, the ratio in the powers will remain unchanged. [1]

(iii) <u>Series Circuit:</u>

$R_{total} = 220 + 640 = 860\ \Omega \quad \Rightarrow \quad I = \dfrac{E}{860}$ [1]

<u>Parallel Circuit:</u> [1]

$R_{total} = \dfrac{220 \times 640}{220 + 640} = 164\ \Omega \quad \Rightarrow \quad I = \dfrac{E}{164}$

Hence, ratio $= \dfrac{164}{860} = \mathbf{0.190}$ [1]

(iv) The two currents become:

$I_1 = \dfrac{E \sin \omega t}{860}$ and $I_2 = \dfrac{E \sin \omega t}{164}$ [1]

Clearly, the ratio of the currents remains unchanged because it depends only on the ratio of the effective resistance.

6 **(a)** The <u>induced e.m.f. is proportional to the rate of change</u> of <u>magnetic flux linkage.</u> [2]

(b) **As the wire moves up, it cuts the magnetic flux between the two poles. By Faraday's law, an e.m.f. is induced in the wire. By Lenz's Law, the direction of the e.m.f. is from A to B.**
As the wire moves down, it cuts the magnetic flux between the two poles again but in the opposite direction. By Faraday's law, an e.m.f. is induced in the wire. By Lenz's Law, the direction of the e.m.f. is from B to A in the opposite direction.

1 mark for using Faraday's Law to explain how e.m.f. is induced.
1 mark for explaining why the direction of e.m.f. alternates.

(c) induced emf $= BLv$

$= 0.250 \times 0.15 \times 0.80$ [1]

$= \mathbf{0.030\ V}$ [1]

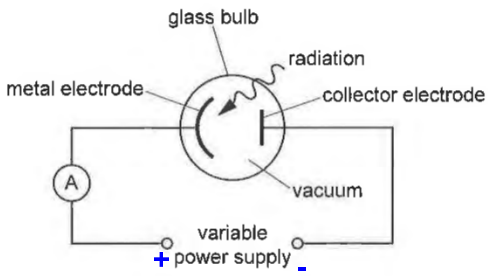
(d) The induced e.m.f. for both the top half and bottom half of the wire is directed into the plane of the paper. Hence, they <u>oppose each other</u> and the e.m.f. induced across X and Y is <u>zero</u>. [1] [1]

7 **(a)** **(i)** Photoelectric effect [1]

Alternatively, Compton effect

(ii) Double-slit interference of light [1]
Diffraction of EM waves

(b) **(i)** [1]



(ii) $E = \Phi + eV_s$ [1]

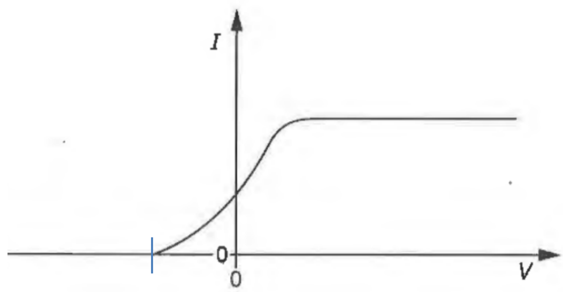
$$V_s = \frac{(12.4 - 4.2)e}{e} = \mathbf{8.2\ V}$$ [1]

(iii) Electromagnetic radiation is made up of <u>photons each of energy $E = hf$</u> where f is the frequency of the radiation. <u>Intensity affects the rate of incidence of photons but not the energy of each photon.</u> [1]

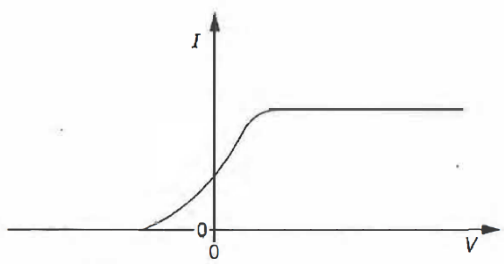
During photoelectric effect, each electron <u>absorbs only one photon</u> so the maximum kinetic energy of each photoelectron is the same. [1]

<u>The stopping potential is given by the equation used in **(ii)** $E = \Phi + eV_s$, which is independent of intensity.</u> [1]

(c) **(i)** [1]



(ii) [2]



Same stopping potential [1]
Higher saturated current [1]

