H2 PHYSICS

Exam papers with worked solutions

(Selected from Top JC)

SET D

PAPER 3

Compiled by

THE PHYSICS CAFE

INSTRUCTIONS TO CANDIDATES

Do Not Open This Booklet Until You Are Told To Do So.

1. Write your name, class, tutor's name and calculator model clearly on this cover page.
2. Check that you have the correct number of pages for this question booklet.
3. **Answer <u>ALL</u> question in Section A (40 Marks).**
4. The total marks for Section A is 40.
5. For numerical answers, **all** working should be shown.
6. You may use a soft pencil for any diagrams, graphs or rough working
7. Do not use paperclips, highlighters, glue or correction fluid.
8. A data and formula list is provided on page 2.
9. You are reminded of the need for clear presentation and good English.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets [ ] at the end of each question or part question.

Name of Student :	
Class:	
Name of Tutor :	
Calculator model:	
For Examiner's Use :	
Section A	
1	**/10**
2	**/7**
3	**/10**
4	**/7**
5	**/6**
Section B	
Question No.	
	/20
	/20
Deductions	
Paper 3	**/80**

Data

speed of light in free space,
c = 3.00×10^{8} m s^{-1}

permeability of free space,
μ_o = $4\pi \times 10^{-7}$ H m^{-1}

permittivity of free space,
ε_o = 8.85×10^{-12} F m^{-1}
≈ $(1/(36\pi)) \times 10^{-9}$ F m^{-1}

elementary charge,
e = 1.60×10^{-19} C

the Planck constant,
h = 6.63×10^{-34} J s

unified atomic mass constant,
u = 1.66×10^{-27} kg

rest mass of electron,
m_e = 9.11×10^{-31} kg

rest mass of proton,
m_p = 1.67×10^{-27} kg

molar gas constant,
R = 8.31 J K^{-1} mol^{-1}

the Avogadro constant,
N_A = 6.02×10^{23} mol^{-1}

the Boltzmann constant,
k = 1.38×10^{-23} J K^{-1}

gravitational constant,
G = 6.67×10^{-11} N m^{2} kg^{-2}

acceleration of free fall,
g = 9.81 m s^{-2}

Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on/ by a gas,	$W = p\,\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential,	$\phi = -Gm/r$
displacement of particle in s.h.m.,	$x = x_o \sin \omega t$
velocity of particle in s.h.m.,	$v = v_o \cos \omega t$ $= \pm\omega\sqrt{(x_o^2 - x^2)}$
resistors in series,	$R = R_1 + R_2 + \ldots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential,	$V = Q/4\pi\varepsilon_o r$
alternating current / voltage,	$x = x_o \sin \omega t$
transmission coefficient,	$T = \exp(-2kd)$
where	$k = \sqrt{\frac{8\pi^2 m(U - E)}{h^2}}$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

SECTION A (40 Marks)

Answer all questions

1 An experiment is conducted to measure the standing vertical jump height of a person.

The person stands on a platform embedded with a force sensor. He then exerts maximum effort to jump vertically off the platform. Figure 1.1 shows the stick figures representing 5 different positions of the jumper at successive times. Assume air resistance is negligible.

