H2 PHYSICS

Exam papers with worked solutions

(Selected from Top JC)

SET D

PAPER 3

ANSWER

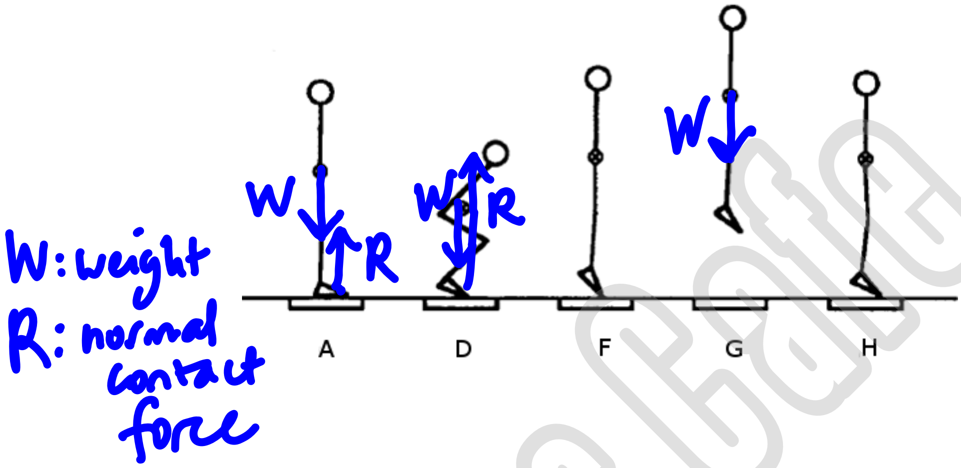
Compiled by

THE PHYSICS CAFE

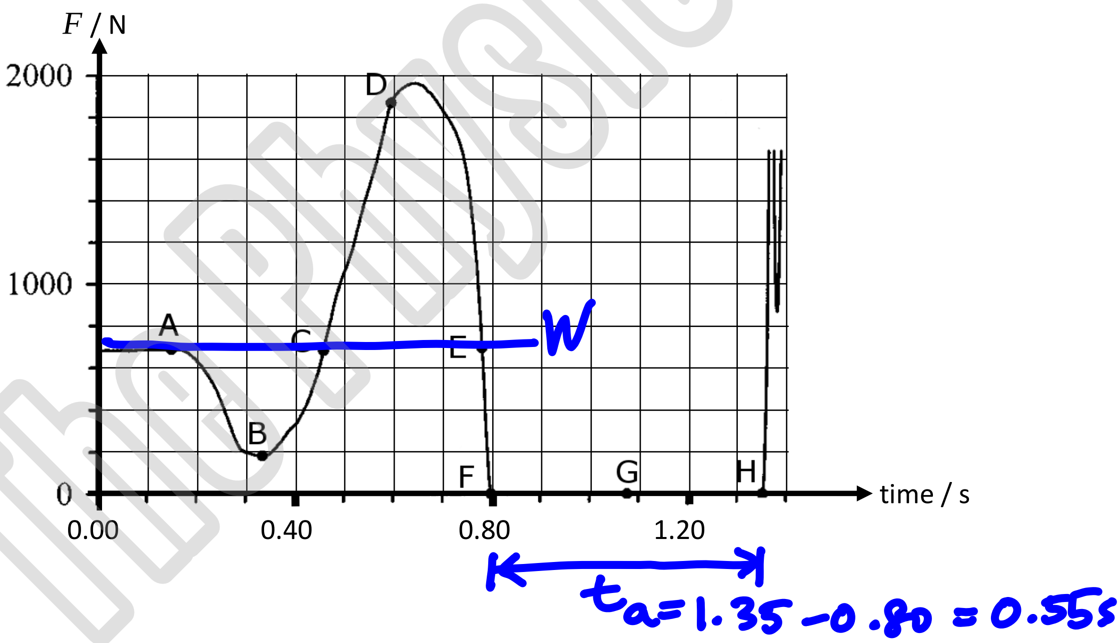
PAPER 3 SUGGESTED SOLUTIONS

Section A

1 (a) 1. & 2. Weight vector is constant (same length) for both D and G. 1
Normal contact force larger than weight in position D and no contact force in G. 1