8 **(a)** **peak to peak = 6.0 small square**
period = 6.0 × 0.10 = 0.60 s [1]

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.60} = 10.5 \text{ rad s}^{-1}$$ [1]

(b) A pulsar is formed through the gravitational collapse of a star, which means that it has a much smaller radius than the original star. Since angular momentum is conserved and using $L = \frac{2}{5}mr^2\omega$, much smaller radius means much larger angular velocity. [1]

(c) **Iron nuclides have the <u>highest binding energy per nucleon</u>.** [1]
<u>Fusion of iron nuclides will result in products with lower binding energy per nucleon</u> and is unlikely to occur in nature. [1]

(d) (i)

$$g = \frac{GM}{r^2}$$

$$= \frac{6.67\times10^{-11}\times1.4\times2.0\times10^{30}}{10000^2}$$ [1]

$$= 1.8676\times10^{12}$$

$$= \mathbf{1.87 \times 10^{12}\ N\,kg^{-1}}$$ [1]

(ii)

$$g_1 = \frac{GM}{r^2}$$

$$= \frac{6.67\times10^{-11}\times1.4\times2.0\times10^{30}}{10001^2}$$

$$= 1.867226\times10^{12}\ \text{N kg}^{-1}$$

$$\Delta g = (1.8676 - 1.867225)\times10^{12} = 3.74\times10^{8}\ \text{N kg}^{-1}$$ [1]

(iii) The gravitational force nearer the star is much larger than the gravitational force at the further end of the rod. Hence, the length of the rod will i<u>ncrease</u>. [1]

(e) (i)

$$v = r\omega = 100000\times\frac{2\pi}{2.0\times10^{-3}} = 3.14\times10^{8}\ \text{m s}^{-1}$$ [1]

Since this exceeds the speed of light, it is not possible for the pulsar to have this period. [1]

(ii) To prevent disintegration, acceleration due to gravity ≥ centripetal acceleration [1]

$$\frac{GM}{r^2} \geq r\omega^2$$ [1]

$$\frac{G\times\frac{4}{3}\pi r^3\rho}{r^2} \geq r\left(\frac{2\pi}{T}\right)^2$$ [1] [1]

$$G\times\frac{4}{3}\pi\rho \geq \frac{4\pi^2}{T^2}$$

$$\rho \geq \frac{3\pi}{GT^2}$$

(iii)

$$\rho = \frac{3\pi}{GT^2} = \frac{3\pi}{6.67\times10^{-11}\times0.600^2} = \mathbf{3.93\times10^{11}\ kg\,m^{-3}}$$ [1]

(f) $$\text{age} = \frac{33.5\times10^{-3}}{2\times\left(\dfrac{38\times10^{-9}}{24\times3600}\right)} = 3.8084\times10^{10}\ \text{s} = 1210\ \text{years}$$ [1]

(g) $hf = 400\times10^{12}\ \text{eV}$

$h\dfrac{c}{\lambda} = 400\times10^{12}\times1.6\times10^{-19}$ [1]

$\lambda = 3.11\times10^{-21}\ \text{m}$ [1]

(h) The amount of electromagnetic energy captured per second by the telescope is proportional to its area. Larger telescope means it is more sensitive to weak radiation emitted by distant pulsars. [1]

Paper 3 Section A

1 (a) Unit of E is pascal = unit of Force / area = (kg m s^{-2})(m^{-2}) = kg m^{-1} s^{-2} [1]

[1]

Unit on right hand side of equation = (m^3)(m s^{-2})(kg)(m^{-1})(m^{-3})(kg m^{-1} s^{-2})$^{-1}$
= m
= unit of x [1]

Hence equation is homogeneous.

(b)

$$E = \frac{L^3 gM}{4xwt^3}$$

$$= \frac{(0.800)^3(9.81)(0.300)}{4(0.0100)(0.0210)(0.00456)^3}$$ [1]

$$= 1.8918 \times 10^{10} \text{ Pa}$$

$$\frac{\Delta E}{E} \times 100\% = \left\{3\frac{\Delta L}{L} + \frac{\Delta M}{M} + \frac{\Delta x}{x} + \frac{\Delta w}{w} + 3\frac{\Delta t}{t}\right\} \times 100\%$$ [1]

$$= \left\{3(\frac{0.005}{0.800}) + \frac{2}{300} + \frac{0.01}{1.00} + \frac{0.02}{2.10} + 3(\frac{0.01}{4.56})\right\} \times 100\%$$

$$= 5.15\%$$

$$= 5\%$$ [1]

Therefore E = <u>1.89×10^{10}</u> Pa ± <u>5</u> % [1]
*Based on examiner's report, answer has to be in 3 s.f.

