Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2003
Advanced Level Examination

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

Friday 31 January 2003 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 15 and 16 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 allocation 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 (a) Explain what is meant by a flux density of 1 tesla (T).

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(1 mark)

(b) Complete the diagram in **Figure 1** to show a current balance, which may be used to measure the magnetic flux density between the poles of the ceramic magnets. Clearly label the directions of the current and the magnetic force acting on the conductor in the field.

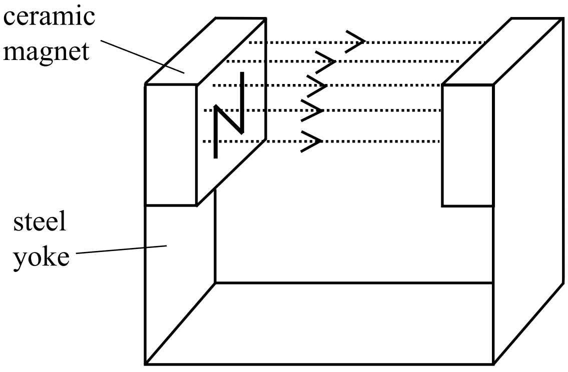


Figure 1

(3 marks)

(c) (i) The armature of a simple motor consists of a square coil of 20 turns and carries a current of 0.55 A just before it starts to move. The lengths of the sides of the coil are 0.15 m and they are positioned perpendicular to a magnetic field of flux density 40 mT. Calculate the force on each side of the coil.

(2 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, $R = R_1 + R_2 + R_3 + \ldots$..

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

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

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

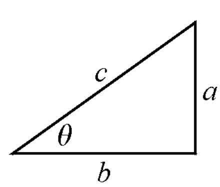
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

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

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

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



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

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

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

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

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

$$Ft = \Delta(mv)$$

$$E = hf$$

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

$$hf = E_2 - E_1$$

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

(ii) Explain why the current falls below 0.55 A once the coil of the motor is rotating.

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(2 marks)

(iii) The resistance of the coil is 0.50 Ω. When the coil is rotating at a constant rate the minimum current in the coil is found to be 0.14 A. Calculate the maximum rate at which the flux is cut by the coil.

(4 marks)

12

TURN OVER FOR THE NEXT QUESTION

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

2 **Figure 2** (not to scale) shows the planet Neptune (N) with its two largest moons, Triton (**T**) and Proteus (**P**). Triton has an orbital radius of 3.55×10^8 m and that of Proteus is 1.18×10^8 m. The orbits are assumed to be circular.

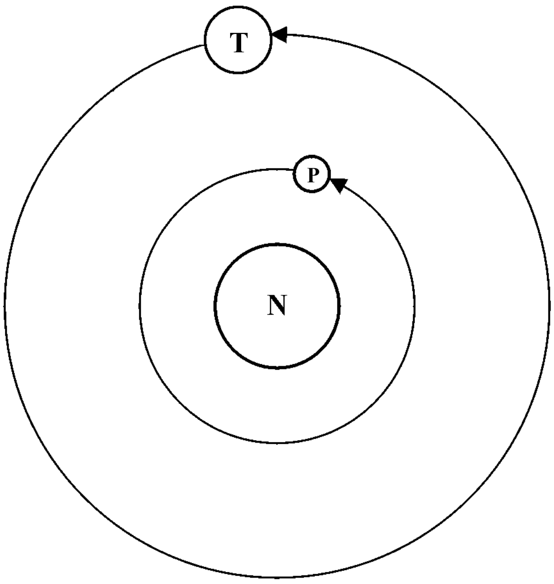

Figure 2

(a) Explain why the velocity of each moon varies whilst its orbital speed remains constant.

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(1 mark)

(b) Write down an equation that shows how Neptune's gravitational attraction provides the centripetal force required to hold Triton in its orbit. Hence show that it is unnecessary to know the mass of Triton in order to find its angular speed.

(3 marks)

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(c) Show that $\dfrac{\text{the orbital period of Triton}}{\text{the orbital period of Proteus}}$ is approximately 5.2.

