E and M fields

1. Electric field strength can have the units

A C m^{-1}

B N C^{-1}

C N V^{-1}

D V m

(Total 1 mark)

2. The distance, in m, from an electron at which the electric field strength equals 6.4×10^{8} J C^{-1} m^{-1} is

A 1.7×10^{-19}

B 6.0×10^{-19}

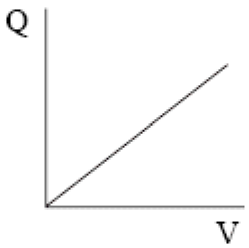
C 2.2×10^{-18}

D 1.5×10^{-9}

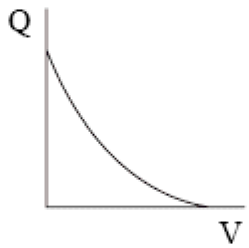
(Total 1 mark)

3. An uncharged capacitor is connected to a battery.

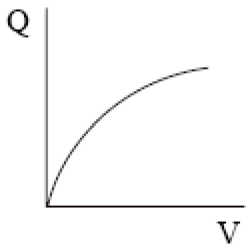
Which graph shows the variation of charge with potential difference across the capacitor?



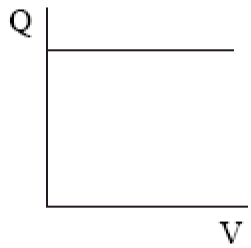
A



B



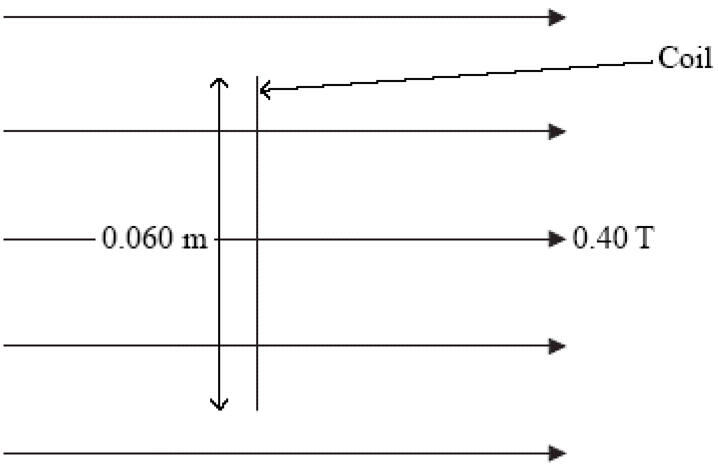
C



D

(Total 1 mark)

4. A 50 turn square coil, side 0.060 m, is placed in a magnetic field of flux density 0.40 T. The plane of the coil is at right angles to the direction of the magnetic field.



The flux linkage with the coil is

A 0.072 Wb

B 0.45 Wb

C 1.2 Wb

D 333 Wb

(Total 1 mark)

5. The diagram shows the path of an electron in a bubble chamber.

Which of the following can you deduce from the diagram?

A The electron is moving anti-clockwise.

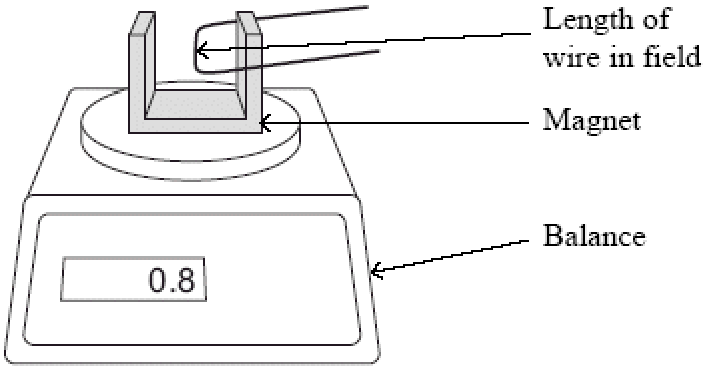
B The electron is moving clockwise.

C The magnetic field is acting out of the page.

D The speed of the electron is increasing.

(Total 1 mark)

6. The diagram shows a horizontal wire which is at right angles to a magnetic field. The magnetic field is produced by a horseshoe magnet which is on a balance adjusted to read zero when the current in the wire is zero.



When the current is 4 A, the reading on the balance is 0.8 gram.

The length of wire in the magnetic field is 0.05 m.

Calculate the average magnetic flux density along the length of the wire.

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Magnetic flux density = ...

(Total 3 marks)

7. Faraday's and Lenz's laws are summarised in the list of formulae as

$$\varepsilon = -\frac{d(N\phi)}{dt}$$

(a) State the meaning of the term *Nø*.

....

....
(2)

(b) Explain the significance of the minus sign.

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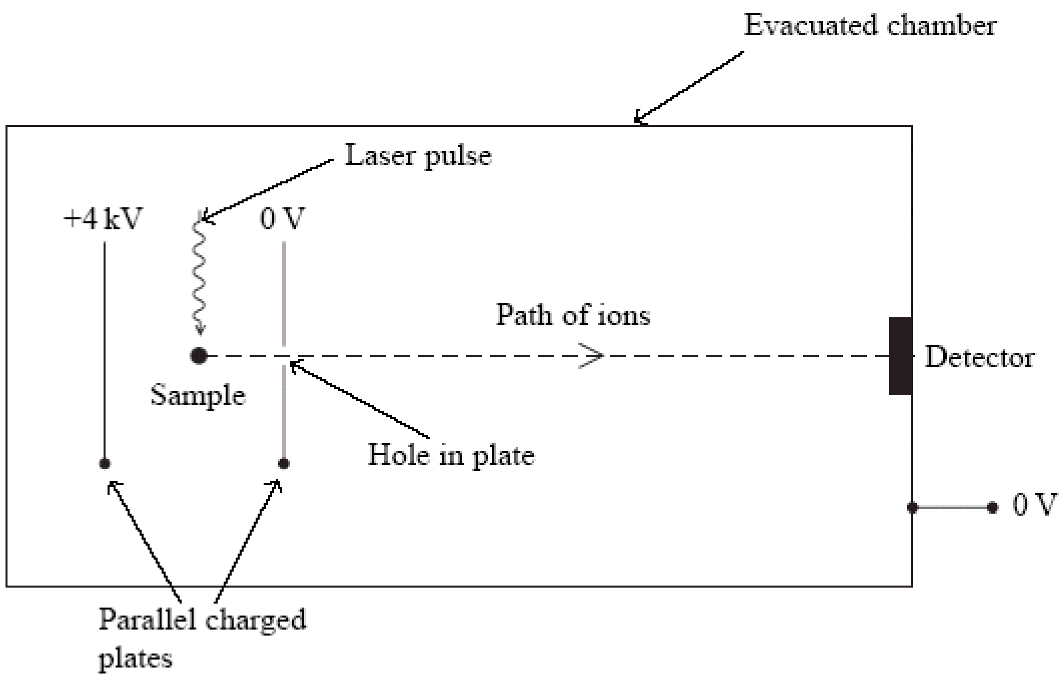
(3)
(Total 5 marks)

8. Time-of-flight mass spectroscopy uses the arrangement below to measure the mass of molecules. A laser pulse knocks an electron out of a molecule in a sample leaving it as a positively charged ion.



(a) Add to the diagram to show the electric field lines between the two plates.

(3)

(b) The sample is midway between the charged plates. Show that the speed, *v*, of an ion as it reaches the hole in the plate is given by

$$v = \sqrt{\frac{6.4 \times 10^{-16} \text{ joule}}{m}}$$

where *m* is the mass of the molecule in kg.

....

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(3)

(c) The distance between the hole in the plate and the detector is 1.5 m. The time taken for a molecule to cover this distance is 23 μs.

Calculate the mass of this molecule.

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Mass = ...

(3)

(d) There is some uncertainty in the time a molecule with a particular mass will take to cover this distance.

Suggest **two** reasons for this.

1. ....

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2. ....

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(2)
(Total 11 marks)

9. Figure 1 shows the output from the terminals of a power supply labelled d.c. (direct current).

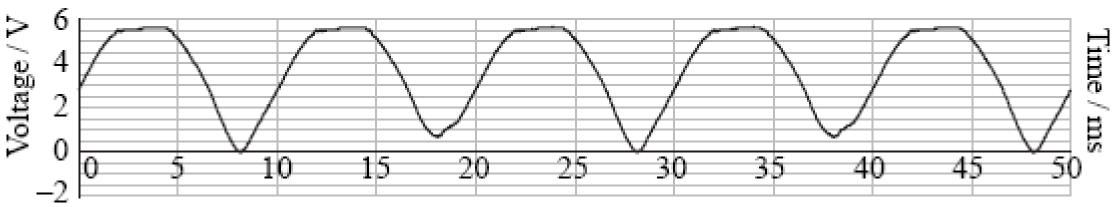

Figure 1

(a) An alternating current power supply provides a current that keeps switching direction.

Explain why the output shown in Figure 1 is consistent with the d.c. label.

....

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....

(2)

(b) A teacher suggests that certain electronic circuits require a constant voltage supply to operate correctly.

(i) A student places a capacitor across the terminals of this power supply. Suggest how this produces a constant voltage.

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(2)

(ii) She uses a 10 μF capacitor. Calculate the maximum energy stored in the capacitor.

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Maximum Energy = ...

(3)

(c) She now adds an electronic circuit to the power supply plus capacitor. Figure 2 shows the supply to the electronic circuit. This is shown in Figure 2.

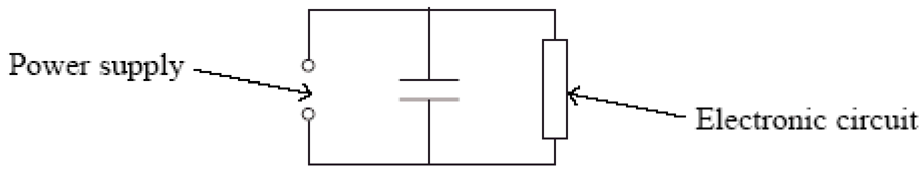

Figure 2

The variation in potential difference is shown by the graph in Figure 3.

