2022 VJC Prelim H2 P2 Suggested solution

1(a) His explanation is not correct as even though the force that the truck acts on him is equal and opposite to the force that he acts on the truck, the 2 forces act on different bodies [APPLICATION] so they do not cancel out. [CONCLUSION]

As Adam pushes the truck, the truck exerts a friction <u>on the surface of the roadside</u> [be specific: friction at where?]. By Newton's 3rd law [CONCEPT], the surface of the roadside will exert an equal and opposite friction back on the truck. [APPLICATION]

The truck does not move because the friction that the surface of the roadside exerted on the truck and the force exerted on the truck by Adam are acting on the same object and are equal and opposite, therefore there is no net force on the truck, [APPLICATION] and hence by Newton's 1st law [CONCEPT], it doesn't move [CONCLUSION].

(b)(i) The principle of conservation of momentum states that total momentum of the system before the collision is equal to the total momentum of the system after the collision, <u>provided no net external force acts on the system</u>.

(ii) 1. Total initial momentum of the system is 0 since nobody is moving.

By conservation of momentum [CONCEPT],
Taking upwards as positive,
Total initial momentum of system = total final momentum of system

$0 = M_{balloon}V_{balloon} + m_{man}v_{man}$

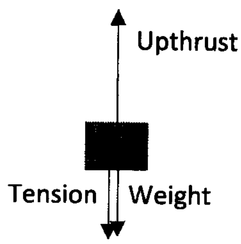
$0 = (320)V_{balloon} + 80(2.5)$

$V_{balloon} = -0.625 \text{ m s}^{-1}$

Since upwards is taken to be positive, -0.625 m s^{-1} would indicate that the balloon is moving in the negative direction, which is downwards.

2. Speed of the balloon is zero [because initial total momentum = 0].

2(a) (i)



(a)(ii) Total upward forces = total downward forces [CONCEPT]

$T + mg = U$

$kx + mg = U$

$L = \frac{V\rho g - mg}{k} = \frac{\frac{2}{3}\left(\frac{5.0}{650}\right)(1000)(9.81) - (5.0)(9.81)}{160}$ where $x = L$

$L = 7.86 \times 10^{-3}$ m

(b)(i) Taking pivot at A, total clockwise moment = total anti-clockwise moment, [CONCEPT]

$(\frac{AC}{2}\cos 65°)(1200) + (AC\cos 65°)(2000) = T(AB)$

$(\frac{AC}{2}\cos 65°)(1200) + (AC\cos 65°)(2000) = T(\frac{3}{4}AC)$

$T = 1.47 \times 10^3$ N

(b)(ii) Since tension exerted on the boom is at an angle, there will be a horizontal component. [APPLICATION]

For the boom to be in equilibrium, there must be a horizontal force to counter this force. [CONCEPT: FORCES IN EQUILIBRIUM] Therefore, the force at the hinge is not vertical but at an angle to provide a horizontal component to counter the horizontal component of the tension. [CONCLUSION]

3(a) Using pV = nRT, [CONCEPT]

Volume $V_f = \dfrac{nRT}{p}$

$= \dfrac{\text{Total mass}}{\text{Molar mass}} \dfrac{RT}{p}$

$= \dfrac{350}{18} \times \dfrac{8.31\times(273+100)}{1.0\times10^5}$

$= 0.60271$

$\approx 0.60\ m^3$

(b) Work done, $W = p\Delta V$ [CONCEPT]

$= p(V_f - V_i)$

$= p(V_f - \dfrac{m}{\rho})$

$= 1.0 \times 10^5 (0.6027 - \dfrac{0.350}{1000})$

$= 60235$

$\approx 6.0 \times 10^4$ J

(Note: Volume of a gas at atmospheric pressure is so much larger than its volume as a liquid, so it's OK not to include V_i in the calculation.)

