2024 H2 Physics Preliminary Examination Solution and Comments

Paper 2

1 **(a)** **(i)** Take direction up the slope as positive.

$$v^2 = u^2 + 2as_0$$

$$0 = 7.0^2 + 2(-9.81\sin 30°)s_0$$

$$s_0 = 4.9949 = 4.99 \text{ m}$$

OR

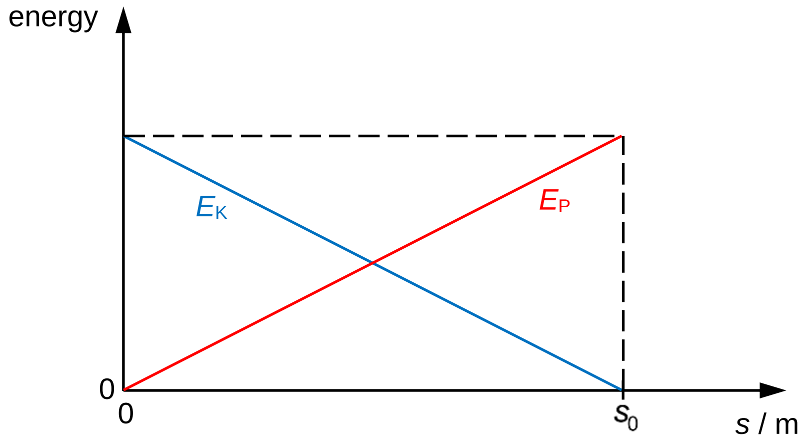
By the principle of conservation of energy,
increase in G.P.E. = decrease in K.E.

$mg(\Delta h) = \frac{1}{2}mv^2 - 0$, where Δh is the max. vertical height from ground

$$\Delta h = \frac{v^2}{2g} = \frac{7.0^2}{2(9.81)}$$

$$s_0 = \frac{\Delta h}{\sin 30°} = \frac{7.0^2}{2(9.81)} \div \sin 30° = 4.9949 = 4.99 \text{ m}$$

(ii)



*Both graphs aligned at the same total energy and s_0 and clearly labelled.

1. $E_K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(u^2 + 2[-g\sin\theta]s\right)$

$E_K = \frac{1}{2}mu^2 - (mg\sin\theta)s$

Graph of E_K-s is a straight line with negative gradient and vertical intercept $\frac{1}{2}mu^2$.

2. $E_P = mg(\Delta h) = mg(s\sin\theta)$

$E_P = (mg\sin\theta)s$

Graph of E_P-s is a straight line through the origin with positive gradient.

(b) (i) $v^2 = u^2 + 2as$

$$v^2 = 14.0^2 + 2\left(-9.81\sin 30°\right)\left(\frac{4.0}{\sin 30°}\right)$$

$$v = 10.841 = 10.8 \text{ m s}^{-1} \quad \text{(shown)}$$

OR

decrease in K.E. = increase in G.P.E.

$$\frac{1}{2}mu^2 - \frac{1}{2}mv^2 = mg\left(\Delta h\right)$$

$$v^2 = u^2 - 2g\left(\Delta h\right) = 14.0^2 - 2\left(9.81\right)\left(4.0\right)$$

$$v = 10.841 = 10.8 \text{ m s}^{-1} \quad \text{(shown)}$$

(ii) Take directions to the right and upwards as positive.

Time of flight after the ball leaves the top of the slope to the ground:

$$s_y = u_y t + \tfrac{1}{2}a_y t^2$$

$$-4.0 = \left(10.8\sin 30°\right)t + \frac{1}{2}\left(-9.81\right)t^2$$

$$t = 1.6080 \text{ s or } -0.50713 \text{ s (NA)}$$

Horizontal distance travelled:

$$s_x = u_x t + \tfrac{1}{2}a_x t^2$$

$$= \left(10.8\cos 30°\right)\left(1.6080\right) + 0$$

$$= 15.040 = 15.0 \text{ m}$$

*State both values of *t* and reject the negative one.

