TJC 2022 H2 Physics Prelim Solutions P3

1 **(ai)** Internal energy is determined by the state of the system and it can be expresses as the sum of a random distribution of kinetic energy associated with the molecules of the system. [B1]

(ii) $pV = NKT$

$(1.05 \times 10^5) \times (2.9 \times 10^{-4}) = N \times (1.38 \times 10^{-23}) \times (303)$ [M1]

$N = 7.282 \times 10^{21} = 7.28 \times 10^{21}$ [A1]

(iii)
$$E_K = \frac{3}{2}kT$$
$$= \frac{3}{2} \times \left(1.38 \times 10^{-23}\right) \times (303)$$
$$= 6.272 \times 10^{-21} = 6.27 \times 10^{-21} \text{ J}$$ [A1]

(b) **(i)**
$$\Delta U = \frac{3}{2}Nk\Delta T$$ [M1]
$$= \frac{3}{2}\left(7.282 \times 10^{21}\right)\left(1.38 \times 10^{-23}\right) \times (357 - 303)$$ [A1]
$$= 8.14 \text{ J}$$

Allow e.c.f. from aii

(ii) Since gas A undergoes an adiabatic compression, $Q = 0$.

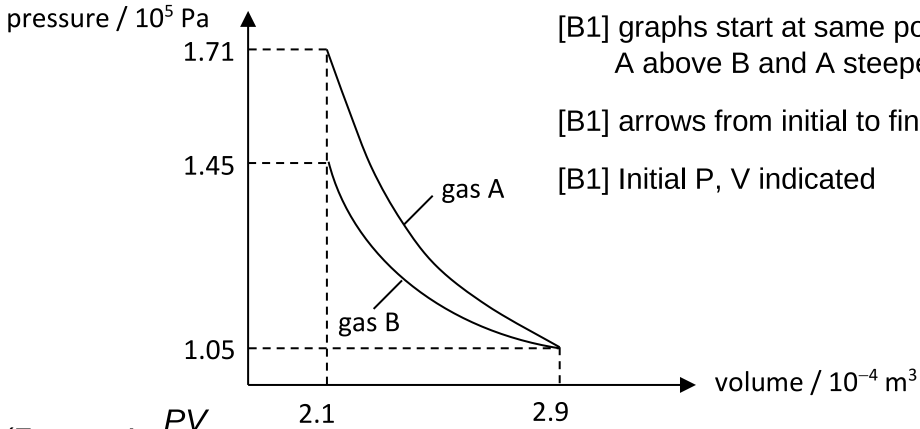
From the 1st law of thermodynamics,

$\Delta U = Q + W$

8.14 = 0 + W

W = 8.14 J [A1]

(iii)



[B1] graphs start at same point, with A above B and A steeper than B

[B1] arrows from initial to final state.

[B1] Initial P, V indicated

(For gas A, $\frac{PV}{T} = \text{constant}$.

$$\frac{1.05 \times 10^5 \times 2.9 \times 10^{-4}}{303} = \frac{p_A \times 2.1 \times 10^{-4}}{357} \Rightarrow p_A = 1.71 \times 10^5 \text{ Pa}$$

For gas B, PV = constant.

$(1.05 \times 10^5) \times (2.9 \times 10^{-4}) = p_B \times (2.1 \times 10^{-4}) \Rightarrow p_B = 1.45 \times 10^5$ Pa)

2 **(a)** The acceleration of the particle is proportional to its displacement from the equilibrium position B1
and is always directed towards that position. B1

(b) At y = 0.000 m,
TE = *KE* + *GPE* + *EPE* C1
= 0 + 0 + 0.445
= 0.445 J A1

-Accept answer between 0.440 J and 0.445 J.

(c) Straight line B1

passing through the origin and (0.393, 0.160). B1

1. At y = 0.160 m, TE = KE + GPE + EPE

0.445 = 0 + GPE + 0.049 ⇒ GPE = 0.396 J

Acceptable value for the GPE at y = 0.160 m ranges from 0.390 J to 0.396 J.