(c) $\Delta U = Q - W_{by}$ [CONCEPT]

$= mL_v - W_{by}$

$= (0.350 \times 2.26 \times 10^6) - 60235$

$= 730770$

$\approx 7.3 \times 10^5$ J

(d) The increase in internal energy takes the form of an increase in potential energy due to intermolecular forces of attraction.

4(a)(i) Since *g* and *r* are constant, so *a* is proportional to *x*.
Negative sign shows that *a* and *x* are in opposite direction. [APPLICATION]
Hence the ball undergoes simple harmonic motion [CONCLUSION]

(ii) $\omega^2 = \frac{g}{r}$ and $\omega = \frac{2\pi}{T}$ [CONCEPT]

$\omega^2 = \frac{9.81}{0.28} = 35$

$T = 1.06$ s

$\tau = 0.53$ s

(b) Sketch:
time period constant (or increases very slightly)
drawn lines always 'inside' given loops, up to given time duration
successive decrease in peak height

5(a)(i) Faraday's law states that the emf induced in a conductor is proportional to the rate of change of magnetic flux linkage.

(ii) The steel string near the permanent magnet gets magnetised (and produces its own magnetic field). [APPLICATION]

When the string vibrates, the magnetic flux density at the location of the coil changes. [APPLICATION]

There is a changing magnetic flux linkage with the coil [APPLICATION] so, according to Faraday's law [CONCEPT], an emf is induced in the coil [CONCLUSION].

(iii) Nylon string cannot be magnetised.

(b) The nodes of the stationary wave are located at the clamps, giving the first harmonic, so the length of 64 cm is equal to half a wavelength of the wave.

λ/2 = 64 cm
(need to explain properly and not just write the equation)

Frequency of the wave, $f = \frac{v}{\lambda} = \frac{300}{2(0.640)} = 234.4\ \text{Hz}$ [SHOW: GIVE MORE DP]

≈ 230 Hz

(c) maximum vibrational velocity of the string,

$$v_{\max} = \omega x_0 = (2\pi f)x_0 \text{ [CONCEPT]}$$
$$= (2\pi)(230)(1.50\times10^{-2})$$
$$= 21.68\ \text{m s}^{-1}$$

Maximum induced emf, $\varepsilon_{\max} = BLv_{\max}$ [CONCEPT]

$$= (4.50\times10^{-3})(2.00\times10^{-2})(21.68)$$
$$= 1.95\times10^{-3}\ \text{V} \text{ or } 2.0\times10^{-3}\ \text{V}$$

6(a)(i) As the half-life of X (in years) is very long, it means that the decay constant is very, very small. Thus the fraction of nuclei that would decay during the time of measurement is very low, and the number of nuclei N in the sample remains almost constant. [APPLICATION]

Since activity, A = λN [CONCEPT], then the activity will remain almost constant. [CONCLUSION]

(ii) **1.** Decay constant of Y, $\lambda_Y = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{1.5\times60\times60}$ = 1.283 x 10^{-4} s^{-1} = 1.3 x 10^{-4} s^{-1}

2. Equilibrium is reached when the rate of production of Y (from the decay of X) is equal to its rate of decay of Y. Hence, the number of isotope Y in the sample will stabilise at a constant value.

3. Thus, the activity of Y is about 1.1 x 10^7 Bq.

Amount of Y, $N_Y = \frac{A_Y}{\lambda_Y} = \frac{1.1\times10^7}{1.283\times10^{-4}}$ = 8.6 x 10^{10} atoms

b(i) By $N = N_o e^{-\lambda t}$: [CONCEPT]

$5N = 6Ne^{-\lambda t}$

Take ln on both sides,

$\ln 5 = \ln 6 - \lambda t$

$t = \frac{\ln 6 - \ln 5}{4.95\times10^{-11}} = 3.683\times10^9$ yrs = 3.7 x 10^9 years

(ii) Decay of Th-232 will give rise to a radioactive series where there will be a number of radioactive daughter products before ending up as the stable Pb-208. It is assumed that these intermediate radioactive daughter products have very short half-lives (much shorter than that of Th-232) so the number of intermediate daughter products are insignificant compared to Th-232 and Pb-208.