2 **(a)** The initial total momentum of both balls is not zero.

Since there is no net external force acting on the balls as a system, by the principle of conservation of momentum, the total momentum of both balls must remain unchanged and cannot be zero.

Hence, the balls could not be stationary at the same time.

(b) By the principle of conservation of momentum,

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$
$$u_A + u_B = v_A + v_B$$
$$4.0 + (-1.0) = v_A + v_B$$
$$v_A + v_B = 3.0 \qquad \text{----- (1)}$$

Since collision is elastic,

$$u_B - u_A = v_A - v_B$$
$$(-1.0) - 4.0 = v_A - v_B$$
$$v_A - v_B = -5.0 \qquad \text{----- (2)}$$

$$(1) - (2) \qquad 2v_B = 3.0 - (-5.0)$$
$$v_B = 4.0 \text{ m s}^{-1} \text{ (shown)}$$

(c) By Newton's second law, the average force on ball B by ball A is

$$F_{net,B} = \frac{\Delta p_B}{\Delta t}$$
$$= \frac{0.50\left(4.0 - (-1.0)\right)}{0.25}$$
$$= 10 \text{ N}$$

By Newton's third law, the average force on ball A by ball B has the same magnitude of 10 N.

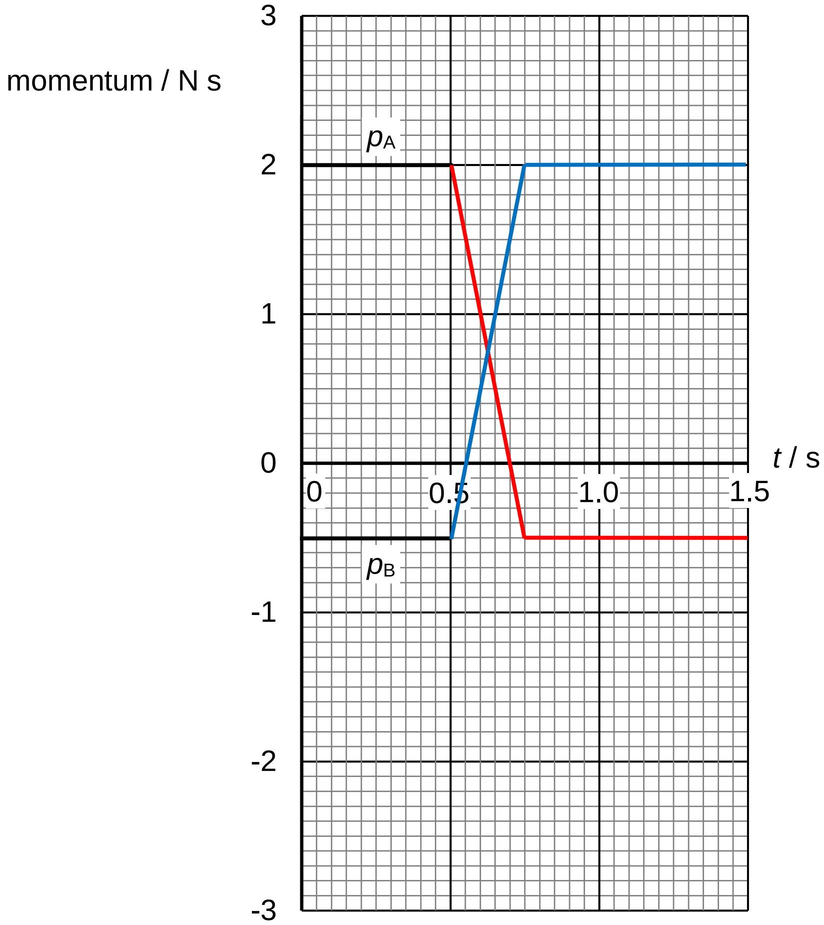
OR

From equation (1) or (2) in part (b), $v_A = 3.0 - v_B = 3.0 - 4.0 = -1.0$ m s^{-1}.