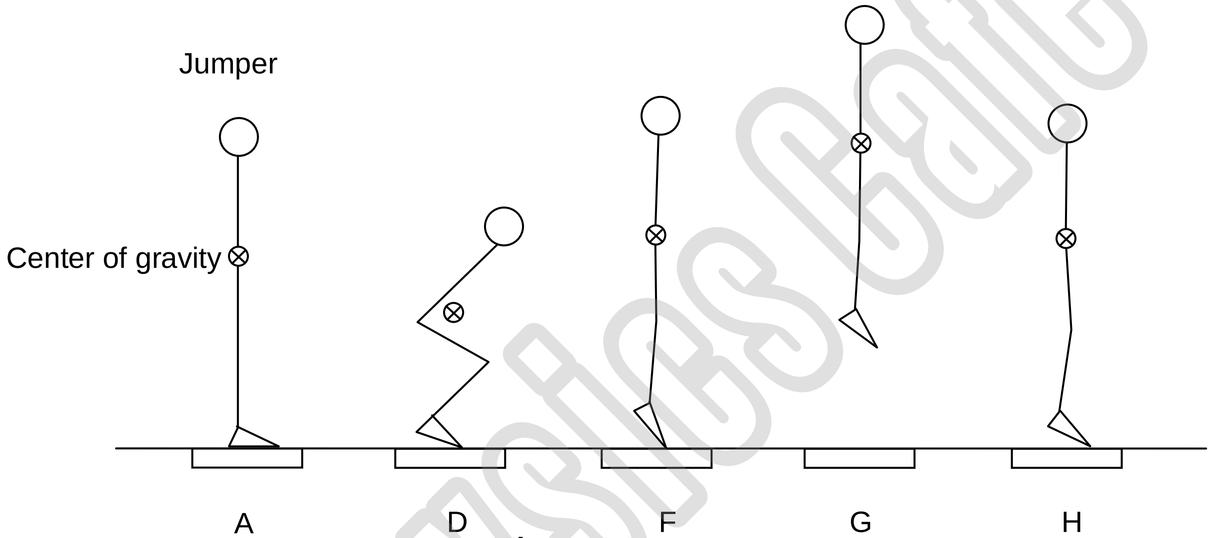

Figure 1.1

The variation with time t of the total force F exerted by the feet on the platform is shown in the graph in Figure 1.2. The time t = 0.80 s is the instant of take-off.

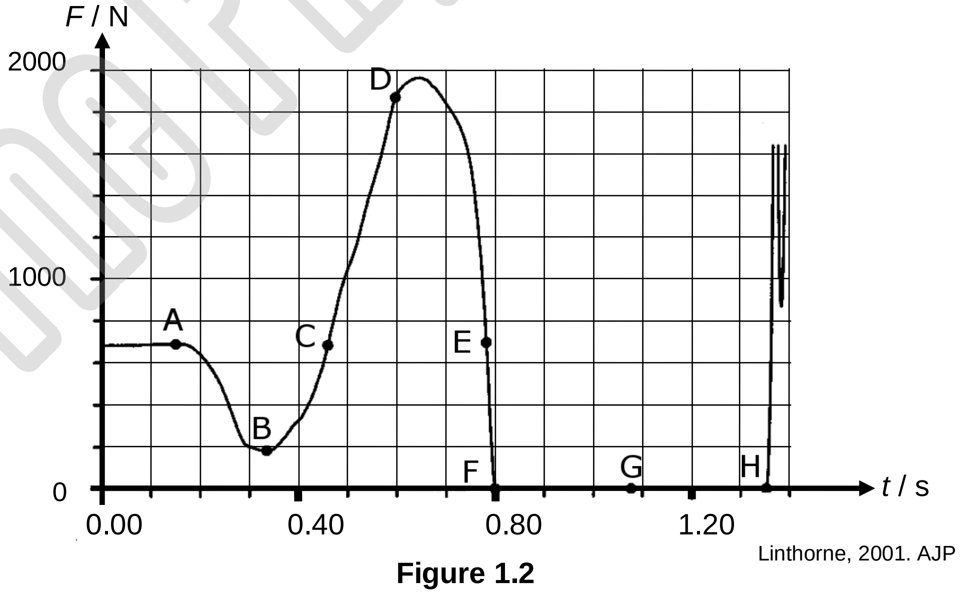

Figure 1.2

(a) Draw labelled force diagrams on the stick figures in Figure 1.1 to show the forces acting on the jumper when he is
1. in position D
2. in position G. [2]

(b) (i) Use Figure 1.2 to determine the length of time t_a the jumper is completely airborne. **Indicate the length of time t_a clearly on the graph.**

t_a = ____________ s [1]

(ii) Hence, show that the vertical velocity, v_0 at the instant of take-off is 2.7 m s^{-1}.

[1]

(iii) Calculate the maximum vertical jump height, *h*.

h = _______________ m [2]

(c) By considering all forces acting on the jumper from A to F only, a second method can be used to determine the take-off velocity v_0.

(i) Draw a line on the graph in Figure 1.2 to represent the weight of the jumper. Label this line *W*. [1]

(ii) Hence, sketch in Figure 1.3 the variation with *t* of the net force F_{net} acting on the jumper from *t* = 0.00 to 0.80 s (from A to F).

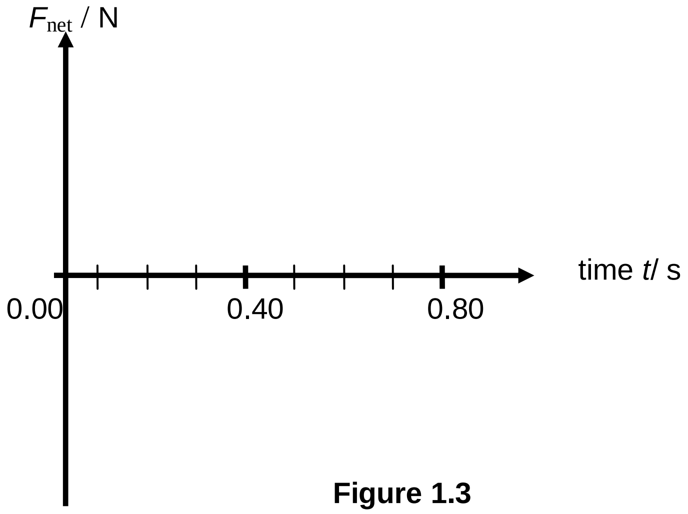

Figure 1.3 [1]

(iii) Explain how the vertical velocity v_0 can be calculated from the graph of F_{net} against time.