(iii) If the assumption is not valid, there would have been more Th-232 in the beginning which have decayed and is still in the form of the intermediate daughter products, therefore the fraction of undecayed Th-232 is less than $\frac{5}{6}$. This means that the rock would have been older, as a longer time would have been elapsed, thus answer for **(b)(i)** will be an under-estimate.

7(a) Potential difference used to accelerate the ions, ΔV = 1060 – (–225) = 1285 V

The gain in kinetic energy of the ion = its loss of electric potential energy

$\frac{1}{2}mu^2 = q\Delta V$, where u is the speed of the ion. [CONCEPT]

$$u = \sqrt{\frac{2q\Delta V}{m}} = \sqrt{\frac{2(1.60\times10^{-19})(1285)}{2.2\times10^{-25}}} = 4.323\times10^4 \text{ ms}^{-1}$$

$$= 4.3\times10^4 \text{ ms}^{-1}$$

(b)(i) The passage says it takes 4 days (or more) to eject 1 kg of xenon.

maximum mass of xenon ejected per second,

$$\frac{\Delta m}{\Delta t} = \frac{1 \text{ kg}}{4 \text{ days}}$$

$$\frac{\Delta m}{\Delta t} = \frac{1}{4\times24\times60\times60} = 2.894\times10^{-6} \text{ kg s}^{-1}$$ = 2.9 × 10^{-6} kg s^{-1}

(ii) Maximum force exerted on the ejected xenon,

$$F = \frac{\Delta p}{\Delta t} \text{ [CONCEPT]}$$

$$= \left(\frac{\Delta m}{\Delta t}\right)u$$

$$= (2.9\times10^{-6})(4.3\times10^{4})$$

$$= 0.1247 \text{ N}$$

By Newton's 3rd law, the maximum thrust = F = 0.12 N

(c) Assume that, at the start, the mass of Deep Space 1 (M_{DS}) and the mass of the xenon (m_{Xe}) are at rest. So their total initial momentum $p_{initial} = 0$

Applying the principle of conservation of momentum, [CONCEPT]
their total final momentum $p_{final} = p_{initial} = 0$

So the momentum of DS must be equal and opposite to that of Xe,

$$M_{DS}v_{DS} = m_{Xe}v_{Xe}$$

$$M_{DS} = \frac{m_{Xe}v_{Xe}}{v_{DS}} = \frac{(74)(4.3\times10^{4})}{(4.3\times10^{3})} = 740 \text{ kg}$$

(d) The positive ions will be attracted to the negatively charged spacecraft even as the ions are ejected away, so they will be ejected at a lower speed than intended.

(e) Any 2 reasonable points:

- Ion engines use fuel more efficiently than chemical rockets, so they can travel larger distances per unit mass of fuel. *[Nasa source: Chemical rockets have demonstrated fuel efficiencies up to 35%, but ion thrusters have demonstrated fuel efficiencies over 90%.]*
- Ion engines can produce a larger increase in speed per unit mass of fuel used, compared to chemical rockets, so they can travel longer distances with less fuel.
- Ion engines use their fuel much more slowly, so the fuel can last for much longer periods of time.
- Ion engines use inert gases (like xenon) for propellant and there is no risk of the explosions associated with chemical rockets, so ion engines are less risky (for long missions).