(b) (i) An indication of the graph that t_a starts from t = 0.80 s till 1.35 s.
t_a = 0.55 s 1



(ii) Taking upward as positive and recognizing that it takes half of t_a for the jumper to reach the top of his jump,

$$v = u + at$$

$$0 = v_0 + (-9.81)\frac{(0.55)}{2}$$ 1

$$v_0 = 2.7\ \mathrm{m\,s^{-1}}$$

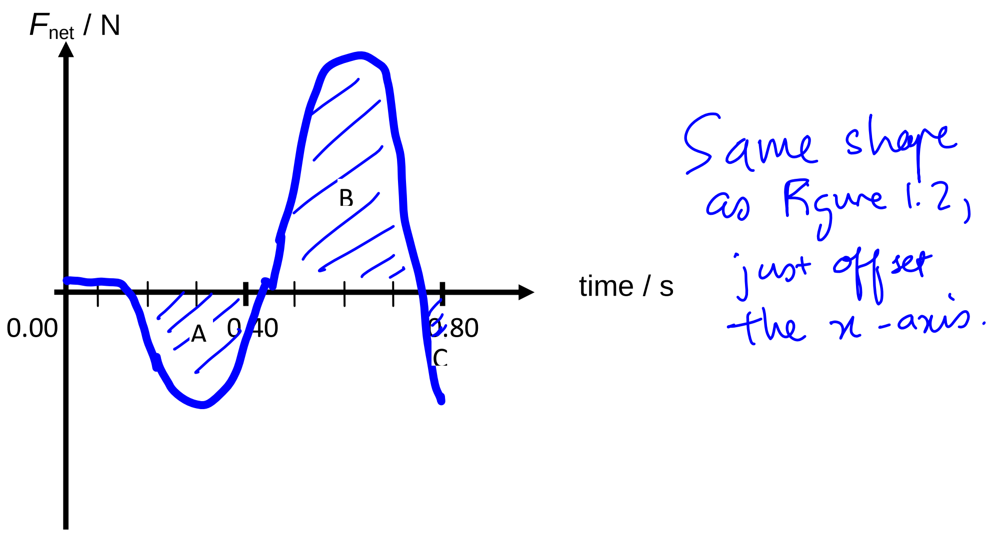
(iii) $v^2 = u^2 + 2as$

$0 = 2.7^2 + 2(-9.81)h$ 1

$h = 0.37 \text{ m}$ 1

(c) (i) See answer to (b)(i) above. 1

(ii) 1



Same shape as Figure 1.2, just offset the x-axis to 0. Must cross x-axis at t = 0.45 s and around t = 0.75 s.

(Shading and labels A,B,C is for next question)

(iii) By Newton's 2nd Law, the rate of change of linear momentum of the jumper is proportional to the net external force acting on him. 1
Therefore, the area under the force-time graph is equal to the change in momentum Δp of the jumper.

Since the initial velocity is zero, the final velocity v_0 can just be calculated from $\Delta p/m$. 1

<u>Extra</u>:

Δp = Area B – Area A – Area C
= $mv_0 - 0$

v_0 = $\Delta p/m$

2 (a) 1 Tesla is a unit of the magnetic flux density of a magnetic field if the force acting per unit length on an infinitely long conductor carrying a current of 1 A and placed perpendicular to the magnetic field is 1 N m^{-1}. 1

(b) (i)

$$B_c = \frac{4\pi(10^{-7})(0.100)(50)}{2(0.050)} = 6.3\times10^{-5}\text{ T}$$ 1

