Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2006
Advanced Level Examination

PHYSICS (SPECIFICATION B) **PHB5**
Unit 5 Fields and their Applications

Thursday 22 June 2006 1.30 pm to 3.30 pm

For this paper you must have:
- a calculator
- a ruler

Time allowed: 2 hours

Instructions
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- Answer the questions in the spaces provided.
- Show all your working.
- Do all rough work in this book. Cross through any work you do not want marked.
- *Formulae Sheets* are provided on pages 3 and 4. Detach this perforated page at the start of the examination.
- Pages 15 and 16 are perforated sheets and should be detached from this booklet. Use these sheets to help you to answer Questions 7, 8 and 9.

Information
- The maximum mark for this paper is 100.
- The marks for questions are shown in brackets. 4 of these marks will be awarded for the Quality of Written Communication.
- You are expected to use a calculator where appropriate.
- You are reminded of the need for good English and clear presentation in your answers. Questions 4(b) and 8(a) should be answered in continuous prose. Quality of Written Communication will be assessed in these answers.

For Examiner's Use			
Number	Mark	Number	Mark
1		7	
2		8	
3		9	
4			
5			
6			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

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Answer **all** questions.

1 (a) Radioactive lead–214 changes to lead–206 by a series of decays involving alpha (α) and negative beta (β^-) emissions. Explain clearly how many alpha and beta particles are emitted during this change.

(4 marks)

(b) The *half-life* of lead–214 is 26.8 minutes.

(i) Explain what is meant by half-life.

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(ii) Show that the decay constant of lead–214 is approximately 0.026 minute^{-1}.

(iii) Calculate the **percentage** of the original number of nuclei of lead–214 left in a sample after a period of 90 minutes.

(7 marks)

11

Detach this perforated page at the start of the examination.

Foundation Physics Mechanics Formulae

moment of force $= Fd$

$v = u + at$

$s = ut + \tfrac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \tfrac{1}{2}(u + v)t$

for a spring, $F = k\Delta l$

energy stored in a spring $= \tfrac{1}{2}F\Delta l = \tfrac{1}{2}k(\Delta l)^2$

$T = \dfrac{1}{f}$

Foundation Physics Electricity Formulae

$I = nAvq$

terminal p.d. $= E - Ir$

in series circuit, $R = R_1 + R_2 + R_3 + \ldots\ldots$

in parallel circuit, $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \ldots\ldots$

output voltage across $R_1 = \left(\dfrac{R_1}{R_1 + R_2}\right) \times$ input voltage

Waves and Nuclear Physics Formulae

fringe spacing $= \dfrac{\lambda D}{d}$

single slit diffraction minimum $\sin\theta = \dfrac{\lambda}{b}$

diffraction grating $n\lambda = d\sin\theta$

Doppler shift $\dfrac{\Delta f}{f} = \dfrac{v}{c}$ for $v << c$

Hubble law $v = Hd$

radioactive decay $A = \lambda N$

Properties of Quarks

Type of quark	Charge	Baryon number
up u	$+\tfrac{2}{3}e$	$+\tfrac{1}{3}$
down d	$-\tfrac{1}{3}e$	$+\tfrac{1}{3}$
$\overline{\text{u}}$	$-\tfrac{2}{3}e$	$-\tfrac{1}{3}$
$\overline{\text{d}}$	$+\tfrac{1}{3}e$	$-\tfrac{1}{3}$

Lepton Numbers

Particle	Lepton number L		
	L_e	L_μ	L_τ
e^-	1		
e^+	–1		
ν_e	1		
$\overline{\nu}_e$	–1		
μ^-		1	
μ^+		–1	
ν_μ		1	
$\overline{\nu}_\mu$		–1	
τ^-			1
τ^+			–1
ν_τ			1
$\overline{\nu}_\tau$			–1

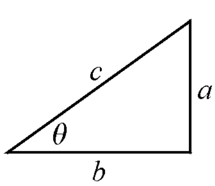
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

area of a circle $= \pi r^2$

surface area of sphere $= 4\pi r^2$

volume of sphere $= \tfrac{4}{3}\pi r^3$



$\sin\theta = \dfrac{a}{c}$

$\cos\theta = \dfrac{b}{c}$

$\tan\theta = \dfrac{a}{b}$

$c^2 = a^2 + b^2$

Detach this perforated page at the start of the examination.