2 (a) (i) $v^2 = u^2 + 2as$
$= (5.0)^2 + 2(-9.81)(-1.5)$ [1]
Hence speed = <u>7.38</u> m s^{-1} [1]

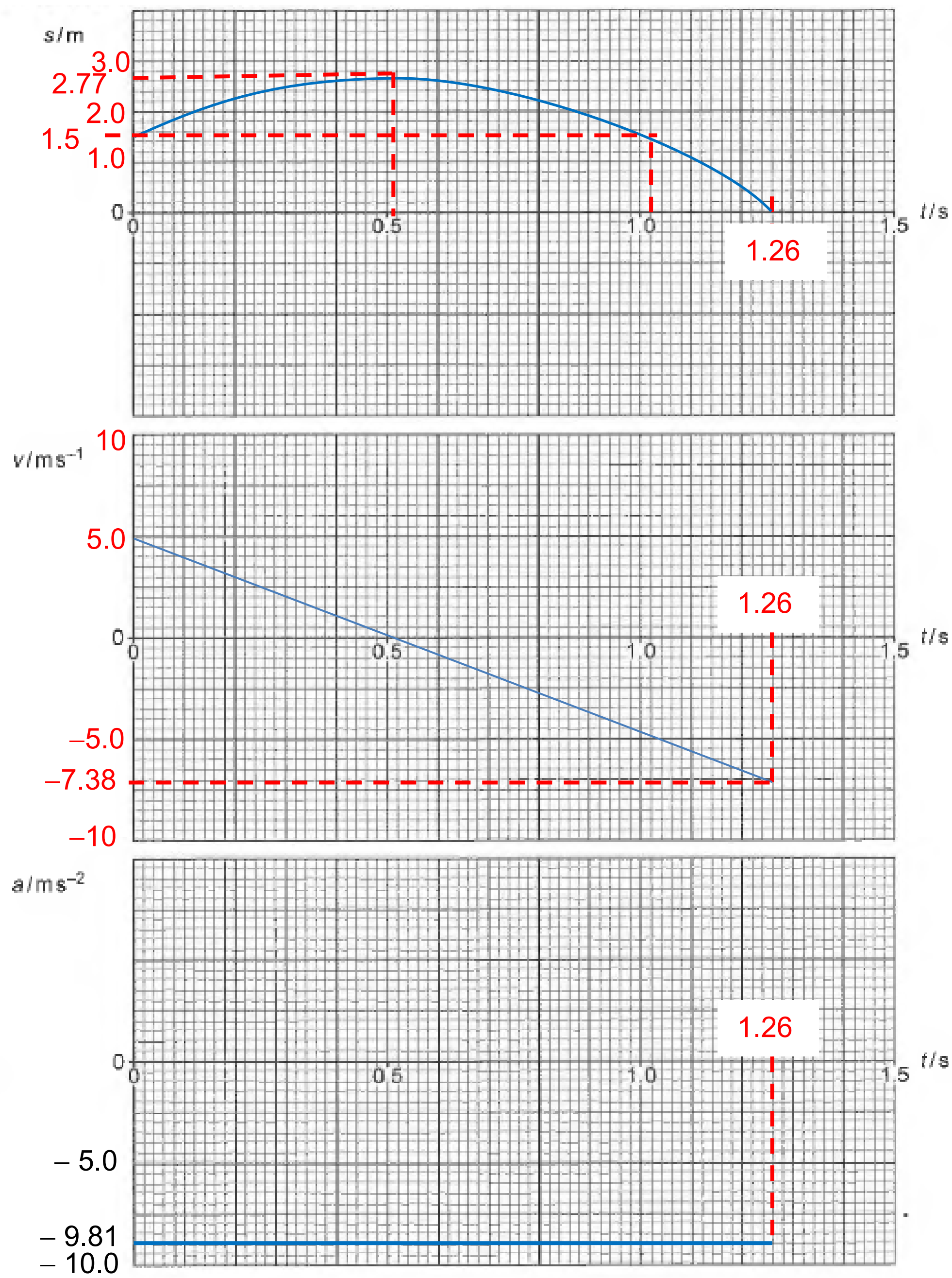
(note: velocity is –7.38 m s^{-1})

