Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2004
Advanced Level Examination

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

Friday 30 January 2004 Afternoon Session

In addition to this paper you will require:
- 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 in the spaces provided.
- Do all rough work in this book. Cross through any work you do not want marked.
- All working must be shown, otherwise you may lose marks.
- A *Formulae Sheet* is provided on pages 3 and 4. Detach this perforated page at the start of the examination.
- Pages 13 and 14 are perforated sheets and should be detached from this booklet. Use this sheet to help you to answer questions 5, 6, 7 and 8.

Information
- The maximum mark for this paper is 100.
- Mark allocations are shown in brackets.
- Marks are awarded for units in addition to correct numerical answers and for the use of appropriate numbers of significant figures.
- You will be expected to use a calculator where appropriate.
- You will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary where appropriate.
- The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.

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

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Answer **all** questions in the spaces provided.

Total for this question: ***10 marks***

1 (a) Explain what is meant by the term *magnetic flux linkage*. State its unit.

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(2 marks)

(b) Explain, in terms of electromagnetic induction, how a transformer may be used to step down voltage.

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(4 marks)

(c) A minidisc player is provided with a mains adapter. The adapter uses a transformer with a turns ratio of 15:1 to step down the mains voltage from 230 V.

(i) Calculate the output voltage of the transformer.

(2 marks)

(ii) State **two** reasons why the transformer may be less than 100% efficient.

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(2 marks)

10

Detach this perforated page at the start of the examination.

Foundation Physics Mechanics Formulae

moment of force $= Fd$

$v = u + at$

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

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

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

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

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

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

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, $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots$

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

Waves and Nuclear Physics Formulae

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

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

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

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

Hubble law $v = Hd$

radioactive decay $A = \lambda N$

Properties of Quarks

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

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

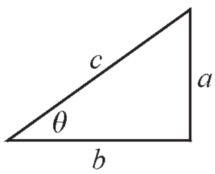
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

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

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

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



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

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

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

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

Turn over

Detach this perforated page at the start of the examination.

Circular Motion and Oscillations

$$v = r\omega$$

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

$$x = A \cos 2\pi f t$$

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

$$\text{maximum } v = 2\pi f A$$

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

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

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

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

$$\text{in parallel, } C = C_1 + \mathrm{C}_2$$

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

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

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

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

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

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

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

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

Momentum and Quantum Phenomena

$$Ft = \Delta(mv)$$

$$E = hf$$

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

$$hf = E_2 - E_1$$

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

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Total for this question: ***20 marks***

2 **Figure 1** shows the general relationship between the nuclear binding energy per nucleon (B) and nucleon number (A).