2. Students who draw curves get zero mark.

(d) Method 1:
Consider (0.393, 0.160) on *GPE* line,
mg (0.160) = 0.393
m = 0.250 kg C2
A0

Method 2:
At y = 0.080 m, the equilibrium position of the SHM, extension e of spring is 0.040 m. (See Fig. 4.1). There is no net force on m, thus
$ke = mg$
(61.4)(0.040) = m (9.81) ⇒ m = 0.250 kg

(e) Method 1:

$$KE_{\max} = \frac{1}{2}mv_o^2 = \frac{1}{2}m\omega^2 x_o^2 \quad \Rightarrow \quad 0.196 = \frac{1}{2}(0.250)(\frac{2\pi}{T})^2(0.080)^2$$ C1

$$T = 0.401 \text{ s}$$ A1

Method 2:

$$\omega^2 = \frac{k}{m} \quad \Rightarrow \quad \left(\frac{2\pi}{T}\right)^2 = \frac{k}{m}$$

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{0.25}{61.4}} = 0.401 \text{ s}$$

Method 3:
At y = 0.000 m, the extension of spring is maximum, e_{max} = 0.120 m. The mass is at its amplitude position in its SHM, so displacement is x_o = 0.080 m. (See Fig. 4.1).

$$\uparrow+: F_{net} = ma \quad \Rightarrow \quad ke_{\max} - mg = ma_o$$

$$ke_{\max} - mg = m(\omega^2 x_o)$$

$$(61.4)(0.12) - (0.25)(9.81) = (0.25)(\omega^2(0.08))$$

$$T = \frac{2\pi}{\omega} = 0.401 \text{ s}$$

3 **(a)**

$$F = qE = q\frac{\Delta V}{d}$$

$$1.12\times10^{-16} = 1.6\times10^{-19}\frac{\Delta V}{0.10}$$ [C1]

$$\Delta V = V_A - 0 = 70.0\ V$$

$$V_A = 70.0\ \text{V}$$ [A1]

(b)(i) Gain in PE = Loss in K.E. of electron

$$q\Delta V = \frac{1}{2}mv^2$$

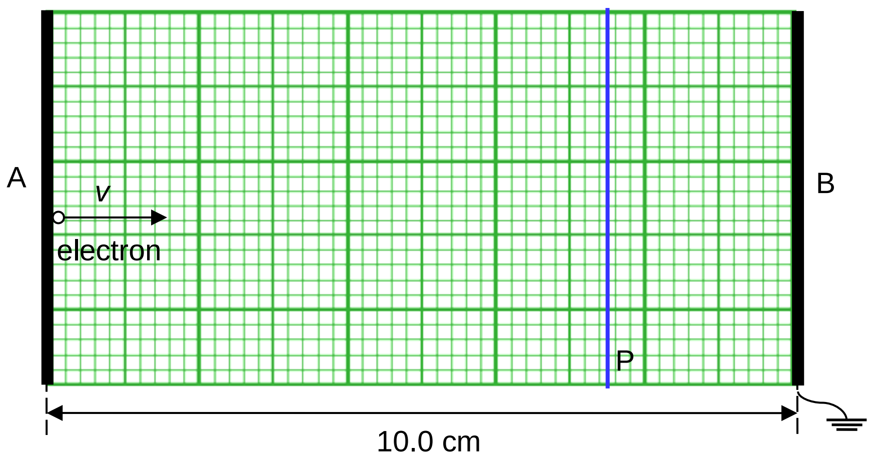
[C1]

$$-1.6\times10^{-19}\Delta V = \frac{1}{2}\times9.11\times10^{-31}\times(4.30\times10^6)^2$$

$$V_P - 70 = -52.6\ \text{V}$$ [A1] (ecf)

$$V_P = 17.4\ \text{V}$$

(b)(ii)



(b)(ii) E = ΔV/d = 70/10 = 7.0 V cm^{-1}

$\therefore$ for ΔV = 52.6 V, d = 52.6/7.0 = 7.5 cm [C1] (ecf)