(ii) $v = u + at$
$-7.38 = 5.0 + (-9.81)\, t$ [1]
t = <u>1.26</u> s [1]

(b) To calculate highest point reached :
$v^2 = u^2 + 2as$
$0 = (5.0)^2 + 2(-9.81)\, s$
s = 1.27 m
hence it is 1.5 + 1.27 = 2.77 m above ground

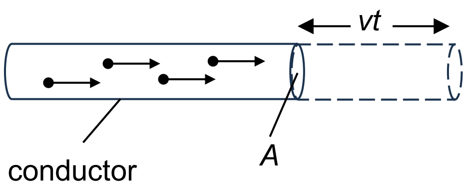
To calculate time to reach highest point:
$v = u + at$
$0 = 5.0 + (-9.81)\, t$
t = 0.510 s
(this value can be also obtained from v-t graph without calculation)

(b)



3 **(a)** Current is the rate of flow of charge. [1]

(b)



Consider a conductor with cross-sectional area *A* with charge carriers moving with drift velocity *v* as shown. If we observe for a time *t*, the charge carriers that cross the labelled area will fill up a cylindrical volume of length *vt*. Hence,

Number of charge carriers that cross the area = $nAvt$ [1]
Amount of charge that cross the area = $nAvt \times q$ [1]
Current = rate of flow of charge across A $= I = \dfrac{nAvt \times q}{t} = nAvq$ [1]

(c) (i) $I = nAvq = \frac{N}{Al}Avq$ [1]

$= \frac{N}{l}vq$

$2.00 = \frac{1.45 \times 10^{23}}{3.00}v(1.6 \times 10^{-19})$ [1]

$v = 2.59 \times 10^{-4}$ m s^{-1} [1]

(ii) Drift velocity describes the bulk motion of the charge carriers in the direction of the electric field applied across the conductor (using an e.m.f. source). It is the average velocity of all the electrons in one direction along the wire. [1]

However, even without any applied electric field, the electrons are moving at very high speed in random directions due to thermal agitation. Hence, the average speed of each individual electron is much higher than the drift velocity. [1]

4 (a) The **magnetic flux density** of a magnetic field is numerically equal to the force per unit length per unit current acting on a long straight current-carrying conductor placed at right angles to the magnetic field. [2]

(b) (i) Since the reading decreases, the wire exerts an upward force on the magnet. [1]
By Newton's third Law, the force exerted on the wire is downward. [1]
By Fleming's left hand rule, the current is from X to Y. [1]

(ii) Let mass of magnet be M.
Magnetic force on wire $= BIL$

When reading is 201.62 g : $Mg - BIL = (0.20162)(9.81)$ …….. (1) [1]

When reading is 202.17 g : $Mg + BIL = (0.20217)(9.81)$ ………(2) [1]

Equation (2) – (1) : $2B(1.6)(0.12) = (5.5 \times 10^{-4})(9.81)$ [1]

$B =$ 0.014 T [1]

(iii) The magnetic force is dependent on the current and not directly dependent on resistivity and since the current is unchanged, the result obtained will be the same as **(b)(ii)**. [1]

