Version 1.1

Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2003
Advanced Level Examination

ASSESSMENT and QUALIFICATIONS ALLIANCE

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

Thursday 26 June 2003 Morning 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, 8 and 9.

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			
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9			
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: ***15 marks***

1 Faraday's law of electromagnetic induction predicts that the induced emf, E, in a coil is given by $E = \dfrac{\Delta(N\phi)}{t}$.

(a) (i) What quantity does the symbol ϕ represent?

....

(1 mark)

(ii) State the SI unit for ϕ .

....

(1 mark)

(b) In **Figure 1** the magnet forms the bob of a simple pendulum. The magnet oscillates with a small amplitude along the axis of a 240 turn coil that has a cross-sectional area of $2.5 \times 10^{-4}\,m^2$.

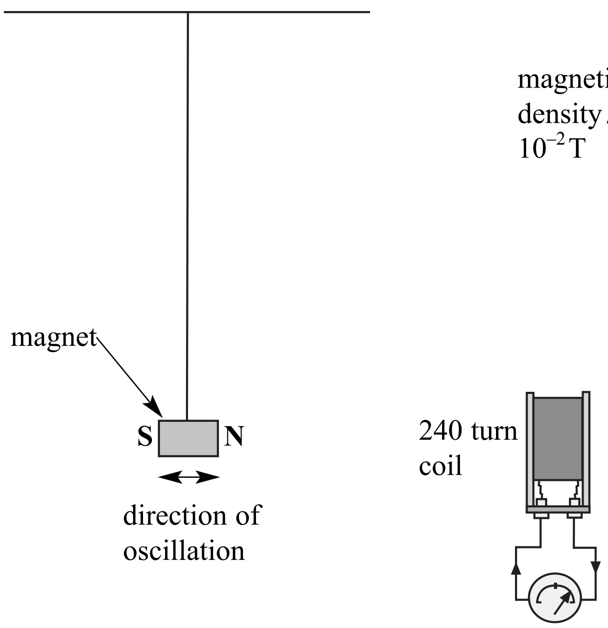

Figure 1

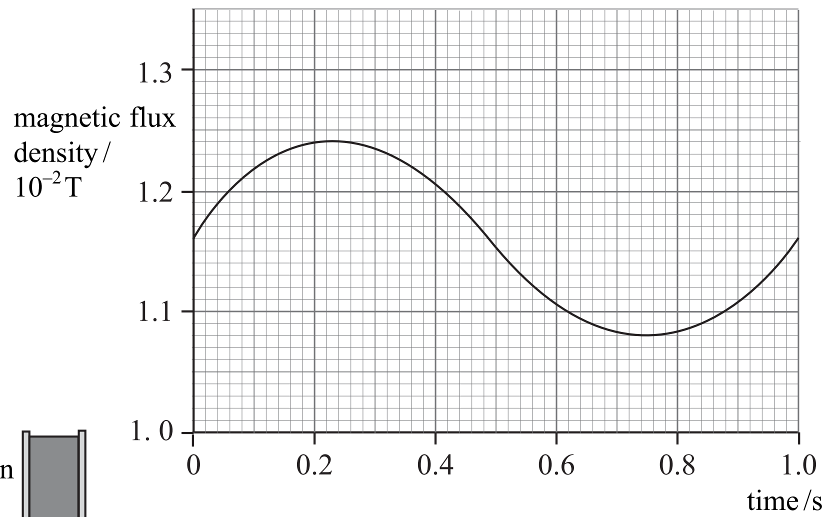

Figure 2

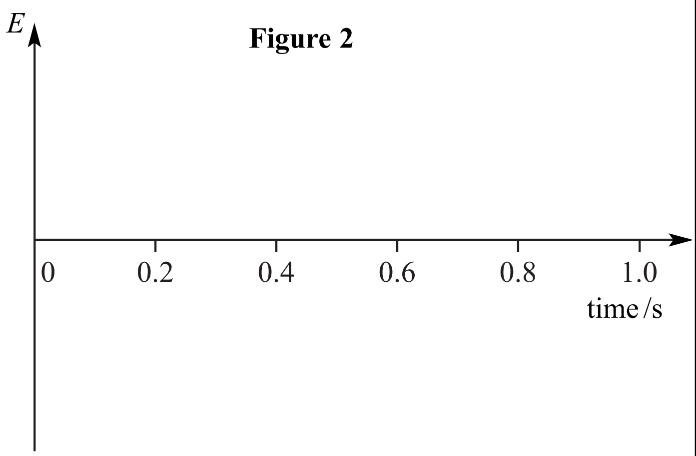

Figure 3

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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