(4 marks)

8

TURN OVER FOR THE NEXT QUESTION

LEAVE MARGIN BLANK

Total for this question: ***17 marks***

3 **Figure 3** shows the plan view of a cyclotron in which protons are emitted in between the dees. The protons are deflected into a circular path by the application of a magnetic field. **Figure 4** shows a view from in front of the cyclotron.

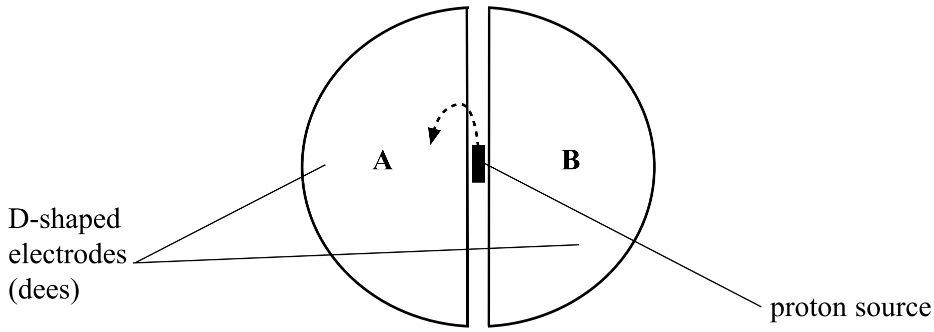

Figure 3

Figure 4

(a) (i) Mark on **Figure 4** the direction of the magnetic field in the region of the dees such that it will deflect the proton beam in the direction shown in **Figure 3**.

(2 marks)

(ii) Show that the velocity of the proton, v, at some instant is given by:

$$v = \frac{B\,e\,r}{m}$$

where m is the proton mass, r the radius of its circular path, B the magnetic flux density acting on the proton and $+e$ the proton charge.

(2 marks)

(iii) Write down an equation for the time T for a proton to make a complete circular path in this magnetic field.

(2 marks)

(iv) Explain how your equation leads to the conclusion that T is independent of the speed with which the proton is moving.

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(1 mark)

(b) In addition to this magnetic field there is an electric field provided between the dees. This accelerates the proton towards whichever dee is negatively charged. An alternating potential difference causes each dee to become alternately negative and then positive. This causes the proton to accelerate each time it crosses the gap between the dees.

(i) Describe and explain the effect the acceleration has on the path in which the proton moves.

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(2 marks)

(ii) In terms of T, write down the frequency with which the p.d. must alternate to match the period of motion of the proton.

(1 mark)

QUESTION 3 CONTINUES ON THE NEXT PAGE

(c) (i) Calculate the velocity of a proton of energy 0.12 keV.

the proton mass, $m = 1.7 \times 10^{-27}$ kg
the magnitude of the electronic charge, $e = 1.6 \times 10^{-19}$ C

(3 marks)

(ii) Calculate the de Broglie wavelength of the 0.12 keV proton.

the Planck constant, $h = 6.6 \times 10^{-34}$ J s

(3 marks)

(iii) Name the region of the electromagnetic spectrum which has an equivalent wavelength to that of the proton.

....

(1 mark)

17

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

4 **Figure 5** shows a radioactive decay series starting with radium-224 ($^{224}_{88}$Ra).

parent nuclide	**emitter**	**daughter nuclide(s)**	**half-life**	**comments**
radium-224	alpha	radon-220 (Rn)	3.64 days	
radon-220	alpha	polonium-216 (Po)	55 seconds	
polonium-216	alpha	lead-212 (Pb)	0.15 seconds	
lead-212	beta	bismuth-212 (Bi)	10.64 hours	
bismuth-212	beta alpha	polonium-212 thallium (Tl)	60.6 minutes	64% decays by beta emission 36% decays by alpha emission
polonium-212	alpha	lead-208	3.0×10^{-7} seconds	lead-208 is stable
thallium	beta	lead-208	3.1 minutes	lead-208 is stable

Figure 5

(a) (i) State the values for the proton and nucleon numbers of the isotope of thallium.

Show clearly how you arrived at your values.

(4 marks)

(ii) Explain how lepton number is conserved in the beta decay from thallium to lead.