____

____

____

____

____

____ [2]

2 (a) Define the *tesla*.

____

____

____ [1]

(b) At the equator, a thin coil of 50 turns and of diameter 10.0 cm is in a vertical plane (with axis in the East-West direction) as shown in Figure 2.1. A compass, which is in a horizontal plane, has its pivot coinciding with the centre of the coil. Initially, no current flows through the coil and the compass is pointing North as shown.

The magnetic flux density at the centre of a thin coil follows the formula $B = \frac{\mu_0 NI}{2R}$, where I represents the current, N the number of turns of coil and R the radius of the coil. The Earth's magnetic field is 50.0 μT.

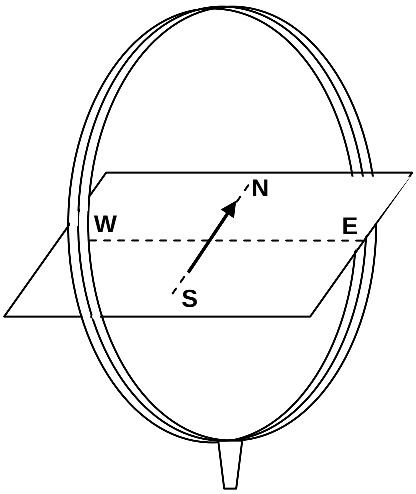

Figure 2.1

When a current of 100 mA flows in a clockwise direction as viewed from the West, determine

(i) the magnetic flux density, B_c, and its direction at the centre of the coil, due only to the current flowing in the coil.

B_c = ________________ T

Direction: ______________________________ [2]

(ii) the resultant magnetic flux density at the centre of the coil, B_R, and the new direction (angle θ from the North) which the compass will be pointing.

B_R = _______________ T

Direction: _____________________________ [2]

(c) A powerful electromagnet produces a uniform field in the gap between its poles, each of which measures 4.00 cm × 4.00 cm and are facing each other. There is no field due to the electromagnet outside the gap. The circular coil in (b) is placed between the poles such that its plane is perpendicular to the field lines and encloses all the field lines, as shown in Figure 2.2.

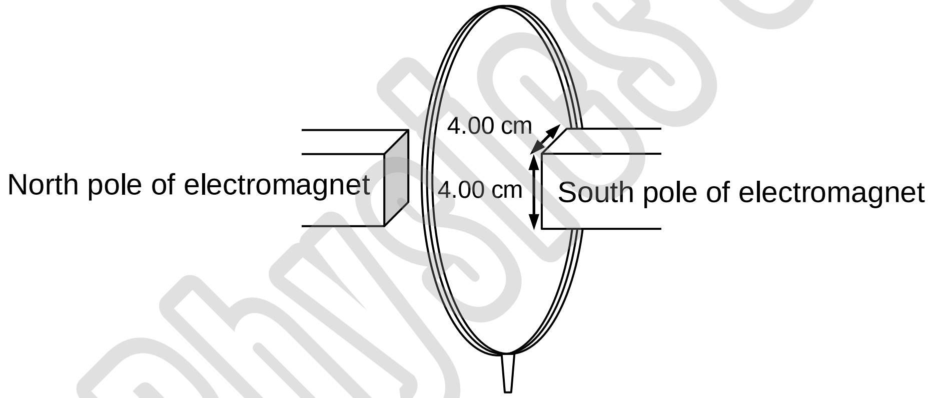

Figure 2.2

The magnetic field produced by the electromagnet is adjusted so that the field strength steadily decreases from 0.40 T to zero in 0.50 s. Calculate the e.m.f. generated in the coil.

e.m.f. = ____________ V [2]

3 (a) X-rays are produced when electrons are accelerated through a potential difference towards a metal target such as tungsten. Figure 3.1 shows a typical X-ray intensity spectrum that can be produced from an X-ray tube.