(f)(i) Energy of a photon, $E = \frac{hc}{\lambda}$ and momentum of a photon, $p = \frac{h}{\lambda}$
where λ is the wavelength of the photon

Substitute $p = \frac{h}{\lambda}$ into $E = \frac{hc}{\lambda}$ gives, $E = \frac{hc}{\lambda} = \left(\frac{h}{\lambda}\right)c = pc$

['Show' question: need to explain your steps and show substitution of equation for p into equation for E]

(ii) Power received by 1 m^2 of sail, power = intensity × area = 1400 W
Energy received by 1 m^2 of sail in 1 s, E = power × time = 1400 J

From $E = pc$, we have

Momentum in 1 s, $p = \frac{E}{c} = \frac{1400}{3.00\times10^{8}} = 4.667\times10^{-6}$ N s

$\approx 4.7\times10^{-6}$ N s

(iii) total momentum of the photons incident on 32 m^2 of sail in 1 s,

$p_{total} = p\times32 = (4.7\times10^{-6})(32) = 1.504\times10^{-4}$ N s

Change of momentum upon reflection,

$\Delta p = 2p_{total} = 2(1.504\times10^{-4}) = 3.008\times10^{-4}$ N s

Force = change of momentum per unit time = 3.008×10^{-4} N

By Newton's 3rd law, the force on the whole sail = 3.0×10^{-4} N

(iv) If all the light is absorbed, then the final momentum of the light is 0.
So the change of total momentum is half of that in (iii).
Hence, the force on the sail is also halved.

(g) LightSail orbits Earth with an orbital radius of 7020 km.
The centripetal acceleration of LightSail = the gravitational field strength at that orbit. [CONCEPT]

$$a_c = \frac{GM}{r^2} = \frac{(6.67\times10^{-11})(6.0\times10^{24})}{(7020\times10^{3})^2} = 8.12\text{ m s}^{-2}$$

So the centripetal acceleration of LightSail 2 cannot be 0.058 mm s^{-2}.

(h) Advantage: (or some other reasonable point)

- The solar sail will never run out of "fuel" so long as there is light shining on the sail, whereas ion engines can run out of fuel.

Disadvantage: (any 1 or some other reasonable point)

- The thrust of a solar sail (3.0×10^{-4} N) is much lower than that of an ion engine (0.12 N).
- The sail is very thin (4.5 μm) and may be easily damaged by space rocks. (whereas an ion engine is not so fragile)
- The total surface area of a solar sail needs to be very big, but that makes it more susceptible to collisions with space rocks.

2022 VJC Prelim H2 P3 Suggested solution

1(a) At maximum height,

Loss in KE of mass = gain in GPE of mass + gain in EPE in cord [CONCEPT]

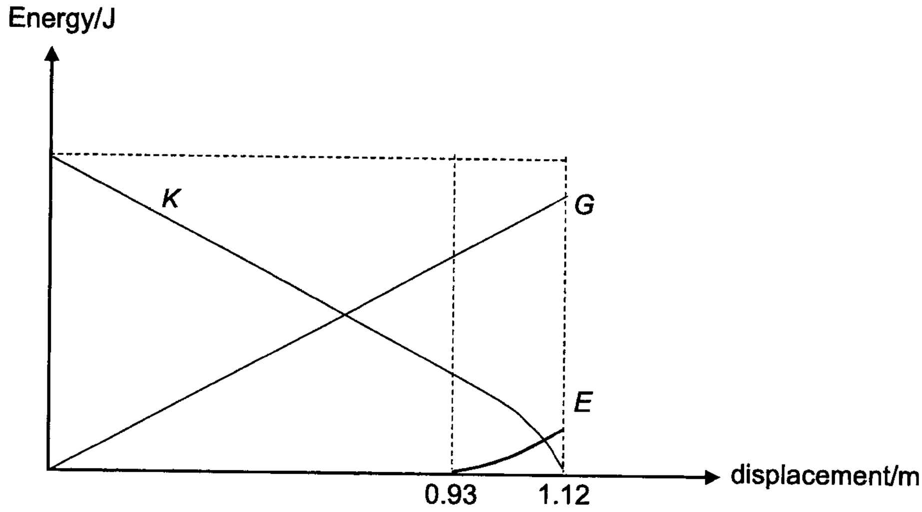
$$\frac{1}{2}mv^2 - 0 = mgh + \frac{1}{2}kx^2$$

$$\frac{1}{2}(150\times10^{-3})(5.7^2) - 0 = (150\times10^{-3})(9.81)(1.12) + \frac{1}{2}(45)x^2$$

$$x = 0.19 \text{ m}$$

(b) Length of unstretched cord = 1.12 – 0.19 = 0.93 m

(c)