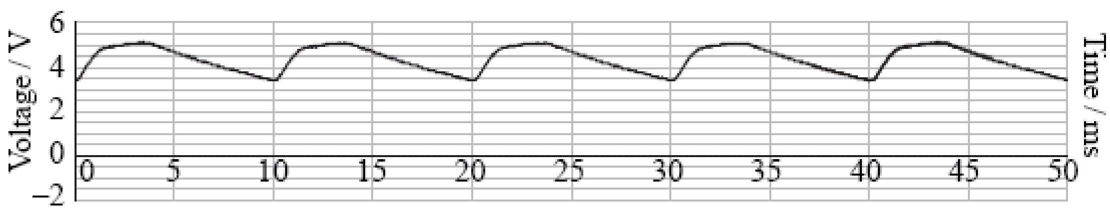

Figure 3

(i) Explain the shape of this graph.

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(3)

(ii) Take readings from the graph to show that the resistance of the electronic circuit is in the range 1000 Ω to 2000 Ω.

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(3)

(iii) Figure 3 shows that the voltage supplied to the electronic circuit still varies. How could the student make it more constant?

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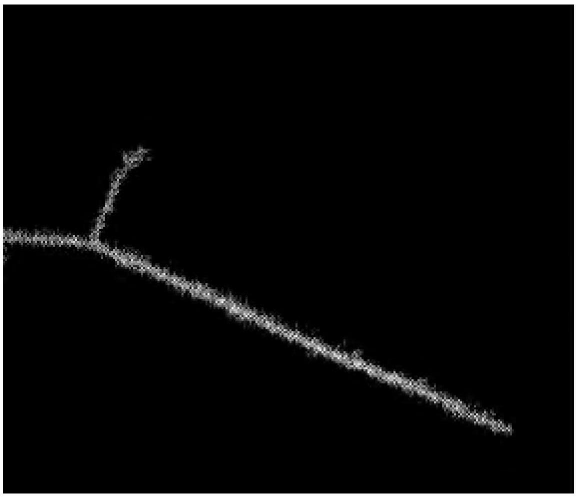
(1)
(Total 14 marks)

10. A low-energy particle collides elastically with a stationary particle of the same mass. The particle enters from the left of the photograph.



(a) State what is meant by collides *elastically*.

....

.... **(1)**

(b) Sketch a labelled vector diagram to show how the momentum of the initial moving particle relates to the momenta of the two particles after the collision.

(2)

(c) Use your answers to (a) and (b) to confirm that the angle between the subsequent paths of both particles must be 90°.

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....

.... **(2)**

(d) (i) Explain the process by which a proton is given energy in a particle accelerator.

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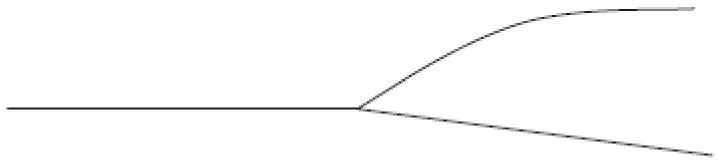
The diagram shows a collision between a high-energy proton (track from the left) and a stationary proton in a particle accelerator experiment.



(3)

(ii) Explain why the angle between the two paths is not 90°.

....

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(2)

(e) Deduce the direction of the magnetic field in this particle accelerator experiment. Circle the correct direction from those given below.

left to right across the paper   out of the plane of the paper   into the plane of the paper

(1)
(Total 11 marks)

11. The potential difference across a capacitor is V. The energy stored on the capacitor is X joules. The potential difference across this capacitor is increased to 3 V. The energy stored, in joules, is increased to

A 3X

B 6X

C 9X

D 27X

(Total 1 mark)

12. Figure 1 shows a vertical plane square coil of 50 turns, carrying a current of 3.0 A. The length of each side of the coil is 4.0 cm. Figure 2 shows a view of this coil from above within a horizontal magnetic field of flux density 0.20 T.

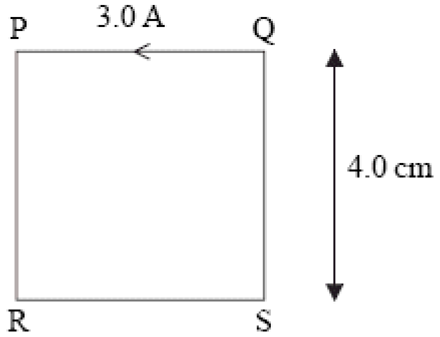


Figure 1

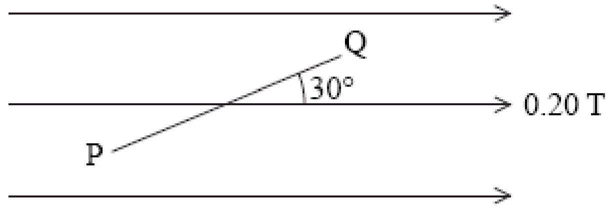


Figure 2

The force on side QS is

A 120 N

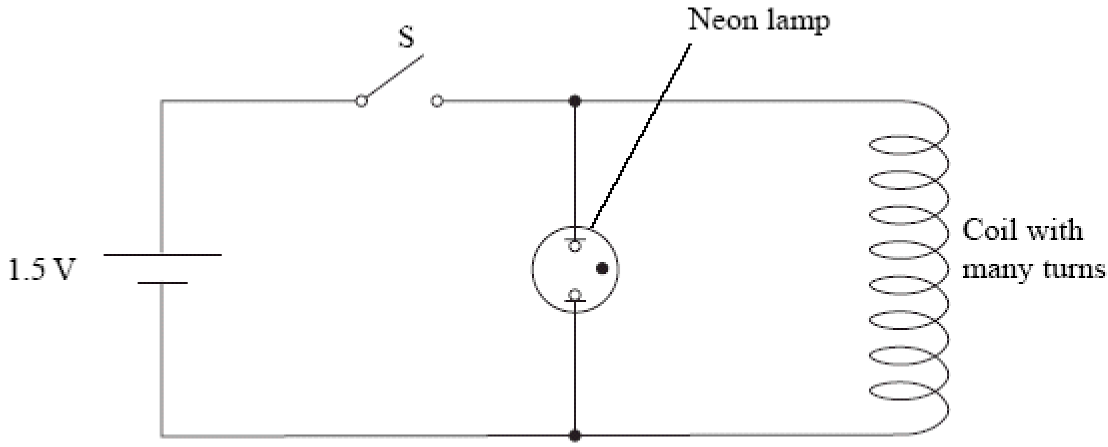
B 60 N

C 1.2 N

D 0.60 N

(Total 1 mark)

13. A 1.5 V cell is connected to a switch S, a neon lamp and a coil with many turns as shown. Nothing is observed when the switch is closed but the neon lamp flashes as soon as it is opened. The neon lamp flashes when the potential difference across it is about 200 V.



Use Faraday's law to explain why the lamp flashes once when the switch S is **opened**.

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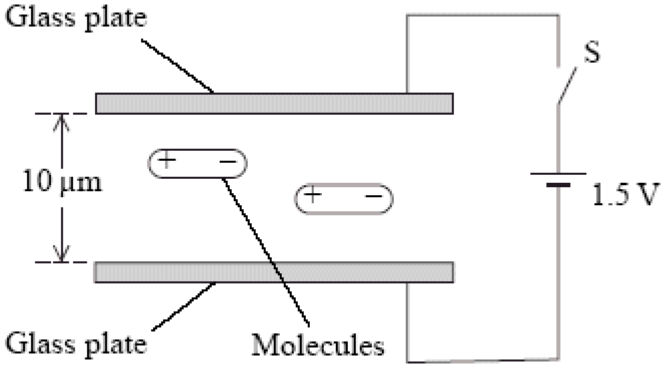
(Total 4 marks)

14. Liquid crystal displays (LCDs) are made from two parallel glass plates, 10 μm apart, with liquid crystal molecules between them. The glass is coated with a conducting material.



The molecules are positive at one end and negative at the other. They are normally aligned parallel with the glass plates as shown.

The switch S is closed and 1.5 V is applied across the glass plates.

(a) Calculate the electric field strength between the plates.

....

....

....

Electric field strength = ...

(2)

(b) Explain what happens to the liquid crystal molecules.

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(3)
(Total 5 marks)

15. The diagram represents a proton.

(a) Draw lines to represent its electric field.

(3)

(b) Calculate the electrostatic force on the electron in a hydrogen atom.

Average distance between proton and electron = 5.4×10^{-11} m

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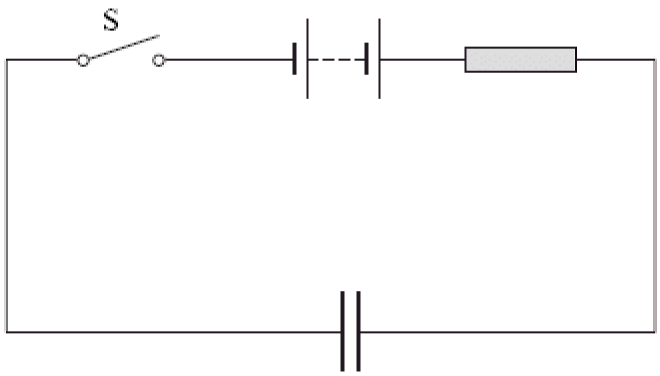
Force = ...

(3)
(Total 6 marks)

16. An uncharged capacitor is connected into a circuit as shown.



(a) Describe what happens to the capacitor when the switch S is closed.

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....

(2)

(b) A student models the behaviour of the circuit using a spreadsheet. The student uses a 100 μF capacitor, a 3.00 kΩ resistor and 5.00 V power supply. The switch is closed at time t = 0 s.

	A	B	C	D	E
1	t / s	I / mA	ΔQ / μC	Q / μC	p.d. across capacitor/V
2	0	1.67	167	167	1.67
3	0.1	1.11	111	278	2.78
4	0.2	0.74	74	352	3.52
5	0.3	0.49	49	401	4.01
6	0.4	0.33	33	434	4.34
7	0.5	0.22	22	456	4.56
8	0.6	0.15	15	471	4.71
9	0.7	0.10	10	480	4.80
10	0.8	0.07	7	487	4.87

(i) Explain how the value in cell C4 is calculated.

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....
(2)

(ii) Explain how the value in cell E3 is calculated.

