Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2005
Advanced Level Examination

AQA
ASSESSMENT and QUALIFICATIONS ALLIANCE

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

Tuesday 1 February 2005 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 17 and 18 are perforated sheets and should be detached from this booklet. Use this sheet to help you to answer questions 6 and 7.

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			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

Answer **all** questions

1 **Total for this question:** ***26 marks***

(a) (i) State what is meant by the terms *nuclear binding energy, mass defect* and *strong nuclear force*.

Nuclear binding energy ....

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Mass defect ....

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Strong nuclear force ....

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(3 marks)

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, $R = R_1 + R_2 + R_3 + ...$

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

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	$-\frac{1}{3}e$	$+\frac{1}{3}$
$\bar{u}$	$-\frac{2}{3}e$	$-\frac{1}{3}$
$\bar{d}$	$+\frac{1}{3}e$	$-\frac{1}{3}$

Lepton Numbers

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

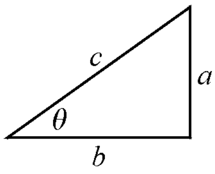
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

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

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

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



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

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

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

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

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

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

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

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

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

$$Ft = \Delta(mv)$$

$$E = hf$$

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

$$hf = E_2 - E_1$$

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

(ii) **Figure 1** shows the variation of binding energy per nucleon with nucleon number.

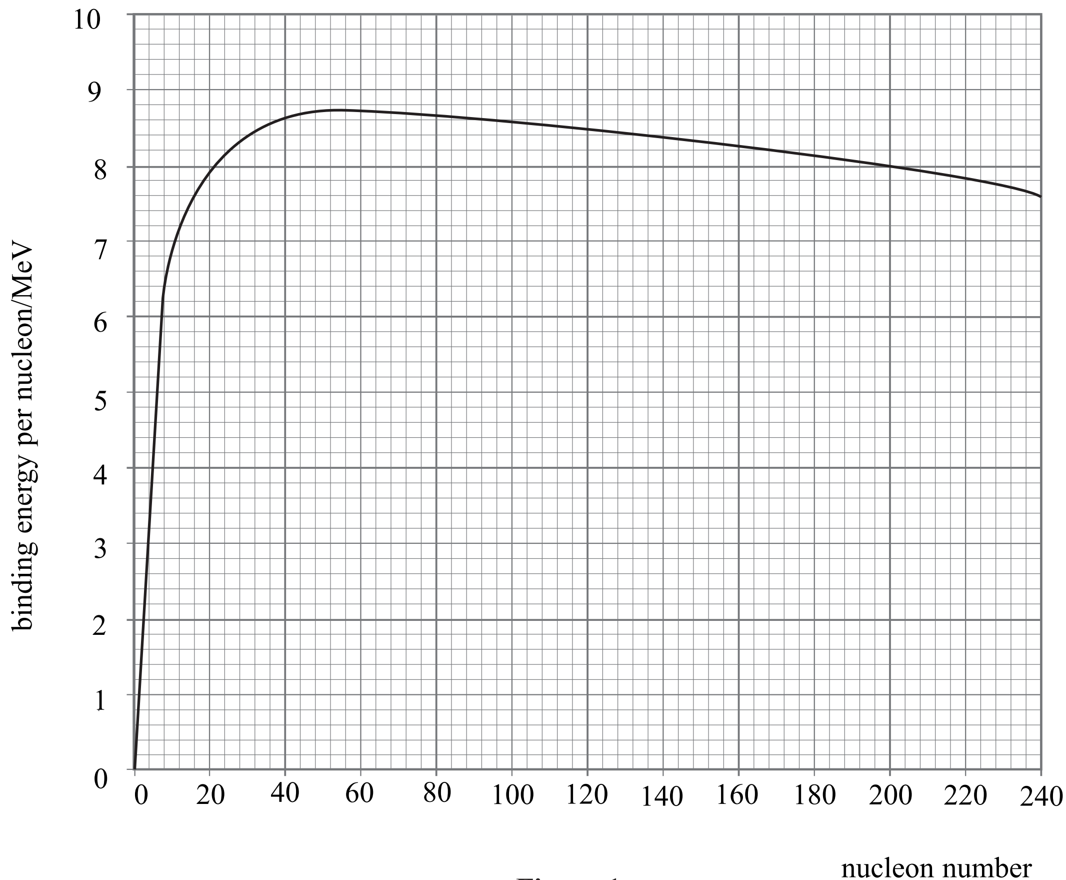


Figure 1

A uranium-235 nucleus undergoes fission and produces two fission products of approximately equal nucleon number. Using data from **Figure 1**, estimate the energy released from the fission of one uranium-235 nucleus.