Towards the East. 1

(ii)

$$B_R = \sqrt{(62.8)^2 + (50)^2}$$

$$B_R = 8.0\times10^{-5}\text{ T}$$ 1

$$\tan\theta = \frac{62.8}{50}$$

$\theta = 51.6^o$ (East of North) 1

(c)

$$emf = \frac{d\phi}{dt}$$

$$= \frac{50\times(0.40-0)\times(0.0400)^2}{0.5}$$ 1

$$= 0.064\text{ V}$$ 1

3 (a) (i) 1 The accelerated electrons first knocks out/ejects electrons out of the inner shells of the target atoms, leaving a vacancy/hole. The atom is left in an excited/unstable state and an electron from an outershell/hole falls in to achieve greater stability. 1

The transition is accompanied by a decrease in energy of the atom and x-ray photon is emitted with energy equal to this decrease. 1

2. The accelerated electrons can be slowed down or stopped by the target, and part or all of the kinetic energy is directly converted to photons. The cut-off wavelength corresponds to the most energetic photon that can be produced. That happens when **all the kinetic energy** gained by **an** accelerated electron goes to producing **one** photon. 1

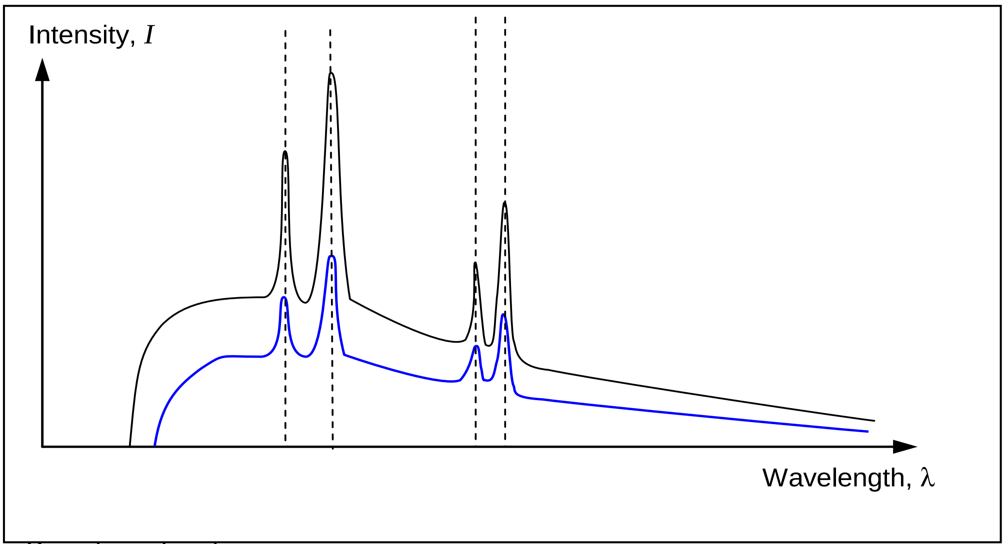
Remarks: Concept of all the k.e of a single electron goes to one photon must be explicit in the answer for the mark to be awarded.

(ii) Energy of the most energetic electron = Energy of the most energetic photon

$$\Rightarrow eV = h\frac{c}{\lambda}$$ 1

$$\lambda = \frac{hc}{eV} = \frac{(6.63\times10^{-34}\text{ J s})(3.00\times10^{8}\text{ m s}^{-1})}{(1.60\times10^{-19}\text{ C})(75.0\times10^{3}\text{ V})} = 1.66\times10^{-11}\text{ m}$$ 1

(iii)



See above for shape.
Key features:
- Longer cut-off wavelength, 1
- Shorter peaks and Positions of characteristics lines are unchanged. 1

(b) (i)

From the L_β line, $E_N - E_L = h\dfrac{c}{\lambda}$

$$\Rightarrow \quad E_N = h\frac{c}{\lambda} + E_L$$ 1

$$= \frac{(6.63\times10^{-34}\text{ Js})\dfrac{(3.00\times10^{8}\text{ m s}^{-1})}{(129\times10^{-12}\text{ m})}}{(1.60\times10^{-19})(1000)\dfrac{\text{J}}{\text{keV}}} + (-11.4)$$