By Newton's second law, the average force on ball A by ball B is

$$F_{net,A} = \left|\frac{\Delta p_A}{\Delta t}\right|$$
$$= \left|\frac{0.50\left((-1.0) - 4.0\right)}{0.25}\right|$$
$$= 10 \text{ N}$$

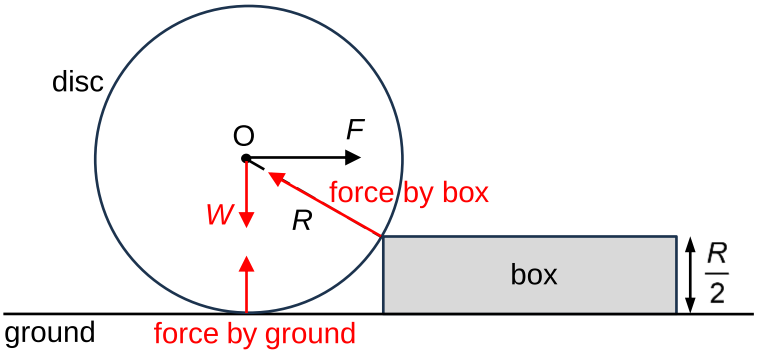
(d)



Balls A and B will exchange velocities and momenta as both balls have the same mass.
From (b), $p_{B,f} = (0.50)(4.0) = 2.0$ N s.

Since duration of collision is 0.25 s, constant final momenta to start from 0.75 s to 1.5 s, with lines joining 0.50 s to 0.75 s during the collision.

3 **(a)**



When the disc is just about to rotate, the contact force by the ground just becomes zero.

Perpendicular distance from corner of box to line-of-action of F is $\frac{R}{2}$.

Perpendicular distance from corner of box to line-of-action of W is $\sqrt{R^2 - \left(\frac{R}{2}\right)^2} = \frac{\sqrt{3}}{2}R$.

Applying the principle of moments about the corner of box,

$$F \times \frac{R}{2} = W \times \frac{\sqrt{3}}{2}R$$

$$\frac{F}{W} = \sqrt{3} = 1.7321 = 1.73$$

(b) F acting at O needs to be <u>inclined upwards</u> such that it is at an angle <u>above the horizontal</u> to <u>produce a clockwise moment</u> about the corner to <u>overcome the anticlockwise moment due to the weight</u>.

OR

F acting at O needs to be <u>inclined upwards</u> so that there is an <u>upward vertical component to produce a clockwise moment</u> about the corner to <u>overcome the anticlockwise moment due the weight</u>.

OR

F needs to be <u>shifted upwards above O</u> so that there is a <u>moment arm from the corner of the box to the line-of-action of F</u>, to <u>produce a clockwise moment</u> about the corner to <u>overcome the anticlockwise moment due to the weight</u>.

Note: Increasing the magnitude of the horizontal force F acting at O will not cause any rotation as F has no moment about the corner of the box because the perpendicular distance from the corner to the line-of-action of F is zero.

4 **(a)** **(i)** At the top of the circle,

$$T_T + mg = \frac{mv_T^{\,2}}{L}$$

For the ball to just complete the vertical circle, the <u>tension T_T at the top of the circle is zero</u>.

$$mg = \frac{mv_T^{\,2}}{L}$$
$$v_T^{\,2} = gL$$
$$v_T = \sqrt{gL}$$

(ii) By the principle of conservation of energy, <u>as the ball moves from the top to the bottom of the circle, its gravitational potential energy decreases and its kinetic energy increases</u>. This means the <u>speed at the bottom is greater than the speed at the top</u>. Hence $\frac{v_B}{v_T} > 1$.