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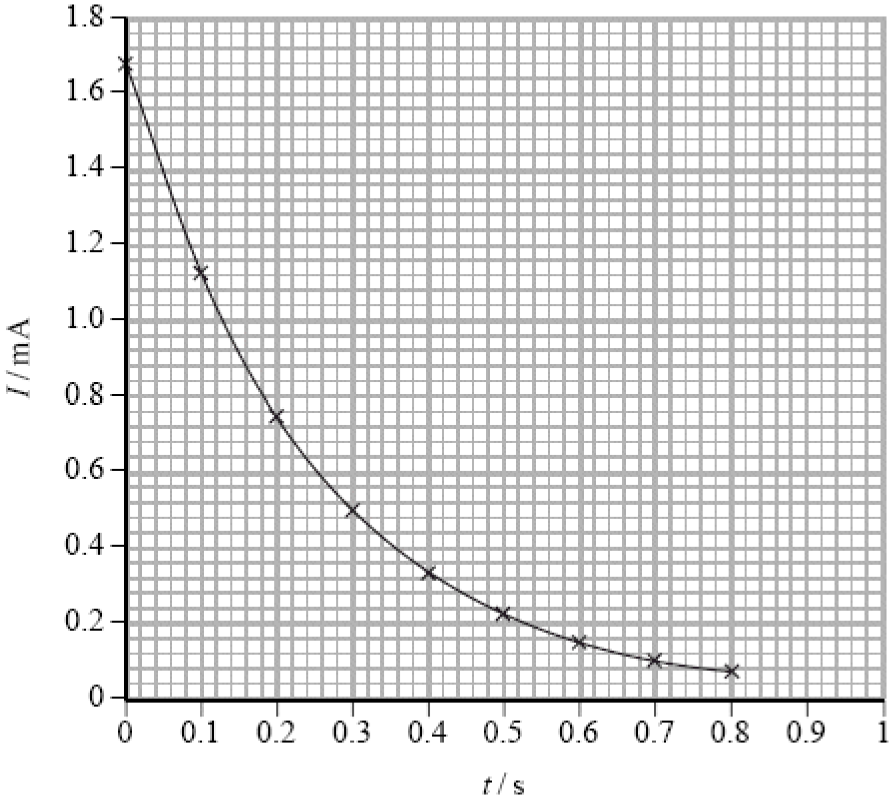
(2)

(c) The graph shows how the spreadsheet current varies with time.



(i) Use the graph to show that the time constant is approximately consistent with the component values.

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(4)

(ii) The student thinks that the graph is an exponential curve. How would you use another graph to confirm this?

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(3)
(Total 13 marks)

17. Which of the following is the same unit as the farad?

A Ω s

B Ω s^{-1}

C Ω^{-1} s

D Ω^{-1} s^{-1}

(Total 1 mark)

18. An emf will only be induced across the wing tips of an aircraft if it is flying horizontally in

A a north-south direction

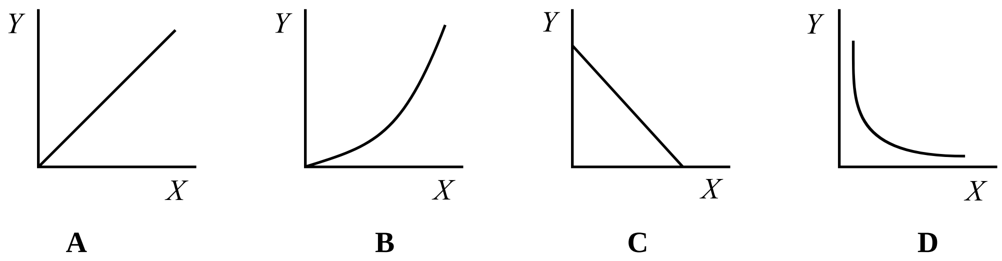
B an east-west direction

C a region where there is a horizontal component of the earth's magnetic field

D a region where there is a vertical component of the earth's magnetic field.

(Total 1 mark)

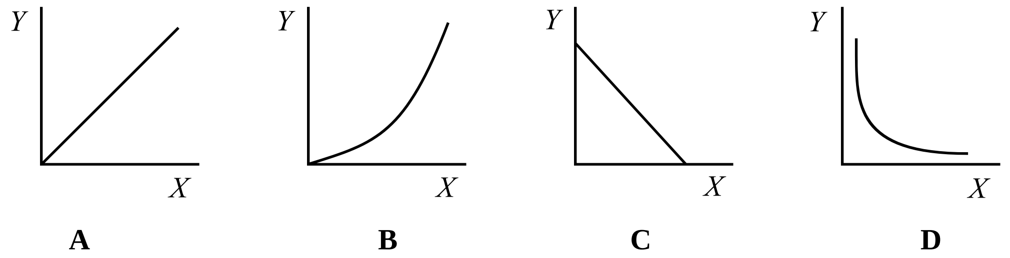
19. The following are four possible graphs of a quantity *Y* plotted against another quantity *X*.



Which graph **best** represents *Y* when it is the electric field strength between two parallel plates with a constant potential difference across them and *X* is the distance apart of the plates?

(Total 1 mark)

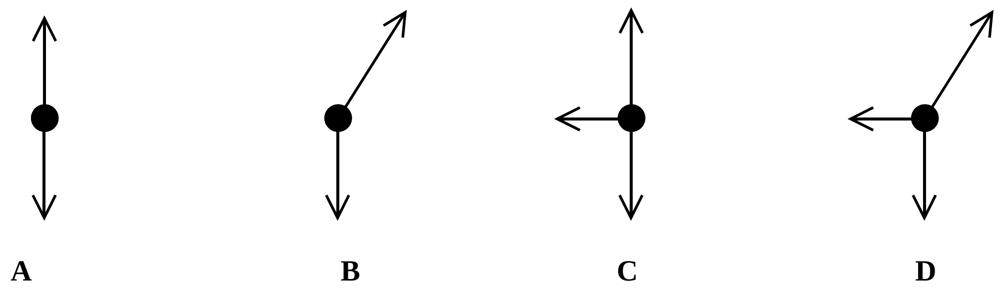
20. The following are four possible graphs of a quantity *Y* plotted against another quantity *X*.



Which graph **best** represents *Y* when it is the radius of the circle described by an electron in a constant magnetic field at right angles to the path of the electron and *X* is the momentum of the electron?

(Total 1 mark)

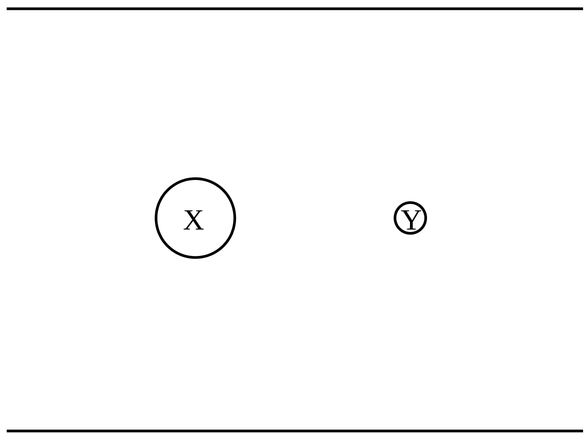
21. Each of the diagrams below is a free-body force diagram representing the forces acting on a body.



Which diagram best illustrates the forces acting on a charged sphere, supported on a nylon thread, in equilibrium alongside a second similarly charged sphere?

(Total 1 mark)

22. The diagram shows two charged spheres X and Y, of masses 2*m* and *m* respectively, which are just prevented from falling under gravity by the uniform electric field between the two parallel plates.



Which of the following is a property of a **uniform** electric field?

A The field strength is the same at all points.

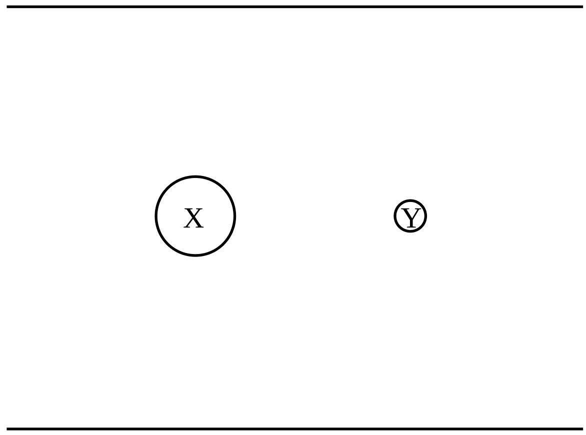
B The field acts equally in all directions.

C The field produces no force on a stationary charged particle.

D The field produces a force on a moving charged particle which is always perpendicular to its direction of travel.

(Total 1 mark)

23. The diagram shows two charged spheres X and Y, of masses 2*m* and *m* respectively, which are just prevented from falling under gravity by the uniform electric field between the two parallel plates.



If the plates are moved closer together

A X and Y will both remain stationary.

B X and Y will both move upwards with the same acceleration.

C X will have a greater upward acceleration than Y.

D Y will have a greater upward acceleration than X.

(Total 1 mark)

24. (a) A 2200 μF capacitor is charged to a potential difference of 12 V and then discharged through an electric motor. The motor lifts a 50 g mass through a height of 24 cm.

(i) Show that the energy stored in the capacitor is approximately 0.16 J.

Energy = ...

(2)

(ii) What is the efficiency of the electric motor in this situation?

Efficiency = ...

(2)

(b) The capacitor is charged to 12 V again and then discharged through a 16 Ω resistor.

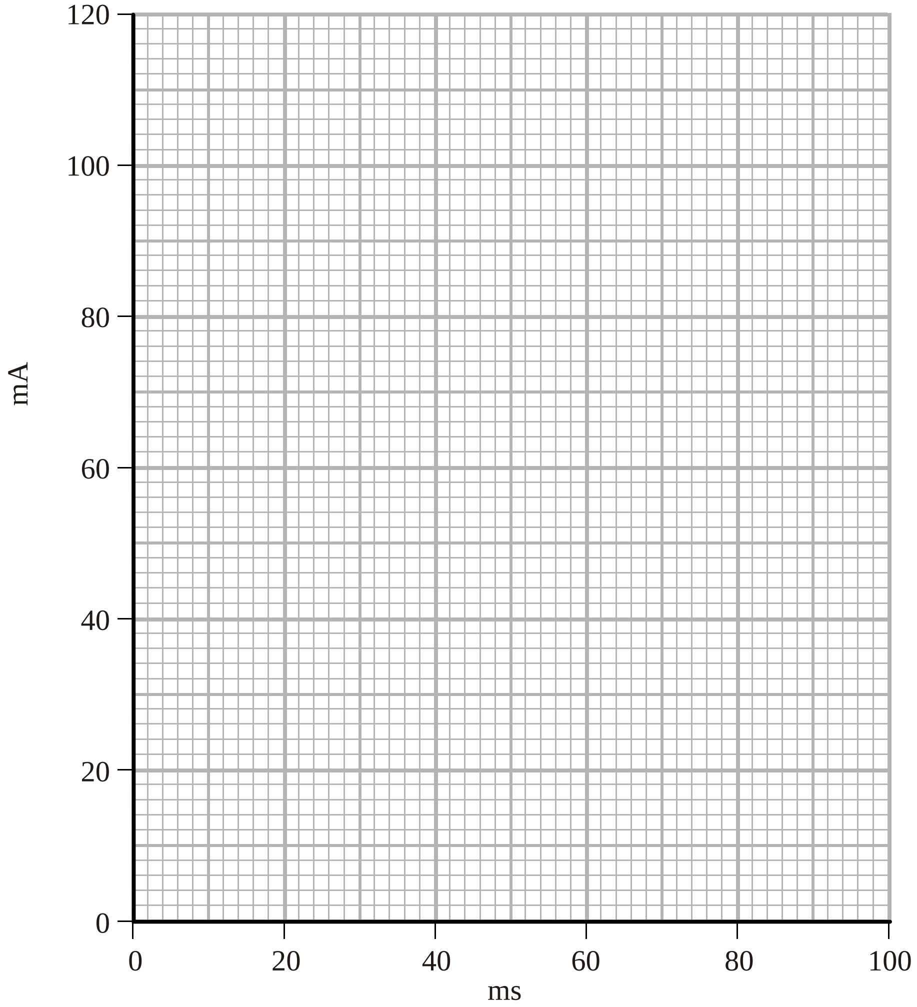
(i) Show that the time constant for this discharge is approximately 35 ms.