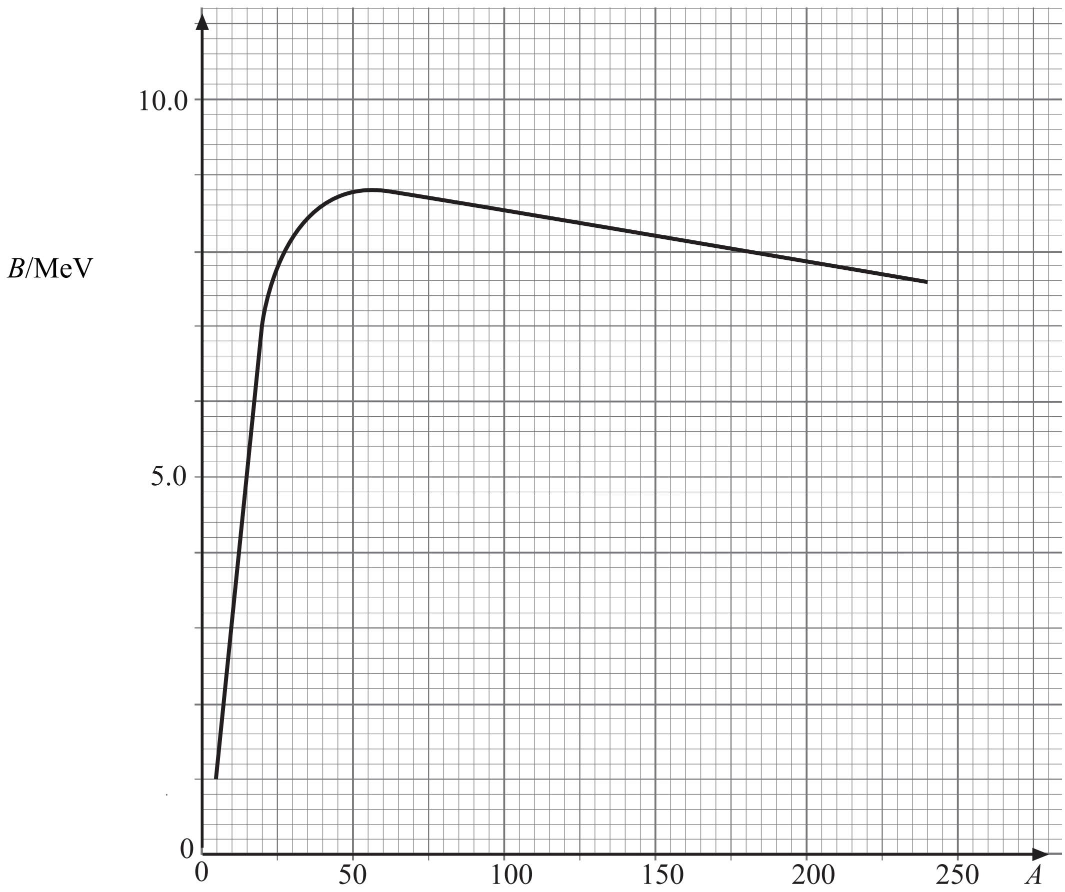

Figure 1

(a) (i) Mark **Figure 1** with the letter **S** to show the nucleon number and the nuclear binding energy per nucleon for the nuclide with the most stable nuclear structure.

(1 mark)

(ii) Write down the nucleon number and the nuclear binding energy per nucleon for this nuclide.

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(1 mark)

(iii) Calculate the total binding energy of this nuclide.

(1 mark)

QUESTION 2 CONTINUES ON THE NEXT PAGE

Turn over

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(b) A fusion reaction in which two protons combine to form a deuterium nucleus is summarised by the equation:

$$^{1}_{1}H + ^{1}_{1}H \longrightarrow ^{2}_{1}H + ^{0}_{1}e + \nu + 1.44\,\text{MeV}$$

(i) State what the following symbols represent.

$^{0}_{1}e$...

ν ....

(2 marks)

(ii) By considering charge, baryon number and lepton number for each side of the equation show that this reaction satisfies the conservation laws for these quantities.

(3 marks)

(iii) The protons in this reaction may need to be at a temperature approaching 1 GK in order for this reaction to occur. Explain why such a high temperature may be needed.

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(2 marks)

(iv) Subsequently two γ-ray photons are released, each with an energy of 0.51 MeV. Calculate the wavelength of these photons.

Planck constant = 6.6×10^{-34} J s
charge on an electron = -1.6×10^{-19} C
speed of electromagnetic waves in free space = 3.0×10^{8} m s^{-1}

(3 marks)

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(c) With reference to **Figure 1** explain why the fission of a heavy nucleus is likely to release more energy than when a pair of light nuclei undergo nuclear fusion.

You may wish to sketch the general shape of **Figure 1** in order to aid your explanation.

Two of the 7 marks in this question are available for the quality of your written communication.

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(7 marks)

20

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Total for this question: ***7 marks***

3 For an object, such as a space rocket, to escape from the gravitational attraction of the Earth it must be given an amount of energy equal to the gravitational potential energy that it has on the Earth's surface. The minimum initial vertical velocity at the surface of the Earth that it requires to achieve this is known as the escape velocity.