(iii)
$$\frac{v_B}{v_T} = 3$$
$$v_B = 3v_T$$

As the ball moves from the top to the bottom,
increase in K.E. = decrease in G.P.E.

$$\frac{1}{2}mv_B^{\,2} - \frac{1}{2}mv_T^{\,2} = mg\left(2L\right)$$
$$\frac{1}{2}m\left(3v_T\right)^2 - \frac{1}{2}mv_T^{\,2} = mg\left(2L\right)$$
$$\frac{9}{2}mv_T^{\,2} - \frac{1}{2}mv_T^{\,2} = 2mgL$$
$$4mv_T^{\,2} = 2mgL$$
$$v_T = \sqrt{\frac{1}{2}}\sqrt{gL}$$

As $\underline{\sqrt{\frac{1}{2}}\sqrt{gL} < \sqrt{gL}}$<u>, where $\sqrt{gL}$ is the value of v_T at which the string just goes slack, the ball will not be able to complete a full circle</u> if $\frac{v_B}{v_T} = 3$. Hence, $\frac{v_B}{v_T} = 3$ is <u>not possible to achieve</u>.

(b) Considering forces along the radial direction,

$$T\sin\theta = mr\omega^2$$

Since $r = L\sin\theta$,

$$T\sin\theta = m\left(L\sin\theta\right)\omega^2$$
$$T = mL\omega^2$$

Since m and L are constants, $T \propto \omega^2$. Hence when the angular velocity is doubled, the tension in the string is <u>$4T$</u>.

5 **(a)** **(i)** Gravitational potential at a point in a gravitational field is the work done per unit mass by an external force in bringing a small test mass from infinity to that point.

(ii) Gravitational potential at infinity is zero.

Since gravitational force is attractive in nature, to bring a mass from infinity to a point in the gravitational field, the direction of the external force is opposite to the direction of displacement of the mass. This results in negative work done per unit mass by the external force.

Hence, based on its definition, gravitational potential is a negative value.

(b) **(i)**

$$\Delta E_P = \left(-\frac{GM_E m}{x}\right) - \left(-\frac{GM_E m}{R_E}\right)$$

$$= GM_E m\left(\frac{1}{R_E} - \frac{1}{x}\right)$$

$$= \left(6.67\times10^{-11}\right)\left(6.0\times10^{24}\right)(1600)\left(\frac{1}{6400\times10^{3}} - \frac{1}{\left(6400\times10^{3}\right)+\left(2.1\times10^{7}\right)}\right)$$

$$= 7.6681\times10^{10} = 7.67\times10^{10} \text{ J}$$

(ii) **1.** Gravitational force provides the centripetal force on the satellite.

$$\frac{GM_E m}{r^2} = \frac{mv^2}{r}$$ where m is the mass of the satellite

$$v = \sqrt{\frac{GM_E}{r}}$$

2. By the principle of conservation of energy, if the satellite has just enough energy to escape to infinity, its total energy is zero.

Let E_{K1} be the kinetic energy of satellite just after the boost.

$$E_P + E_{K1} = 0$$

$$-\frac{GM_E m}{r} + E_{K1} = 0$$

$$E_{K1} = \frac{GM_E m}{r}$$

Just before the boost, kinetic energy of satellite in orbit,

$$E_K = \frac{1}{2}mv^2$$

$$= \frac{1}{2}m\left(\sqrt{\frac{GM_E}{r}}\right)^2$$

$$= \frac{GM_E m}{2r}$$

$$\text{ratio} = \frac{E_{K1}}{E_K} = \frac{GM_E m}{r}\bigg/\frac{GM_E m}{2r} = 2$$

6 (a) (i) Effective resistance of Q and LDR,

$$R_{eff} = \left(\frac{1}{R_Q} + \frac{1}{R_{LDR}}\right)^{-1}$$

$$= \left(\frac{1}{6.0} + \frac{1}{8.0}\right)^{-1}$$

$$= 3.4286 \text{ k}\Omega$$

$$I_{A_1} = \frac{E}{R_T}$$

$$= \frac{9.0}{(3.4286 + 4.0) \times 10^3}$$

$$= 1.2115 \times 10^{-3} \;\; = 1.21 \times 10^{-3} \text{ A}$$

(ii) Potential difference across Q and LDR,

$$V_{eff} = \frac{R_{eff}}{R_{eff} + R_P} \times E$$

$$= \left(\frac{3.4286}{3.4286 + 4.0}\right) \times 9.0$$

$$= 4.1539 \text{ V}$$

$$I_{A_2} = \frac{V_{LDR}}{R_{LDR}}$$

$$= \frac{4.1539}{8.0 \times 10^3}$$

$$= 5.1924 \times 10^{-4} \;\; = 5.19 \times 10^{-4} \text{ A}$$

(b) (i) Resistance of the LDR increases when light intensity is lowered. The effective resistance of Q and the LDR increases.