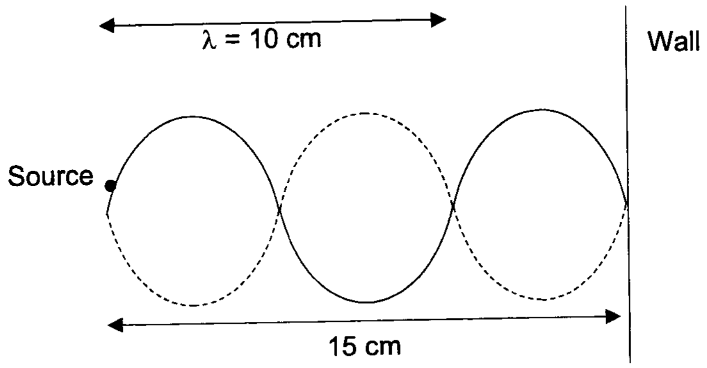
(G should end lower so that G + E = initial K at 1.12 m)

(d) Since the tension acting on the ball is always towards the center and perpendicular to the displacement of the ball [APPLICATION], there is no work done by the tension. [CONCLUSION]
[CONCEPT: WD = force x displacement in the direction of the force]

2(a) When the sound wave hits the wall, it will be <u>reflected</u> in the opposite direction and <u>interfere</u> with the original wave. [APPLICATION]

Now we have 2 waves of the <u>same amplitude, frequency and wavelength moving in opposite directions interfering with each other [APPLICATION]</u>, giving rise to a stationary wave. [CONCLUSION]
[CONCEPT: conditions for formation of stationary wave]

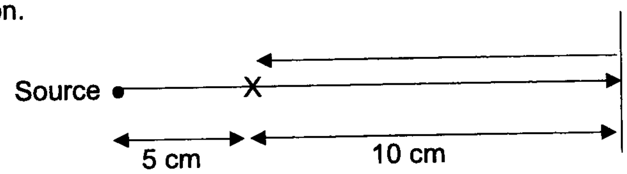
(b)



(c) From above diagram, $\lambda = 10$ cm

Frequency $f = \frac{v}{\lambda} = \frac{360}{0.10} = 3600$ Hz

d(i) After hitting the wall, the wave will continue to spread out as before, but in the opposite direction.



From diagram, reflected wave travels 25 cm.

$r_1 = 5$ cm, amplitude $A_1 = 3.0 \times 10^{-5}$ m
$r_2 = 25$ cm, $A_2 = ?$

Intensity $I \; \alpha \; A^2 \; \alpha \; \frac{1}{r^2}$ [CONCEPT]

$\therefore A \; \alpha \; \frac{1}{r}$

$\frac{A_2}{A_1} = \frac{r_1}{r_2}$

$A_2 = A_1 \frac{r_1}{r_2}$

$= 3.0 \times 10^{-5} \times \frac{5}{25}$

$= 6.0 \times 10^{-6}$ m

(ii) Since X was originally a node, it is a place of destructive interference.
$\therefore$ resultant amplitude = (3.0 – 0.6) = 2.4 x 10^{-5} m

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

(b)(i) (Before x = 10 cm, the electric field points to the right. After 10 cm, it points to the left.)
Since the electric field changes direction between A and B,
the charges have the same sign.
OR
At a point between A and B, the electric fields due to each charge cancel out to give a resultant field strength of zero.
So the charges have the same sign.

(ii) Any 1 point:
- Charge A is not the only charge present.
- The electric field strength is also influenced by charge B.
- The electric field strength is due to two/both charges.
- The electric field strength is the resultant of the two fields due to charges A and B.