(a) (i) Write down the equation for the gravitational potential energy of a rocket when it is on the Earth's surface. Take the mass of the Earth to be M, that of the rocket to be m and the radius of the Earth to be R.

(1 mark)

(ii) Show that the escape velocity, v, of the rocket is given by the equation

$$v = \sqrt{\frac{2GM}{R}}\,.$$

(2 marks)

(b) The nominal escape velocity from the Earth is $11.2\,\text{km}\,\text{s}^{-1}$. Calculate a value for the escape velocity from a planet of mass four times that of the Earth and radius twice that of the Earth.

(2 marks)

(c) Explain why the actual escape velocity from the Earth would be greater than the nominal value calculated from the equation given in part (a)(ii).

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(2 marks)

7

Total for this question: ***19 marks***

4 **Figure 2** shows part of a linear accelerator, which accelerates ions along the axis of a line of hollow cylindrical electrodes (**A**-**D**). Alternate electrodes are connected together and an alternating voltage is applied to them such that the ions are accelerated by the electric field in between each adjacent pair of electrodes.

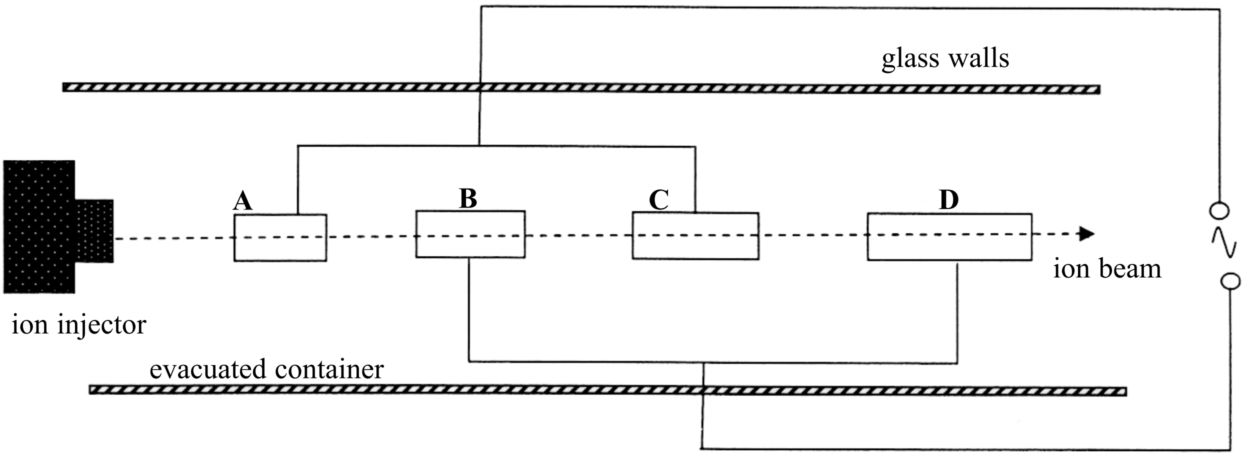
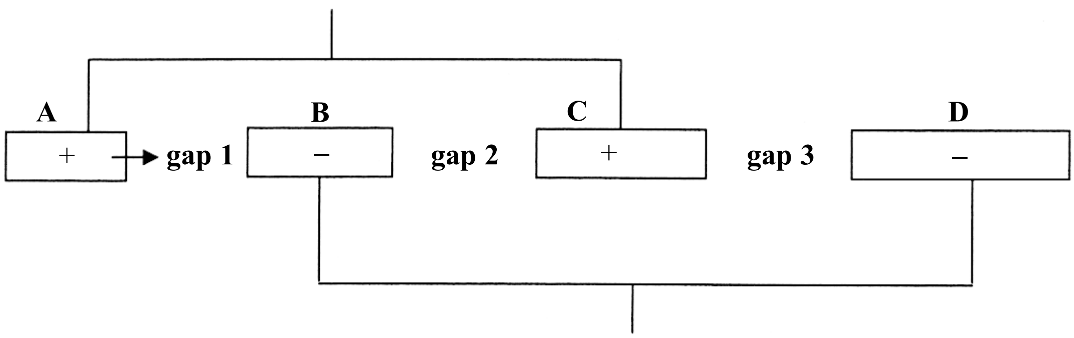