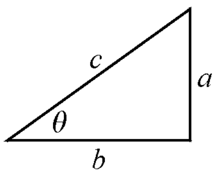
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

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

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

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



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

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

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

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

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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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Figure 2 shows how the magnetic flux density, *B*, through the coil varies with time, *t*, for one complete oscillation of the magnet. The magnetic flux density through the coil can be assumed to be uniform.

(i) Calculate the maximum emf induced in the coil.

(3 marks)

(ii) Sketch on **Figure 3** a graph to show how the induced emf in the coil varies during the same time interval. *(2 marks)*

(iii) Explain how the pendulum may be modified to double the frequency of oscillation of the magnet.

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(2 marks)

(iv) The frequency of oscillation of the magnet is increased without changing the amplitude. Explain why this increases the maximum induced emf.

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(2 marks)

(v) State **two** other ways of increasing the maximum induced emf.

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(2 marks)

(vi) Explain how the output from the coil would have to be processed in order to store the information in a computer memory.

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(2 marks)

15

Turn over

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Total for this question: *11 marks*

2 (a) State the factors that affect the gravitational field strength at the surface of a planet.

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(2 marks)

(b) **Figure 4** shows the variation, called an anomaly, of gravitational field strength at the Earth's surface in a region where there is a large spherical granite rock buried in the Earth's crust.

