Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2004
Advanced Level Examination

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

Monday 28 June 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.
- *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 this sheet to help you to answer Questions 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: ***12 marks***

1 In a television cathode ray tube, electrons are accelerated through a potential difference of 12 kV in a vacuum before striking the screen.

(a) (i) Calculate the speed of an electron accelerated through this potential difference.

charge on electron = -1.6×10^{-19} C
mass of electron = 9.1×10^{-31} kg

(2 marks)

(ii) The beam current is 25 mA. Calculate the number of electrons that strike the screen in one second.

charge on electron = -1.6×10^{-19} C

(2 marks)

(b) The electron beam is deflected in the television tube by a changing magnetic field produced by currents in coils placed around the tube.

(i) Explain how this changing magnetic field can lead to induction effects in other electrical circuits in the television.

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(2 marks)

(ii) Explain how this changing magnetic field could lead to faults in these other electrical television circuits.

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(1 mark)

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 $= \frac{1}{2}F\Delta l = \frac{1}{2}k(\Delta l)^2$

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

Foundation Physics Electricity Formulae

$I = nAvq$

terminal p.d. $= E - Ir$

in series circuit, $R = R_1 + R_2 + R_3 + ...$

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

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	$+\frac{2}{3}e$	$+\frac{1}{3}$
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

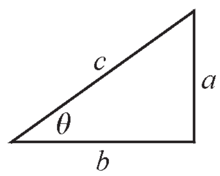
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

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

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

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



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

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

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

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

Turn over

Detach this perforated page at the start of the examination.

Circular Motion and Oscillations

$$v = r\omega$$

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

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

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

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

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

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

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

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

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

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

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

$$Ft = \Delta(mv)$$

$$E = hf$$

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

$$hf = E_2 - E_1$$

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

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(iii) The electron beam is moved from the left-hand side of the screen to the right-hand side by uniformly varying the field from -3.5×10^{-4} T to $+3.5 \times 10^{-4}$ T in a time of 50 µs. Each turn of a 250-turn coil of wire in this changing field has an area of 4.0×10^{-3} m^2.

Calculate the **maximum** emf that can appear in the 250-turn coil.

(3 marks)

(iv) Explain why the answer to part (b)(iii) is a maximum value .

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(2 marks)

12

Turn over

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

2 (a) **Figure 1** shows part of a precipitation system used to collect dust particles in a chimney. It consists of two large parallel vertical plates maintained at potentials of +25 kV and –25 kV. **Figure 1** also shows the electric field lines between the plates.