Circular Motion and Oscillations

$$v = r\omega$$

$$a = -(2\pi f)^2 x$$

$$x = A\cos 2\pi ft$$

$$\text{maximum } a = (2\pi f)^2 A$$

$$\text{maximum } v = 2\pi fA$$

$$\text{for a mass-spring system, } T = 2\pi\sqrt{\frac{m}{k}}$$

$$\text{for a simple pendulum, } T = 2\pi\sqrt{\frac{l}{g}}$$

Fields and their Applications

$$\text{uniform electric field strength, } E = \frac{V}{d} = \frac{F}{Q}$$

$$\text{for a radial field, } E = \frac{kQ}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

$$g = \frac{F}{m}$$

$$g = \frac{GM}{r^2}$$

$$\text{for point masses, } \Delta E_p = GM_1M_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{for point charges, } \Delta E_p = kQ_1Q_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{for a straight wire, } F = BIl$$

$$\text{for a moving charge, } F = BQv$$

$$\phi = BA$$

$$\text{induced emf} = \frac{\Delta(N\phi)}{t}$$

$$E = mc^2$$

Temperature and Molecular Kinetic Theory

$$T/\mathrm{K} = \frac{(pV)_T}{(pV)_{tr}} \times 273.16$$

$$pV = \tfrac{1}{3} Nm\langle c^2 \rangle$$

$$\text{energy of a molecule} = \tfrac{3}{2}kT$$

Heating and Working

$$\Delta U = Q + W$$

$$Q = mc\Delta\theta$$

$$Q = ml$$

$$P = Fv$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{power input}}$$

$$\text{work done on gas} = p\Delta V$$

$$\text{work done on a solid} = \tfrac{1}{2}F\Delta l$$

$$\text{stress} = \frac{F}{A}$$

$$\text{strain} = \frac{\Delta l}{l}$$

$$\text{Young modulus} = \frac{\text{stress}}{\text{strain}}$$

Capacitance and Exponential Change

$$\text{in series, } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\text{in parallel, } C = C_1 + C_2$$

$$\text{energy stored by capacitor} = \tfrac{1}{2}QV$$

$$\text{parallel plate capacitance, } C = \frac{\varepsilon_0\varepsilon_r A}{d}$$