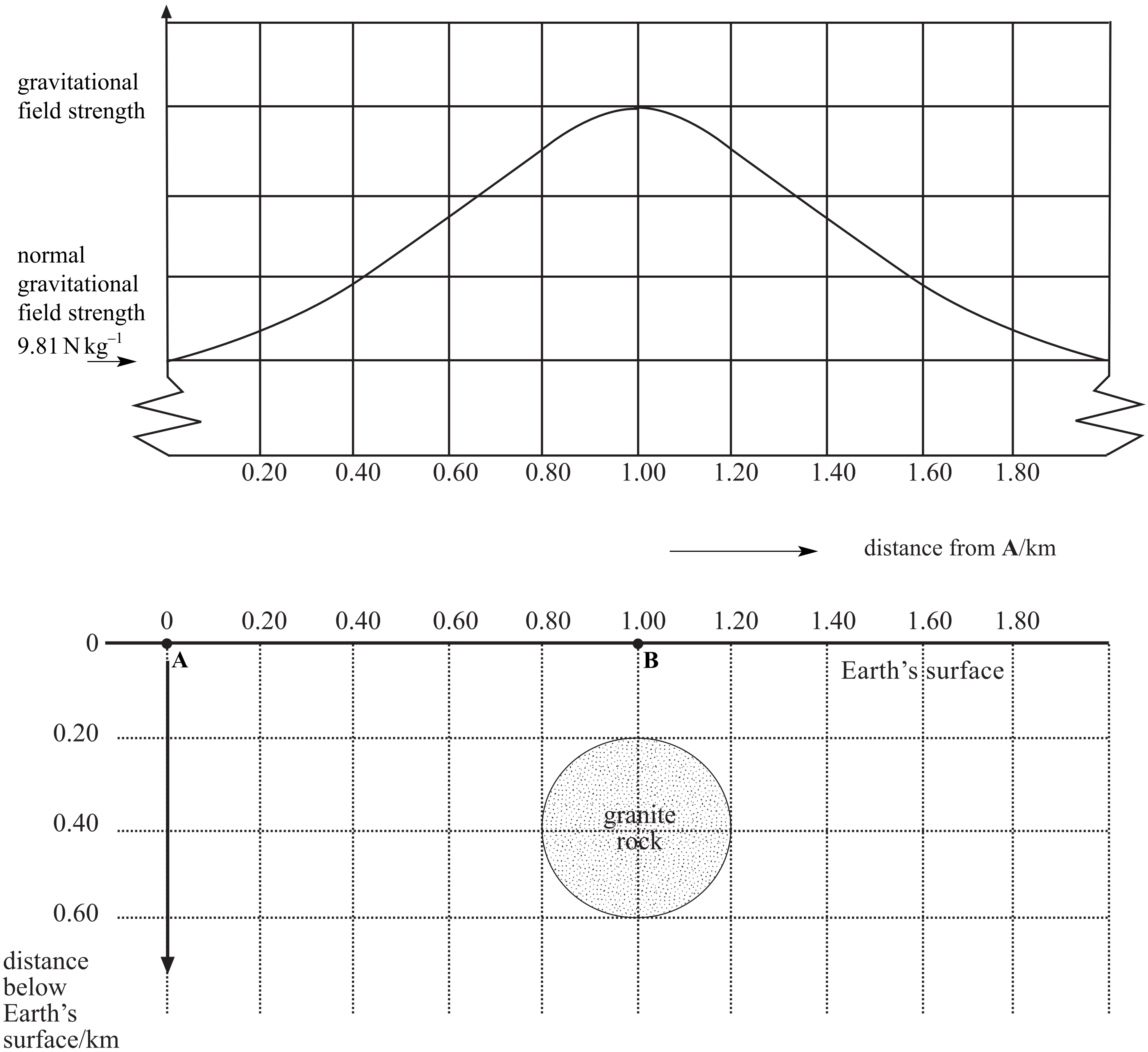

Figure 4

The density of the granite rock is $3700\,kg\,m^{-3}$ and the mean density of the surrounding material is $2200\,kg\,m^{-3}$.

(i) Show that the difference between the mass of the granite rock and the mass of an equivalent volume of the surrounding material is 5.0×10^{10} kg.

(4 marks)

(ii) The universal gravitational constant $G = 6.7 \times 10^{-11}\,N\,m^2\,kg^{-2}$. Calculate the difference between the gravitational field strength at **B** and that at point **A** on the Earth's surface that is a long way from the granite rock.

(4 marks)

(iii) Add to **Figure 4** a graph to show how the variation in gravitational field strength would change if the granite rock were buried deeper in the Earth's crust. *(1 mark)*

11

TURN OVER FOR THE NEXT QUESTION

Total for this question: *16 marks*

3 **Figure 5** shows some of the equipotential lines that are associated with a point negative charge Q. The potential of each line is shown on the diagram which is full size.

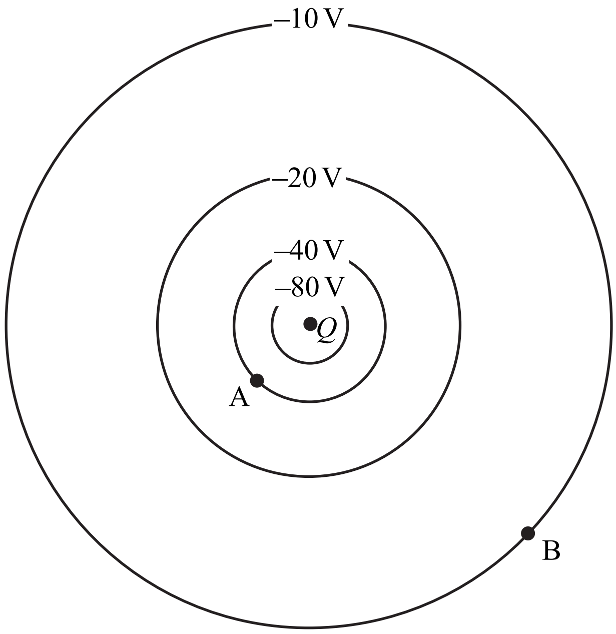

Figure 5

(a) (i) Explain why the potentials have a negative sign.