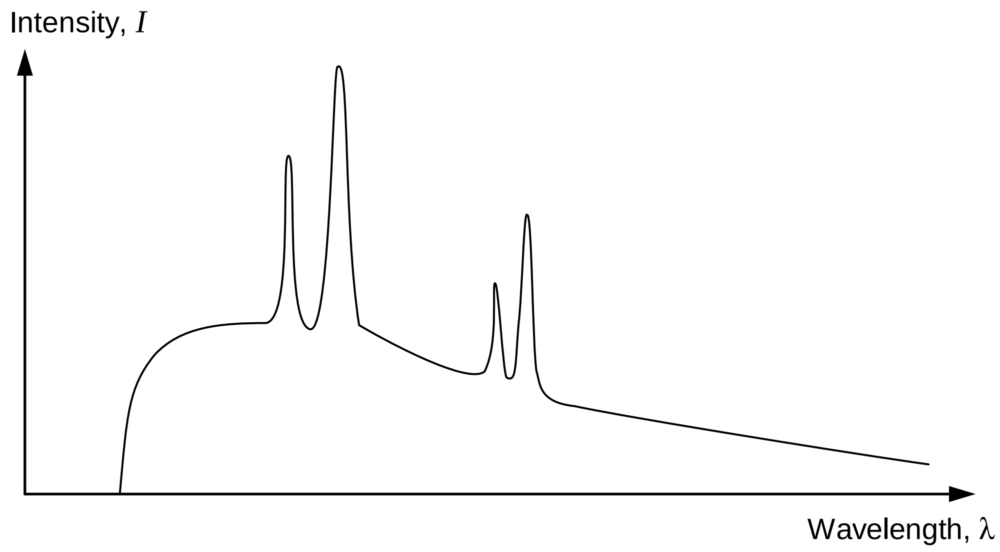

Figure 3.1

(i) Explain the origins of the following features of Figure 3.1:

1. characteristic lines

____

____

____

____

____

____ [2]

2. cutoff wavelength

____

____

____ [1]

(ii) If the electrons are accelerated through a potential difference of 75.0 kV, determine the cutoff wavelength λ_{cutoff} of X-rays that can be produced by the tube.

λ_{cutoff} = _______________ m [2]

(iii) Suppose now the potential difference used to accelerate the electrons is decreased, sketch in Figure 3.1, the new spectrum obtained. [2]

(b) Figure 3.2 shows some of the energy levels within an atom of tungsten in the target in Figure 3.1 and four possible transitions (K_α , K_β , L_α and L_β) that can be observed for the experiment depicted in (a).

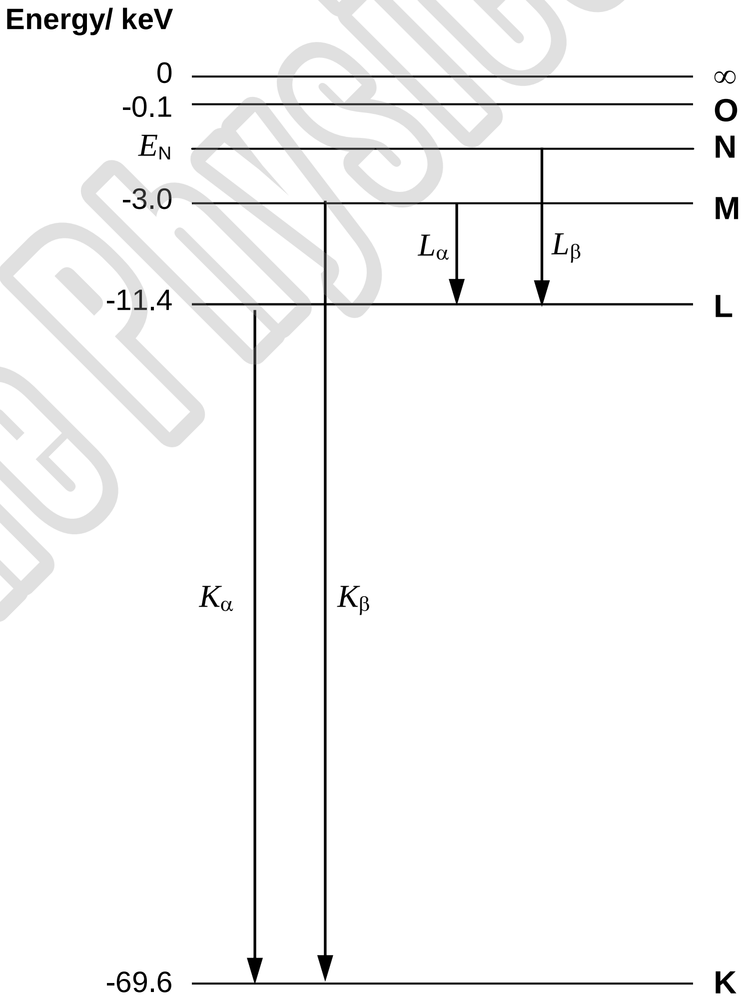

Figure 3.2

The corresponding wavelengths of the X-rays for the transitions are given in the table below.

	Wavelength/ pm
K_α line	21.3
K_β line	18.6
L_α line	148
L_β line	129

(i) Deduce the energy level E_N (in keV) for the N-shell electrons.

E_N = ____________ keV [2]

(ii) In reality, transitions from *O to L* or *N* to *K* shells are also possible, but in practice their intensity is low. Suggest a possible reason why this is so.