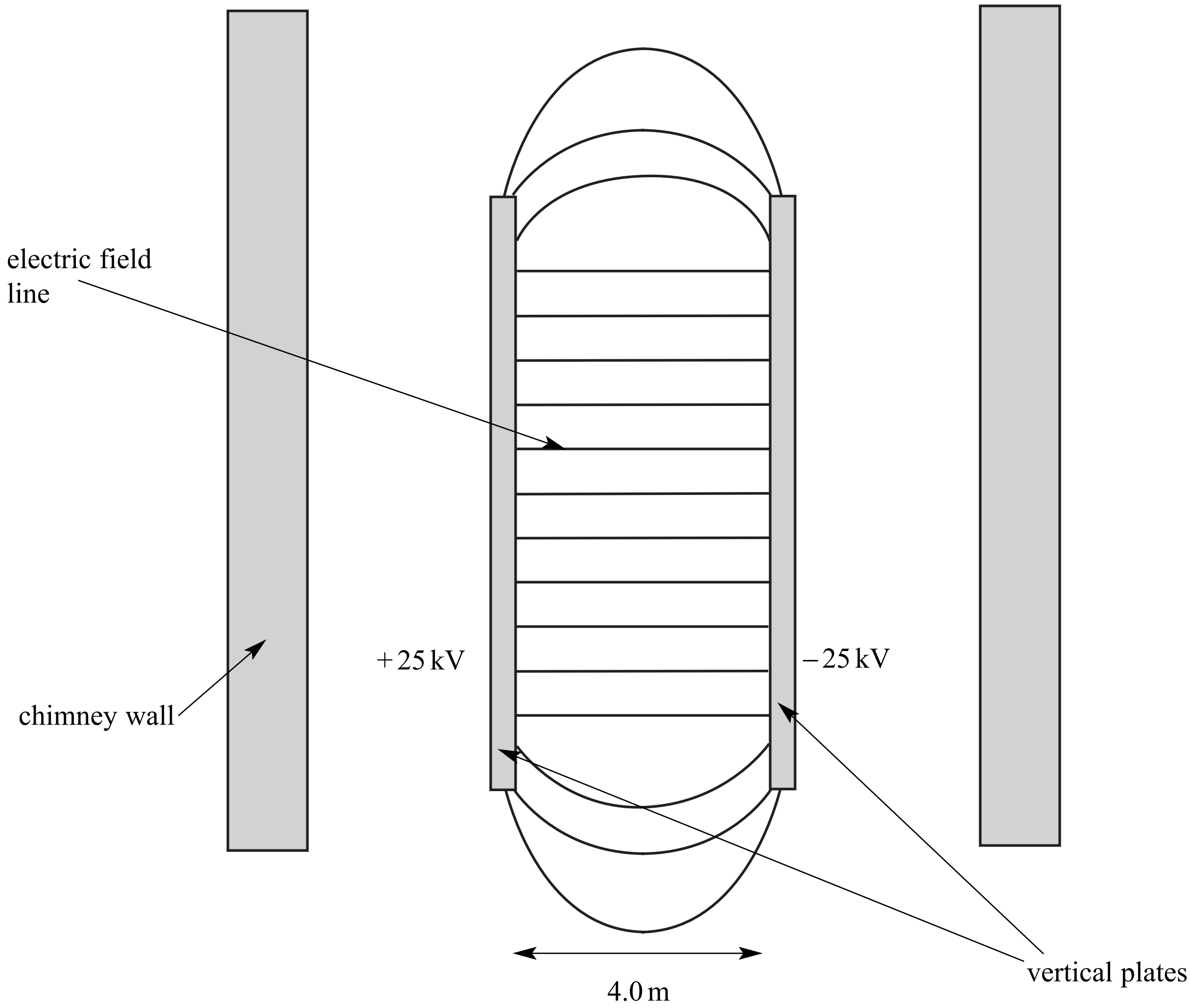

Figure 1

(i) Add arrows to **Figure 1** to show the direction of the electric field. *(1 mark)*

(ii) Explain what is meant by an *equipotential surface*.

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(1 mark)

(iii) Draw and label on **Figure 1** equipotentials that correspond to potentials of –12.5 kV, 0 V, and +12.5 kV.

(2 marks)

(b) A small dust particle moves vertically up the centre of the chimney, midway between the plates.

(i) The charge on the dust particle is +5.5 nC. Show that there is an electrostatic force on the particle of about 0.07 mN.

(2 marks)

(ii) The mass of the dust particle is 1.2×10^{-4} kg and it moves up the centre of the chimney at a constant vertical speed of $0.80\ \mathrm{m\,s^{-1}}$.

Calculate the minimum length of the plates necessary for this particle to strike one of them. Ignore air resistance.

(4 marks)

10

Total for this question: ***12 marks***

3 NASA wishes to recover a satellite, at present stranded on the Moon's surface, and to place it in orbit around the Moon.

(a) (i) **Figure 2** shows a graph of gravitational field strength against distance from the **centre** of the Moon. Mark on the figure the area that corresponds to the energy needed to move 1 kg from the **surface** of the Moon to a vertical height of 4000 km **above the surface**.

radius of the Moon = 1700 km

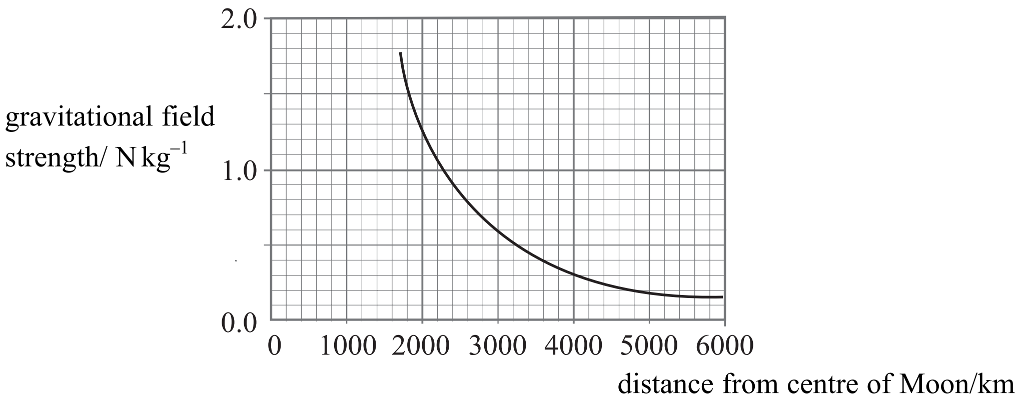

Figure 2

(2 marks)

(ii) The satellite has a mass of 450 kg. Estimate the change in gravitational potential energy of the satellite when it is moved from the surface of the Moon to a vertical height of 4000 km above the surface.