....

....

(2 marks)

(ii) Draw on the diagram **three** electric field lines. Use arrows to show the direction of the field. *(2 marks)*

(b) (i) Use data from **Figure 5** to show that the charge Q is about -4.5×10^{-11} C.

permittivity of free space $\varepsilon_0 = 8.9 \times 10^{-12}\,\mathrm{F\,m^{-1}}$

(2 marks)

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(ii) Calculate the electric field strength at **B**.

(2 marks)

(c) (i) Calculate the energy, in J, transferred when an electron moves from **A** to **B** in the field.

charge on an electron = -1.6×10^{-19} C

(2 marks)

(ii) State and explain

- why the kinetic energy of the electron increases as it moves from **A** to **B**,
- how the de Broglie wavelength of the electron changes as it moves from **A** to **B**.

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

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(6 marks)

16

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Total for this question: *10 marks*

4 **Figure 6** shows a diagram of a mass spectrometer.

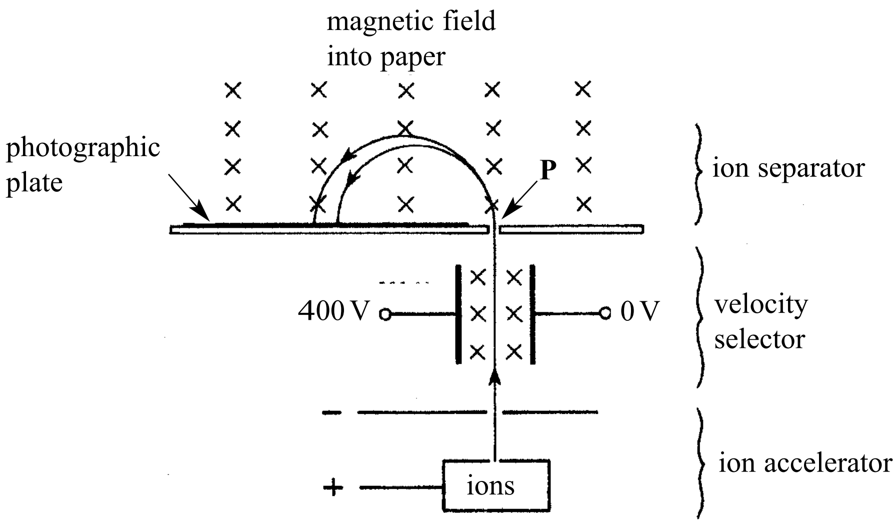

Figure 6

(a) The magnetic field strength in the velocity selector is 0.14 T and the electric field strength is 20 000 V m^{-1}.

(i) Define the unit for magnetic flux density, the tesla.

....

....

(2 marks)

(ii) Show that the velocity selected is independent of the charge on an ion.

(2 marks)

(iii) Show that the velocity selected is about 140 km s^{-1}.

(1 mark)

(b) A sample of nickel is analysed in the spectrometer. The two most abundant isotopes of nickel are $^{58}_{28}\text{Ni}$ and $^{60}_{28}\text{Ni}$. Each ion carries a single charge of $+1.6 \times 10^{-19}$ C.

mass of a proton or neutron = 1.7×10^{-27} kg

The $^{58}_{28}\text{Ni}$ ion strikes the photographic plate 0.28 m from the point **P** at which the ion beam enters the ion separator.

Calculate:

(i) the magnetic flux density of the field in the ion separator;

(3 marks)

(ii) the separation of the positions where the two isotopes hit the photographic plate.

(2 marks)

10

TURN OVER FOR THE NEXT QUESTION

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Total for this question: ***13 marks***

5 A physicist wants to design an experiment in which two free protons collide to produce two delta-plus (Δ^+) particles. This is an allowed reaction and is fully represented by the equation

$$p^+ + p^+ \rightarrow \Delta^+ + \Delta^+$$

Two options are available that are shown as **A** and **B** in **Figure 7**.