____

____

____ [1]

4 Diodes used in rectifying alternating current to direct current are p-n junctions made of semiconductors. A p-n junction is formed when p-type and n-type extrinsic semiconductors are joined, as shown in Figure 4.1.

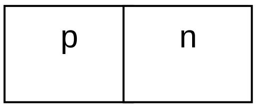

Figure 4.1

Figure 4.2 shows a sinusoidal power supply with a peak output of 3.0 V at a frequency of 50 Hz. The power supply is connected to a 68 Ω load resistor. The p.d. across the load resistor is displayed on an oscilloscope.

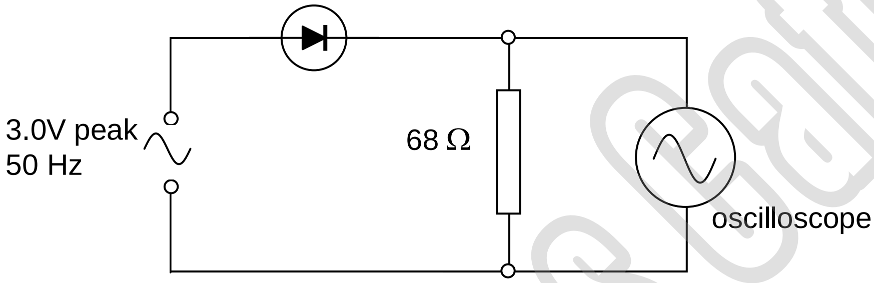

Figure 4.2

(a) Explain how the p-n junction acts as an open or closed switch in the circuit as the voltage varies. You may draw a diagram if you wish.

____ [4]

(b) The oscilloscope is set to a voltage sensitivity of 1.0 V cm^{-1}. The trace in Figure 4.3 is seen on the grids of the oscilloscope. Calculate the average power dissipated in the load resistor.

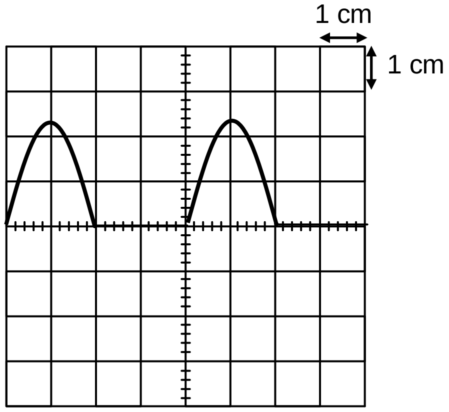

Figure 4.3

average power dissipated = ______________ W [3]

5 Figure 5.1 shows an experimental arrangement used to estimate the activity of a radioactive source which emits β-particles.

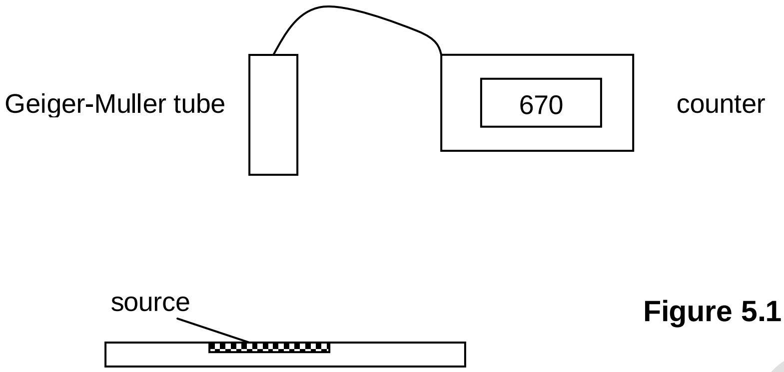

Figure 5.1

The following count-rates, as detected by the Geiger-Muller tube, are taken at two different times *t*. **Note that background-count has been established to be 50 min^{-1}**.

***t* / hour**	**count-rate / min^{-1}**
0	3248
6.0	851

0.80% of the β-particles leaving the source are recorded by the counter. Each β-particle produces a count of one.

(a) Determine the activity of the source at the start of the experiment.

activity = __________ Bq [2]

(b) Determine the half-life of the source.

half-life = ___________ hours [2]

(c) Counting is ended when the recorded count-rate falls to less than 100 min^{-1}. Determine the time after the start of the experiment at which this occurs.

time = ___________ hours [2]

SECTION B (40 Marks)

Answer ANY TWO questions.
CIRCLE the question you have chosen on the cover sheet.

6 (a) (i) 1. What is meant by *internal energy* of a system?