(3 marks)

(iii) One possible fission reaction is

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{236}_{92}U \longrightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}n$$

Calculate the energy released by this reaction.

The masses of particles are given below in atomic mass units, u, where 1u is a mass of 1.66×10^{-27} kg.

mass of ${}^{1}_{0}n$	=	1.009 u
mass of ${}^{235}_{92}U$	=	235.124 u
mass of ${}^{144}_{56}Ba$	=	143.923 u
mass of ${}^{90}_{36}Kr$	=	89.920 u
speed of electromagnetic radiation	=	3.00×10^{8} m s^{-1}

(4 marks)

(b) (i) In one type of nuclear reactor, carbon dioxide is used as the primary coolant. Treating the carbon dioxide as an ideal gas, use the following data to calculate the mass of carbon dioxide needed for the reactor.

average working temperature	=	650 °C
volume of coolant	=	460 m^{3}
molar gas constant	=	8.3 J mol^{-1} K^{-1}
working pressure	=	1.6 MPa
mass of one mole of carbon dioxide	=	4.4×10^{-2} kg

(4 marks)

(ii) The carbon dioxide coolant in a fission reactor is circulated by a series of large fans, called gas circulators. **Figure 2** shows the circulation of the carbon dioxide through the core, the gas circulators and the heat exchangers.

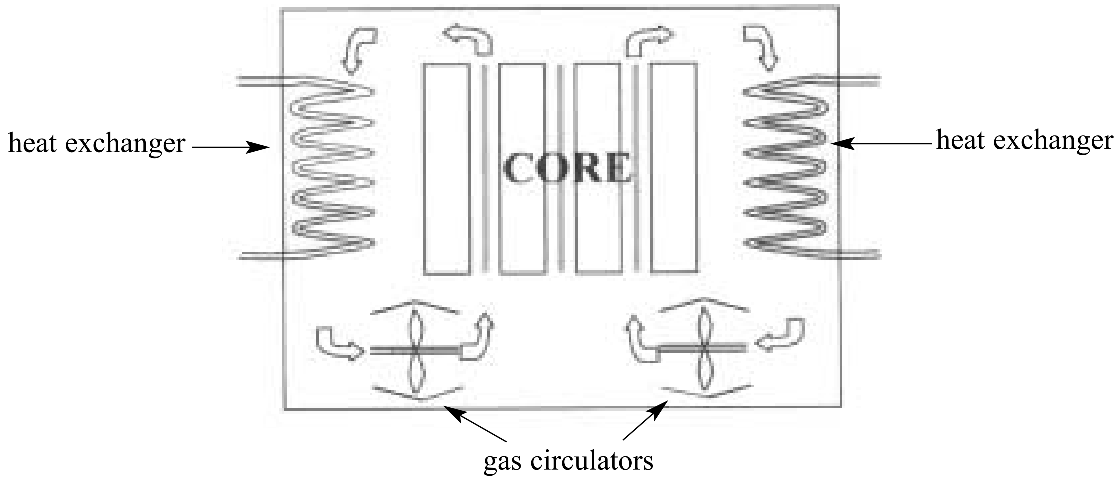


Figure 2

Explain how the first law of thermodynamics applies to a fixed mass of the coolant as it makes one complete circuit of the reactor.

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

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(7 marks)

(c) A fast neutron with an initial velocity of $1.4 \times 10^{7}\,\mathrm{m\,s^{-1}}$ collides with a stationary helium atom and rebounds in the opposite direction after the collision. The momentum of the helium atom after the collision is $3.81 \times 10^{-20}\,\mathrm{kg\,m\,s^{-1}}$.

(i) Show that the velocity of the neutron after the collision is $-8.4 \times 10^{6}\,\mathrm{m\,s^{-1}}$.

mass of a neutron = $1.7 \times 10^{-27}\,\mathrm{kg}$

(3 marks)

(ii) Calculate the percentage loss of kinetic energy of the neutron during the collision.