....

....

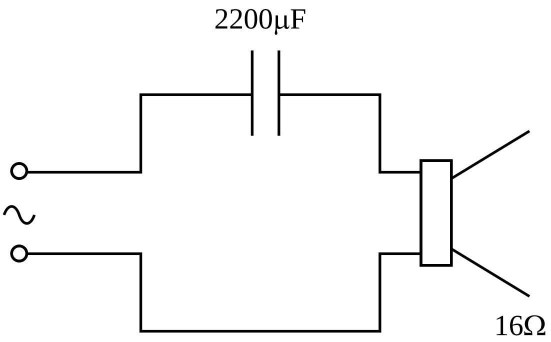
(1)

(ii) Sketch a graph of current against time for this discharge on the grid below. You should indicate the current at t = 0 and t = 35 ms.



(3)

(c) Capacitors are used in audio systems when connecting the amplifier to the loudspeaker. In one such circuit the capacitor has a value of 2200 μF and the loudspeaker has a resistance of 16 Ω.



(i) The loudspeaker produces longitudinal waves. What is meant by longitudinal in this context?

....

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....

(2)

(ii) Ideally, the time constant for such a circuit should be much greater than the time period of the lowest frequency note. Discuss the extent to which this circuit would be effective if the lowest frequency note is 20 Hz.

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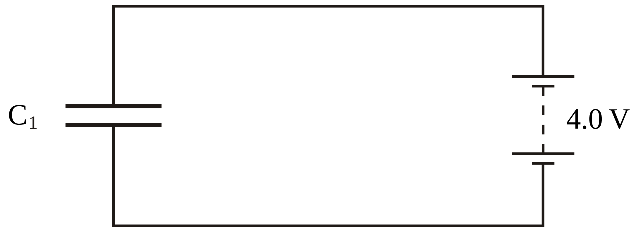
(2)

(Total 12 marks)

25. A capacitor C_1 is connected to a supply. When a potential difference of 4.0 V is applied across the capacitor, it stores a charge of 0.80 nC.



(a) (i) Calculate the electrical work done by the supply as it transfers this charge.

....

....

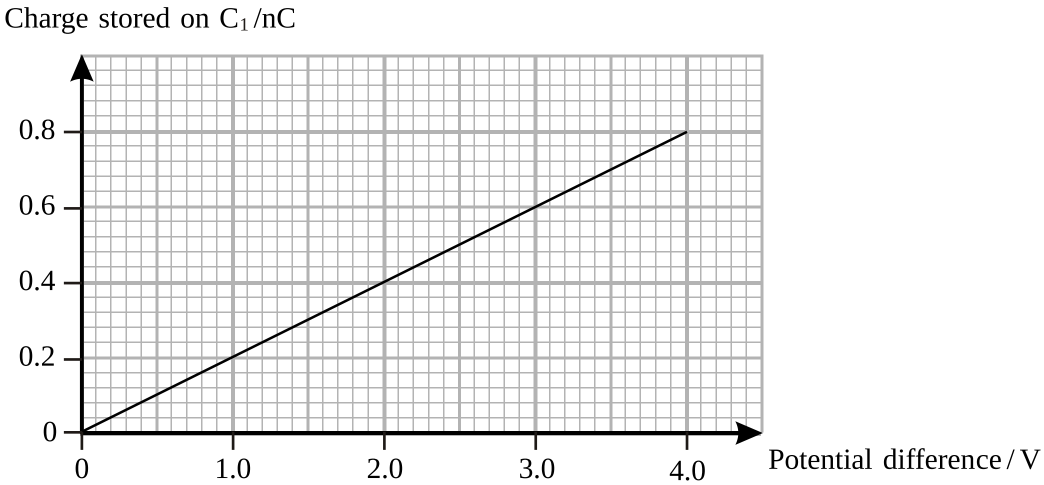
Work done = ...

(2)

(ii) Mark on the diagram above the magnitudes and polarities of the charges stored on the plates of the capacitor.

(1)

(b) A graph of charge stored against potential difference across the capacitor is shown.



Explain how this graph supports the fact that the charged capacitor is storing 1.6 nJ of energy.

....

....

....

(2)

(c) With capacitor C_1 charged to 4.0 V, the supply is removed and a second, uncharged capacitor C_2 is connected in its place as shown.

Capacitor C_1 transfers some of its charge to the plates of capacitor C_2. As a result the potential difference across C_1 falls to 3.0 V.

(i) By referring to the graph for capacitor C_1, deduce how much charge transfers to capacitor C_2.

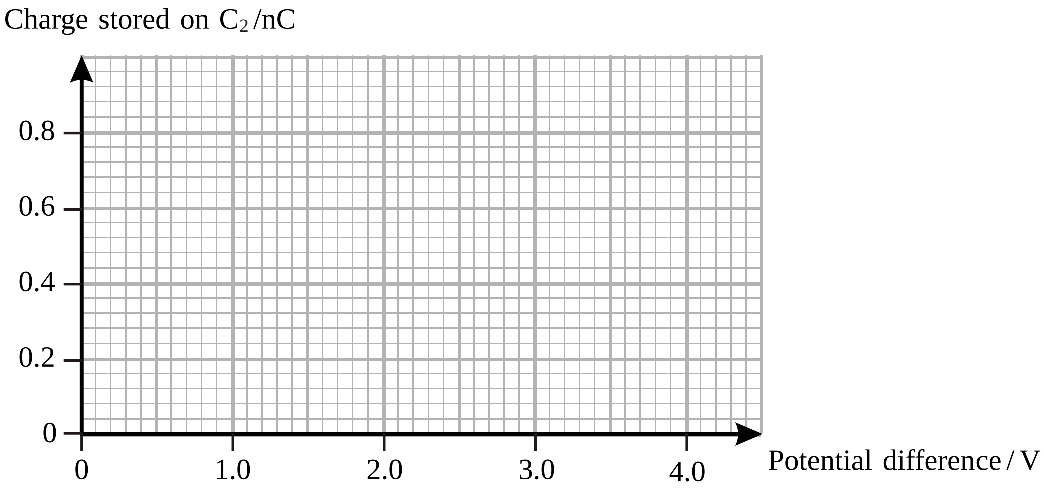
....

....

Charge transferred to C_2 = ...

(1)

(ii) On the grid below, show how the charge stored on capacitor C_2 varies with potential difference during this charge transfer process.



(2)

(iii) Use the values you have plotted to find the capacitance of capacitor C_2.

....

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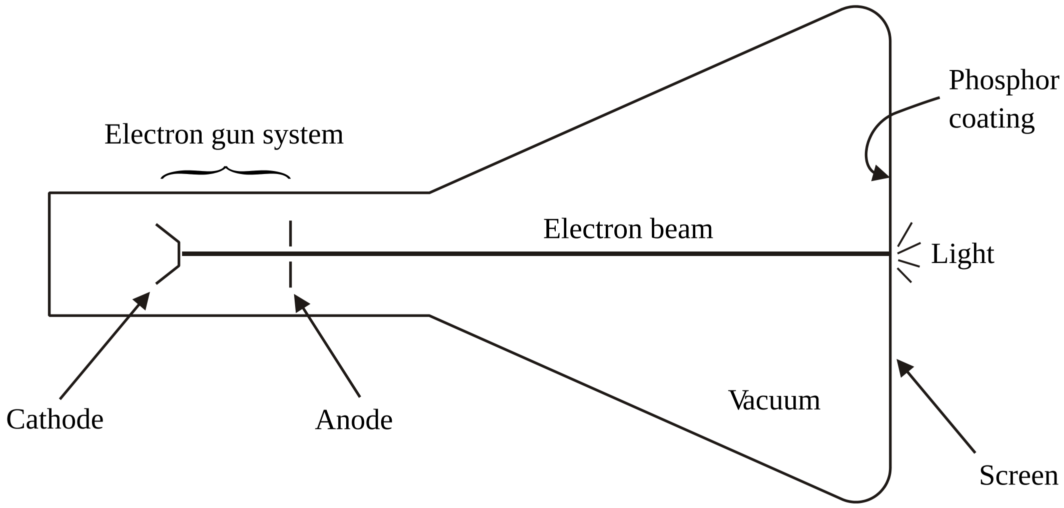
....

Capacitance of C_2 = ...

(2)
(Total 10 marks)

26. A simplified diagram of a cathode ray oscilloscope is shown.



(a) Electrons liberated from the cathode are accelerated to the anode through a large potential difference, giving each electron in the beam an energy of 1.2 keV.

(i) Calculate the velocity of electrons in the beam.

....

....

....

....

Velocity = ...

(3)

(ii) The phosphor coating produces green light, each photon of which has an energy of 2.4 eV. The efficiency of the conversion of electron kinetic energy to light in the phosphor is 8.0%. Calculate the number of photons that will be liberated from the phosphor coating by the arrival of one electron in the beam.

....

....

....

....

Number of photons = ...