____

____ [1]

2. Explain how the concept of internal energy is applied to an ideal gas as compared to a real gas.

____

____

____

____ [2]

(ii) The following is an excerpt from American Scientific (May 2009):

Many of the gases that make up Earth's atmosphere and those of the other planets are slowly leaking into space. This leakage explains many of the solar system's mysteries. For instance, Mars is red because its water vapour got broken down into hydrogen and oxygen, the hydrogen moved at higher speeds and drifted away, and the remaining oxygen reacted with rocks to form rust, and gives Mars its characteristic red colour.

Explain the following.

1. Hydrogen molecules are faster-moving than oxygen molecules.

____

____

____

____

____ [2]

2. Fast-moving molecules are able to escape.

____

____ [1]

3. Some oxygen molecules are also able to escape.

____

____ [1]

(b) 1.00×10^{-2} mol of neon gas is contained in a vessel capped by a light moveable piston. At equilibrium the volume enclosed by the vessel is 250 cm^3. Take the mass of a neon atom to be 20.0 u and atmospheric pressure to be 1.01×10^5 Pa. Assume behaviour of the gas to be ideal.

(i) Using $p = \frac{1}{3}\rho < c^2 >$, where p is the pressure of the gas, ρ is the density of the gas, and $<c^2>$ is the mean-square speed, calculate the root-mean-square speed of the neon atoms.

root-mean-square speed = ______________ m s^{-1} [3]

(ii) The vessel is submerged in a pure ice-water mixture and allowed to come to thermal equilibrium with its surroundings. The piston settles at a new position, X.

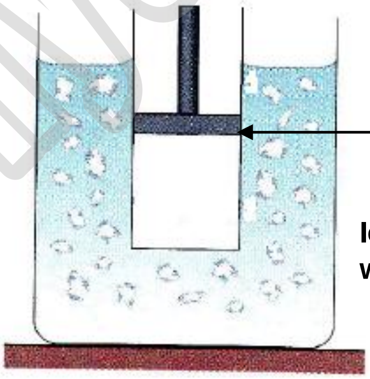

Figure 6.1

1. Explain what is meant by *thermal equilibrium*.

____

____ [1]

2. Calculate the change in the volume of the gas in the vessel.

change in volume = ____________ cm^3 [2]

(iii) The gas is subjected to a cycle of changes A→ B→ C→ A as shown in Figure 6.3.

A→ B: The piston is quickly pushed down from position X to position Y. You can assume that this process takes place so quickly that there is no heat transfer with the surroundings.

B→ C: The piston is held at position Y until the gas is again at the temperature of the ice-water mixture.

C→ A: The piston is slowly raised back (such that there is ample time for heat transfer between the gas and its surroundings and there is no temperature change in the gas) to position X.

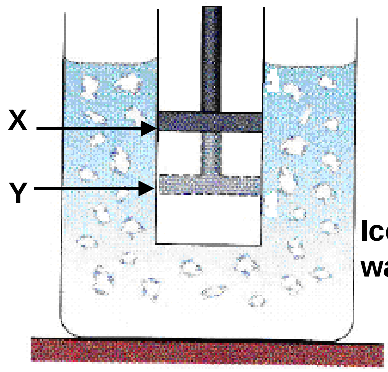

Figure 6.2

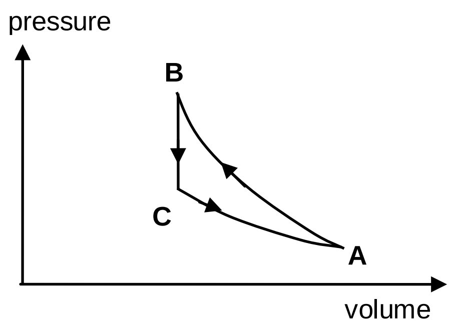

Figure 6.3

1. The first law of thermodynamics can be expressed as

$$\Delta U = Q + W,$$

where ΔU is the increase in internal energy, Q is the heat supplied and W is the work done on the system.

Complete the following table. Use '+' to indicate a positive change in the quantity, a '–' to indicate a negative change in the quantity and '0' to indicate no change in the quantity.

	ΔU	Q	W
A→ B:			
B→ C:			
C→ A:			
Entire Cycle			

[4]

2. The cycle is repeated many times. If 2.00 g of ice is melted by this action, calculate the total work done on the gas. Show your working clearly. Take the specific latent heat of fusion of ice to be 3.36×10^5 J kg^{-1}.

work done on gas = ___________ J [3]

7 (a) Two transverse waves, P and Q, of equal frequency, have intensities I and $0.64I$ respectively. Wave P has amplitude A. Waves P and Q interfere to form an interference pattern.

(i) State two necessary conditions for the waves to produce an observable interference pattern.