Since the potential difference across P and Q is the same at 9.0 V, by the potential divider principle, the potential difference across Q is a larger proportion of the 9.0 V. Hence the potential difference across Q increases.

OR

Resistance of the LDR increases when light intensity is lowered. The overall resistance of the circuit increases.

Current from the battery decreases. As the resistance of P is the same, the potential difference across P decreases. Since the potential difference across P and Q remains the same at 9.0 V, this means the potential difference across Q increases.

(ii) Since the potential difference across Q increases, the current through Q increases for the same resistance of Q.

Total current in the circuit is the sum of the current through Q and the LDR. Since the total current from the battery decreases due to overall increase in resistance, and the current in Q increases, this means the current through the LDR decreases. Hence the current reading on ammeter A_2 decreases.

7 **(a)** In a nuclear fusion reaction, two low nucleon number (OR lighter) nuclei combine into a high nucleon number (OR heavier) nucleus.

(b) Since fusion occurs when the two nuclei touch each other, the distance at which the two nuclei fuse is $d = 2 \times \left(1.2 \times 10^{-15}\right) = 2.4 \times 10^{-15}$ m .

Both nuclei must possess sufficient kinetic energy to overcome the electrostatic repulsion as they approach each other to fuse.

Minimum K.E. needed is when both nuclei just <u>come to rest</u> when they start to fuse.

By the principle of conservation of energy, as the two hydrogen nuclei approach each other,
decrease in K.E. = increase in E.P.E.

$$2 \times E_{k,\min} - 0 = \frac{e^2}{4\pi\varepsilon_0 d}$$

$$E_{k,\min} = \frac{e^2}{8\pi\varepsilon_0 d}$$

$$= \frac{\left(1.60 \times 10^{-19}\right)^2}{8\pi\left(8.85 \times 10^{-12}\right)\left(2.4 \times 10^{-15}\right)}$$

$$= 4.7956 \times 10^{-14} \text{ J}$$

$$= \frac{4.7956 \times 10^{-14}}{10^6\left(1.60 \times 10^{-19}\right)} \text{ MeV}$$

$$= 0.299725 \text{ MeV} = 0.30 \text{ MeV} \quad \text{(shown)}$$

(c)

$$E_{k,\min} = \frac{3}{2}kT$$

$$T = \frac{2E_{k,\min}}{3k}$$

$$= \frac{2\left(4.7956 \times 10^{-14}\right)}{3\left(1.38 \times 10^{-23}\right)}$$

$$= 2.3167 \times 10^9 = 2.32 \times 10^9 \text{ K}$$

(d) **(i)** ${}^{0}_{1}X$
Particle X is a positron.

(ii) Since deuteron ${}^{2}_{1}H$ is more readily found, it suggests that reaction (2) is more probable than reaction (1) and that ${}^{2}_{1}H$ is <u>more stable</u> than ${}^{2}_{2}He$.
Hence, reaction (2) <u>releases more energy</u> than (1).

(e) Energy released,

$$
\begin{aligned}
E &= \Delta mc^2 \\
&= (\text{mass of reactants} - \text{mass of products})c^2 \\
&= (2\times1.007825 - 2.014102 - 0.000549)(1.66\times10^{-27})\times(3.00\times10^{8})^2 \\
&= 1.4925\times10^{-13} = 1.49\times10^{-13}\ \text{J}
\end{aligned}
$$

(f) Nuclear fission reaction of heavy nuclei requires much less energy to trigger (initiate) and can occur at a lower (room) temperature while the nuclear fusion reaction of light nuclei requires an extremely high temperature to trigger.