(2)

(b) In a badly-designed cathode ray tube, electrons arriving at the screen are not conducted away but build up in the area where the beam hits it. Explain how this will have an adverse effect on the amount of light emitted by the phosphor. You may be awarded a mark for the clarity of your answer.

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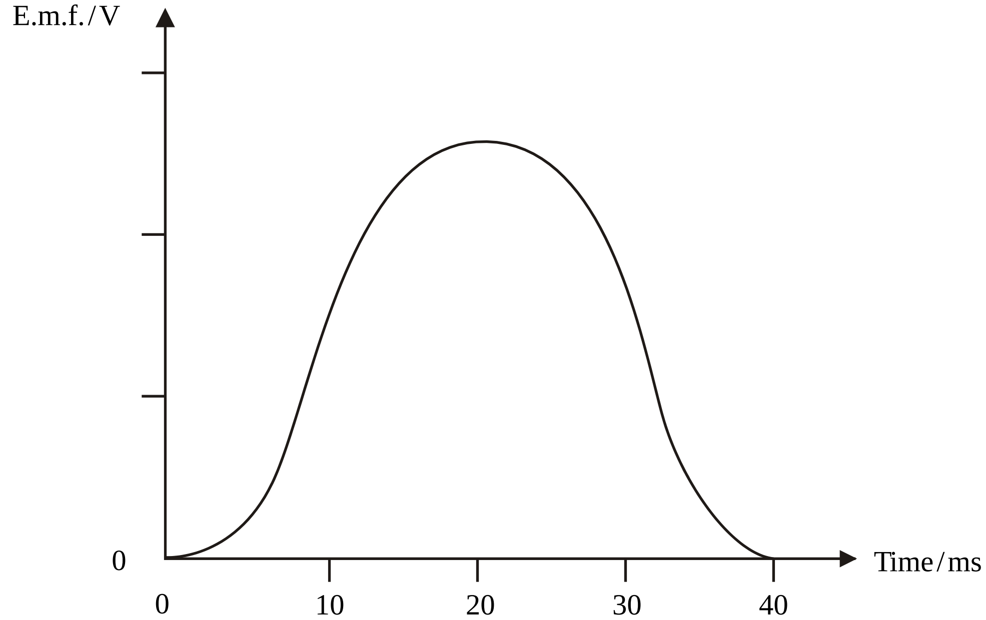
(4)
(Total 9 marks)

27. A small 'search coil', connected to a data-logger, is used to investigate a steady magnetic field. The coil is placed so that the field is perpendicular to the plane of the coil. The coil is then turned through 90° in 40 ms, finishing with its plane parallel to the field. This induces an e.m.f. across the ends of the coil.

The data-logger indicates that the **mean** value of the e.m.f. during the process is 0.12 V.

It also displays the following trace.



(a) Add an appropriate scale to the vertical axis on the graph above.

(1)

(b) The search coil has 5000 turns.

(i) The mean e.m.f. induced during the rotation is 0.12 V. Show that the magnetic flux through the coil before rotation was approximately 1 μWb.

....

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(2)

(ii) The coil has a diameter of 1.0 cm. Calculate the magnetic flux density of the magnetic field in which the coil is rotated.

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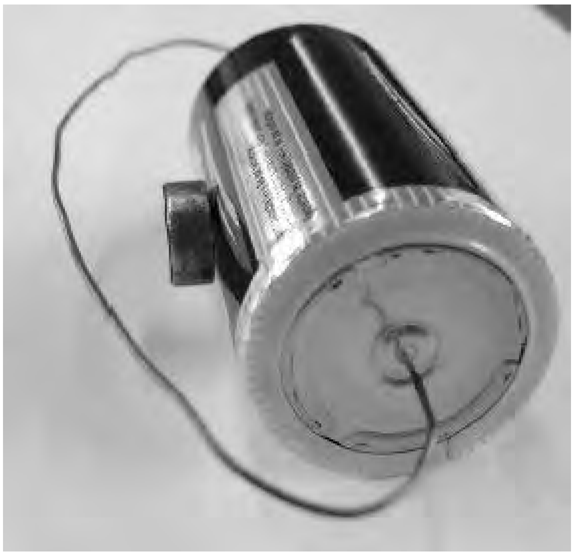
....

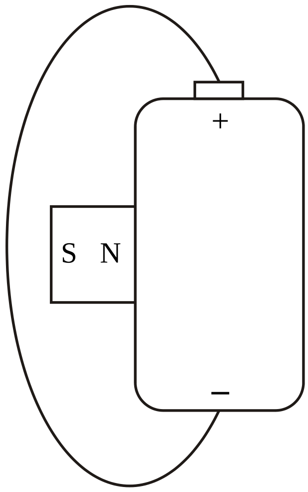
Magnetic flux density = ...

(2)
(Total 5 marks)

28. The photograph shows a flexible copper wire attached to the terminals of a dry cell. A strong circular magnet, 12 mm in diameter, is attached to the side of the cell. The interaction between the current in the wire and the magnetic field of the magnet causes the wire to levitate.



The diagram shows the arrangement viewed from above.



NOT TO SCALE

(a) Draw on the diagram the magnetic field produced by the magnet.

(2)

(b) The following measurements were made:

upward force on wire = 8.0×10^{-3} N

current in wire = 5.8 A

length of wire in magnetic field = 12mm

(i) Show that the magnetic flux density is about 0.1 T.

....

....

....

....

....

(2)

(ii) State one assumption you made in your calculation.

....

....

(1)

(c) The manufacturer's data sheet supplied with the magnets gives a value of 0.3 T for the magnetic flux density. Suggest a reason why this is different from the value given in (b)(i).

....

....

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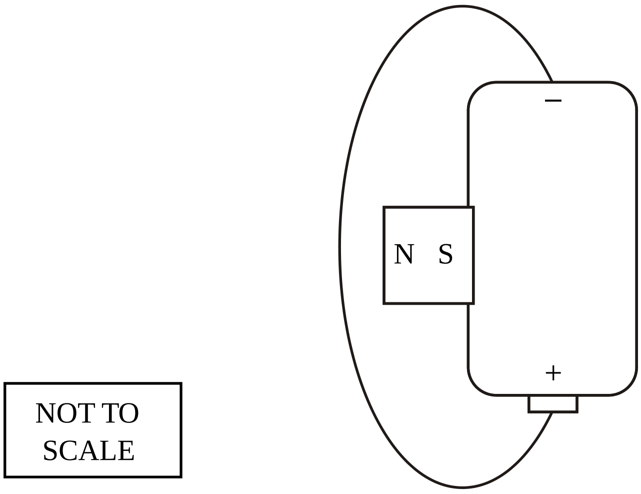
....

....

(1)

(d) Explain what would happen to the wire in the following arrangement.



....

....

....

....

....

(2)
(Total 8 marks)

29. Devices which contain electrically charged grids are sometimes used to control the numbers of flying insects. The grids are connected to capacitors that store charge at a high voltage.

(a) Explain why a capacitor cannot be charged directly from the mains supply.

....

....

....

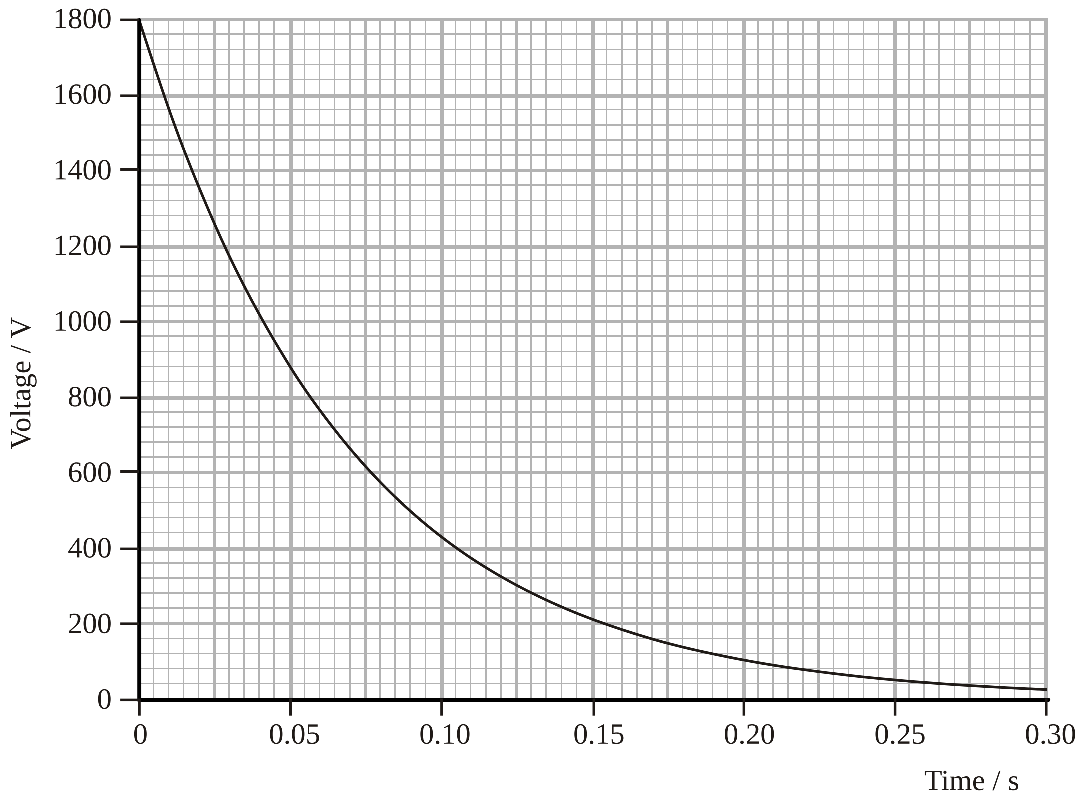
....

....

(2)

(b) A user reports on his device in a magazine: "The grids in my device didn't work very well, so I opened it up to have a look. I found that it only produced a voltage of 600 V, which was too low. I replaced it with a circuit that charged a 100 nF capacitor to 1800 V. This worked better."

The graph shows how the voltage across the 100 nF capacitor varies with time as it discharges through an insect.



(i) Use the graph to estimate the time constant for the circuit containing the capacitor and the insect.

....

....

....

Time constant = ...

(2)

(ii) Calculate a value for the resistance of the insect.

....

....

....

....

Resistance = ...

(2)

(c) The user continues: "The manufacturers have recently introduced a new device incorporating a capacitor of 100 μF charged to 300 V."

(i) Calculate the charge stored on this capacitor when fully charged.

....

....

....

....

Charge = ...