(iii) From the graph, $E = 1.8 \times 10^3$ N C^{-1} where $x = 6.0$ cm.

Electric force on proton, $F_E = qE = (1.60 \times 10^{-19})(1.8 \times 10^3) = 2.88 \times 10^{-16}$ N

Acceleration of proton, $a = \frac{F_E}{m} = \frac{2.88\times10^{-16}}{1.67\times10^{-27}} = 1.72 \times 10^{11}$ m s^{-2}

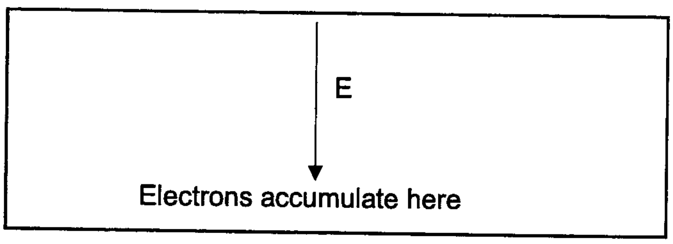
(iv) At x = 10 cm, field strength due to A = field strength due to B (in magnitude)
$|E_A| = |E_B|$ [CONCEPT]

$$\frac{Q_A}{4\pi\varepsilon_0 r_A^2} = \frac{Q_B}{4\pi\varepsilon_0 r_B^2}$$

$$\frac{Q_A}{Q_B} = \frac{r_A^2}{r_B^2} = \frac{(10.0\text{ cm})^2}{(5.0\text{ cm})^2} = 4$$

4(a) Magnetic force F_B = Bev = (4.0 x 10^{-3}) x (1.60 x 10^{-19}) x (0.60 x 10^{-3}) = 3.84 x 10^{-25} N

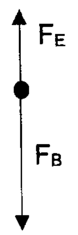
(b)



[Note: Direction of conventional current is opposite to that of electron flow.
Using FLHR, magnetic force is downwards, so electrons accumulate at the bottom.]

(c)(i) See above diagram.

(ii) **1.**



- The electric force F_E points upwards [APPLICATION].
- As the electric field gets stronger, F_E also gets stronger [APPLICATION]. The net force $\underline{F_{net} = F_E - F_B}$ gets weaker [CONCEPT: net force = vector addition]. So the rate of accumulation drops [CONCLUSION].
- Eventually $\underline{F_E = F_B}$, there's no more net force acting on the electron [APPLICATION], and the accumulation stops [CONCLUSION].

2. Accumulation stops: eE = Bev [CONCEPT]

$E = Bv$

Potential Difference, $V = Ed = Bvd$ [CONCEPT]

$= (4.0 \times 10^{-3}) \times (0.60 \times 10^{-3}) \times (1.5 \times 10^{-2}) = 3.6 \times 10^{-8}$ V

5(a) Higher frequency/lower wavelength means higher energy photons OR E = hf [CONCEPT]

violet photons are energetic enough to liberate electrons, while red are not
OR
Energy of violet photons is higher than work function, while red photons is not [APPLICATION]

Increasing intensity means higher rate of photons [CONCEPT]. Higher rate of photons (incident on potassium leads to) more electrons produced for violet light [CONCLUSION].

Since red light photons are not energetic enough to liberate electrons, even at very high intensity it will still not emit any electrons from the metal surface [CONCLUSION].

(b) Work function, $\phi = hf_o$ where f_o is the threshold frequency

$$f_o = \frac{\phi}{h} = \frac{4.5 \times 10^{-19}}{6.63 \times 10^{-34}}$$
$$= 6.78 \times 10^{14}$$
$$= 6.8 \times 10^{14} \text{ J}$$

'Show' question: Write to more sf than the show answer

So photons below threshold frequency of 6.8×10^{14} Hz will not release electrons from the metal surface.

(c)(i) E_k is 0 for f below the threshold frequency 6.8×10^{14} Hz (allow $\pm0.4\times10^{14}$ Hz) because no electrons are emitted from the metal surface.