____

____

____ [2]

(ii) Determine, in terms of I, the maximum intensity of the interference pattern.

maximum intensity = ____________ [3]

(b) Figure 7.1 shows two loudspeakers S_1 and S_2 placed in an open field on a still day. Their separation is 3.81 m. D is a microphone placed in the same horizontal plane as the loudspeakers, and at a distance of 10.0 m from S_1. The lines S_1S_2 and S_1D are perpendicular to each other. When the speakers are switched on, sound of frequency f = 1650 Hz is emitted in phase. Assume the loudspeakers and microphone are point objects.

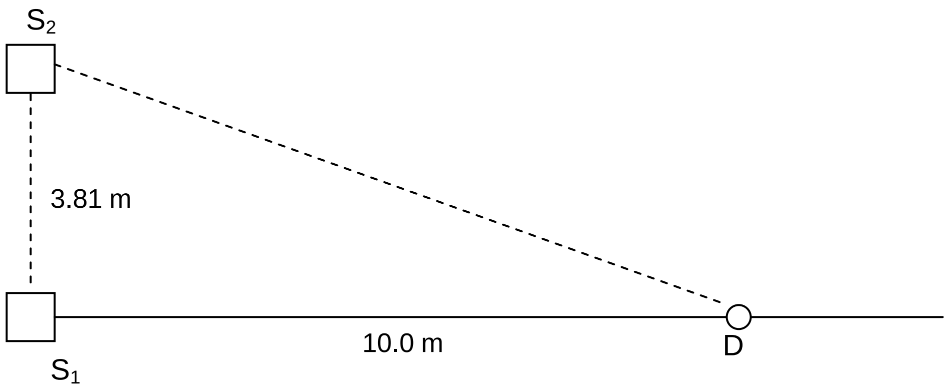

Figure 7.1

(i) Given that the speed of sound in air is 330 m s^{-1}, calculate the wavelength of the sound emitted.

wavelength = ______________ m [2]

(ii) Calculate the distance S_2D.

S_2D = ______________ m [1]

(iii) 1. Determine the phase difference between the sound waves reaching D from S_1 and S_2.

Phase difference = _________ rad

2. Hence explain whether a minimum of intensity or a maximum of intensity would be detected by D.

____

____ [3]

(iv) When the frequency of the sound was slowly increased to a value f_1, the microphone D detected *three* cycles of change in intensity. Calculate f_1.

f_1 = ____________________ Hz [3]

(c) Figure 7.2 shows the energy level diagram of a three-level laser. Lasing takes place between E_2 and E_1.

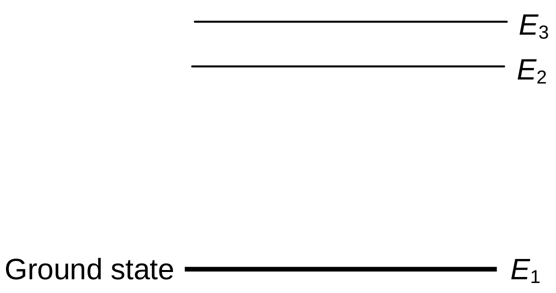

Figure 7.2

(i) State the unique characteristic of energy level E_2 that is important in the operation of this laser.

____

____ [1]

(ii) Explain the general action of the laser represented by Figure 7.2 in terms of *population inversion* and *stimulated emission*.

____

____

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____ [4]

(iii) Figure 7.3 shows the energy level diagram of a four-level laser. Lasing takes place between E_3 and E_2.

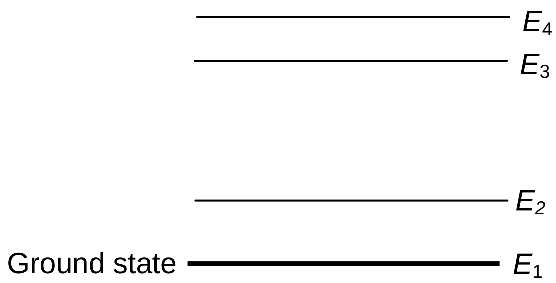

Figure 7.3

What is the advantage of the four-level laser over the three-level laser?

____

____ [1]

8 (a) The radioactive isotope of Bismuth, $^{210}_{83}\text{Bi}$ decays into Polonium (chemical symbol: Po) with the emission of a beta particle.

(i) What is a beta particle?

____

____ [1]

(ii) Write down the equation representing the beta decay of $^{210}_{83}\text{Bi}$.

____ [1]

(iii) State two quantities that are conserved in any radioactive decay process.

____

____ [2]

(iv) The mass of a $^{210}_{83}\text{Bi}$ nucleus is 209.939 u. Show that its mass defect is 1.767 u. (mass of proton, m_p = 1.00729 u; mass of neutron, m_n = 1.00867 u)

[2]

(v) Hence calculate the binding energy, in MeV, of $^{210}_{83}\text{Bi}$.

binding energy = _______________ MeV [2]

(b) James Chadwick, in some experiments conducted prior to World War I, used a Geiger Counter to study beta particles emitted from a source and deflected by a uniform magnetic field. He found that the beta particles had a wide range of radii of curvature in the field, indicating that the beta particles were emitted with a distribution of energies rather than with a distinct single value of energy.