(2)

(ii) Calculate the energy stored in this capacitor when fully charged.

....

....

....

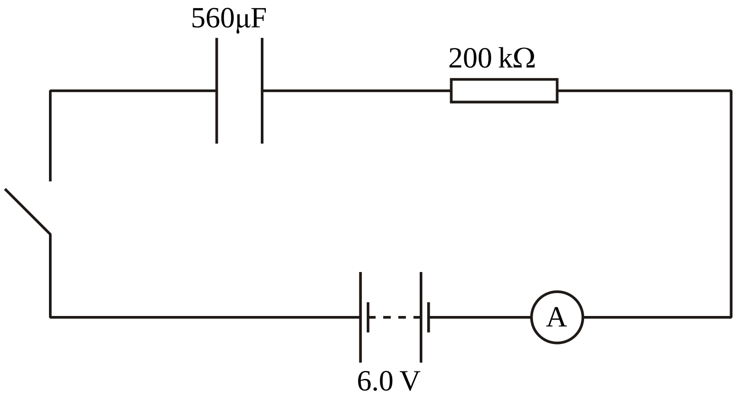
....

Energy stored = ...

(2)

(Total 10 marks)

30. The diagram shows a capacitor and a resistor connected to a 6.0 V battery. Both the ammeter and the battery have negligible internal resistance.



The switch is closed. Some time later the ammeter reads 20 µA.

(a) Show that the potential difference across the capacitor at this instant is 2.0 V.

....

....

....

....

(2)

(b) Calculate the charge stored in the capacitor when the potential difference across it is 2.0 V.

....

....

Charge = ...

(2)

(c) Calculate the electrical energy now stored in the capacitor.

....

....

Electrical energy stored = ...

(1)

(d) Calculate the electrical energy transferred in the battery up to this instant.

....

....

Electrical energy transferred = ...

(1)

(e) What is the main reason for the difference between the energy values you have calculated in (c) and (d)?

....

....

....

(1)
(Total 7 marks)

31. (a) A proton has a mass of 1.67×10^{-27} kg. Calculate the magnitude of the potential difference needed to accelerate it from rest to a speed of 2.77×10^{5} ms^{-1} in a vacuum.

....

....

....

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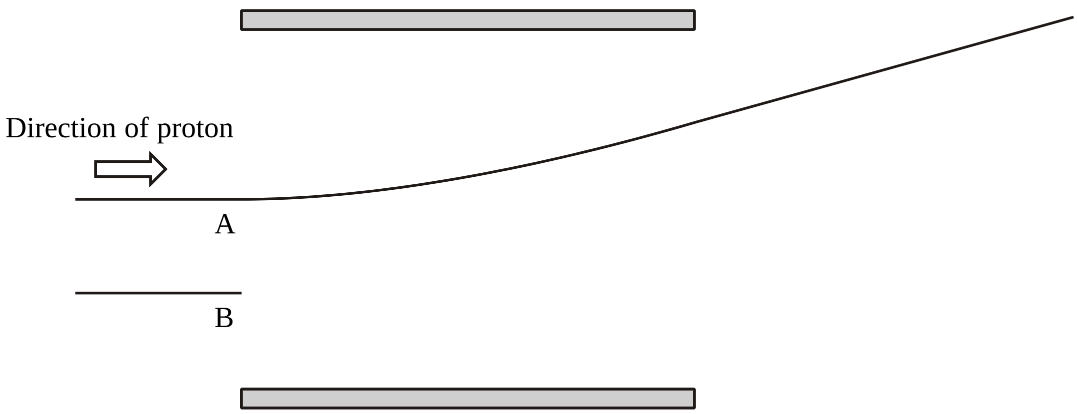
....

....

Potential difference = ...

(3)

(b) The proton now passes the point A between two parallel conducting plates across which a steady potential difference is maintained. The path of the proton is shown in the diagram.



Add to the diagram the path the same proton would have taken had it entered at the point B.

(1)

(c) (i) An alpha particle enters at point A with the same velocity as the proton. Add its path to the diagram.

(2)

(ii) Explain your answer to (c)(i).

....

....

....

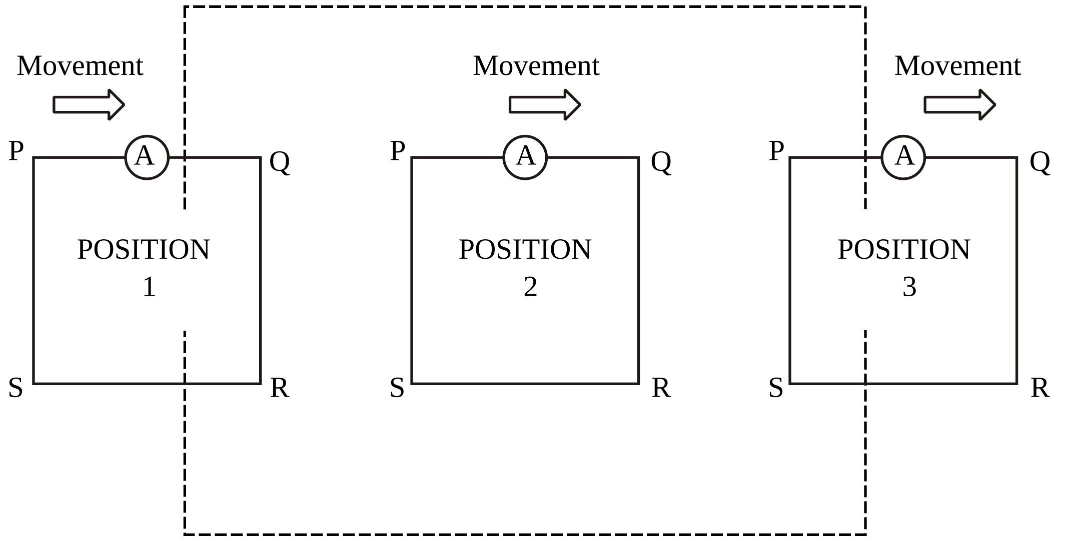
....

....

(2)
(Total 8 marks)

32. A square rigid metal frame PQRS, of side 12 cm, forms a closed circuit with an ammeter.

The area enclosed by the dotted line is a region of uniform magnetic field of flux density 2.0×10^{-2} T. The field is confined to this area and directed into the page.



(a) The frame is moved at a constant speed of 5.0 cm s^{-1} through the uniform magnetic field region as shown in the diagram.

(i) For each position of the frame shown in the diagram either give the direction of the current through the ammeter, or if there is no current, state 'no current'.

Position 1 = ...

Position 2 = ...

Position 3 = ...

(2)

(ii) The total electrical resistance of the frame and ammeter is 2.0 Ω. Calculate the maximum current recorded by the ammeter.

....

....

....

....

....

....

Maximum current = ...

(4)

(b) The frame is now moved with uniform acceleration through the magnetic field. Explain how the magnitude of the current changes as the frame moves from position 1, through position 2 to position 3. You may be awarded a mark for the clarity of your answer.

....

....

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....

(4)
(Total 10 marks)

33. Research suggests that big capacitors may soon be able to act alongside batteries as a way of storing significant amounts of energy. Researchers used a capacitor of capacitance 2500 F.

One part of the research concerns the leakage of charge through the insulating material between the two capacitor plates.

In one experiment, researchers charged the 2500 F capacitor to a potential difference (p.d.) of 8.00 V.

(a) Calculate how much energy this capacitor stores when charged to a p.d. of 2.0 V.

....

....

....

....

....

Energy = ...

(2)

They then measured the p.d. across the plates every ten days.

The first two columns in the table are the results they obtained.

Time / days	p.d. across plates/ V	ln(p.d. / V)
0	8.00	2.08
10	6.32	1.84
20	5.04	
30	4.00	
40	3.20	

They suspect that the p.d. is falling exponentially with time. To check this idea, they first find the natural logarithms of all the p.d. values, and enter them in the third column of the table.

(b) Complete the table by filling in the three remaining natural logarithm values.

(2)

(c) Plot an appropriate graph on the grid below to show that the p.d. is falling exponentially.

(4)

(d) Use your graph to find a value for the resistance of the insulating material between the plates of the capacitor.

....

....

....

....

....

....

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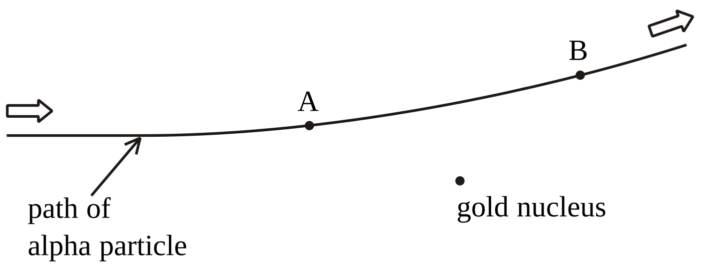
....

....

Resistance = ...

(4)
(Total 12 marks)

34. The diagram shows the path of an alpha particle, ${}^{4}_{2}He$, as it closely approaches and then moves away from a gold nucleus, ${}^{197}_{79}Au$.



(i) Add to the diagram the direction of the electric force acting on the alpha particle at each of the points A and B.

(1)

(ii) At point A the distance of the alpha particle from the nucleus is 1.5×10^{-13} m. Calculate the magnitude of the force acting on the alpha particle at this point.

....

....

....

....

....

....

Magnitude of force = ...