(4 marks)

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(b) NASA now decides to bring the satellite back to Earth. Explain why the amount of fuel required to return the satellite to Earth will be **much** less than the amount required to send it to the Moon originally.

Two of the 6 marks for this question are available for the quality of your written communication.

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(6 marks)

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12

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Total for this question: ***14 marks***

4 A nucleus of plutonium ($^{240}_{94}Pu$) decays to form uranium (U) and an alpha-particle (α).

(a) Complete the equation that describes this decay:

$$^{240}_{94}\text{Pu} \rightarrow$$

(2 marks)

(b) (i) Show that about 1 pJ of energy is released when one nucleus decays.

mass of plutonium nucleus	$= 3.98626 \times 10^{-25}$ kg
mass of uranium nucleus	$= 3.91970 \times 10^{-25}$ kg
mass of alpha particle	$= 6.64251 \times 10^{-27}$ kg
speed of electromagnetic radiation	$= 2.99792 \times 10^{8}$ m s^{-1}

(3 marks)

(ii) The plutonium isotope has a half-life of 2.1×10^{11} s. Show that the decay constant of the plutonium is about 3×10^{-12} s^{-1}.

(2 marks)

(iii) A radioactive source in a school laboratory contains 3.2×10^{21} atoms of plutonium. Calculate the energy that will be released in one second by the decay of the plutonium described in part (b)(i).

(3 marks)

(iv) Comment on whether the energy release due to the plutonium decay is likely to change by more than 5% during 100 years. Support your answer with a calculation.

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(4 marks)

14

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Total for this question: *17 marks*

5 **Figure 3** shows a simple model of a hydrogen atom in which a single electron stationary wave fits the radius of an atom. This model suggests that the electron cannot exist outside this atomic sphere. The atomic radius is 3.0×10^{-10} m.

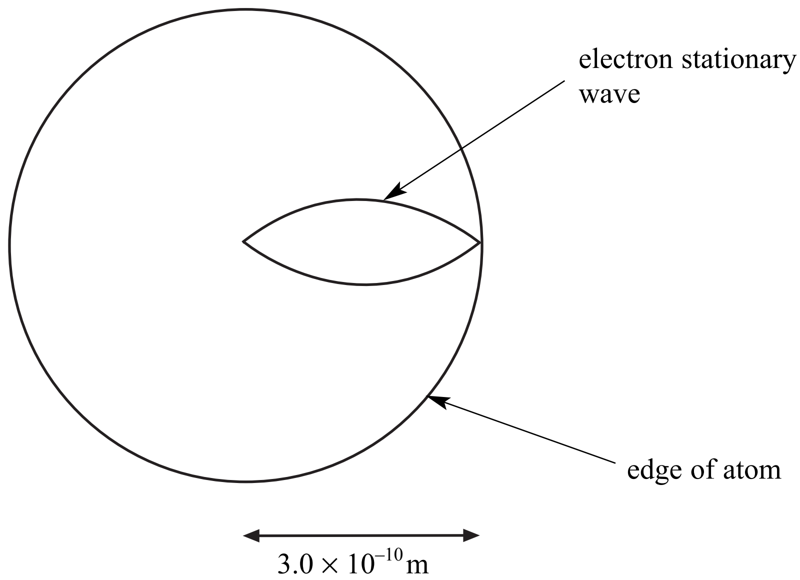

Figure 3

(a) Explain what the electron stationary wave represents and state what you can infer about the location of the electron.

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(3 marks)

(b) (i) Show that the kinetic energy of the electron can be written as

$$\frac{p^2}{2m_e}$$

where p is the momentum and m_e is the mass of the electron.

(1 mark)

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(ii) Show that the kinetic energy of this electron can be written as

$$\frac{h^2}{2m_e\lambda^2}$$

where h is the Planck constant and λ is the wavelength of the electron stationary wave.

(2 marks)

(c) (i) Calculate the kinetic energy of the electron shown in **Figure 3**.

mass of electron $= 9.1 \times 10^{-31}$ kg
Planck constant $= 6.6 \times 10^{-34}$ J s

(3 marks)

(ii) Calculate the potential energy of the electron in a hydrogen atom when it is at a distance of 1.5×10^{-10} m from the proton that forms the nucleus of the atom.

permittivity of free space $= 8.9 \times 10^{-12}$ F m^{-1}

(4 marks)

Turn over

(iii) Hence, calculate the total energy of the electron.