Figure 2

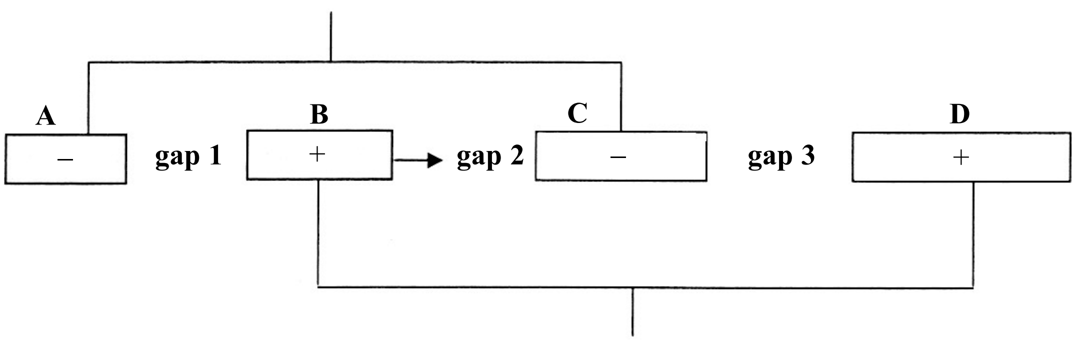
Positive ions are accelerated in the following sequence:

Step 1
The positive ion accelerates across **gap 1** in a very short time when the voltage is at a peak. Electrode **B** is negative with respect to electrode **A**.



Step 2
The ion moves at constant speed in electrode **B** for nearly half a period of the alternating voltage. The polarity of the electrodes reverses whilst the ion is inside **B**.

Step 3
The positive ion emerges from **B** and accelerates across **gap 2** because electrode **C** is now negative with respect to **B**.



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(a) Explain why the ions do not accelerate whilst they are inside the cylindrical electrodes.

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(2 marks)

(b) The following data relates to an experiment using mercury ions (Hg^+):

accelerating voltage between adjacent pairs of electrodes	= 71 kV
frequency of the alternating voltage	= 4.0 MHz
charge on a mercury ion	= 1.6×10^{-19} C
mass of mercury ion	= 3.35×10^{-25} kg

(i) Show that each mercury ion gains kinetic energy of approximately 1.1×10^{-14} J as it accelerates between a pair of electrodes.

(2 marks)

(ii) Ions are injected into electrode **A** with an initial velocity of $2.1 \times 10^5\,\text{m s}^{-1}$. Show that the velocity of a mercury ion as it enters electrode **B** is about $3.3 \times 10^5\,\text{m s}^{-1}$.

(4 marks)

(iii) At each gap ions are accelerated for a time equivalent to 5% of the alternating voltage period. Calculate the force on a mercury ion as it accelerates in **gap 1**.

(4 marks)

QUESTION 4 CONTINUES ON THE NEXT PAGE

Turn over ▶

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(iv) Calculate the electric field strength across **gap 1**. Assume that the electric field is uniform whilst the ion is accelerating.

(2 marks)

(v) Calculate the length of **gap 1**.

(2 marks)

(vi) Calculate the length of electrode **B**.

(3 marks)

19

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*The passage printed on pages 13 and 14 is for answering Questions **5 - 8**.*
*Detach these pages and read the passage before answering Questions **5 - 8**.*

Non-destructive testing of materials

A number of techniques are used to determine whether or not internal or surface defects are present in different structures or specimens of material. Such defects can seriously weaken the material and lead to fatigue or failure when the material is deformed. Fatigue commonly occurs in structures which are subject to repeated loads. It is essential that the means used to determine the flaw affects neither the structure or properties of the sample nor its ability to be used in the manner for which it was designed. Certain techniques offer a range of advantages over other techniques and it is essential that the most appropriate means of detection is used to determine the exact position of any flaw as precisely as possible in order to ensure quality control.