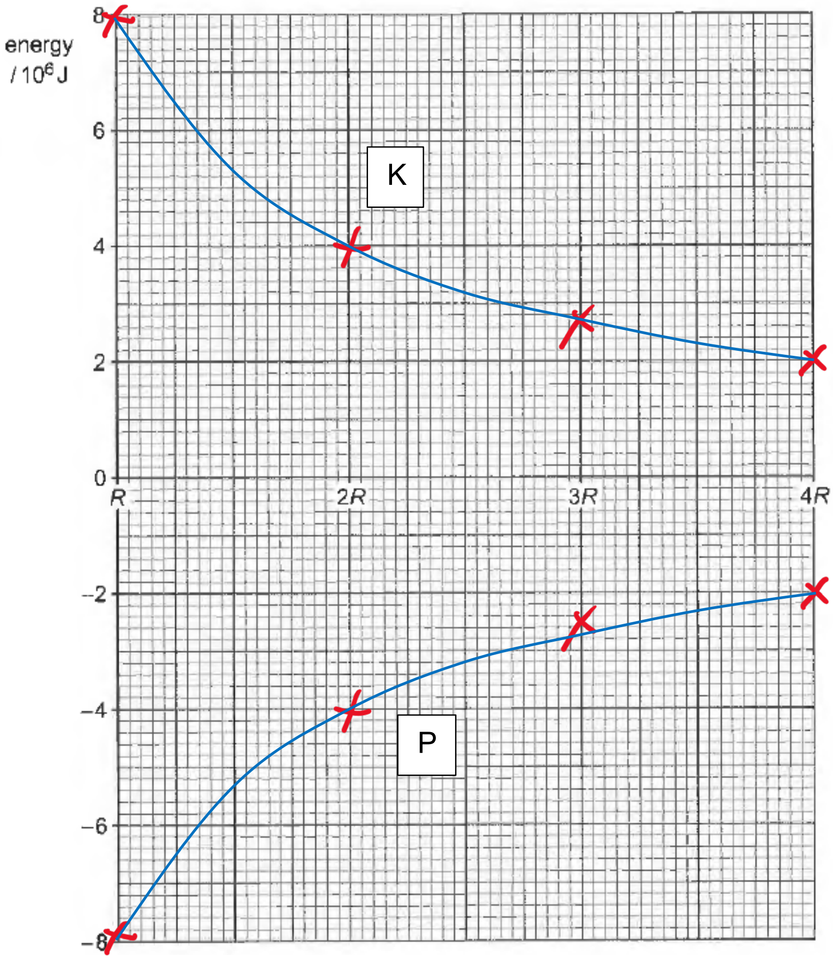
5 (a) The **gravitational potential** at a point in a gravitational field is defined as the work done per unit mass by an external force in bringing a small test mass from infinity to that point. [2]

(b) If the projectile doesn't return, it will travel to the point of infinity.
At the point of infinity, gravitational potential energy of projectile is zero while the minimum kinetic energy is also zero. [1]
Hence minimum total energy is zero.
$E_P + E_K = 0$ [1]

$-\frac{GMm}{R} + \frac{1}{2}mv^2 = 0$

$v = \sqrt{\frac{2GM}{R}}$ [1]

(c)



$GPE_{surface} = -\dfrac{GMm}{R}$

$= -8.0 \times 10^6$ J

GPE graph passes through

(R, 8); (2R, 4); (3R, 8/3); (4R, 2)

KE graph is a reflection of GPE graph. For projectile to just able to escape, its total energy is constant at zero.

6 (a) (i) For ideal gas, mean KE of a gas molecule is proportional to temperature.

Since the gases in both containers are at the same temperature, the ratio = <u>1</u>

[1]

(ii) For ideal gas, $pV = NkT$

Since gases in both containers are at the same temperature and pressure,

$pV = NkT$

$\dfrac{N_A}{N_B} = \dfrac{V_A}{V_B} = \dfrac{1}{4} = 0.25$ [1]

(iii) For ideal gas, $p = \dfrac{1}{3}\dfrac{Nm}{V} < c^2 >$

$\dfrac{\sqrt{< c^2 >_A}}{\sqrt{< c^2 >_B}} = \sqrt{\dfrac{V_A}{V_B}\dfrac{N_B}{N_A}\dfrac{m_B}{m_A}}$

[1]

$= \sqrt{\dfrac{1}{4} \times \dfrac{4}{1} \times \dfrac{2}{1}}$

$= 1.41$ [1]

(b) $\dfrac{\sqrt{<c^2>_A}}{\sqrt{<c^2>_B}} = 1.41$

$\sqrt{<c^2>_A} = 1.41 \times 940 = 1329$ [1]

Nm = total mass = (1.6)(0.004) = 6.4×10^{-3} kg [1]

$pV = nRT$ and $pV = \dfrac{1}{3}Nm<c^2>$

hence $nRT = \dfrac{1}{3}Nm<c^2>$

$(1.6)(8.31)T = \dfrac{1}{3}(6.4 \times 10^{-3})(1329^2)$ [1]

$T = 283$ K [1]

Alternative Solution:

For ideal gas, mean translational KE $= \dfrac{1}{2}mc^2 = \dfrac{3}{2}kT$. Hence,