$E_k = hf - \phi$, so plotting E_k against f gives a graph of constant gradient/straight line is obtained (after threshold frequency).

(ii) $h = \text{gradient} = \dfrac{(5.0-0)\times10^{-18}}{(14.4-6.8)\times10^{14}} = 6.6\times10^{-34}$ J s

6(a) Binding energy is defined as the amount of energy needed to split a nucleus into its individual nucleons.

(b) **(i)** ${}^{4}_{2}He \rightarrow {}^{3}_{2}He + {}^{1}_{0}n$

(ii) Q = Difference in total BE [CONCEPT]

= 4(6.8465) – 3(2.2666)

= 20.5862 MeV

(iii) mass of neutron + mass of ${}^{3}_{2}He$ – mass of ${}^{4}_{2}He$ = $\frac{Q}{931.494}$

mass of ${}^{4}_{2}He$ – mass of ${}^{3}_{2}He$ = mass of neutron - $\frac{Q}{931.494}$

= 1.0097 u - $\frac{20.5862}{931.494}$

= 0.9876 u

(iv) Since energy is supplied to make the process happen, this is a mass excess reaction.
So $m_{helium\text{-}4} < m_{helium\text{-}3} + m_{neutron}$
$m_{helium\text{-}4} - m_{helium\text{-}3} < m_{neutron}$

7 (a) Newton's law of gravitation states that the force of attraction between two point masses is directly proportional to the product of their masses and inversely proportional to the square of their distance apart.

(b) (i)

$$g = \frac{GM_E}{r^2} = \frac{GM_E}{\left(R_E + 350\times10^3\right)^2}$$
$$= \frac{\left(6.67\times10^{-11}\right)\left(6.0\times10^{24}\right)}{\left(6.4\times10^6 + 350\times10^3\right)^2}$$
$$= 8.78\ Nkg^{-1}$$

It is along the line joining point P and the centre of the Earth and is pointing towards the Earth's centre.

(ii)

$$F_G = m\omega^2 r \text{ [CONCEPT]}$$
$$gm = m\left(\frac{2\pi}{T}\right)^2 r$$
$$T = \sqrt{\frac{4\pi^2 r}{g}} = \sqrt{\frac{4\pi^2\left(6.4\times10^6 + 350\times10^3\right)}{8.78}} = 5510\ s$$

(c) (i) Gravitational potential at a point is defined as work done per unit mass by an external agent to move the unit mass from infinity to that point.

(ii) Since gravitational force is attractive, the force that the external agent exerts (which points towards infinity) is opposite to the displacement of the unit mass. So the work done by external agent to move unit mass from infinity to that point is always negative [APPLICATION]. So the gravitational potential at that point is also negative [CONCLUSION].
[CONCEPT: WD by force = force x displacement in the direction of the force]

(iii) Gravitational field strength, a *vector*, is given by the gradient of the potential graph. [CONCEPT]

Near the surface of the Earth, the net gravitational strength is directed *towards* the Earth. Near the surface of the Moon, the net gravitational strength is directed *towards* the Moon [APPLICATION.

Therefore, the gradient of the potential graph near the surface of the Earth and that near the surface of the Moon have *opposite* signs [CONCLUSION].

(iv) To reach the surface of the Earth, the spacecraft require a minimum kinetic energy that is just sufficient to overcome the gravitational potential energy difference between the surface of the moon and point P [APPLICATION].

Therefore, $\frac{1}{2}mv^2 = m\left(\phi_P - \phi_{Moon}\right)$, where v is the minimum speed of the spacecraft. [CONCEPT]

$$\therefore v=\sqrt{2(\phi_P-\phi_{Moon})}=\sqrt{2((-1.3)-(-3.9))\times10^6}=2.28\times10^3\ \text{ms}^{-1}$$

(d) (i) To *escape* the planet means the mass must have sufficient kinetic energy at the surface of the planet to just reach infinity with zero speed at infinity [CONCEPT].