Radiography

X-rays or γ-rays may be used for a range of materials, both metals and non-metals. The absorption of these electromagnetic waves by a material depends upon the thickness of the material in a manner given by the equation:

$$I = I_0 e^{-\alpha x}$$

where I is the intensity after passing through thickness x, I_0 is the intensity of the incident radiation and α is the absorption coefficient of the material. For these waves photoelectric absorption is the major cause of attenuation of the photons penetrating the material. Here the ray gives up its energy in a single interaction with an electron. The electromagnetic waves affect photographic film in the same way as light and so when the sample is positioned between the source of waves and the film the *differential absorption* of the waves reveals the presence of any flaws. Less absorption shows up as a darker image.

Magnetic flux leakage

The magnetic flux leakage principle used with ferromagnetic tubes is illustrated in **Figure 3**.

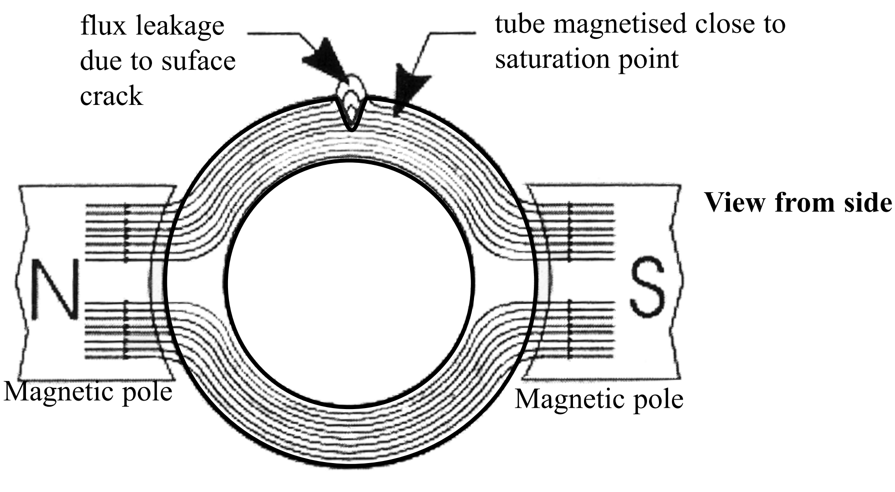

Figure 3

Turn over

In a flux leakage system, permanent magnets or electromagnets are used to *magnetically saturate* the metal tube held between the poles. A sensor is positioned close to the surface of the tube. The tube is moved to enable its whole surface to be scanned by the sensor. The sensor detects any leakage field as a defect passes it.

Figure 4 and **Figure 5** show two perspectives of one of the most common types of magnetic field sensor. This is a semiconductor sensor based on the Hall effect. The sensor consists of a slice of semiconductor through which a current is passed between two contacts (**A** and **B**) on opposite edges of the slice. Two sensing contacts (**C** and **D**) are positioned on the other two edges of the slice, opposite each other, perpendicular to the electron flow. A strong magnetic field perpendicular to the plane of the contacts causes a deviation in the electron flow across the device. This in turn is detected as a potential difference (the Hall p.d.) between contacts **C** and **D**.