$T = \dfrac{mc^2}{3k} = \dfrac{Mc^2}{3R}$, where M is the molar mass. Also,

$$\frac{c_A}{c_B} = \sqrt{2}$$

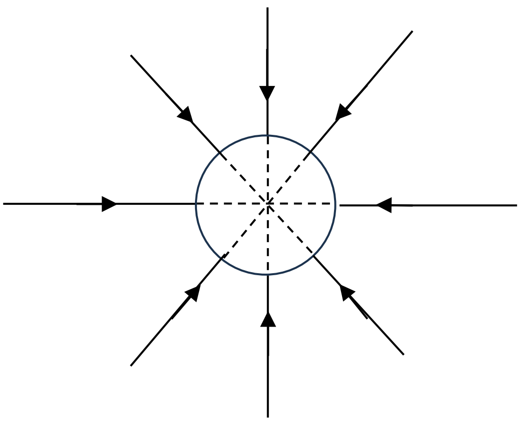
$$c_A = \sqrt{2} \times 940 = 1329.36$$

Hence,

$$T = \frac{Mc^2}{3R} = \frac{0.004\left(1329.36\right)^2}{3 \times 8.31} = 283.5 \ \approx \mathbf{284\ K}$$

7 **(a)** The **electric field strength** at a point is defined as the electric force exerted per unit positive charge placed at that point. [2]

(b) **(i)** [2]



8 straight lines [1]

Arrows pointing inwards [1]

Lines should intersect at centre, equally spaced, perpendicular to surface [1]

(ii) Potential gradient is numerically equal to the electric field strength. [1]

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$130 = \frac{Q}{4\pi(8.85\times10^{-12})(0.15+0.40)^2}$$ [1] [1]

$$Q = 4.37\times10^{-9}\,\text{C}$$

Paper 3 Section B

8 (a) (i) By Hooke's law,

$$F = kx$$

$$k = \frac{F}{x} = \frac{4.0}{0.20} = 20\ \text{N m}^{-1}$$ [1]

(ii)

$$E = \frac{1}{2}Fx$$

$$= \frac{1}{2}(3.0)(0.15)$$ [1]

$$= 0.23\ \text{J}$$ [1]

(iii)

$$\text{GPE} = mgx = Wx = 3.0(0.15) = 0.45\ \text{J}$$ [1]

(b) External force is exerted on the object and <u>negative work</u> is done on the object such that it is stationary at its equilibrium position. Hence, the spring-object-Earth system loses energy and <u>total energy decreases</u>. [1] [1]

Note:
Gravitational potential energy transferred by the object is greater than the (elastic potential) energy stored in the spring.

(c) Let the extension of spring at the equilibrium position of the object be e. Considering vertical forces acting on the object and applying Hooke's law,

$$F_{net} = 0$$

$$ke = mg$$ [1]

After release, by Newton's second law, taking downwards as positive,

$$F_{net} = ma$$

$$mg - ke' = ma$$

$$mg - k(e+x) = ma$$

$$a = -\frac{k}{m}x\ (\text{shown})\quad (\because ke = mg)$$

where $e' = e + x$ is the total extension of spring when displacement of object from the equilibrium position is x.
correct terms [1]
correct sign [1]

(d) (i) Comparing equation in **(c)** with the defining equation of simple harmonic motion,

$$\omega^2 = \frac{k}{m}$$

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{20}{3.0/9.81}} = 8.09 \text{ rad s}^{-1}$$

Taking upward as positive, [1]

$$x = x_0 \sin \omega t$$
$$= x_0 \sin(8.09t)$$

where x_0 is the amplitude of the oscillations.

When $t = 0.50$ s,

$$x = 3.2 \sin(8.09 \times 0.50)$$
$$= -2.5 \text{ cm}$$

Magnitude of displacement $= 2.5$ cm. [1]