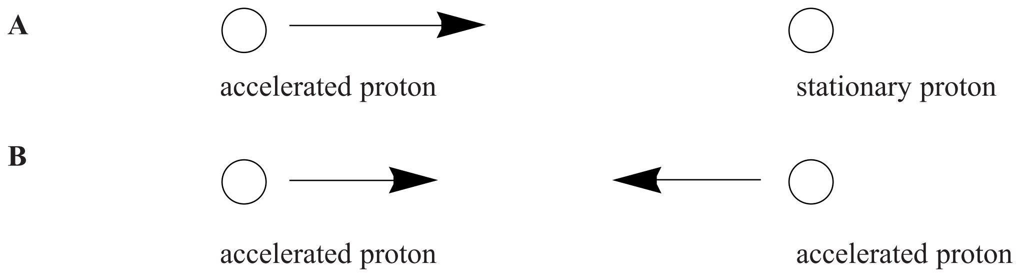

Figure 7

In **A** an accelerated proton collides with a stationary proton and in **B** two accelerated protons, each with the same energy, collide head on.

the charge on a proton = $+1.6 \times 10^{-19}$ C
the rest mass of a proton = 1.7×10^{-27} kg
the permittivity of free space ε_o = 8.9×10^{-12} F m^{-1}

(a) State the baryon number of a Δ^+ particle.

....

(1 mark)

(b) The radius of a proton is 1.5×10^{-15} m.

(i) Calculate the minimum total kinetic energy that the accelerated protons need so that they will touch each other.

(3 marks)

(ii) State what happens in situation **A** when the energy is less than your answer to part(i).

....

....

(1 mark)

(iii) State and explain what happens in situation **B** when the energy is less than your answer to part(i).

....

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(3 marks)

(iv) Explain why the protons can undergo fusion if this energy is exceeded.

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(2 marks)

(c) Calculate the minimum total kinetic energy, in J, of the protons that will allow the two protons to collide and produce the two Δ^+ particles.

speed of electromagnetic radiation in free space = $3.0 \times 10^8\,\text{m}\,\text{s}^{-1}$
rest mass of a Δ^+ particle = $2.2 \times 10^{-27}\,\text{kg}$

(3 marks)

13

*The passage printed on pages **15** and **16** is for answering Questions **6 - 9**.*
*Detach these pages and read the passage before answering Questions **6 - 9**.*

Travelling in space

To make space travel more economical new methods of powering spacecraft are needed. Until now the methods have all been based on the burning of high energy fuel in rockets. In these engines the expanding gases produced by igniting the fuel are ejected from the rocket so that by the principle of conservation of momentum the rocket moves in the opposite direction.

Rocket fuel contains 80 MJ of energy per kilogram so if all the energy in the fuel could be used just to lift a payload from the Earth's surface each kilogram of fuel could provide more than enough energy to allow a 1 kg payload to escape from the Earth. However, using this method of propulsion the spacecraft has to carry the fuel it needs for the later parts of the journey. The ratio of payload to the mass of the rocket is therefore very low. Propulsion methods to reduce the mass of fuel that has to be carried are being considered.

Magnetic levitation

One proposal is to use electrical energy to accelerate the spacecraft on a track that uses magnetic levitation (lift). Magnetic levitation would make the spacecraft float above the track so that friction would be negligible. In a practical system using this method the spacecraft would be accelerated to the speed of sound, 340 m s^{-1}, before the rockets are fired. To achieve this the spacecraft would have to be designed to withstand very large '*g*' forces.

Figure 8 shows the principle of magnetic levitation using a superconducting magnet and a conducting sheet track.