$$Q = Q_0 e^{-t/RC}$$

$$\text{time constant} = RC$$

$$\text{time to halve} = 0.69\,RC$$

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

$$A = A_0 e^{-\lambda t}$$

$$\text{half-life, } t_{\frac{1}{2}} = \frac{0.69}{\lambda}$$

Momentum and Quantum Phenomena

$$Ft = \Delta(mv)$$

$$E = hf$$

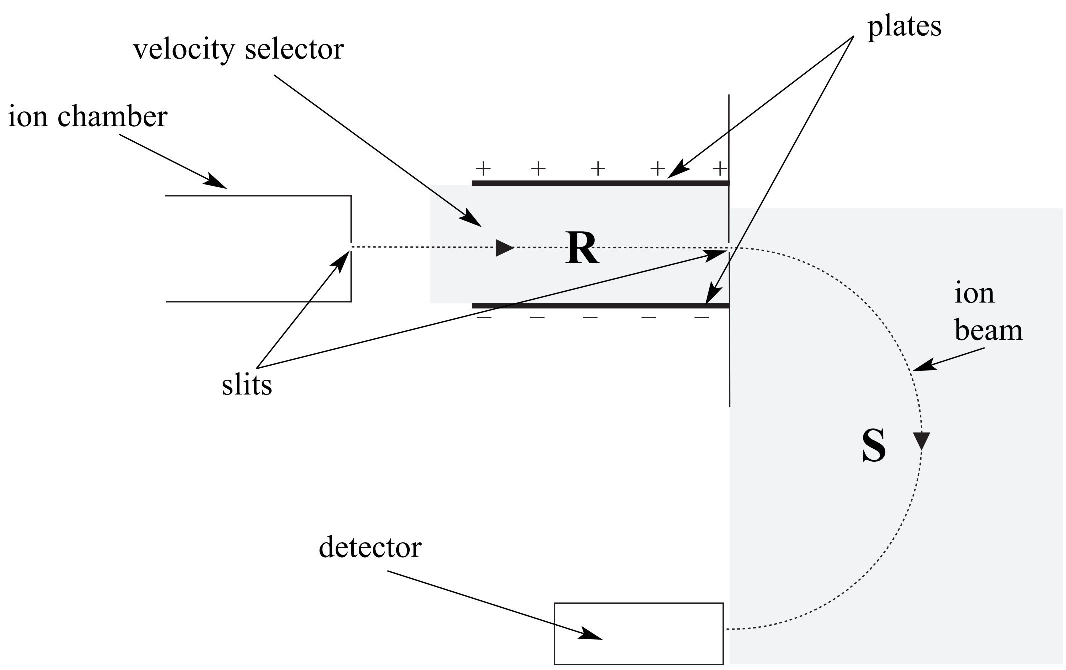
$$hf = \Phi + E_{k(max)}$$

$$hf = E_2 - E_1$$

$$\lambda = \frac{h}{mv}$$

2 **Figure 1** shows the main components of a mass spectrometer.

Figure 1



(a) Clearly mark on **Figure 1** the shape and direction of the electric field between the plates in the velocity selector. *(2 marks)*

(b) Suggest the purpose of the two slits.

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(1 mark)

(c) In shaded regions **R** and **S**, uniform magnetic fields are applied so that the beam of positive ions is undeflected in **R** and then deflected into a circular path in **S**.

(i) Clearly state the directions of the magnetic fields in regions **R** and **S**.

region **R** .... region **S** ....

Question 2 continues on the next page

(ii) Using appropriate equations, explain why **positive** ions passing through the second slit have the same velocity whatever their mass.

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(iii) Explain what happens to ions that move more slowly than the ones passing through the second slit.

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(10 marks)

(d) An ion with a charge of $+3.2 \times 10^{-19}$ C leaves the second slit with a velocity of $3.0 \times 10^{6}\ \mathrm{m\,s^{-1}}$. The mass of the ion is 2.59×10^{-25} kg and the magnetic flux density in region **S** is 2.40 T.
Calculate the radius of its path.

(4 marks)

17

3 (a) (i) Explain what is meant by the *gravitational field strength* at a point in a gravitational field.

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(ii) State the SI unit of gravitational field strength.

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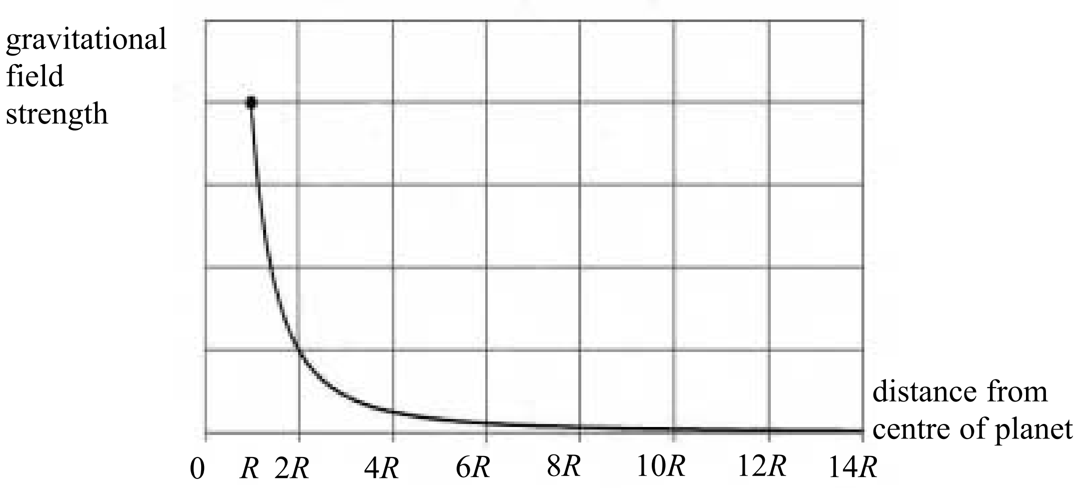
(2 marks)

(b) Planet **P** has mass M and radius R. Planet **Q** has a radius $3R$. The values of the gravitational field strengths at the surfaces of **P** and **Q** are the same.

(i) Determine the mass of **Q** in terms of M.

(ii) **Figure 2** shows how the gravitational field strength above the surface of planet **P** varies with distance from its centre.
Draw on **Figure 2** the variation of the gravitational field strength above the surface of **Q** over the range shown.

Figure 2



(6 marks)

8

4 (a) A transformer, operating from 230 V, supplies a 12 V garden lighting system consisting of 8 lamps. Each lamp is rated at 30 W and they are connected in parallel.