(2 marks)

26

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

(a) (i) State **one** similarity of electric and gravitational fields.

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(1 mark)

(ii) State **one** difference between electric and gravitational fields.

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(1 mark)

(b) A satellite of mass 165 kg has the radius of its orbit reduced from 4.24×10^7 m to 8.08×10^6 m. Calculate the change in potential energy of the satellite and state whether it is an increase or a decrease.

mass of the Earth	=	5.97×10^{24} kg
universal gravitational constant	=	6.67×10^{-11} N m^2 kg^{-2}

(3 marks)

(c) The orbital change mentioned in part (b) reduces the period of the orbit from 24 hours to 2 hours. State and explain why each of these orbits is useful for information collection or transfer.

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(3 marks)

8

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

(a) **Figure 3** shows the electron gun that accelerates electrons in an electron microscope.

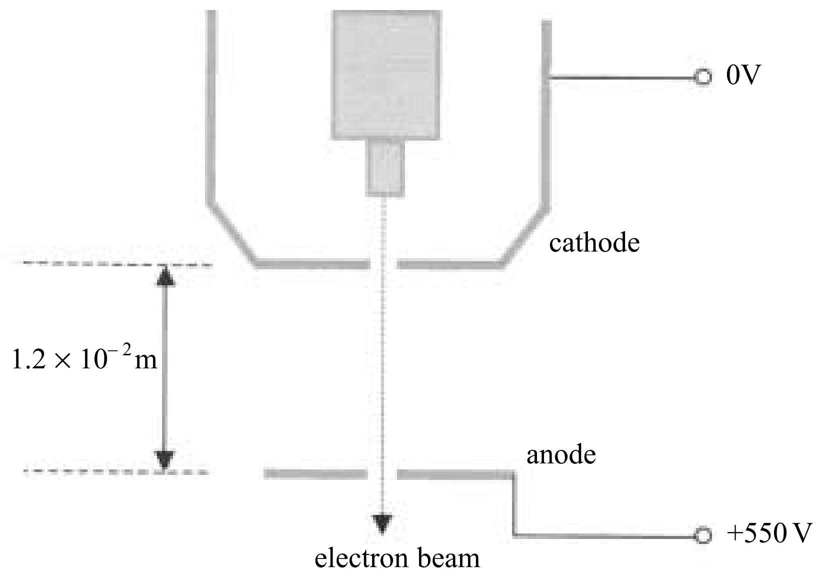

Figure 3

(i) Draw, on **Figure 3**, electric field lines and lines of equipotential in the region between the anode and cathode. Assume that there are no edge effects and that the holes in the plates do not affect the field.
Clearly label your diagram.

(3 marks)

(ii) Calculate the kinetic energy, speed and momentum of an electron as it passes through the hole in the anode.

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

(4 marks)

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(b) By calculating the de Broglie wavelength of electrons coming through the anode of this device, state and explain whether or not they will be suitable for the investigation of the crystal structure of a metal.

Planck constant = 6.6×10^{-34} J s

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(4 marks)

11

TURN OVER FOR THE NEXT QUESTION

4 **Total for this question:** ***16 marks***

(a) Define simple harmonic motion.

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(2 marks)

(b) **Figure 4** shows a system designed to extract energy from waves at sea in order to produce electricity. A buoy floats on the surface and is kept in place by several mooring ropes, two of which are drawn in **Figure 4**. These ropes allow the buoy to move vertically. As a wave passes, the buoy floats with the wave, alternately pulling on and relaxing the steel wire that attaches it to the hydraulic pump on the sea bed. The buoy operates the hydraulic pump, causing a generator to turn, producing electricity.