Draw a vertical line 7.5 cm from plate A [M1]

(c) The electron will stop **before** the equipotential line as the horizontal component of velocity in the direction of the field would be lower. [A1]

(d)(i)

$$F = ma = qE$$

$$1.67\times10^{-27}a_y = 1.6\times10^{-19}\times2.0\times10^4$$

$$a_y = 1.92\times10^{12}\ m\ s^{-2}$$

$$s_y = \frac{1}{2}a_y t^2$$

$$\frac{1}{2}\left(0.50\times10^{-2}\right) = \frac{1}{2}\left(1.92\times10^{12}\right)t^2$$

$$t = 5.1\times10^{-8}\ s$$ [C2]

$$s_x = u_x t = 3.5\times10^6\times5.1\times10^{-8} = 0.179\ m$$ [A1]

(d)(ii) a_{proton} = qE / m

a_{alpha} = 2qE / 4m = ½ a_{proton} = 9.6 x 10^{11} m s^{-2} [C1]

Same vertical displacement for both proton and alpha [C1]

t_{alpha} = 7.2 x 10^{-8} s

Using $s_x = u_x t$, since u_x is the same for both, $(s_x)_{alpha} = 0.252\,m$

therefore alpha particle will exit the plates [A1]

4 (a) The heating effect is due to power dissipation in the coil which is dependent on the root-mean-square current and not on the average current. [C1]
The root mean square current is the value of the steady direct current that would dissipate heat at the same rate as the alternating current in a given resistor and it is non-zero. Hence, there is heating effect in the coil. [C1]

(b) (i) $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p}$

$V_s = 15 \times 16k = 240kV$ [M1]

$P_{loss} = I^2 R$

$= \left(\dfrac{20 \times 10^6}{240 \times 10^3} \right)^2 \times 20 \times 10 = 1.39 \times 10^6 W$ [A1]

(ii) $P_{loss} = \left(\frac{20\times10^6}{16\times10^3}\right)^2 \times 20 \times 10 = 3.13 \times 10^8 W$

$Energy\ saved\ = (3.13 \times 10^8 - 1.39 \times 10^6) \times 24 \div 1000 \quad = 7.48 \times 10^6 kwh$

$Amount\ saved = 7.48 \times 10^6 \times 0.10 = \$7.48 \times 10^5$

5 (a) $R\cos 14^o = W = 8500$

$\Rightarrow\ R = \dfrac{8500}{\cos 14^o}$ B1

Horizontal component of R = $R\sin 14^o = \dfrac{8500}{\cos 14^o}\sin 14^o$ = 2100 N B1

(b) Horizontal component of R provides the centripetal force for circular motion.

$\Rightarrow\quad m\dfrac{v^2}{r} = 2100$

$\Rightarrow\quad \dfrac{8500 \times v^2}{9.81 \times 150} = 2100$ M1

$\Rightarrow\quad v$ = 19 m s^{-1} A1

(c) There is a greater centripetal force to be provided at higher velocity. Hence, there is a horizontal component of frictional force acting on the car besides the reaction force *R,* providing the centripetal force required for its circular motion M1
The car will tend to slide up the slope. A1

6 (a) (i) -When an electron transits from a higher energy level to lower energy level, **energy is released** as electromagnetic wave or in the form of a **photon, of energy hf**. The difference in energy between 2 levels, ΔE is equal to the energy of the photon/ or **ΔE = hf.** B1

-since energy level is discrete, the **difference in energy is also discrete**. Hence, only **certain discrete frequencies exist**, hence line spectra obtained. B1

(ii) Energy has to be supplied to the electron to bring it to infinity/ to remove the electron, where PE is zero without a change in KE B1