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(2 marks)

(b) Radioactive radon is a gas released by rocks such as granite. Suggest why its build up in houses constructed above the granite may be of concern and explain why it is unlikely that the radon produced in this series will accumulate in sufficient quantity to be harmful.

Two of the 5 marks in this question are available for the quality of your written communication.

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(5 marks)

(c) (i) Show that the decay constant (probability of decay) of bismuth-212 is approximately 1.14×10^{-2} minute^{-1}.

(2 marks)

(ii) At some instant during the decay series, 8.0×10^{-3} kg of bismuth-212 are present. Calculate the mass of this bismuth-212 that remains after a period of 240 minutes.

(3 marks)

QUESTION 4 CONTINUES ON THE NEXT PAGE

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(iii) Explain why there will actually be more bismuth-212 present after 240 minutes than the value that you have calculated.

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(2 marks)

18

The passage for answering questions 5, 6, 7 and 8 is printed on pages 15 and 16. Detach pages 15 and 16 and read the passage before answering the questions.

Ink-jet Printing

Ink-jet printing is a non-impact, dot-matrix technology in which ink droplets are projected through an array of tiny nozzles onto paper. The mechanism by which a liquid jet breaks up into single droplets was first described mathematically by Lord Rayleigh in 1878 but it was not until the mid-twentieth century that scientists were able to control the break up of the jet in a totally predictable way.

In the continuous-flow print head, ink-jet droplets can be charged negatively as they pass through a charging ring electrode immediately after they break away from the nozzle of the print head. Whether or not a droplet is charged is controlled by a signal sent to the printer by a computer. An ink droplet that becomes charged gains a charge of around -2×10^{-10} C in order for it to be deflected into a "gutter" by the deflection field. This allows the ink to be recycled for further use. Droplets that are uncharged pass undeflected through the electric field and reach the paper. A pair of charged, parallel plates are used to provide the uniform electric deflection field. It is essential that the droplets have the same radius so that they can be charged by a predictable amount.

A typical arrangement is shown in **Figure 6**.