8 **(a)** This is to reduce collisions between protons and any gas molecules in the beam pipes, so that less harmful ionising radiation is produced.

OR

This is to reduce collisions between protons and any gas molecules in the beam pipes, so that the proton beam can remain focused and not get scattered by these collisions.

OR

This is to reduce collisions between protons and any gas molecules in the beam pipes, so that there is less energy loss and the protons can reach the high speed required.

(b) No. As neutrons are neutral and uncharged, their trajectories cannot be bent / curved by the presence of magnetic fields.

OR

No. As neutrons are neutral and uncharged, they cannot be accelerated by electric fields.

(c) **(i)**

$$E = (\gamma - 1)m_0c^2$$

$$(7.0\times10^{12})(1.60\times10^{-19}) = (\gamma - 1)(1.67\times10^{-27})(3.00\times10^{8})^2$$

$$1.12\times10^{-6} = (\gamma - 1)(1.67\times10^{-27})(3.00\times10^{8})^2$$

$$\gamma = 7452.8$$

$$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 7452.8$$

$$v = \sqrt{\left[1-\left(\frac{1}{7452.8}\right)^2\right]c^2} = 0.999999991\,c \qquad \text{(shown)}$$

(ii) Since beam current is defined as the average rate of flow of charge,

$$\text{beam current} = \frac{\text{total charge in the ring}}{\text{period}} = \frac{Q}{T}$$

$$T = \frac{\text{distance travelled along the ring}}{\text{speed of protons}} = \frac{26659}{0.999999991\,c} = 8.8863\times10^{-5}\ \text{s}$$

$$0.58 = \frac{Q}{8.8863\times10^{-5}}$$

$$Q = 5.1541\times10^{-5}\ \text{C}$$

number of protons per proton beam,

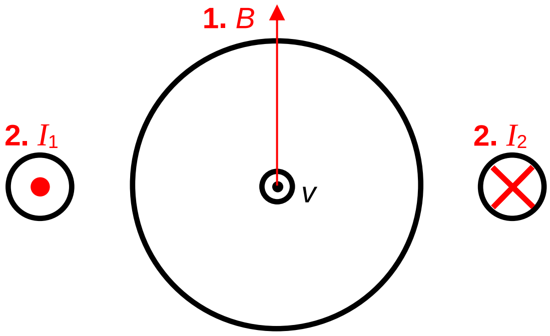
$$N = \frac{Q}{e} = \frac{5.1541\times10^{-5}}{1.60\times10^{-19}} = 3.22\times10^{14}$$

Since there are 2808 bunches per proton beam,

$$\text{number of protons in each bunch} = \frac{3.22\times10^{14}}{2808}$$

$$= 1.1467\times10^{11} = 1.15\times10^{11} \qquad \text{(shown)}$$

(d) (i) 1.
2.



1. Since proton velocity is out of the page, beam current is out of the page. Since centre of circular path of the proton's trajectory is on the left, the magnetic force on the proton that provides the centripetal force points to the left.
Using Fleming's left-hand rule, direction of *B* is upwards.

*Straight line with arrowhead pointing upwards at the centre of pipe.

2. Since each combined cable carries current of the same magnitude, the direction of the current in each cable must be such that each produces a magnetic flux density that points upwards at the centre of the pipe, giving a resultant magnetic flux density as deduced in **(d)(i)1.**

Using the right-hand grip rule, I_1 points out of the page and I_2 points into the page.

*Correct directions, positions and symbols of both currents.