= -1.76 keV

1

Alternatively,

Difference between the energy levels = Energy of the photon produced

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

$$\Rightarrow \quad \Delta E \propto \frac{1}{\lambda}$$

Using ,

$$\frac{E_N - E_L}{E_L - E_K} = \frac{\lambda_{L_\alpha}}{\lambda_{K_\beta}}$$ 1

$$\Rightarrow \quad \frac{E_N - (-11.4\text{ keV})}{-11.4\text{ keV} - (-69.6\text{ keV})} = \frac{21.3\text{ pm}}{129\text{ pm}}$$

$\Rightarrow$ E_N = -1.79 keV 1

(ii) The probability of electrons transiting from the L and M shell to the K shell as well as the M, and N shell to the L shell is higher as **they are closer**. 1

4 (a) When the potential at the p-side is positive with respect to the n-side, the p-n junction is in forward bias. When the potential at the p-side is negative with respect to the n-side, the p-n junction is in reverse bias. 1

Forward-bias (closed switch)
The electric field of the source and the junction electric field are in opposite directions – the effective electric field in the depletion region is reduced, 1
The potential energy barrier is reduced and the depletion width is reduced. 1
(or, the electrons in n-side and holes on p side are pushed towards the depletion region, reducing its width)
Electrons are able to flow from n to p side and holes from p to n side, resulting in a current. 1

Note: To earn full credit, the points above must be matched by a corresponding point when the junction is in reverse-bias.

Reverse-bias (open switch)
The electric field of the source reinforces the junction electric field – the effective electric field in the depletion region is increased,

the potential energy barrier is increased and the depletion width is larger. (or, the electrons in n-side and holes on p side are pulled away form the depletion region, widening its width)
There is no flow of electrons and holes across the junction – no current.

(b) From Fig 4.3,
Peak voltage V_o = 2.4 V (acceptable range: from 2.25 V to 2.4 V, error carried forward) 1

EITHER 1
Average power dissipated in load for **sinusoidal a.c.**
= ½ (peak power) = ½ (V_o^2/R)
1
Average power dissipated in load for **half-wave rectified d.c.**
= ½ average power dissipated in full sinusoidal a.c.
= ¼ (V_o^2/R)
= ¼ (2.4^2/68) = 0.021 W (acceptable range: from 0.0186 W to 0.0212 W)

OR

For **complete sinusoidal a.c.**, mean-square voltage, = $\frac{V_o^{\,2}}{2}$

For **half-wave rectified d.c.**,
Area under the V^2 – t graph for 1 period is halved,

mean-square voltage = $\frac{V_o^{\,2}/2}{2} = \frac{V_o^{\,2}}{4}$

(OR root-mean-square voltage for half-wave rectified d.c. = $\frac{V_o}{2}$)

average power dissipated = mean-square voltage/resistance

$$= \frac{V_o^2/4}{R} = \frac{2.4^2/4}{68}$$

= 0.021 W

5 (a)

Activity $= \dfrac{(3248-50)}{0.80/100}$ = 39975 per min 1

$= \dfrac{39975}{60}$ Bq

= 6660 Bq 1

(b)

$$C = C_0 e^{-\frac{\ln 2}{t_{1/2}}t}$$

$$(851-50) = (3248-50)e^{-\frac{\ln 2}{t_{1/2}}(6.0)}$$ 1

$t_{1/2} = 3.0$ h 1

OR

$\dfrac{C}{C_o} = \left(\dfrac{1}{2}\right)^n$ where n = number of half – lives

$$n = \frac{\ln\left(\frac{1}{2}\right)}{\ln\frac{C}{C_o}} = \frac{\ln\left(\frac{1}{2}\right)}{\ln\left(\frac{851-50}{3248-50}\right)} = 2.00$$

$$t_{1/2} = \frac{t}{n} = \frac{6.0}{2.00} = 3.0h$$

(c)

$$C = C_0 e^{-\frac{\ln 2}{t_{1/2}}t}$$

$$(100-50) = (3248-50)e^{-\frac{\ln 2}{3.0}t}$$ 1

$t = 18.0$ h 1

OR

Use $\dfrac{C}{C_o} = \left(\dfrac{1}{2}\right)^n$ where n = number of half – lives

n = 6.0

$$t = nt_{1/2} = (6.0)(3.0) = 18.0 \text{ h}$$

Note: if the count rates are not corrected the first time, marks will be deducted. Error carried forward for subsequent questions.