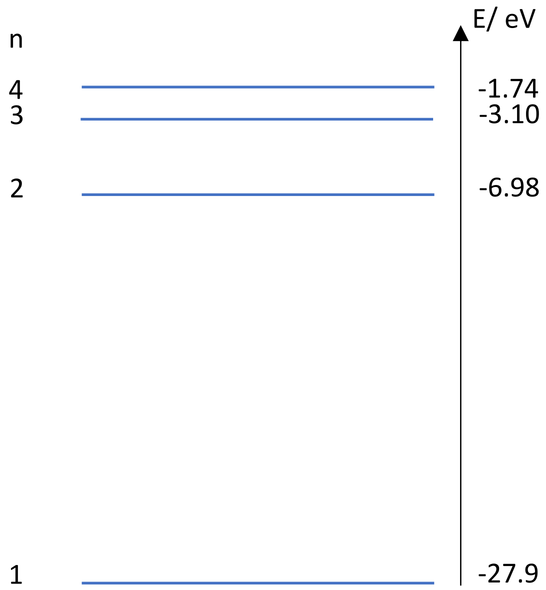
OR

The electron is **bound** to the nucleus. Total energy of the system/atom is negative. Hence work has to be done to remove the electron from the atom.

(ii)

Using $E_n = -\frac{27.9}{n^2}$

n	E_n / eV
1	–27.9
2	–6.98
3	–3.10
4	–1.74



All E values correct – B1

Relative spacing between energy levels correct – B1

Diagram must be fully labelled with n and E values – B1

(iii) Using $\Delta E = E_n - (-27.9) = 27.9 - \frac{27.9}{n^2}$, where ΔE represents the remaining energy of the colliding electron.

n	ΔE / eV
1 → 2	20.92
1 → 3	24.80
1 → 4	26.16
1 → 5	26.78

Calculation of ΔE for 1 → 4 **and 1 → 5**

Electron does not have enough energy to excite to n = 5 M1

Hence highest energy level reach is n = 4 A1

(iv) Using

$$\Delta E = \frac{hc}{\lambda} \quad \Rightarrow \quad \lambda = \frac{hc}{\Delta E}$$

Shortest wavelength

$$\lambda = \frac{hc}{\Delta E_{4\to1}} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{26.16\times1.60\times10^{-19}} = 47.5 \text{ nm}$$ C1 A1

(b) (i) Maximum energy of electron is equal to energy of photon with shortest wavelength.

$$E_{max} = \frac{hc}{\lambda_{min}}$$ [C1]

C1

Accelerating potential

$$V = \frac{hc}{e\lambda_{min}} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.60\times10^{-19}\times2.00\times10^{-10}}$$

$$= 6220 \text{ V}$$

A1

Note: λ_{min} must be read to **½ small square**, otherwise minus 1 mark

(ii) -Bombarding high energy electrons **knock out** the inner shell electrons of the target atoms. Hence, electrons transit from higher orbital shells to the vacant inner shells B1

-These transitions result in the emission of (X-ray) photons whose energies are given by the difference in the energy levels = $\frac{hc}{\lambda}$, resulting in sharp peaks at **specific** wavelengths of 4.00 x 10^{-10} m, 6.60 x 10^{-10} m and 9.95 x 10^{-10} m. B1

7 (a) (i) 1 By Newton's 3rd law, the rocket exerts a force on the gases so the gases exert an equal and opposite force on the rocket. B1

By Newton's 2nd law, this (net) force on the rocket will cause it to accelerate. B1

2 Total momentum of rocket and gas as a system remains constant since there is no (net) external force acting on it. B1

After engine is turned on, gases gain momentum to the left, rocket will gain equal magnitude of momentum to the right. B1

3 Force on gases = rate of change of momentum of gases

= Rv B1

So force on rocket = Rv B1

Hence $ma = Rv$ B1

$$\Rightarrow \quad a = \frac{Rv}{m}$$ A0

(ii) After the fuel in the 1st stage is used up, the acceleration of the rocket will be higher since *m* decreases. M1

Hence, the 2 stage rocket will have a larger final speed. A1

(b) (i) 1 constant net force = weight of the girl = 350 N

mass of the girl $= \frac{350}{9.81}$ C1

$= 36$ kg A0

2 Time taken for the girl to fall before touching the trampoline = 0.50 s

$v = u + at$

$= 0 + 9.81(0.50)$

$= 4.91 \text{ m s}^{-1}$ A1

3 Maximum upward net force, F_{net} = 1400 N

$F_{net} = N - W$ C1

$N = F_{net} + W$ = 1400 + 350 = 1750 N A1

(ii) 1 The net force decreases as normal contact force increases. B1
Therefore, the acceleration decreases.
Speed increases at a decreasing rate. B1