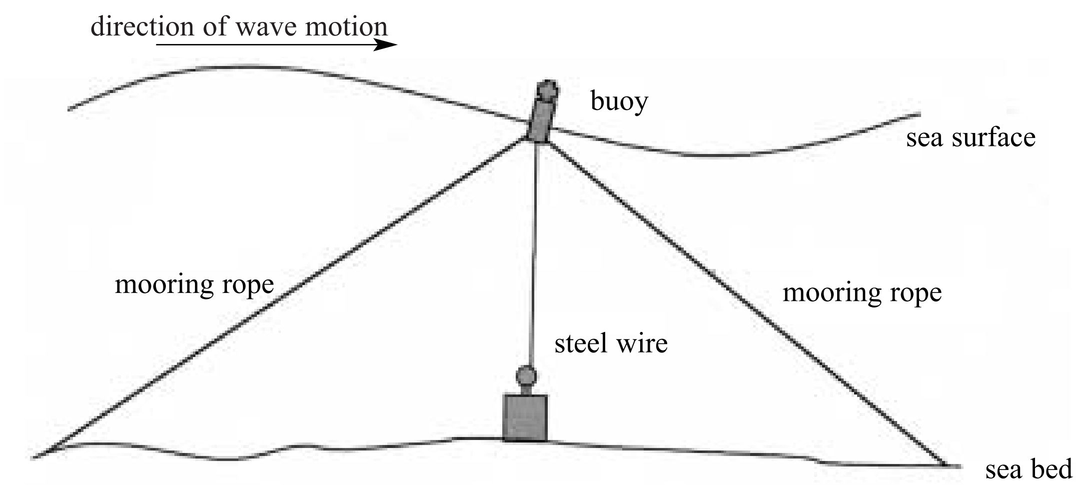

Figure 4

(i) Explain why the buoy in **Figure 4** moves with a motion that is only approximately simple harmonic.

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(2 marks)

(ii) Explain how the maximum power that could be extracted from the wave would be affected by a doubling of the amplitude of the wave.

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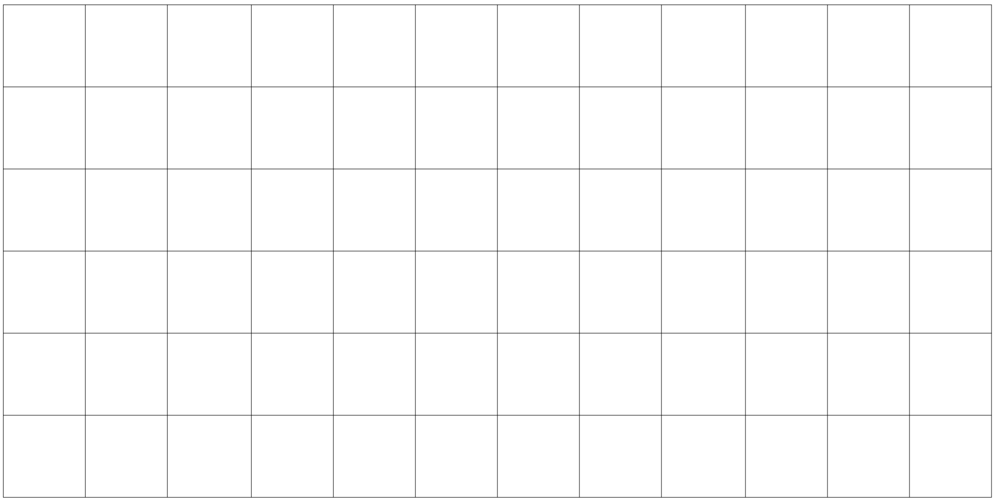
(1 mark)

(iii) The waves, of amplitude 3.4 m, move with a speed of $4.9\,\text{m}\,\text{s}^{-1}$ and have a wavelength of 28 m. Assuming that the buoy moves vertically with simple harmonic motion, show that its maximum vertical speed is approximately $3.7\,\text{m}\,\text{s}^{-1}$.

(4 marks)

(iv) The device only produces power when the buoy is rising with the wave. On the grid below sketch a graph showing the variation of output power with time.
Put a suitable scale on the time axis.

(3 marks)



QUESTION 4 CONTINUES ON THE NEXT PAGE

(c) The steel wire connecting the buoy to the hydraulic pump has a radius of 2.5×10^{-3} m and an unstretched length of 18 m. Calculate the extension of the wire when the tensile force applied to it is 2.4 kN.

Young modulus of steel $= 2.1 \times 10^{11}$ Pa

(4 marks)

16

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

Figure 5 shows a simple d.c. motor. The rotor is a rectangular coil of length 7.3×10^{-2} m and width 3.8×10^{-2} m. There are 25 turns on the coil and the magnetic field has a uniform flux density of 0.17 T. The coil carries a current of 2.3 A.