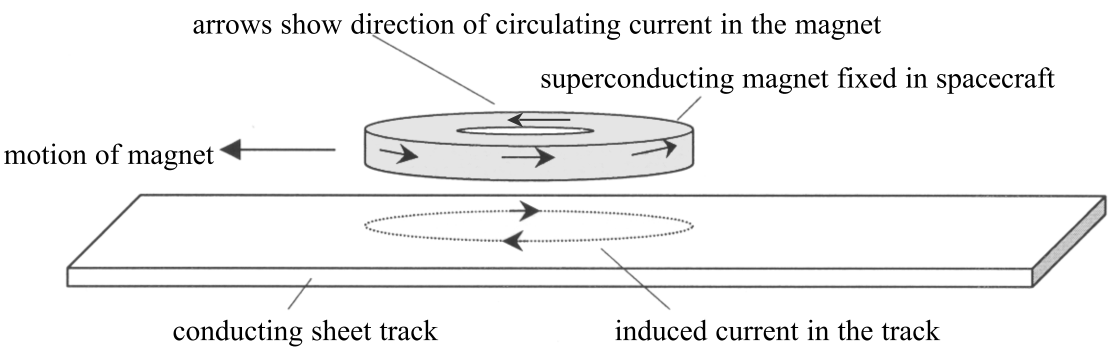

Figure 8

As the superconducting magnet moves, eddy currents are induced in the track which provide the lift for as long as the magnet is moving. The system is very stable because if the gap between the magnet and track decreases, the induced current increases producing more lift to maintain the original gap. This method of reducing frictional forces has problems that have to be overcome in practical systems. Although there is no power loss in the magnet, power is lost due to the electrical resistance in the track. There is also a magnetic drag force due to induced currents and a drag force due to air resistance acting on the spacecraft.

Lightcraft

Another method suggests making a *lightcraft* which is powered by a pulsed infrared laser beam from a laser that is mounted on the Earth. The principle of this spacecraft is shown in **Figure 9**.

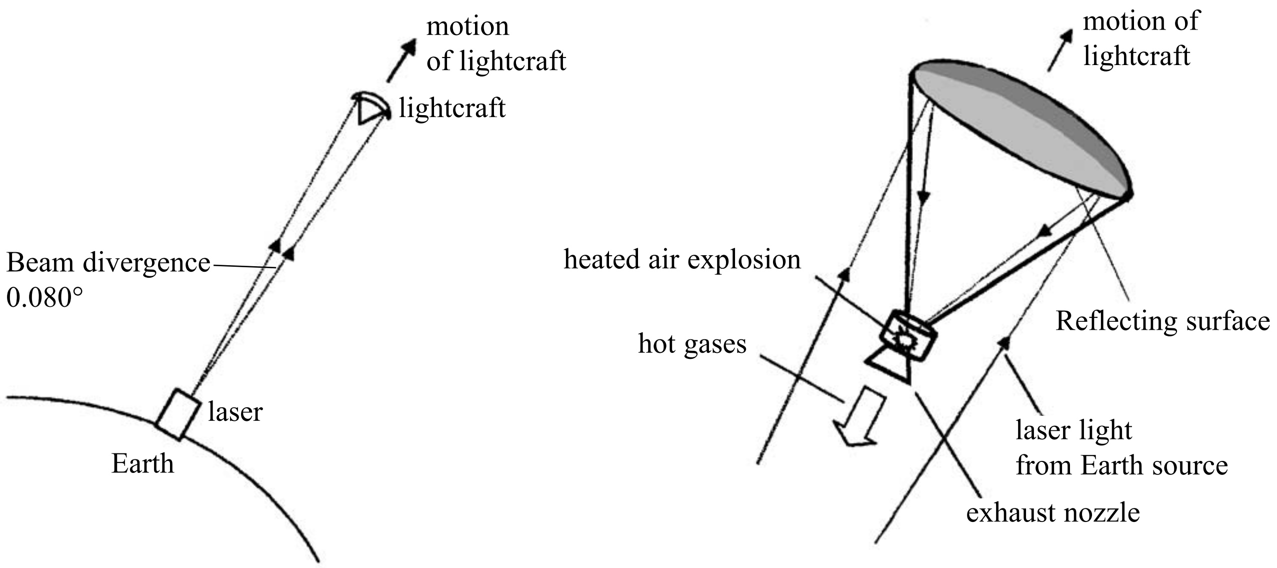

Figure 9

Air from the front of the craft is directed to the 'engine' which is essentially a cylindrical vessel fitted with an exhaust nozzle. The energy in the laser beam is reflected on to the air in the 'engine' which is rapidly heated to a temperature of about 40 000 K. This causes the air to expand explosively and the air that is propelled backwards provides the thrust. Further thrust is provided by the gases that move forward, the reflecting surface acting like a sail.