Section B

6 (a) (i) 1. Internal energy refers to the sum of the microscopic kinetic and potential energies due to the random motion of the molecules. 1

2. For an ideal gas, there is no potential energy because there are no intermolecular forces of attraction. 1
The internal energy is entirely kinetic energy. 1

(ii) 1. Both hydrogen and oxygen are at the same temperature and therefore have the same average kinetic energy. 1

For the same kinetic energy, the lighter hydrogen molecule has a larger velocity. 1

2. They are moving at a velocity larger than that needed to escape gravitational attraction, i.e. they are at least the escape velocity necessary to overcome gravitational attraction. 1

3. Even at the same temperature the oxygen molecules have a spread or range of velocities (Maxwell-Boltzmann distribution curve). There are some moving fast enough to overcome gravitational attraction. 1

(b) (i)

$$c_{rms} = \sqrt{\frac{3p}{\rho}}$$

$$= \sqrt{\frac{3p}{\text{total mass}/\text{volume}}}$$ 1

$$= \sqrt{\frac{3\left(1.01\times10^{5}\right)}{0.01N_A\left(20u\right)/250\times10^{-6}}}$$ 1

$= 616$ m s^{-1} 1

(ii) 1. The two objects are at the **same temperature** and there is **no net transfer of heat** between them. 1

(ii) 2.

New volume $= \dfrac{0.01R(273)}{1.01\times10^{5}}$ = 2.246× 10^{-4} m^3. 1

Change in volume = 225 – 250 = - 25 cm^3. (negative sign necessary) 1

(iii) 1.

	ΔU	Q	W
A→ B:	+	0	+
B→ C:	-	-	0
C→ A:	0	+	-
Entire Cycle	0	-	+

4

[minus 1 for every mistake up to max 4 mistakes]

2. Energy supplied to ice = mL_f = (0.00200)(3.36 × 10^5) = 672 J 1
Heat supplied to gas, Q = -672 J and ΔU = 0 1
$\Delta U = Q + W_{on}$
$0 = -672 + W_{on}$
$W_{on} = 672$ J 1
mL_f carries a negative sign because heat is extracted from the system.

7 (a) (i) <u>Any 2 of the conditions below</u> 2
The two sources must be coherent.
The two waves have about the same amplitude.
The two waves must be of the same type / nature.
The two waves must be either unpolarised or have about the same plane of polarization.

(ii) Let amplitude of wave Q be A_Q and since I is proportional to A^2

$$\frac{I}{0.64I} = \frac{A^2}{A_Q^2}$$

$A_Q = 0.8A$ 1
Maximum intensity occurs when constructive interference occur.
Amplitude during constructive interference = 1.8 A 1

$$\frac{I}{I_{max}} = \frac{A^2}{(1.8A)^2}$$

Thus $I_{max} = 3.2\ I$ 1

(b) (i) $v = f\lambda$ 1

$\lambda = \frac{v}{f} = \frac{330}{1650} = 0.200$ m 1

(ii) $S_2D = \sqrt{3.81^2 + 10.0^2} = 10.7$ m 1

(iii) 1. Path difference = 10.7 – 10.0 = 0.7 m = 3.5 λ 1
Phase difference, φ = 0.5 x 2π = π rad or 180° 1

2. The waves meet **out of phase at D** and thus results in **destructive interference**. Therefore an intensity minimum is formed. 1

Note: Not acceptable to say the path difference is 3.5 λ without adding that the sound waves are emitted by the sources in phase.