(i) The primary coil of the transformer has 3000 turns. Calculate the number of turns on the secondary coil.

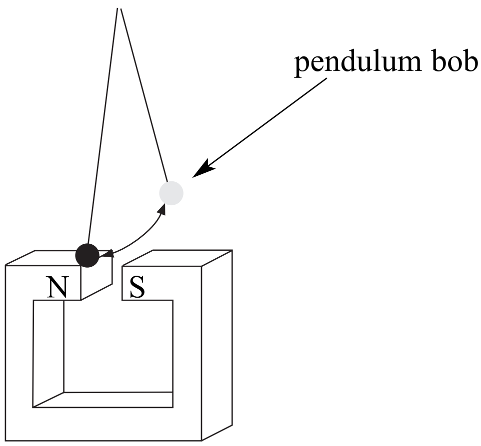
(ii) Show that the total resistance of the lamps when they are working at normal brightness is 0.60 Ω.

(iii) Calculate the power input to the transformer, assuming that the transformer is perfectly efficient.

(8 marks)

(b) **Figure 3** shows a brass pendulum bob swinging through the magnetic field above a strong magnet. Its oscillations are observed to be quite heavily damped.

Figure 3



Explain, using the principles of electromagnetic induction, why this pendulum is heavily damped.
Two of the 6 marks are available for the quality of your written communication.

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(6 marks)

5 A scanning photometer is a device in which the voltage across an LDR (light dependent resistor) varies with the light intensity incident on the LDR.

(a) Draw a circuit diagram showing suitable components which would allow an LDR to be used in this way.

(2 marks)

(b) **Figure 4** shows a laser beam of wavelength 633 nm incidental normally on a diffraction grating. The LDR of a scanning photometer is moved across the diffracted beam and produces the scan shown in **Figure 5**. This shows the central bright fringe with one further maximum (the first order image) on each side of it. The distance from the diffraction grating to the LDR is 265 mm.

Figure 4

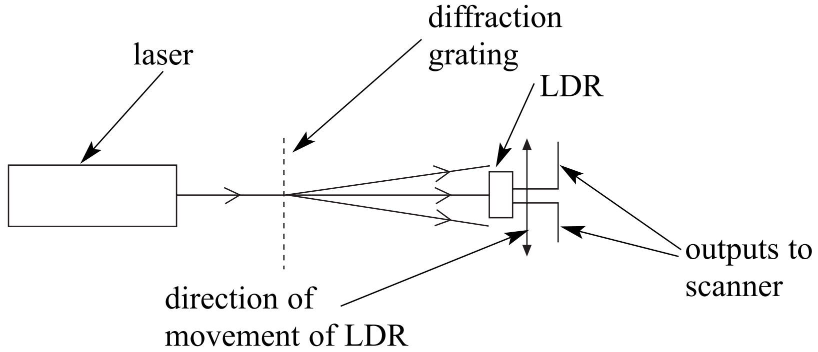

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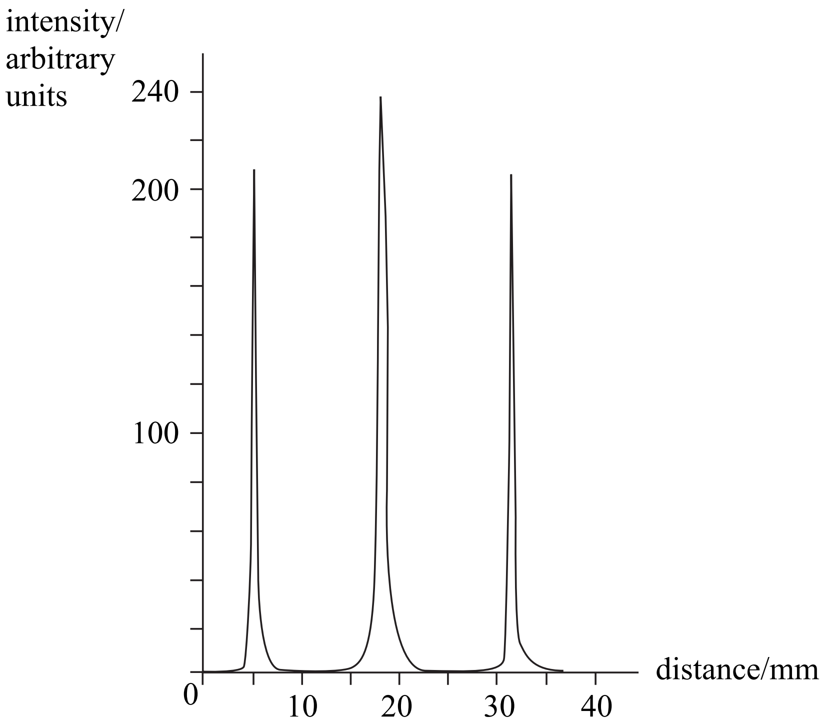
Figure 5