(ii)

$$x = x_0 \sin \omega t$$
$$v = \omega x_0 \cos \omega t$$

When $t = 0.50$ s, [1]

$$v = (8.09 \times 3.2) \cos(8.09 \times 0.50)$$
$$= -16 \text{ cm s}^{-1}$$

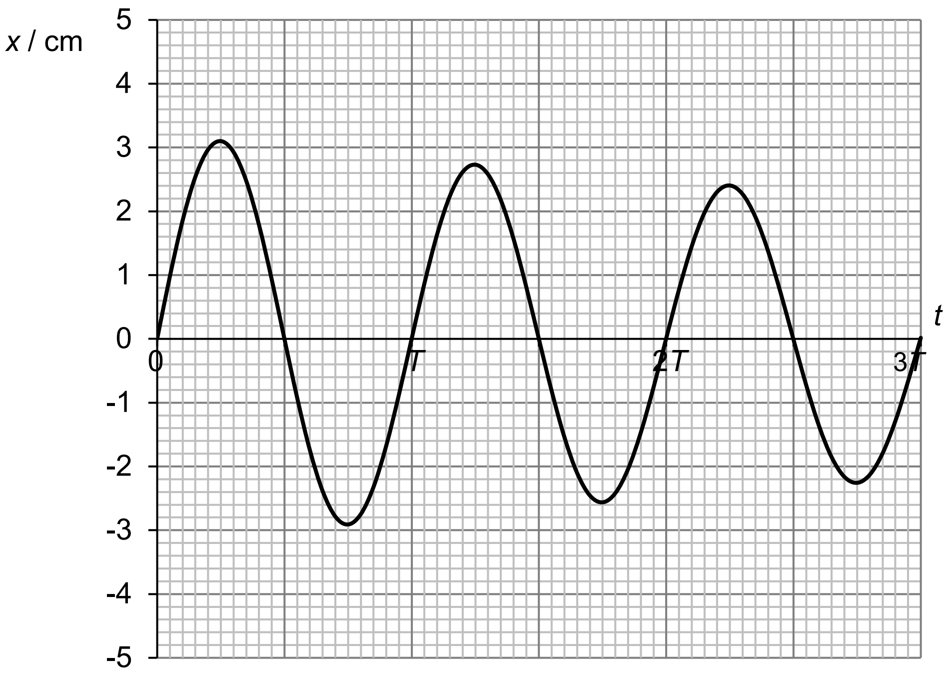
Magnitude of velocity $= 16$ cm s^{-1}. [1]

Alternatively, magnitude of velocity v,

$$v = \omega\sqrt{{x_0}^2 - x^2}$$
$$= \sqrt{\frac{k\left({x_0}^2 - x^2\right)}{m}}$$ [1]

$$= \sqrt{\frac{20\left(3.2^2 - (-2.5)^2\right)}{\frac{3.0}{9.81}}}$$
$$= 16 \text{ cm s}^{-1}$$ [1]

(e)



[3]

sine curve (starting from $x = 0$) [1]
decreasing amplitude [1]
constant period [1]

(f) **(i)** Extension of the spring combination is twice that of the single original spring as the force exerted on each spring is the same and the extension of each spring is the same (as they are identical). [1] [1]

OR: [1]
Each spring has a tension of 3.0 N and hence each will extend by 0.15 m. [1]
As a result, the total extension will be 0.30 m.

(ii) The effective force constant of the spring combination is half that of the single original spring and therefore the angular frequency decreases ($\frac{1}{\sqrt{2}}$ times the angular frequency in **(c)** $\because \omega = \sqrt{\frac{k}{m}}$). Since period is inversely proportional to angular frequency ($\because T = \frac{2\pi}{\omega}$), period increases ($\sqrt{2}$ times the period of oscillations in **(c)**). [1] [1]

9 **(a)** **(i)**

$$E = \left[m_{\text{Am}} - \left(m_{\text{Np}} + m_{\text{He}}\right)\right]c^2$$ [1]

$$= \left\{\left[400.19774 - \left(393.54304 + 6.64466\right)\right]10^{-27}\right\}\left(3.00 \times 10^8\right)^2$$ [1]

$$= 9.04 \times 10^{-13}$$

$$= 9.0 \times 10^{-13} \text{ J (shown)}$$

(ii) When bodies in a system interact, the total momentum of the system remains constant, provided no net external force acts on it. [2]

(iii) By principle of conservation of linear momentum,

$$0 = p_{\text{Np}} - p_{\text{He}} \quad (\because \text{Am is stationary})$$

$$p_{\text{Np}} = p_{\text{He}} \ (= p)$$

$$\frac{K_{\text{Np}}}{K_{\text{He}}} = \frac{m_{\text{He}}}{m_{\text{Np}}} \quad \left(\because K = \frac{p^2}{2m} \text{ and } p \text{ is the same}\right)$$ [1]

$$K_{\text{Np}} = \left(\frac{m_{\text{He}}}{m_{\text{Np}}}\right)K_{\text{He}}$$ [1]

$$= \left(\frac{6.64466}{393.54304}\right)\left(8.784 \times 10^{-13}\right)$$ [1]

$$= 1.483 \times 10^{-14} \text{ J (shown)}$$ [1]