Figure 8.1 shows the energy spectrum for beta particles emitted during the decay of Bi-210. The intensity (vertical axis) indicates the number of beta particles emitted with each particular kinetic energy (horizontal axis).

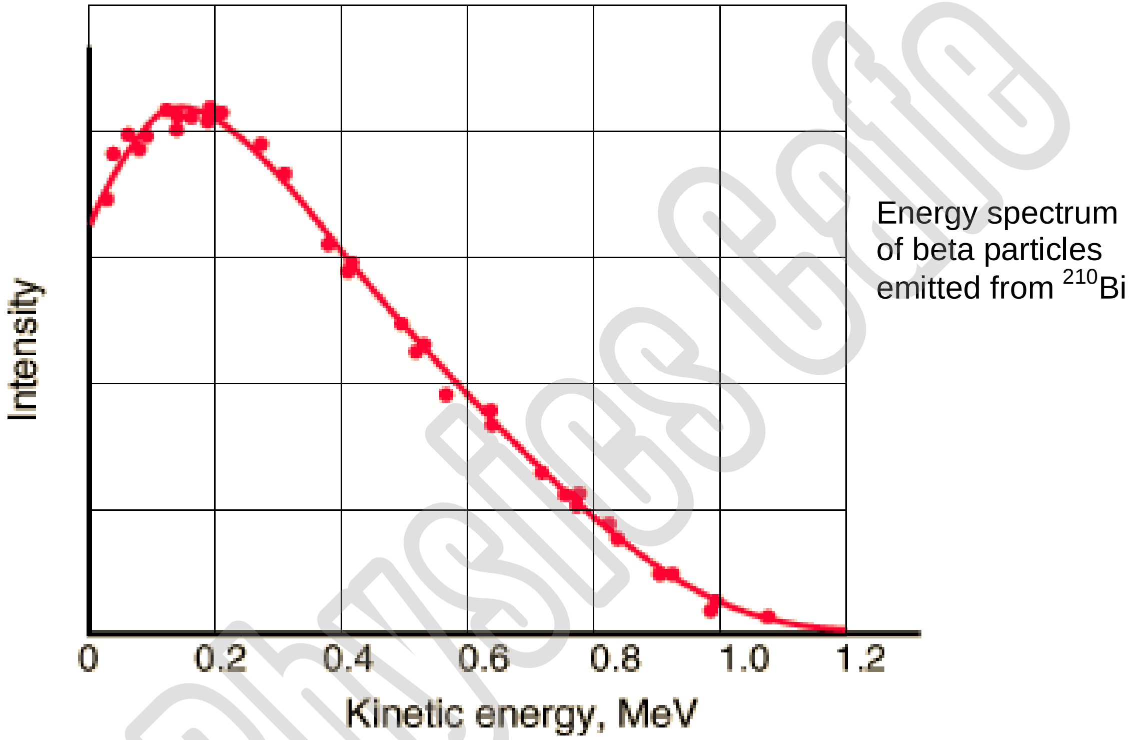

Figure 8.1

(i) 1. Determine, from Figure 8.1 above, Q, the maximum possible energy of the beta particle emitted from $^{210}_{83}\text{Bi}$.

Q = _______________ MeV [1]

2. Hence calculate the velocity of the beta particle.

Comment on the value you obtained.

____

____ [2]

3. Using values in (b)(i)1. and (a)(iv), determine the mass of the resultant Polonium nucleus, in units of u, and express your answer to 3 decimal places.

mass = ______________ u [3]

(ii) From Figure 8.1, identify the most probable energy value for the beta particle to be detected with.

most probable energy value = _____________ MeV [1]

(iii) It is noted that for stable isotopes of heavy elements, there is an optimal neutron to proton ratio. Unstable isotopes of a particular element will undergo radioactive decay in order to achieve this optimal ratio. Suggest, with a reason, whether ${}^{210}_{83}\text{Bi}$ has an excess of neutrons or protons, as compared to the optimal ratio.

____

____

____

____ [2]

(iv) The continuous spectrum of kinetic energy values of the beta particle presented a problem to early physicists.

Consider a stationary nucleus decaying into a beta particle and the daughter nucleus, and assume the daughter nucleus is in a stable state that does not emit any gamma particles. By considering the conservation of linear momentum and energy, explain how the continuous spectrum of beta particle energies gave rise to this problem.

____

____

____

____ [2]

(v) Suggest what was hypothesized by physicists to resolve the problem.

____

____ [1]

- End of Paper -