(i) Show that the angle of the first order image measured from the straight through position is approximately 3°.

(ii) Calculate the number of lines per mm on the diffraction grating.

(6 marks)

8

6 (a) (i) Explain why, despite the electrostatic repulsion between protons, the nuclei of most atoms of low nucleon number are stable.

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(ii) Suggest why stable nuclei of higher nucleon number have greater numbers of neutrons than protons.

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(iii) All nuclei have approximately the same density. State and explain what this suggests about the nature of the strong nuclear force.

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(6 marks)

(b) (i) Compare the electrostatic repulsion and the gravitational attraction between a pair of protons the centres of which are separated by 1.2×10^{-15} m.

proton charge	=	1.6×10^{-19} C
proton mass	=	1.7×10^{-27} kg
gravitational constant	=	6.7×10^{-11} N m^2 kg^{-2}
permittivity of free space	=	8.9×10^{-12} F m^{-1}

(ii) Comment on the relative roles of gravitational attraction and electrostatic repulsion in nuclear structure.

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(5 marks)

11

Turn over for the next question

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The passage printed on pages 15 and 16 is for answering Questions 7, 8 and 9.
Detach these pages and read the passage before answering Questions 7, 8 and 9.

7 (a) Explain what is meant by the term continuous X-ray spectrum (lines 4 and 5).

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(1 mark)

(b) Use the data from **Figure 6** to find the ratio of the relative intensities of the 0.04 nm wavelength X-rays when the X-ray tube operates at 40 kV and 50 kV.

(2 marks)

(c) (i) Estimate the highest frequency of the X-rays emitted by the tube used to produce the 40 kV spectrum shown in **Figure 6**.

speed of electromagnetic waves in vacuum = $3.0 \times 10^{8}\ \mathrm{m\,s^{-1}}$

(ii) Calculate the maximum velocity of the electrons when this tube operates at 40 kV. You should assume the electron mass remains 9.1×10^{-31} kg throughout its acceleration.

electron charge = -1.6×10^{-19} C

(6 marks)