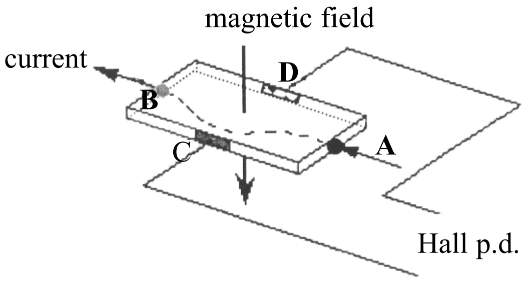

Figure 4

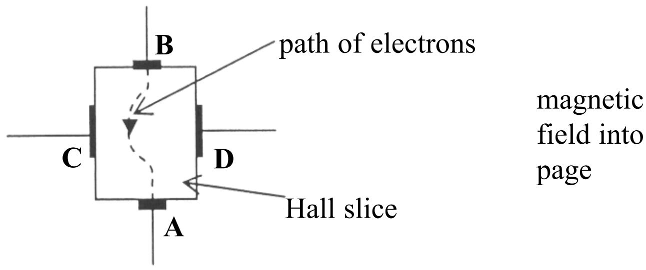

Figure 5

The Hall p.d. is proportional to the magnetic flux density of the field applied to it. Long, continuous defects can be sensed. The main deficiency of a Hall sensor is its temperature dependence.

Ultrasound

This method detects flaws by echo sounding. A short pulse of ultrasound of frequency 3.0 MHz is generated at the surface of the specimen by an oscillating piezo-electric crystal. The pulse travels though the material with very little attenuation. Most of the ultrasound is reflected on reaching the air at a boundary, either at the other side of the specimen or at a defect such as a hole. The piezo-electric crystal receives reflected pulses and generates a voltage, which can be displayed on a cathode ray oscilloscope. Multiple peaks will indicate reflections from flaws or surfaces at different depths in the specimen. The velocity, v, of the pulse in the specimen is related to the Young modulus, E, of the material of the specimen and its density, ρ, by the equation:

$$v = \sqrt{\frac{E}{\rho}}\ .$$

The velocity of ultrasound in steel is around $5.0\,\mathrm{km\,s^{-1}}$.

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*The passage printed on pages 13 and 14 is for answering Questions **5 - 8**.*
*Detach these pages and read the passage before answering Questions **5 - 8**.*

Total for this question: *13 marks*

5 (a) Explain why all methods of non-destructive testing are important both in quality control during manufacture and in testing structures when they are in use.

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(3 marks)

(b) Explain what is meant by *fatigue* and *failure* when a material is deformed (line 3).

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(2 marks)

(c) Suggest a situation for which each technique mentioned in the passage (radiography, magnetic flux leakage and ultrasound) would be the most suitable. In each case explain why the technique is advantageous over other techniques.

Two of the 8 marks in this question are available for the quality of your written communication.

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(8 marks)

13

Turn over

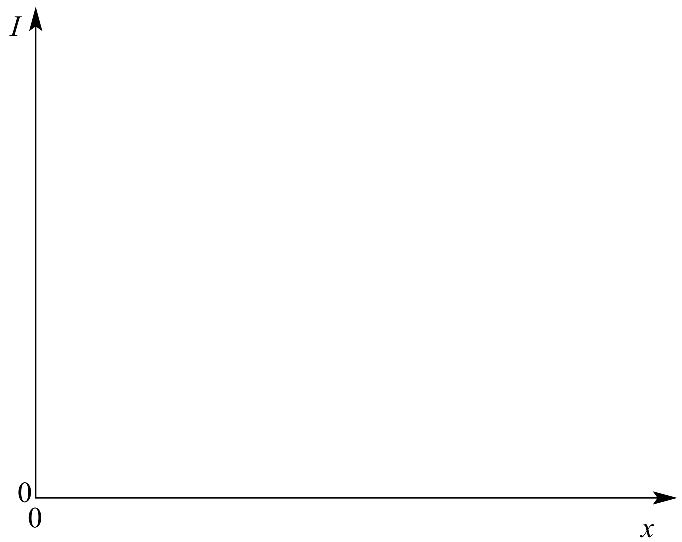
Total for this question: ***11 marks***

6 This question relates to the radiography technique referred to in lines 11 to 21.

(a) (i) State consistent units for the thickness of material, x, and the absorption coefficient α.