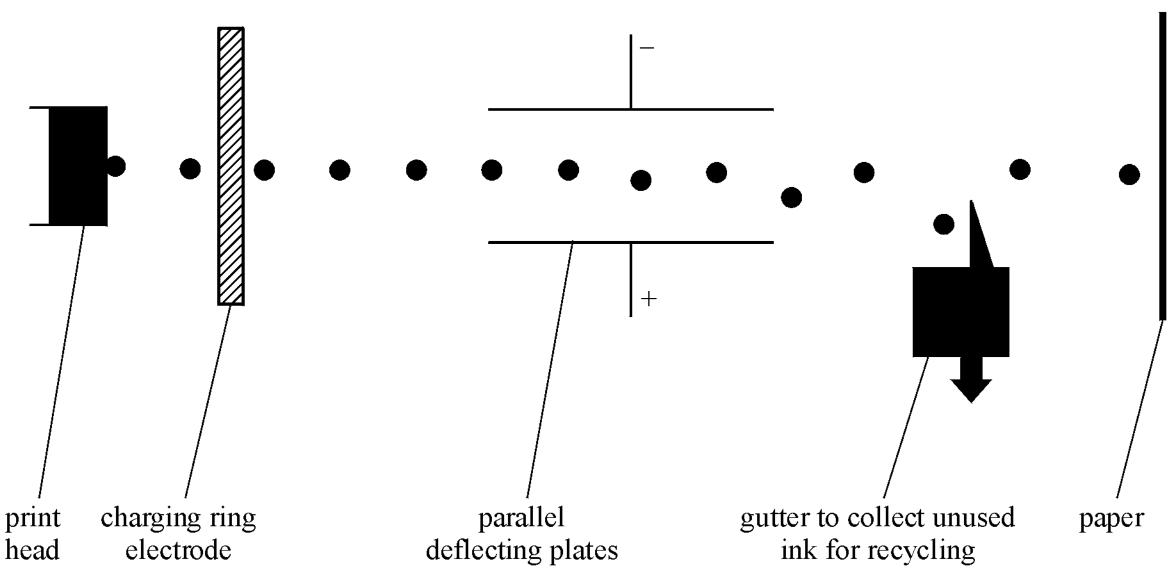

Figure 6

Figure 7 illustrates the droplet generator of one of the most common print cartridges that uses a "thermal ink-jet" continuous delivery method for producing the ink droplets. Behind each nozzle a minute heating resistor carries an electrical current of approximately 0.60 A at a potential difference of 12 V for a period of 3.0 µs. This heats the surrounding ink from its ambient temperature to its boiling point when a "bubble" of vapour forms. Once formed, the bubble continues to be heated and so it expands and pushes the liquid ink through a small nozzle ejecting an ink droplet. The vapour bubble cools, collapses and eventually re-condenses passing the waste internal energy to its surroundings. This collapsing bubble forms a partial vacuum and draws further ink into the nozzle chamber. The useful energy passes to the ink droplet as its kinetic energy. The ejected ink droplets typically reach speeds of 20 m s^{-1} with the whole droplet production process taking a time in the order of 20 µs. The droplet diameter is approximately 80 µm.

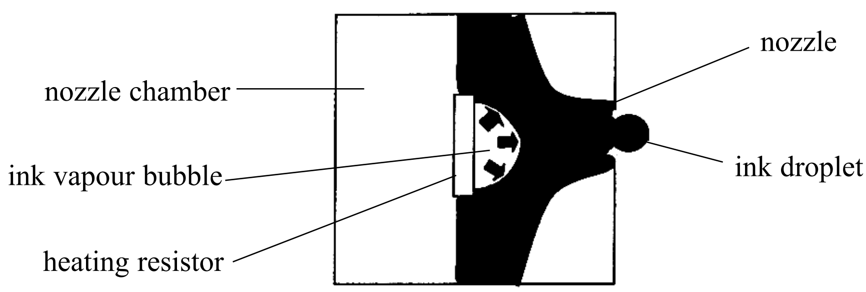

Figure 7

The ink used by ink-jet printers is usually a suspension of dye particles in water, although each printer cartridge manufacturer has its own formula for the ink. The ink density is approximately 1.1×10^3 kg m^{-3}.

Typical ink-jet printers will produce print with between 12 and 40 dots per mm.
The eye has a resolution of about 5×10^{-4} radian so the print appears to be continuous when viewed by the naked eye at a typical reading distance of 300 mm.

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Total for this question: *12 marks*

5 (a) The passage indicates that development of ink-jet technology could not progress until the break up of the jet could be controlled 'in a totally predictable way' (line 4). Give reasons why this control of the jet is necessary.

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

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(6 marks)

(b) (i) Write down an equation to represent the first law of thermodynamics, defining the terms and explaining the sign convention used.

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(3 marks)

(ii) Considering the vapour bubble itself to be a closed system explain how the first law of thermodynamics applies to the bubble pushing out ink and then cooling.

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(3 marks)

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12

Total for this question: *5 marks*

6 (a) Using the data given in line 23 show that an ink-jet printer giving print of 20 dots per mm would take approximately 4 s to print a page. Assume that the printed page is 0.20 m wide and that a single nozzle moves across the page 50 times in producing a page of print.

(3 marks)

(b) Explain what is meant by the phrase "the eye has a resolution of about 5×10^{-4} radian" (line 28) and show that even printing at 12 dots per mm leads to the print appearing continuous.

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(2 marks)

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5

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

7 (a) (i) Using the data given in lines 23 and 26 show that the mass of one ink droplet is approximately 2.9×10^{-10} kg.

(3 marks)

(ii) Each droplet moves with a speed of $20\,\mathrm{m\,s^{-1}}$. When a droplet hits the page it sticks to it. Assuming that droplets are generated at regular intervals of time, calculate the average force exerted on the page when the droplets strike it.

(3 marks)

(b) (i) Calculate the kinetic energy of the ink droplet.

(1 mark)

(ii) Using the data in lines 15 and 16, calculate the electrical energy required to produce the droplet.

(2 marks)

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(iii) Calculate the efficiency of the process used to eject the ink droplet.

(1 mark)

(iv) Suggest why the efficiency is so low and state the most likely energy transformation of the energy not used to eject the ink droplet.