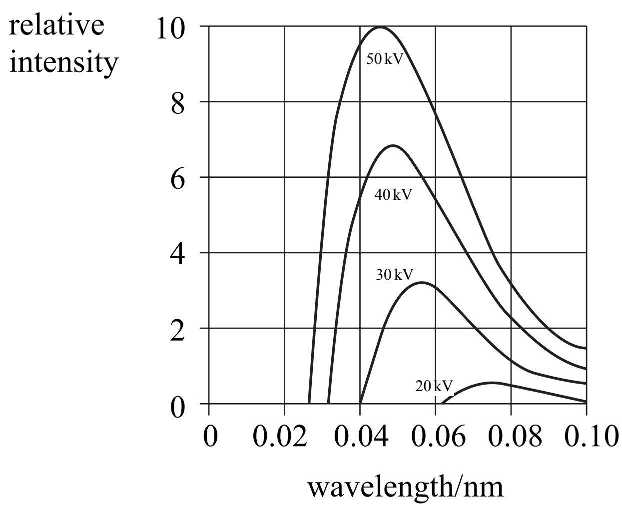
9

X-rays

Spectra

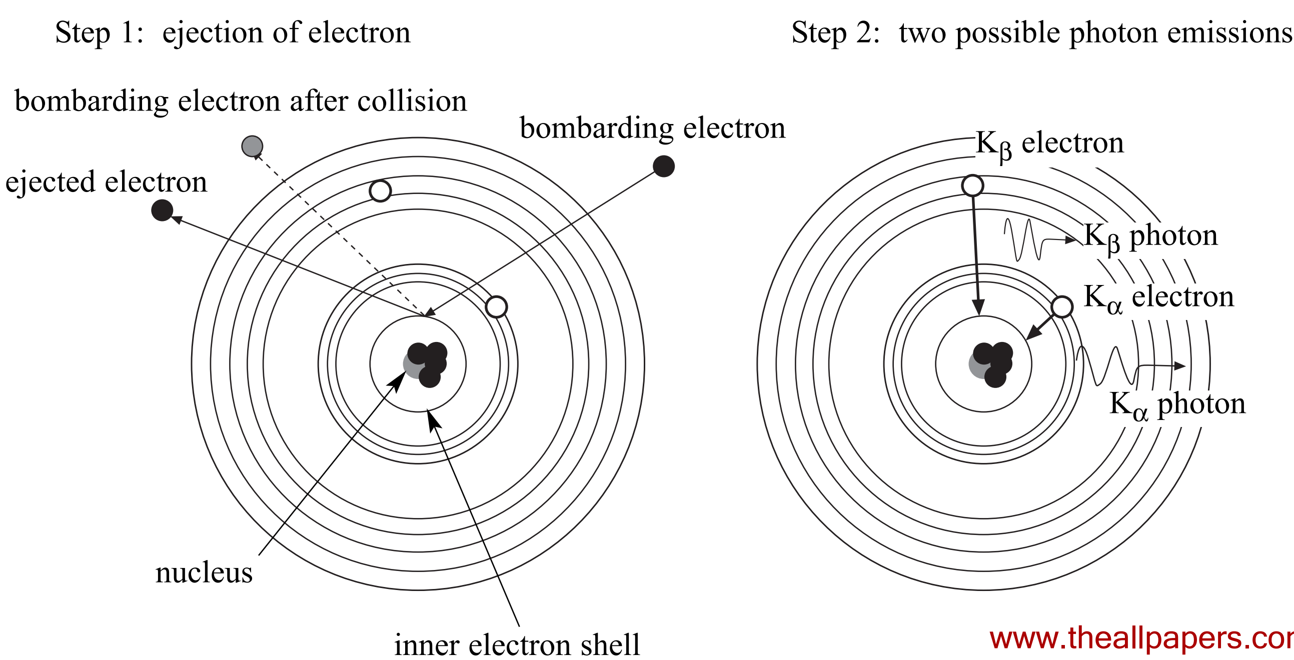
X-rays are the highly penetrating, high frequency electromagnetic radiation produced when high energy electrons strike a heavy metal target. This radiation is produced when the electrons are rapidly decelerated as they collide with the heavy metal target and is called *bremsstrahlung* radiation, which means *braking* radiation. Such collisions cause the emission of a continuous X-ray spectrum with relative intensity which depends on the initial kinetic energy of the colliding electrons. Electrons with higher initial kinetic energy produce spectra with shorter minimum wavelengths. **Figure 6** shows examples of the spectra produced when different potential differences are used to accelerate the electrons towards the target in an X-ray tube.

Figure 6



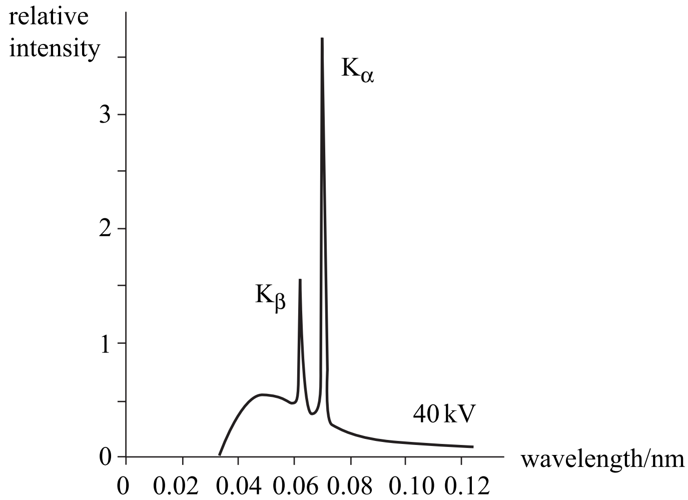
X-rays are also produced when bombarding electrons cause the innermost electrons of the target material to be ejected from their parent atoms. This allows an electron in a high energy level to make a transition to this now empty lower energy level. **Figure 7** illustrates this effect.