By Conservation of Energy,

Total Energy at the surface = Total Energy at infinity [CONCEPT]

$$\frac{1}{2}mv^2+\left(-\frac{GMm}{r}\right)=0+0$$

$$v=\sqrt{\frac{2GM}{r}}$$

$$v=\sqrt{\frac{2(6.67\times10^{-11})(1.20\times10^{24})}{\left(\frac{7.5\times10^6}{2}\right)}}$$

$$=6.53\times10^3\ \text{m s}^{-1}$$

(ii) The average speed of the nitrogen gas is *higher* than the escape speed on this planet [APPLICATION], so most gases would have escaped and hence the planet does not have an atmosphere [CONCLUSION].

8(a)(i) Resistance $R=\frac{\rho l}{A}=\frac{(1.2\times10^{-5})(0.72)}{\pi(6.0\times10^{-2}\times10^{-3})^2}$

$=764\ \Omega$

(ii) Power $P=\frac{V^2}{R}=\frac{230^2}{764}$ [1]

$=69.2\ \text{W}$

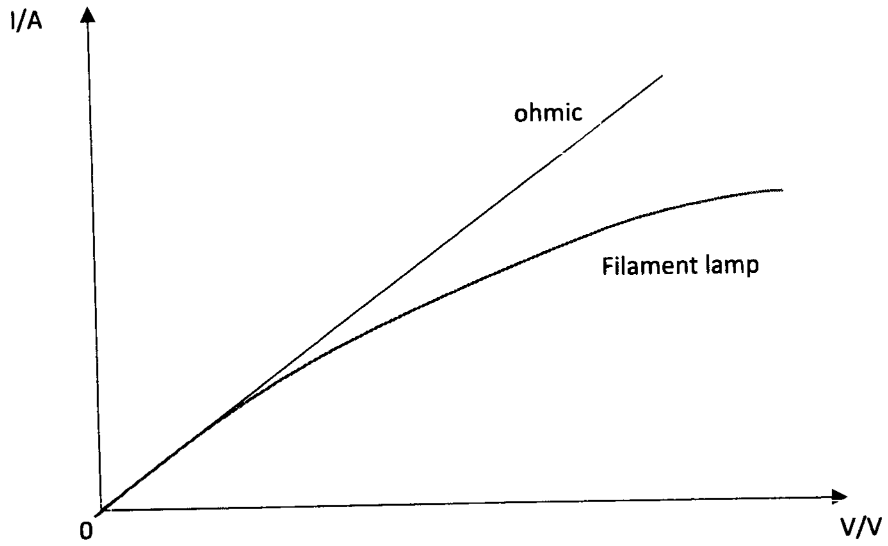
(iii) Material from filament will vaporise at high temperature.

(iv) 1. As filament gets thinner, its cross sectional area becomes effectively smaller [APPLICATION].

Since resistance α 1/cross sectional area [CONCEPT], resistance increases [CONCLUSION].

2. Power output is inversely proportional to resistance ($P=\frac{V^2}{R}$) [CONCEPT]. Since resistance of bulb increases [APPLICATION], power will drop as voltage V is constant [CONCLUSION].

(v)



(b) (i) 1. 2.10 V

2. $W = QV = (1)(2.10) = 2.10$ J

3. No current flows when switch is open and voltmeter is ideal.

No energy is being generated.

(ii) p.d. across internal resistor = E – V = 2.10 -2.00 = 0.10 V

By potential divider principle [CONCEPT],

Voltage across internal resistor = $\frac{r}{r+R}E$

$$0.10 = \frac{r}{r+10}(2.10)$$

$$r = 0.50\ \Omega$$

(iii) Efficiency = $\frac{I^2R}{I^2(R+r)} = \frac{R}{R+r} = \frac{1}{1+\frac{r}{R}}$ [CONCEPT]

As R increases, $1 + \frac{r}{R}$ decreases [APPLCATION], hence efficiency increases [CONCLUSION].