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(2 marks)

12

TURN OVER FOR THE NEXT QUESTION

LEAVE MARGIN BLANK

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

8 **Figure 8** shows the parallel deflecting plates with some dimensions of the ink-jet cartridge. In order to land in the centre of the gutter the ink droplet must leave the plates at an angle of 35 °. On entering the electric field the ink droplet carries a charge of -2×10^{-10} C and travels with a horizontal velocity of 20 m s^{-1}.

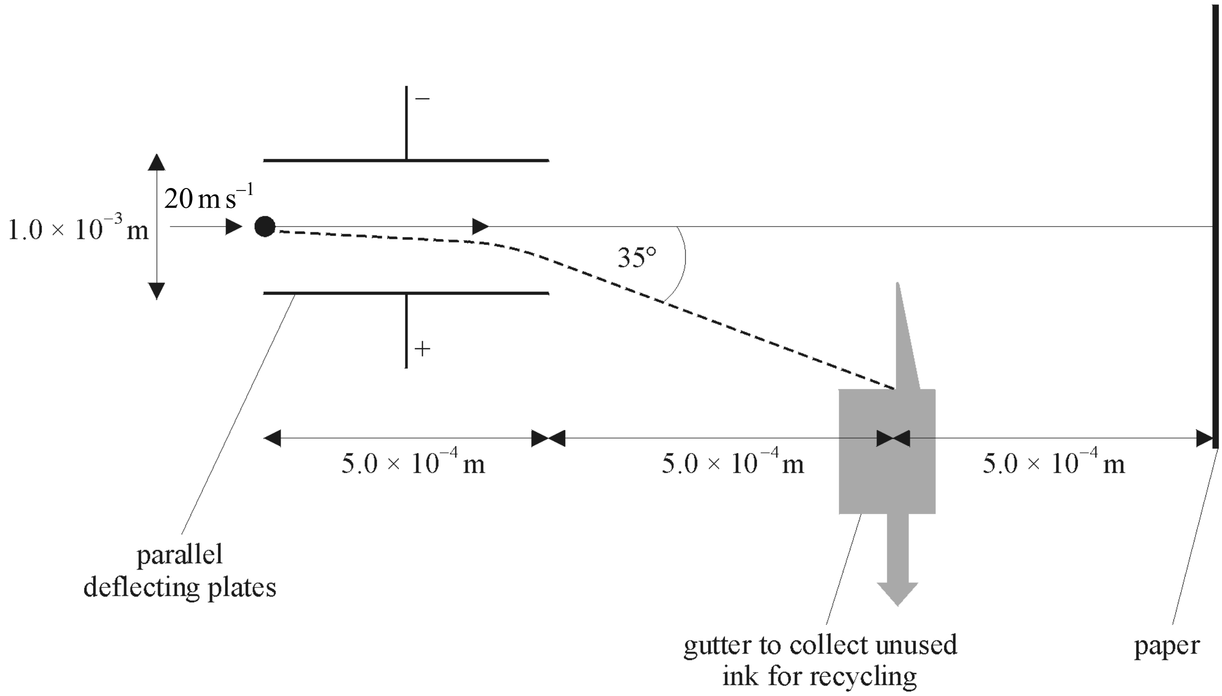

Figure 8

(a) (i) Draw a vector diagram to show the components and the resultant of the velocity of the charged ink droplet as it leaves the deflecting field. Determine the size of the vertical component.

(4 marks)

(ii) Find the time for which the ink droplet is between the deflecting plates and hence calculate its vertical acceleration during this time.

(2 marks)

(iii) For an ink droplet of mass 2.9×10^{-10} kg, calculate the electric force acting on the ink droplet whilst it is between the deflecting plates.

(2 marks)

(iv) Calculate the electric field strength between the deflecting plates.

(2 marks)

(v) Calculate the potential difference between the deflecting plates.

(2 marks)

QUESTION 8 CONTINUES ON THE NEXT PAGE

(b) The uncharged, undeflected ink droplets travel beyond the deflecting plates towards the paper. With the aid of a suitable calculation, discuss whether or not the printer manufacturer needs to take into consideration the droplet falling under gravity.

the gravitational field strength, $g = 9.8\,\mathrm{N\,kg^{-1}}$

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(4 marks)

16

END OF QUESTIONS