(3)

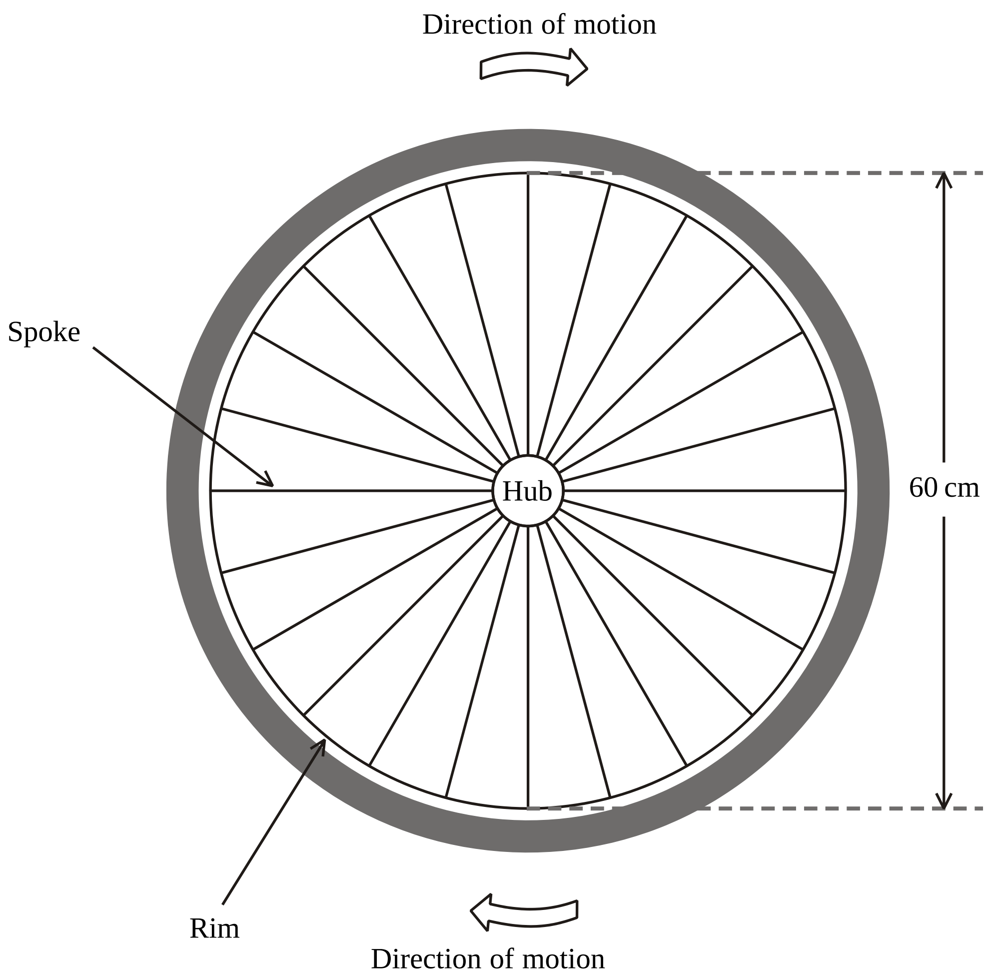
(iii) How does the speed of the alpha particle vary as it moves from A to B?

....

....

(1)
(Total 5 marks)

35. A student is experimenting with a bicycle wheel. He turns the bicycle upside down and spins the wheel in a vertical plane at a constant rate. The diagram shows the wheel. At the place where the experiment is performed, the Earth's magnetic field is in a horizontal direction. It acts into and perpendicular to the paper.



(a) A constant e.m.f. is induced across the length of each spoke.

(i) Label the hub and rim either plus or minus to show the polarity of the e.m.f.

(1)

(ii) Explain why a constant e.m.f. is induced.

....

....

....

....

(2)

(iii) The magnitude of the e.m.f. is 25 μV. Calculate the time it takes for the wheel to complete one revolution. Assume the area of the hub is negligible.

Assume that the Earth's magnetic flux density has a value of 2.8×10^{-5} T.

....

....

....

....

....

Time = ...

(3)

(b) State and explain what effect, if any, there would be on the magnitude of this e.m.f. in each of the following cases.

(i) The student turns the bicycle so that the wheel is still spinning in a vertical plane, but the plane is now at 45° to the Earth's field.

....

....

....

(ii) The student causes the wheel to accelerate.

....

....

....

(iii) The student turns the bicycle so that the wheel spins in a horizontal plane.

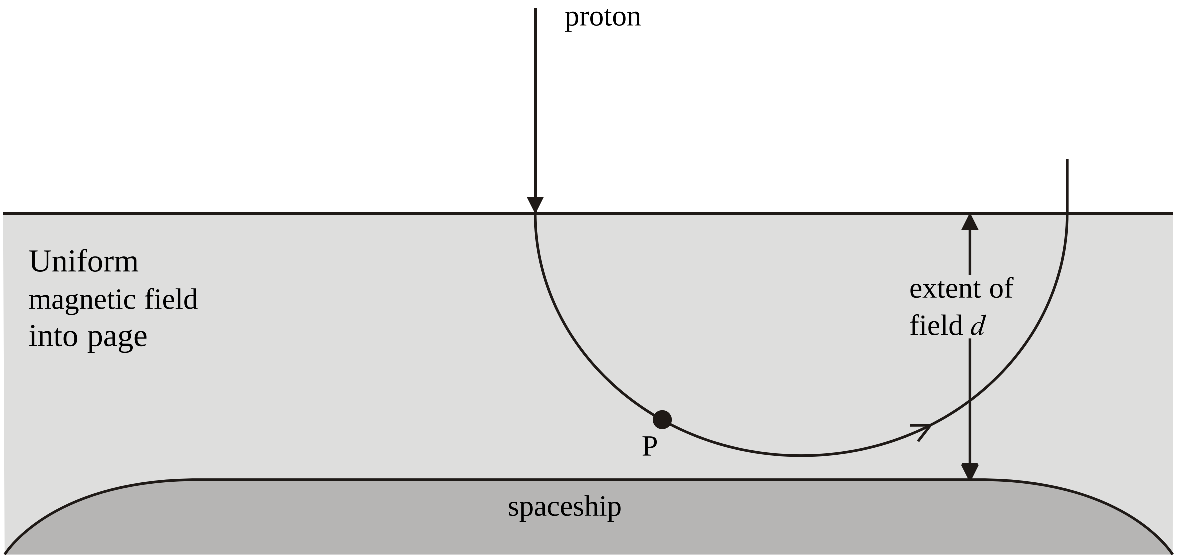
....

....

....

(3)
(Total 9 marks)

36. One of the hazards of long flights in space for humans will be exposure to radiation, particularly high energy protons from the Sun travelling as part of the 'solar wind'.
Magnetic shielding could reduce the radiation reaching the crew. A strong magnetic field would be established around the outside of the spaceship. This field would then deflect the protons.
The path of a proton which just misses the spaceship is shown.



(a) (i) Draw an arrow on the diagram to show the direction of the force on the proton at point P.

(1)

(ii) Calculate the force on a proton entering the field as shown in the diagram with a speed of 800 km s^{-1}. Magnetic flux density = 0.50 T.

....

....

....

....

Force = ...

(2)

(iii) Calculate the minimum value of *d*, the extent of this field, needed to prevent protons of this speed from striking the spaceship.

....

....

....

d = ...

(2)

(iv) Calculate the time this proton spends in the field.

....

....

....

Time = ...

(2)

(v) Calculate the average resultant force exerted on the proton during this process of reversing its direction of travel.

....

....

....

....

....

Force = ...

(3)

(b) An alternative proposal is to maintain a positive charge on a spaceship to repel protons. To repel protons travelling at 800 km s^{-1} would require a spherical ship of 5 m radius to carry a charge of 1.9 μC.

Calculate the force exerted by this positive charge on a proton close to the surface of this spaceship. Assume that this charge acts as though it is concentrated at the centre of the ship.

....

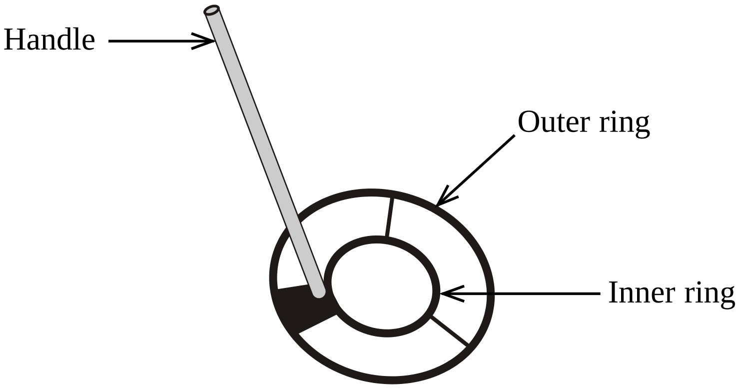
....

....

Force = ...

(2)
(Total 12 marks)

37. The diagram shows the bottom part of a hand-held metal detector.



The outer ring contains the transmitter coil. Alternating current is passed through this coil. This creates a magnetic field which penetrates into the ground.

If the magnetic field encounters a metal object, **a current is induced in the object**. This current generates a magnetic field of its own. **The direction of the object's magnetic field is opposite to the direction of the transmitter coil's magnetic field.**

The inner ring is able to detect varying magnetic fields coming from objects in the ground.

(i) Explain why **a current is induced in the object**.

....

....

....

....

....

....

....

(3)

(ii) Explain why **the direction of the object's magnetic field is opposite to the direction of the transmitter coil's magnetic field**.

....

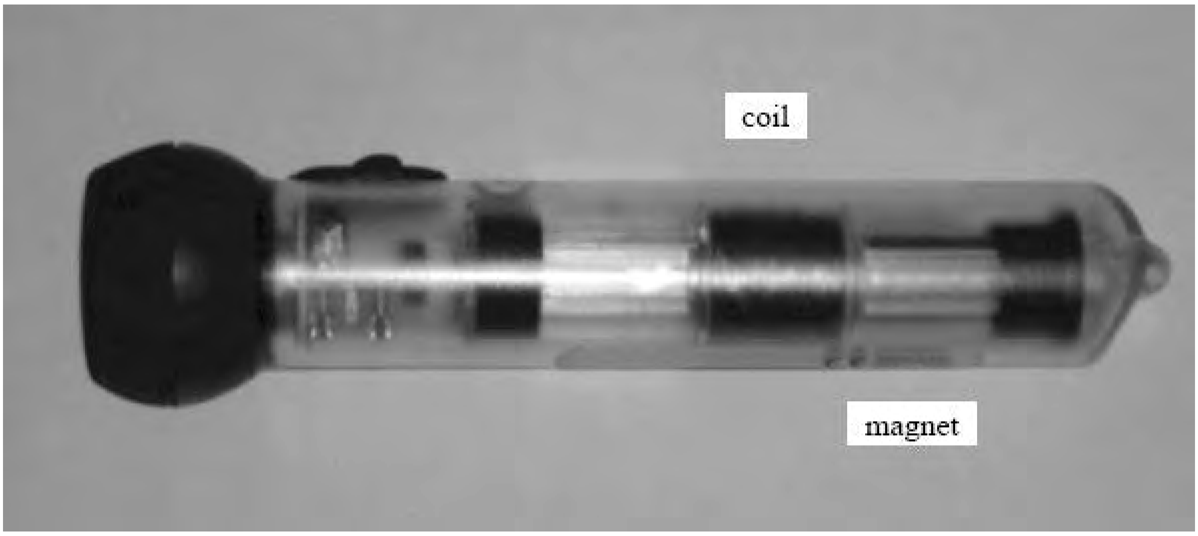
....