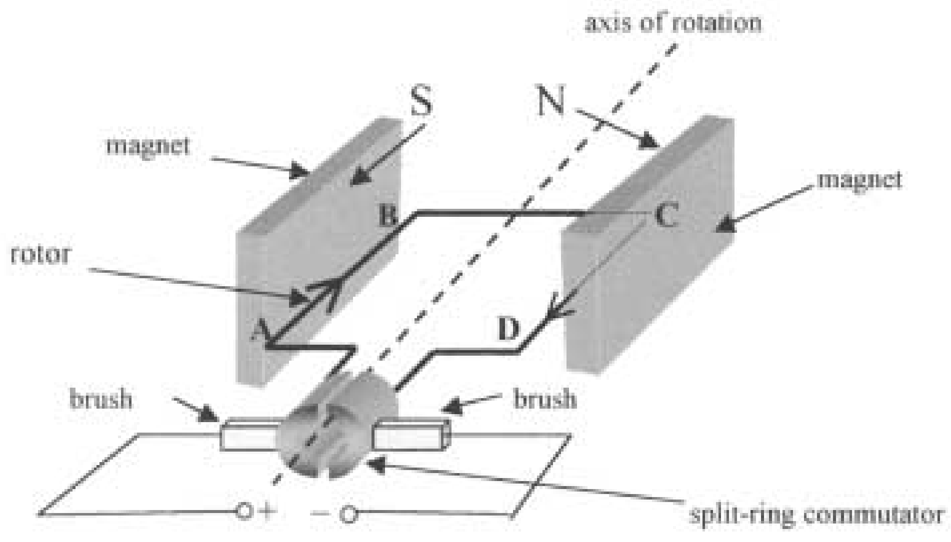


Figure 5

(a) (i) Calculate the magnitude of the force exerted on side **AB** of the rotor.

(3 marks)

(ii) Calculate the maximum torque exerted on the rotor.

(2 marks)

(b) (i) Mark on **Figure 5** the direction of rotation of the rotor. *(1 mark)*

(ii) Explain why the rotor continues to rotate in this direction.

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(2 marks)

(c) **Figure 6** shows how the torque exerted on the rotor varies with time

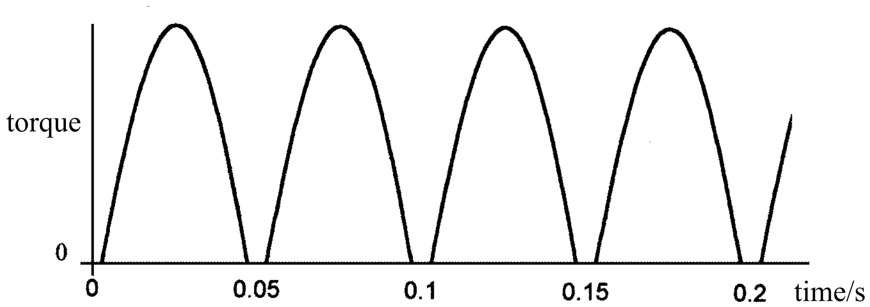

Figure 6

(i) Label, with a letter **H**, **one** time when the coil is horizontal. *(1 mark)*

(ii) Explain the shape of the graph.

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(3 marks)

The passage for answering Questions 6 and 7 is printed on pages 17 and 18.
Detach these pages and read the passage before answering the questions.

6 **Total for this question:** ***18 marks***

(a) Explain why an emf is induced in the rotor in **Figure A** and state what determines the magnitude of this emf.

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(2 marks)

(b) **Figure 7** shows how the flux density B, perpendicular to the plane of the rotor in **Figure A**, varies with time t.