(iv) The frequency can be varied such that the path difference is 6.5 wavelengths. A minimum will be detected when the path difference corresponds to 4.5, 5.5 and 6.5 wavelengths. 1

If path difference is 6.5 λ_1, then
6.5 λ_1 = 3.5 λ 1

$f_1 = (\frac{6.5}{3.5})1650 = 3060\text{Hz}$ 1

(c) (i) E_2 is the metastable state, where the atoms have a longer-lifetime compared to other excited states. 1

(ii) Atoms in the ground state are excited to E_3. These quickly de-excite to the upper laser level E_2.

When more atoms are in the upper laser level than in the ground state (i.e. lower laser level), population inversion is produced between the upper and lower laser levels. 1

When a photon of energy equal to $E_2 - E_1$ passes through the laser medium, it can either be absorbed to cause excitation from E_1 to E_2 or stimulate de-excitation from E_2 to E_1, releasing another photon of energy $E_2 - E_1$ in the process. With population inversion, de-excitation is more probable than absorption. Stimulated emission produces photons of the same phase, energy, frequency, polarization and direction of travel as the incident photon. 2

The photons are sent back and forth in the laser medium (by mirror reflection) and in the process they will cause more stimulated emissions. 1

(iii) Lower laser state is not ground state. After atoms move from the upper laser level (E_3) to the lower laser level (E_2) through stimulated emission, they will quickly depopulate to the ground state (E_1). This **reduces the loss of photons by absorption** between the upper (E_3) and lower (E_2) laser levels. 1

8 (a) (i) An electron 1

(ii) ${}^{210}_{83}\text{Bi} \rightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}\text{e}$ 1

(iii) Any 2 from the list below 2
Charge (proton number)
Nucleon number (mass number), but NOT MASS
Total Energy (mass-energy)
Momentum (linear or angular)

(iv) Mass defect, Δm = $83m_p + 127m_n - m(\text{Bi})$
= 83(1.00729u) + 127(1.00867u) – 209.939u 1
= 1.767 u 1

(v) BE = $(\Delta m)c^2$
= 2.64×10^{-10} J 1
= 1646 MeV 1

(b) (i) 1. from the graph, Q = 1.2 MeV 1

2. $v = \sqrt{(E/(\frac{1}{2} m_e)}$ 1
= 6.5×10^8 ms^{-1} 1
The calculated value of v is more than c, the speed of light.
(This suggests that the classical formula for kinetic energy ½ mv^2, is not valid in calculating the speed of the beta particle.)

3. $m(\text{Po}) = m(\text{Bi}) - m_e - Q/c^2$ 1
= $[(209.939u) - (9.11 \times 10^{-31}/1.66 \times 10^{-27}) - (1.2\times10^6 \times 1.60\times10^{-19}/c^2)]/(1.66 \times$ 1

10^{-27} kg)
= 209.937 u 1

(ii) Range of values accepted : 0.16 - 0.18 MeV 1

(iii) Since ^{210}Bi undergoes spontaneous beta decay, a process in which it increases its proton number by one 1
while decreasing its neutron number by one, it suggests that ^{210}Bi must have an excess of neutrons as compared to the optimal ratio. 1

(iv) For a stationary nucleus decaying into the beta particle and daughter nucleus, the conservation of linear momentum requires that $\underline{p_1} = -\underline{p_2}$.
The sum of kinetic energies will thus be $(p_1)^2/2m_1 + (p_2)^2/2m_2 = E$, which ought to equal the energy released in the reaction, which, if equal to the increase in the total binding energy/decrease in total mass, ought to be constant. 1

The range of beta particle energies and thus the supposed energy released E, seem to suggest that the energy released was not constant, in contradiction to the principle of conservation of energy. 1

(v)
- Energy was not conserved in a beta decay**.** (proven false) 1
- **The existence of another undetected particle.**
- (The actual reason. The undetected particle was the neutrino, and a 3 body interaction allowed for the beta particle to carry away a varying amount of KE whilst still ensuring COE)