(1 mark)

(ii) Using the axes below, sketch a graph to show how the intensity of radiation, I, passing through the material decreases with thickness of the material, starting with an initial intensity, I_0, at depth 0.



(2 marks)

(iii) For one beam of X-rays, the intensity halves when a metal plate of thickness 0.20 m is used. Calculate the absorption coefficient of this metal for these X-rays.

(3 marks)

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(b) One isotope used in this type of radiography is iridium-192. This isotope has a decay constant of $1.1 \times 10^{-7} s^{-1}$.

(i) Show that the half-life of iridium-192 is about 73 days.

(3 marks)

(ii) Suggest why a device using iridium-192 as its source of radiation would need to be recalibrated regularly in order to give accurate results.

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(2 marks)

11

TURN OVER FOR THE NEXT QUESTION

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Total for this question: ***8 marks***

7 This question relates to the magnetic flux leakage technique referred to in lines 22 to 38 in the article.

(a) Suggest what is meant by the metal tube being *magnetically saturated* (line 25).

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(1 mark)

(b) (i) Explain why the presence of the magnetic field causes the electrons to move towards sensing contact **C**.

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(3 marks)

(ii) By reference to balanced electric and magnetic forces, explain why the Hall effect sensor produces a Hall p.d. which increases as the applied magnetic flux density increases (line 36).

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(3 marks)

(c) Explain why it might be difficult to detect cracks which are in the same direction as the lines of magnetic flux.

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(1 mark)

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Total for this question: *12 marks*

8 This question relates to the ultrasound technique referred to in lines 39 to 49 in the article. You should use the data given in the article.

(a) Show that the speed of ultrasound in steel is consistent with steel having a density of about $8 \times 10^3\,kg\,m^{-3}$.

Young modulus for steel = 210 GPa

(2 marks)

(b) (i) Calculate the wavelength of the 3.0 MHz ultrasound.

(1 mark)

(ii) Explain why this value of the wavelength suggests that the minimum flaw size that is detectable using ultrasound of this frequency is of the order of a few millimetres.

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(2 marks)

QUESTION 8 CONTINUES ON THE NEXT PAGE

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(c) **Figure 6** shows a CRO trace, which has been captured in an ultrasound test on a sample of steel.

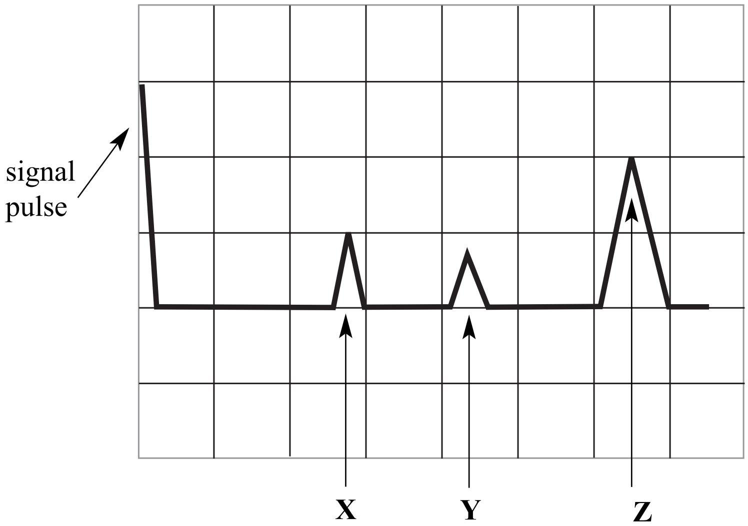

Figure 6

(i) Suggest the most likely causes of each of the peaks **X**, **Y** and **Z**.

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(2 marks)

(ii) The horizontal calibration of the CRO is set at 1 division representing 0.02 ms. Calculate the depth of the cause of peak **Y**.

(3 marks)

(iii) Suggest why peak **Z** is broader than either peak **X** or peak **Y**.

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(2 marks)

12

END OF QUESTIONS