Model 'lightcraft' of mass 50 g and diameter 15 cm have been propelled to heights of 30 m using a carbon dioxide laser (wavelength = 1060 nm) of mean power 10 kW pulsing 28 times a second. Designers are now working on a 1 MW laser which it is hoped will put a 1 kg micro-satellite into orbit. The laser will be used to propel the lightcraft vertically to five times the speed of sound during the first 30 km of the flight. The spacecraft will then use about 1 kg of hydrogen for propellant as air becomes scarce so that the initial mass of the lightcraft will be about 2 kg. Laser beams spread out, a typical angular divergence being 0.080°. Most of the energy in the laser beam falls within this angle and to make full use of the beam a large diameter reflecting surface is needed.

When answering questions on this passage you will need the following data:

universal gravitational constant, G	=	$6.7 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$
mass of the Earth	=	$6.0 \times 10^{24}\,\mathrm{kg}$
radius of the Earth	=	$6.4 \times 10^{6}\,\mathrm{m}$
Planck constant, h	=	$6.6 \times 10^{-34}\,\mathrm{J\,s}$
speed of light in free space, c	=	$3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$
speed of sound in air	=	$340\,\mathrm{m\,s^{-1}}$
acceleration of free fall, g	=	$9.8\,\mathrm{m\,s^{-2}}$

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*The passage for answering Questions **6-9** is printed on pages **15-16**.*
Detach these pages and read the passage before answering the questions.

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

6 (a) Show that the statement in lines 5–7 is true.

(3 marks)

(b) Explain why, since the spacecraft uses the principle of conservation of momentum, the energy in the fuel cannot all be transferred to kinetic energy of the spacecraft.

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(2 marks)

(c) Designers are looking for more economical methods to power spacecraft. Explain why existing methods are uneconomical.

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(2 marks)

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Turn over

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

7 (a) Explain why there is no power loss in the superconducting magnet used in the magnetic levitation system.

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(2 marks)

(b) Magnetic drag forces and power loss due to induced currents are problems that occur in the magnetic levitation system (lines 21-24). Use the laws of electromagnetic induction to explain how these problems occur. For **one** of these problems, explain how the effect will change as the spacecraft accelerates.

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

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(8 marks)

10

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Total for this question: *4 marks*

8 (a) (i) Use the information in lines 32-33 to determine the energy in a single pulse from the laser used when launching the experimental lightcraft.

(1 mark)

(ii) Calculate the number of photons in one pulse of this laser beam.

(3 marks)

—
4

Total for this question: *14 marks*

9 The following questions are about different aspects of the practical lightcraft (lines 34-35).

(a) (i) Calculate the average acceleration that is expected during the first 30 km of flight for the practical lightcraft.

(2 marks)

(ii) Show that the time taken to cover the first 30 km of flight is about 35 s.

(2 marks)

(b) (i) Calculate the total energy gained by the lightcraft during the first 30 km of flight.

(3 marks)

QUESTION 9 CONTINUES ON THE NEXT PAGE

Turn over

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(ii) Calculate the expected efficiency of this method of propulsion.

(2 marks)

(c) Assume that the design of the craft is such that it is to collect all the energy in the laser beam at a height of 30 km. Calculate the diameter of the reflecting surface that is needed in the practical lightcraft.

(1 mark)

(d) (i) Assume that, when using the lightcraft, the air is at 300 K and a pressure of 1.0×10^5 Pa and that the heating takes place at constant volume. Estimate the pressure of the air after heating by the laser.

(2 marks)

(ii) Explain in terms of the way the system operates why it is necessary to switch to hydrogen propulsion after 30 km.

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(2 marks)

14

END OF QUESTIONS