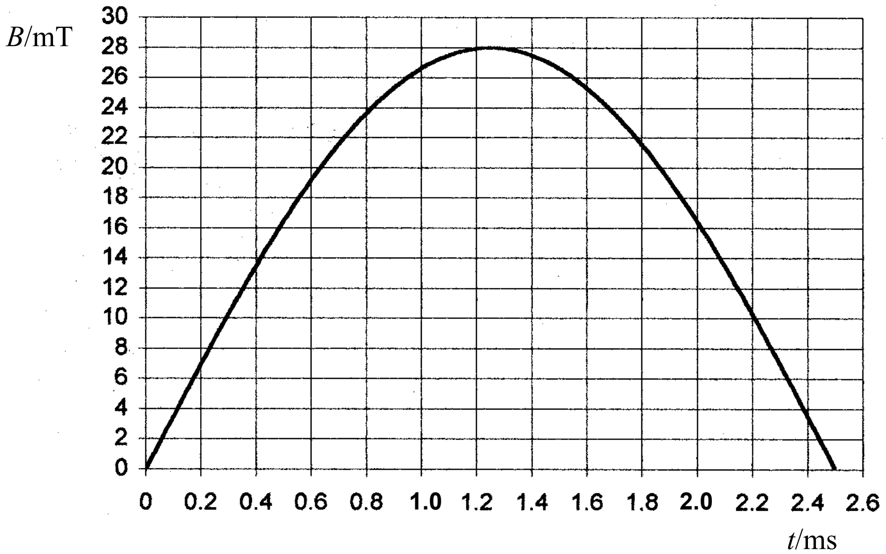

Figure 7

(i) Calculate the rate of change of flux density when $t = 0.80\,\text{ms}$.

(2 marks)

(ii) Calculate the magnitude of the emf induced in the coil when $t = 0.80\,\text{ms}$.

(2 marks)

The passage printed on pages 17 and 18 is for answering Questions 6 and 7.
Detach these pages and read the passage before answering Questions 6 and 7.

Electric motors come in many forms. The essential similarity between them is that the magnetic field from the rotor interacts with the magnetic field produced either by stationary current-carrying coils or by permanent magnets. However, the design adopted in order to achieve this can vary enormously.

An example is the ac induction motor which, as the name suggests, operates from an alternating supply. **Figure A** shows the essential idea:

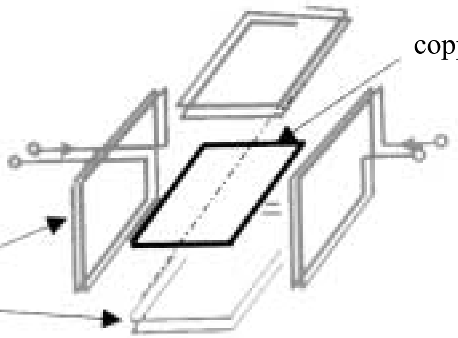

Figure A

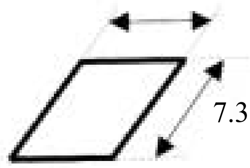

Figure B

Alternating currents, fed to four stationary coils placed around the rotor, produce changing magnetic fields. These changing fields induce an emf in the rotor coil causing a current to flow around it. There is no external electrical connection of any sort to this rotor. One of its advantages over a dc motor is that it does not need brushes and slip rings or commutators. These mechanical systems need maintenance, are a source of mechanical inefficiency and cause sparking as the contacts are made and broken.

Figure B shows the dimensions of the rotor which in this case is made from a single continuous turn of copper wire of radius 0.42 mm.

High power ac motors, called synchronous motors, are used in the *Nozomi* train system in Japan. Each motor has an output power of 300 kW and rotates at up to 5500 revolutions per minute. The running speed of the motor is varied by changing the frequency of the ac supply.

Another feature of this train system is the use of *regenerative braking* instead of more traditional friction methods where the track wheels are slowed by the friction action on brake discs attached to the wheels. In regenerative braking, the motors act as generators. The motors continue to revolve as the trains slow down because the motors are now being turned by the wheels. It would be possible to dissipate the generated electrical energy by passing the current into resistors. However, in the *Nozomi* system the current is passed back into the overhead power lines that supply electricity to the system. This power can be used either by trains nearby or simply absorbed into the grid system.

The *Nozomi* system runs at 270 km per hour and is therefore an advance on the previous *Hikari* system which had a maximum speed of 220 km per hour. Not only is more power required to run trains at higher speeds, but the Japanese requirement to limit noise pollution means that the vehicles have to be lighter. The introduction of lighter synchronous motors has made a significant contribution to the reduction of the mass of the train units from 64 tonnes to 45 tonnes. Other sources of noise pollution include air friction, structural noise from bridges and vehicle vibration, and wheel and rail noise.