Figure 7



The energy difference between the levels is equal to the energy of the emitted X-ray photon. X-rays produced in this way have definite energies producing spectra similar to the visible line spectra resulting from energy-level transitions by an atom's outer electrons. These are called characteristic X-rays since they have energies determined by the atomic energy levels in the target atom. **Figure 8** shows two characteristic lines labelled K_α and K_β, which are superimposed on a continuous spectrum.

Figure 8



X-ray tubes

Figure 9

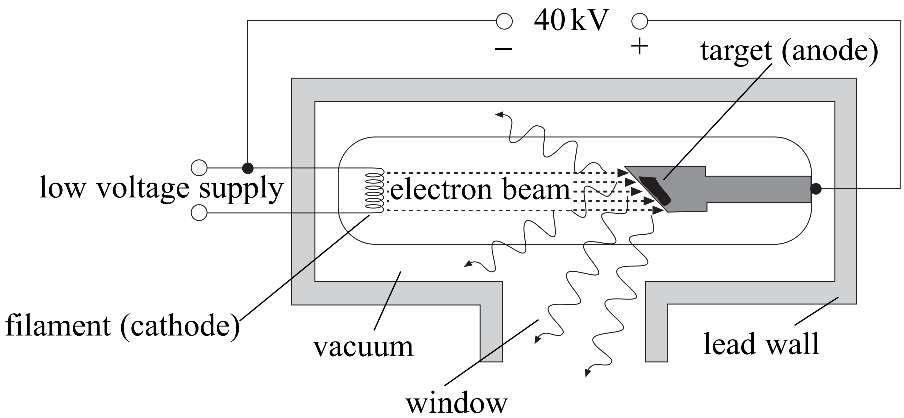


Figure 9 shows a typical X-ray tube. A tungsten filament at one end is heated to around 2000 °C; this causes it to emit electrons through the process called *thermionic emission*. These electrons are accelerated by a large potential difference, applied between the anode and the cathode. This pd ranges from a few kV to several MV, depending on the intended application of the X-rays. The accelerated electrons bombard a metal target (anode). The target is made of tungsten embedded in a comparatively massive copper heat sink. Some X-rays emerge through the window of the tube.

With a heated cathode in a high vacuum tube, the electron current between the cathode and the anode may be controlled simply by varying the filament temperature. Then, by varying the voltage across the tube, the penetrating power of the X-rays may be adjusted to produce a wavelength suitable for use in the chosen application. Thus penetrating power and intensity may be controlled independently. More than 99% of the electrons' energy is converted to internal energy in the target. This energy must be transferred to the surroundings or else the target would melt. To keep the anode cool, water may be circulated through the tubes embedded in the copper heat sink.

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8 (a) Describe the differences and the similarities between the mechanisms that produce characteristic X-ray spectra (see lines 14 and 15) and optical line spectra.
Two of the 6 marks are available for the quality of your written communication.

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(6 marks)

(b) Calculate the difference in the energy levels (in keV) corresponding to the K_α line shown on **Figure 8**.

speed of electromagnetic waves in vacuum	$= 3.0 \times 10^{8}\ \mathrm{m\,s^{-1}}$
electron charge	$= -1.6 \times 10^{-19}\ \mathrm{C}$
Planck constant	$= 6.6 \times 10^{-34}\ \mathrm{J\,s}$

(3 marks)

9 (a) The X-ray tube shown in **Figure 9** is evacuated and surrounded by a lead wall. Explain the reasons for each of these features.

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(4 marks)

(b) (i) The electron beam current in the X-ray tube is 1.50 mA. Show that the maximum power supplied to the target is 60.0 W.

(ii) For a tube in which 99 % of the energy of the incident electrons is converted into internal energy of the target, calculate the amount of energy that must be removed from the target per second.

(iii) The maximum temperature increase allowed for the cooling water is 60 K. Calculate the rate of flow of the water in order to remove the energy at the required rate.

specific heat capacity of water = $4.20 \times 10^3\ \mathrm{J\,kg^{-1}\,K^{-1}}$

(5 marks)

(c) (i) The anode-cathode separation in the small X-ray tube, shown in **Figure 9**, is 72 mm.
Show that the electric field strength is approximately $5.6 \times 10^5\ \mathrm{V\,m^{-1}}$, assuming it to be uniform.

(ii) Calculate the force acting on each electron as it is accelerated by the field.

electron charge = -1.6×10^{-19} C

(4 marks)

13

END OF QUESTIONS

There are no questions printed on this page