(2 marks)

(iv) State and explain whether this model leads to a stable atom or not.

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(2 marks)

17

The passage for answering questions 6, 7, and 8 is printed on pages 15 and 16. Detach pages 15 and 16 and read the passage before answering the questions.

The moving-coil loudspeaker

In 1925 Rice and Kellogg developed what was to become the most common way to convert electrical energy into sound: the moving-coil loudspeaker. As a device, the structure of a moving-coil loudspeaker is relatively straightforward and robust. It does however have its design problems: one of these is linearity. Linearity is the ability of the system to reproduce all required frequencies and to respond faithfully to all changes in signal amplitude. Unfortunately, loudspeakers are non-linear and the enclosures that house them must be designed with a view to improving the linearity of the frequency response.

Figure 4 shows a diagram of a modern moving-coil loudspeaker. It consists of a large cone, often made of paper, or more recently plastic, firmly attached to a small cylinder. A coil of metal wire (typically, copper) is wound on this cylinder. In turn this coil, known as the voice coil, sits inside a radial magnetic field. The outside edge of the cone is connected to a rigid circular frame via a flexible folded hinge that allows the cone a relatively free motion.

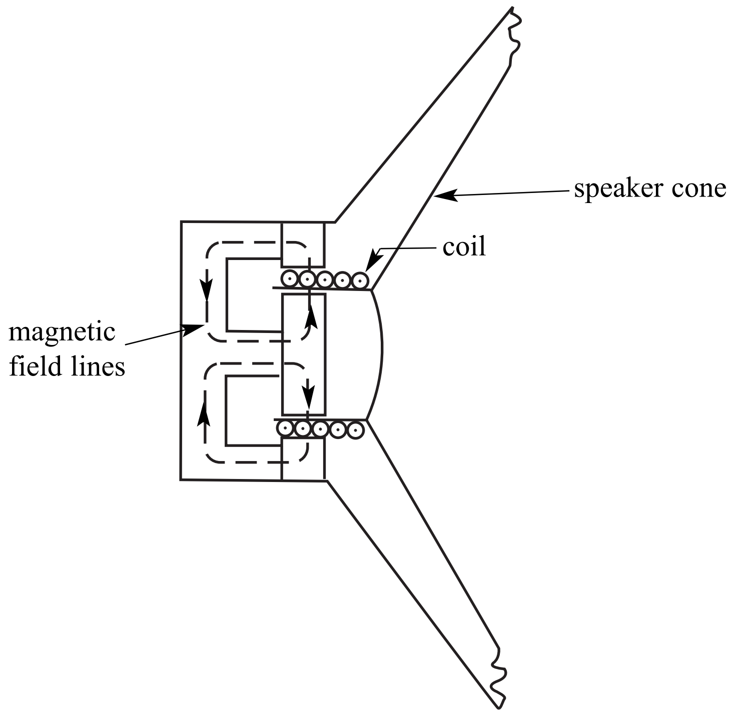

Figure 4

An alternating electric current applied to the coil drives it backwards and forwards, moving the cone too. The relatively large area of the cone (compared to the coil) moves a substantial mass of air leading to the changes in air pressure that we perceive as sound.

Moving-coil loudspeakers can vary enormously in size. Some are large and will radiate hundreds of watts of low-frequency power. Others are much smaller devices with small cones only a few centimetres in diameter that will radiate low audio powers at frequencies towards the upper range of human hearing.

The loudspeakers used in a domestic radio or television will be designed to reproduce most audible frequencies acceptably. Such a speaker typically has a voice coil diameter of 30 mm with 250 turns of wire giving a total d.c. resistance of 8.0 Ω. It might require a current of 50 mA to drive it to its maximum amplitude. The outer diameter of the cone will typically be about 200 mm across and the flux density of the magnetic field will be about 0.70 T.

Turn over ▸

The cone and its coil behave like a mass-spring system and such a system has a resonant frequency. This frequency sets the bottom end of the speaker's useful operating range, it is called the 'bass resonance' and a designer will seek to make this frequency as low as possible. Well above this bass-resonance frequency other effects occur, especially if the loudspeaker is not mounted in an enclosure. Sound diffracts around all objects if the sound wavelength, λ, is larger than the size of the object. Loudspeakers are no exception to this.

The fact that the sound from the back of the speaker travels round to the front might seem to be an advantage as it could add sound energy that is otherwise wasted. However, this is not so, for while the front of the cone is compressing the air, the back of the cone is moving in the opposite direction and the low-frequency sounds are weakened as a result. This is a marked effect and one that is often found in cheaper television sets; the unwanted sound from the back of the cone will be emitted through the many slots that are necessary to cool the interior of the set.