At point D, the net force is zero, normal contact force equals weight and the girl has maximum speed. B1

2 change in momentum = area under graph from C to D

$$= \frac{1}{2} \times 350 \times (0.53 - 0.50)$$ C1

= 5.3 Ns A1

3 $m(v_D - v_C) = \Delta p$ e.c.f. from part (ii)2

$36(v_D - 4.9) = 5.0$ C1

v_D = 5.0 m s^{-1} A1

8 **(a) (i)** $F = \frac{1}{4\pi\varepsilon_0}\left(\frac{1.60\times10^{-19}\times1.60\times10^{-19}}{\left(10^{-14}\right)^2}\right)$ C1

$= 2.3$ N A1

(a) (ii) $\langle KE \rangle = \frac{3}{2}KT$

$70\times10^3\left(1.60\times10^{-19}\right) = \frac{3}{2}\left(1.38\times10^{-23}\right)T$ C1

$T = 5.4\times10^8$ K A1

(a) (iii) Some nuclei will be travelling faster / have greater kinetic energy to overcome electrostatic repulsion and hence cause fusion. B1

(a) (iv) $E = \Delta mc^2$

$18\times10^6\left(1.60\times10^{-19}\right) = \Delta m\left(3.00\times10^8\right)^2$ C1

$\Delta m = 3.2\times10^{-29}$ kg A1

(b) (i) graph: smooth curve in correct direction starting at (0,0) M1
D at 2$t_{½}$ is 1.5 times that at $t_{½}$ (± 2 mm) A1

(b) (ii) *D* = number of parent nuclei that decayed
=original number of parent nuclei – number of parent nuclei remaining at time *t* M1
= $N_0 - N$
= $N_0 - N_0 e^{-\lambda t}$
= $N_0 (1 - e^{-\lambda t})$

(b) (iii) 1. ${}^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + \text{X}\,{}^{4}_{2}He + \text{Y}\,{}^{0}_{-1}e$
238 = 206 +4X ⇒ X = 8 ∴8 alpha decays M1

92 = 82 + 2X – Y
92 = 82 + 2(8) – Y M1
Y = 6 ∴6 beta decays

(b) (iii) 2.

$$D = N_0\left(1 - e^{-\lambda t}\right)$$

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

$$0.39 = e^{-\frac{\ln 2}{4.47\times10^9}t}$$ C1

$$t = 3.19\times10^9 \text{ years}$$ A1

OR

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

$$\frac{N}{N_0} = e^{-\frac{\ln 2}{t_{1/2}}t}$$

$$1 - 0.39 = e^{-\frac{\ln 2}{4.47\times10^9}t}$$

$$t = 3.19\times10^9 \text{ years}$$

(b) (iv) 1.

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

$$N_0 = \frac{N}{e^{-\lambda t}}$$ M1

$$D = N_0 - N$$ M1

$$= \frac{N}{e^{-\lambda t}} - N$$

$$= N\left(\frac{1}{e^{-\lambda t}} - 1\right)$$

(b) (iv) 2.

$$D = N\left(\frac{1}{e^{-\lambda t}} - 1\right)$$

$$\frac{D}{N} = \left(\frac{1}{e^{-\frac{\ln 2}{\lambda}t}} - 1\right)$$ C1

$$22.8 = \left(\frac{1}{e^{-\frac{\ln 2}{7.0\times10^8}t}} - 1\right)$$

$$t = 3.17\times10^9 \text{ years}$$ A1

(b) (iv) 3.

Any two from: B1 B1

- Allows the mean to be calculated
- Some daughter product may have left the sample
- (Use of three series) allows identification of anomalous results/series
- Spread of results indicates uncertainty