(ii) 1.

$$B = \frac{\mu_0 I_1}{2\pi d} + \frac{\mu_0 I_2}{2\pi d}$$

$$8.33 = \frac{\left(4\pi \times 10^{-7}\right)\left(I_1 + I_2\right)}{2\pi\left(\frac{88}{2} \times 10^{-3}\right)}$$

$$I_1 + I_2 = 1832600 \text{ A}$$

Since $I_1 = I_2$,

$$I_1 = \frac{1832600}{2}$$

$$= 916300 \text{ A} = 9.16 \times 10^5 \text{ A}$$

2. Since current in each cable is 11850 A,

$916300 = N(11850)$ where N is the number of cables

$N = 77.3 \approx 77$

3. Force on combined cable 2 by combined cable 1,

$$F = B_1 I_2 L$$
$$= \frac{\mu_0 I_1}{2\pi d} I_2 L$$
$$= \frac{\left(4\pi \times 10^{-7}\right)(916300)}{2\pi\left(88 \times 10^{-3}\right)}(916300)(14.3)$$
$$= 2.7287 \times 10^{7} = 2.73 \times 10^{7} \text{ N}$$

By Newton's third law, force on combined cable 1 by combined cable 2 is equal in magnitude and opposite in direction.

The cables in the dipole magnet setup experience an <u>extremely large repulsive force away from each other</u>. Hence, the stainless-steel collars are used to <u>keep the cables from moving away from the beam pipe</u>.

(e) (i) average volume occupied by one proton

$$= \frac{\text{volume of one bunch}}{\text{no. of protons in one bunch}}$$
$$= \frac{\left(7.48 \times 10^{-2}\right)\left(1.0 \times 10^{-6}\right)}{1.15 \times 10^{11}}$$
$$= 6.5043 \times 10^{-19} \text{ m}^3$$

Approximating volume occupied by a proton to be volume of a cube with sides of length d:

$$d = \sqrt[3]{6.5043 \times 10^{-19}} = 8.6643 \times 10^{-7} \text{ m}$$

average electric force of repulsion between 2 protons,

$$F_E = \frac{e^2}{4\pi\varepsilon_0 d^2}$$
$$= \frac{\left(1.60 \times 10^{-19}\right)^2}{4\pi\left(8.85 \times 10^{-12}\right)\left(8.6643 \times 10^{-7}\right)^2}$$
$$= 3.0663 \times 10^{-16} = 3.07 \times 10^{-16} \text{ N}$$

(ii) Initial velocity v of proton is horizontal along the central axis of the beam pipe.

displacement of proton from centre of beam pipe to bottom of beam pipe,

$$s_y = u_y t + \frac{1}{2}gt^2$$

$$\frac{1}{2}\left(56\times10^{-3}\right) = 0 + \frac{1}{2}(9.81)t^2$$

$$t = 0.075554 \text{ s or } -0.075554 \text{ s (NA)}$$

total horizontal displacement travelled by proton,

$$s_x = vt$$

$$= (0.999999991)\left(3.00\times10^8\right)(0.075554)$$

$$= 22666199.8 \text{ m}$$

$$\text{number of rounds} = \frac{s_x}{\text{circumference of ring}}$$

$$= \frac{22666199.8}{26659}$$

$$= 850.23 = 850$$

(iii) The radiation produced from the accelerating protons will cause the protons to lose energy, resulting in the protons straying away from their original path as the radius of curvature of their trajectory will decrease.

Hence, the quadrupole magnets are needed to help keep the protons travelling along the central axis of the beam pipe.

(f) Advantages:

- Linear accelerators are less expensive to build as they do not require large numbers of electromagnets to keep the particles in a circular path, which need to be kept at extremely low temperatures with large amounts of liquid nitrogen and helium.
- Synchrotron radiation due to the particles accelerating is a lot less as particles are not constantly accelerating unlike when they are travelling in circular paths where they experience centripetal acceleration.
- Synchrotron radiation due to the particles accelerating is a lot less as particles are not constantly changing direction unlike when they are travelling in circular paths.

Disadvantages:

- The chances for collisions to happen is much lower because there is only one collision point in a linear accelerator, whereas there can be multiple collision points in a circular accelerator.
- Linear accelerators are not able to reach the same high energies as a circular accelerator without being unfeasibly long, because particles in a circular accelerator can circulate many times, getting boosts in energy many times before colliding.
- For linear accelerators to reach the same high energies as a circular accelerator they need to be extremely long which is very expensive to build.