One obvious cure to this problem is to separate the speaker from the television set and to mount it in an enclosure that completely separates the front sound from that emerging from the back. Alternatively, a sealed enclosure with no openings at all can prevent the rear pressure changes from escaping but this has the disadvantage of making the cone-coil-air system stiffer and, for a given coil current, reduces the amplitude of the cone's movement. This means that less sound energy will be radiated.

A much better solution is to make the rear pressure variations useful to the listener. This is the approach taken in the acoustic-labyrinth design shown in **Figure 5**. A long tube inside the speaker delays the sound from the rear of the cone so that it emerges in phase with the forward sound and reinforces it. The wave emitted into the labyrinth is 180° out of phase with the wave going out into the free air at the front of the loudspeaker. The labyrinth length, L, will need to be equal to half a wavelength of the sound in order to introduce the required delay of half a cycle.

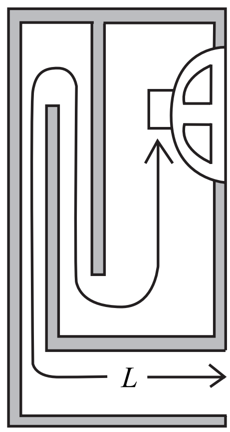

Figure 5

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Total for this question: *19 marks*

6 *The following questions are about the physical properties of the moving-coil loudspeaker in lines 20-24.*

(a) (i) Show that the length of wire in the loudspeaker coil is about 24 m.

(2 marks)

(ii) The voice coil is made of copper wire with a circular cross-section.
Calculate the required diameter of the wire.
resistivity of copper $= 1.7 \times 10^{-8}\,\Omega\,\mathrm{m}$

(4 marks)

(iii) Show that the force acting on the coil when the current is a maximum is about 0.8 N.

(2 marks)

(iv) The effective spring constant of the loudspeaker is $1.2 \times 10^{4}\,\mathrm{N\,m^{-1}}$.

Calculate the displacement of the voice coil that will be produced by the force in part(a)(iii) assuming that the loudspeaker is not mounted in an enclosure.

(3 marks)

Turn over

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(b) (i) The combined mass of the cone and voice coil is 0.050 kg.

Calculate the audio frequency that will produce a maximum amplitude in the cone.

(3 marks)

(ii) The loudspeaker is driven by an alternating current supply that has a constant amplitude but variable frequency.

Sketch a graph showing how you expect the amplitude of the cone's motion to vary with the frequency of the alternating current supply.

(2 marks)

(iii) Explain why the amplitude of the loudspeaker varies with frequency in the way you have shown in part (b)(ii).

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(3 marks)

19

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

7 (a) **Figure 6** shows the magnetic field arrangement and instantaneous current direction in a moving-coil loudspeaker.

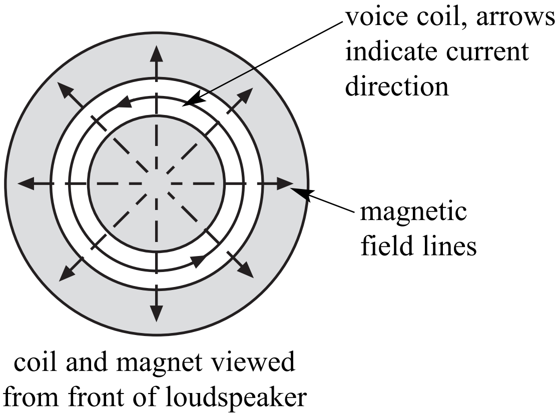

Figure 6

(i) State clearly the direction in which the force acts on the voice coil.

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(1 mark)

(ii) Explain how a current in the voice coil leads to a displacement of the cone in the direction you indicated in part (a)(i).

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(3 marks)

(b) Explain, **in terms of the pressure of the air in the enclosure**, why the cone is more difficult to move when the enclosure is sealed (lines 39-42).

Two of the 6 marks in this question are available for the quality of your written communication.

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(6 marks)

10

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Total for this question: ***6 marks***

8 (a) Explain what is meant by '…*emerges in phase with the forward sound and reinforces it*.' (line 45).

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(3 marks)

(b) **Figure 5** in the passage shows the acoustic-labyrinth arrangement used in some loudspeaker enclosures.

Calculate the shortest labyrinth length L required so that sound of frequency 60 Hz from the rear of the loudspeaker cone emerges in phase with the sound from the front. The speed of sound in the air in the loudspeaker is 340 m s^{-1}.

(3 marks)

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END OF QUESTIONS

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