Another engineering difficulty faced by the development of the faster trains occurs with curved tracks in the system. The local geography dictates that tracks need to have tight curves with radii of as little as 2500 m for the slower, 220 km per hour track and 4000 m for the faster, 270 km per hour track. Where the track needs to have a sharp curve the railway track is banked, that is, built at an angle to the horizontal as shown in **Figure C**.

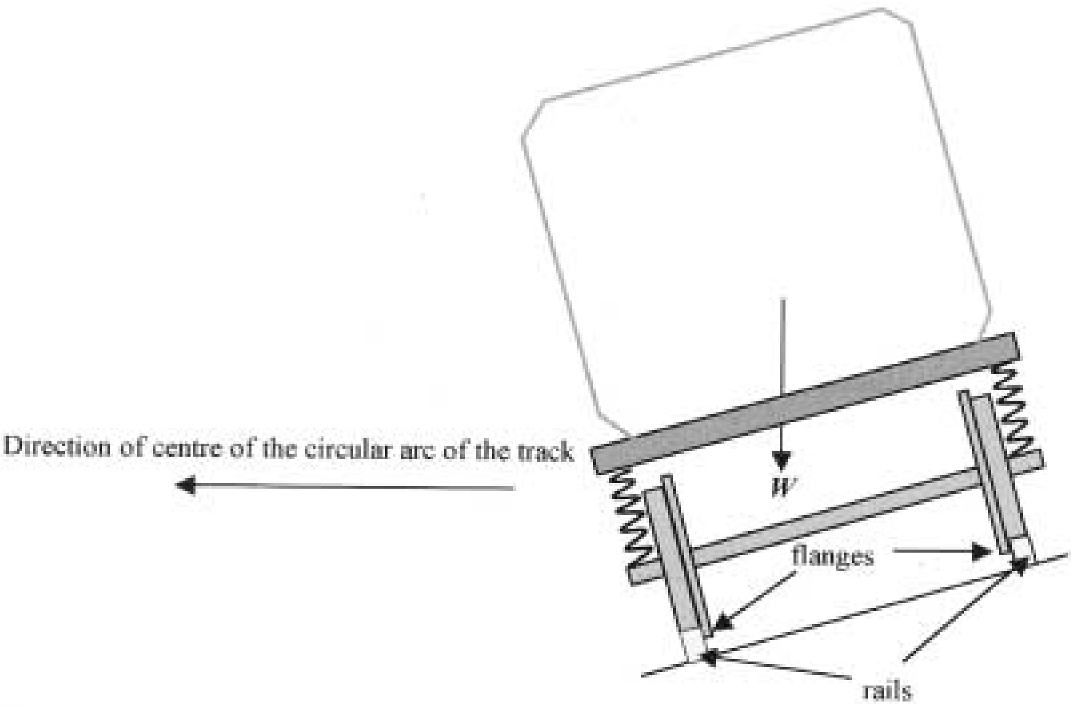

Figure C

The track forms part of a circle. The direction of the centre of the circle is shown on **Figure C**. The diagram also indicates the weight, *W* of the carriage, acting through its centre of gravity. This banked track helps to keep the trains moving in a circular path and improves passenger comfort.

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(iii) Calculate the magnitude of the current in the coil when $t = 0.80\,\text{ms}$.

resistivity of copper $= 1.6 \times 10^{-8}\,\Omega\,\text{m}$

(4 marks)

(c) Consider the advantages of trains using ac synchronous motors with regenerative braking compared with those that use dc electric motors and only traditional friction braking systems.
You may wish to comment on:

- any sources of inefficiency
- energy changes involved where there are inefficiencies
- any other issues that may lead to benefits to passengers

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

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(8 marks)

18

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7 **Total for this question:** ***9 marks***

(a) (i) Explain why it is necessary to exert a centripetal force on the carriage as it moves along the curved track as shown in **Figure C**.

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(2 marks)

(ii) State the origin of **one** force in **Figure C** that may contribute to the centripetal force acting on the carriage as it moves around the curved track. State where this force acts.

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(2 marks)

(b) (i) Use the data in the passage to show that the centripetal force needed for the Nozomi carriage is less than that needed for the Hikari.

(3 marks)

(ii) Suggest why a track with a greater radius is used for the faster train, despite the smaller centripetal force.

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(2 marks)

9

END OF QUESTIONS