(iv) The stationary americium-241 decays to form an excited daughter nucleus i.e., neptunium-237, and an alpha particle. <u>Gamma ray</u> is then <u>emitted</u> when the excited daughter nucleus de-excites. [1]

(b) **(i)**

$$A_0 = \lambda N_0$$

$$N_0 = \frac{A_0}{\lambda}$$

$$= \frac{8.13 \times 10^3}{5.08 \times 10^{-11}}$$ [1]

$$= 1.60 \times 10^{14}$$ [1]

(ii)

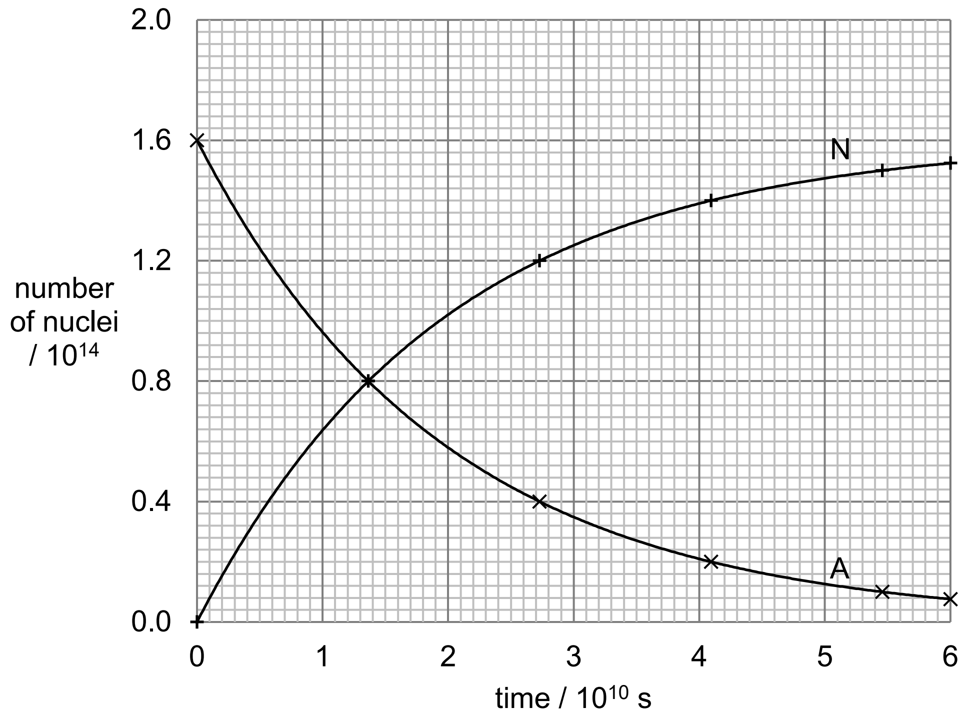
$$\lambda = \frac{\ln 2}{t_{1/2}}$$

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

$$= \frac{\ln 2}{5.08 \times 10^{-11}}$$

$$= 1.36 \times 10^{10} \text{ s}$$ [1]

(iii)
(iv)



[2]

[2]

correct initial points and point of intersection [1]
correct shape [1]

(c) **(i)** Initial activity of the sample of the beta emitter is much larger as the initial number of nuclei N_0 is the same and the probability of decay per unit time of a nucleus λ is much greater $\left(\because A_0 = \lambda N_0\right)$. [1] [1]

(ii)

$$A = A_0 e^{-\lambda t}$$

$$1 = \lambda N_0 e^{-\lambda t}$$

$$\ln \frac{1}{\lambda N_0} = -\lambda t$$

$$t = \frac{\ln \lambda + \ln N_0}{\lambda}$$

The effect of dividing by a larger number (λ) outweighs the increase in the natural logarithm of the same larger number ($\ln\lambda$) i.e., t decreases with an increase in probability of decay per unit time of a nucleus λ. [1]

The time taken for the activity of the sample of beta emitter to fall to 1 Bq is much shorter. [1]