....

....

(1)
(Total 4 marks)

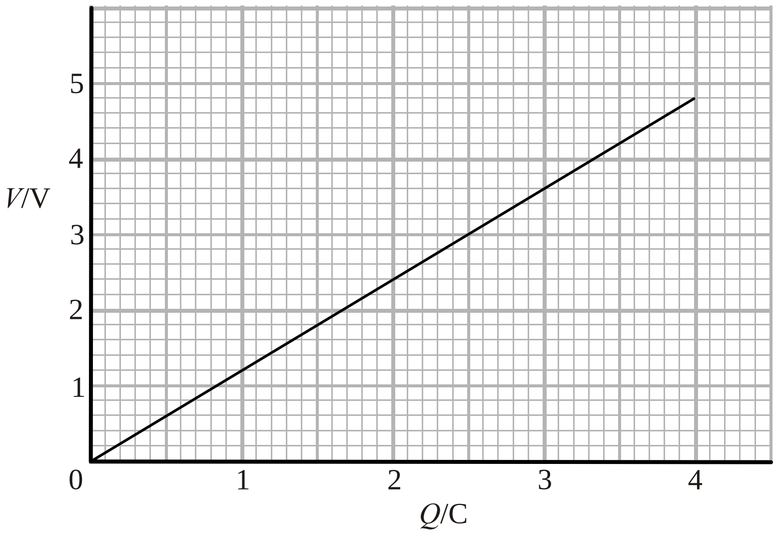
38. The photograph shows an 'everlasting torch' – so called because it operates without batteries.



When the torch is shaken, the strong permanent magnet moves through the coil of copper wire, generating an electric current.

Energy is stored by a capacitor. This then acts as the energy source for an LED.

(a) The following graph shows how the voltage of the capacitor varies with the charge on the capacitor.



(i) Calculate a value for the capacitance of the capacitor.

....

....

....

Capacitance = ...

(2)

(ii) Use the graph to derive the expression $W = \frac{1}{2}QV$ for the energy stored by a capacitor.

....

....

....

....

....

....

....

(3)

(iii) Calculate the energy stored by the capacitor when the voltage across it is 4.0 V.

....

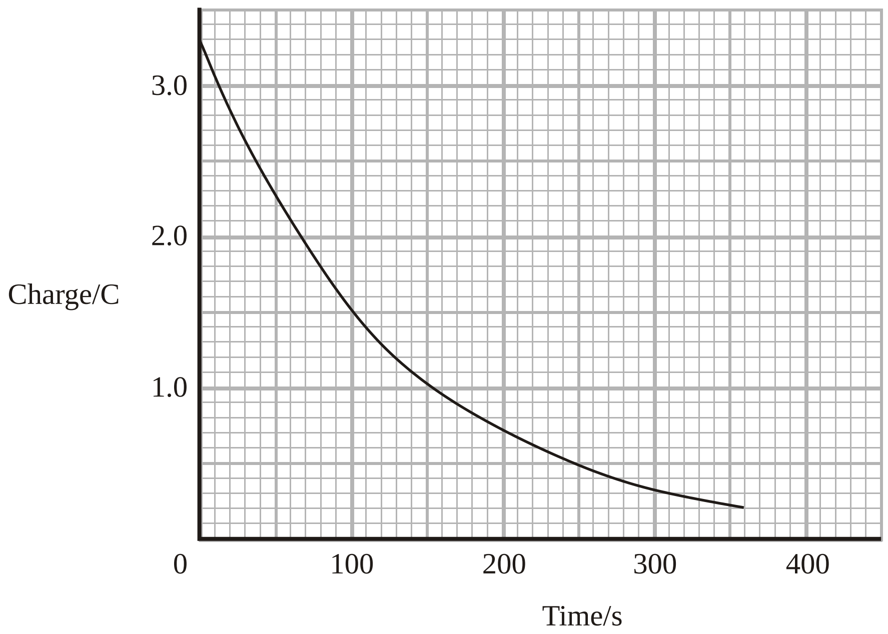
....

....

Energy = ...

(2)

(b) The graph shows how the charge on the capacitor varies with time when the torch is in use.



(i) Explain why the output power from the LED decreases with time.

....

....

....

(2)

(ii) Use the graph to determine the time constant for the capacitor-LED circuit.

....

....

....

....

Time constant = ...

(1)

(Total 10 marks)

39. A student researching capacitance finds the following statements in different sources:

"A human body charged to 30 000 V has only about 0.045 J of stored electrical energy.''

"The human body can be modelled as a capacitor of about 10 pF in parallel with a resistor.''

(a) (i) Determine whether the data given in the **first** statement are consistent with the capacitance quoted in the **second** statement.

....

....

....

....

(3)

(ii) Calculate the static charge on the body referred to in the **first** statement.

....

....

....

....

Charge = ...

(2)

(b) (i) A spark is seen when a person charged to 30 000 V brings his hand towards an earthed metal plate. Such sparks occur when the electric field strength is sufficient to ionise the air. The minimum electric field strength for this is 3.0×10^6 Vm^{-1}. Assume that the hand and the metal plate can be treated as a pair of parallel plates, and that the voltage between the hand and the earth remains 30 000 V. Calculate the greatest separation of hand and plate for which the spark could occur.

....

....

....

Greatest separation = ...

(2)

(ii) Ions and electrons produced in the electric field between the hand and the plate (3.0×10^6 V m^{-1}) are accelerated and may collide with other particles, causing further ionisation.

Calculate the force on an electron in this field.

....

....

....

Force = ...

(2)

(c) The ionization energy of a typical particle in the air is 35 eV. Calculate the maximum number of such particles an electron could ionise while it is moving a total distance of 1 mm in this field.

....

....

....

....

....

Number = ...

(3)
(Total 12 marks)

40. Faraday's and Lenz's laws are given at the back of this paper as $E = -\mathrm{d}(N\Phi)/\mathrm{d}t$.

(a) Explain the symbol *E*.

....

....

(2)

(b) Explain the significance of the minus sign.

....

....

....

(2)

(c) When a car has its headlights on with the engine running, the headlights receive their power from a dynamo which is turned by the engine. A driver sits in his car with the lights off, his foot off the accelerator, and the engine running slowly. He notices that when he switches the lights on, the engine slows slightly. Explain the physics causing this effect.

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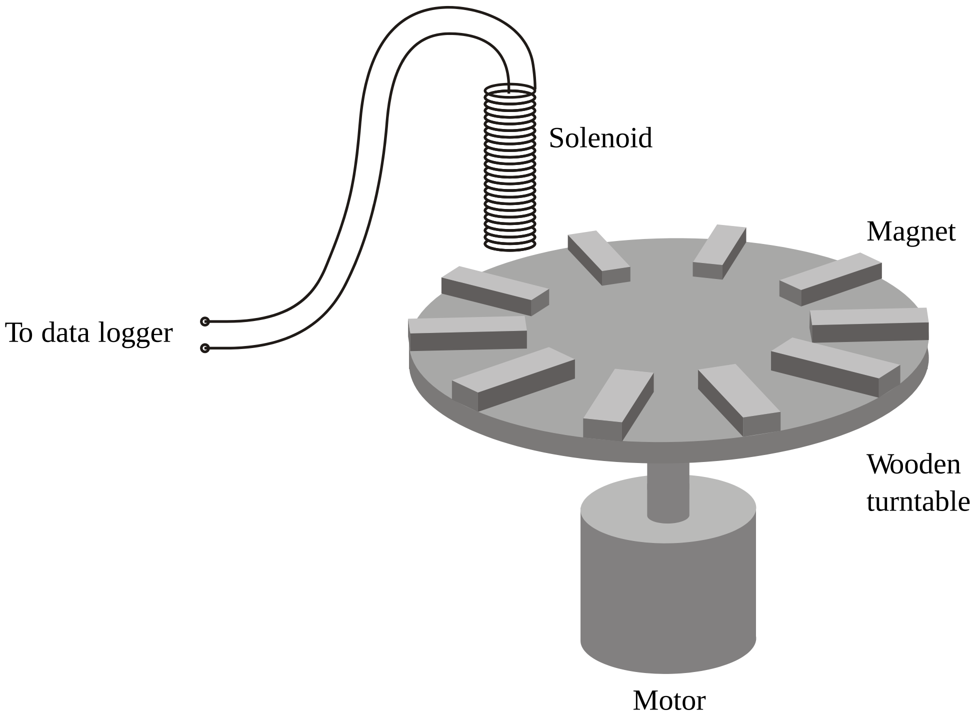
....

(4)
(Total 8 marks)

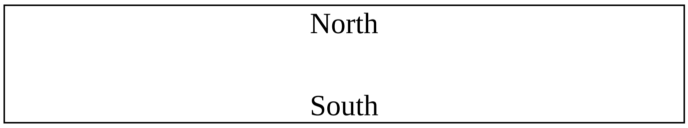
41. Most desktop computers store data on discs coated with a magnetic medium which records the data in a digital form. As a disc spins at very high speeds the magnetic field at each place on the disc can be detected in order to 'read' the data.

The diagram shows a school laboratory model set up to demonstrate how the system works.



The ten flat magnets on this model disc can be arranged with either the north pole or south pole facing upwards. These are interpreted as 1 or 0 respectively and are detected by the coil linked to the datalogger as the disc spins.

(a) The diagram below shows one of the magnets on this model. Sketch its magnetic field.



(2)

(b) Figure 1 shows how the magnetic flux varies as an upward-facing north pole moves beneath the coil. Figure 2 shows the corresponding output from the coil.

Figure 1

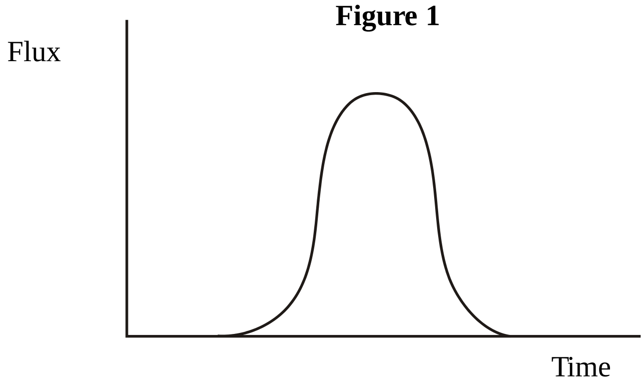
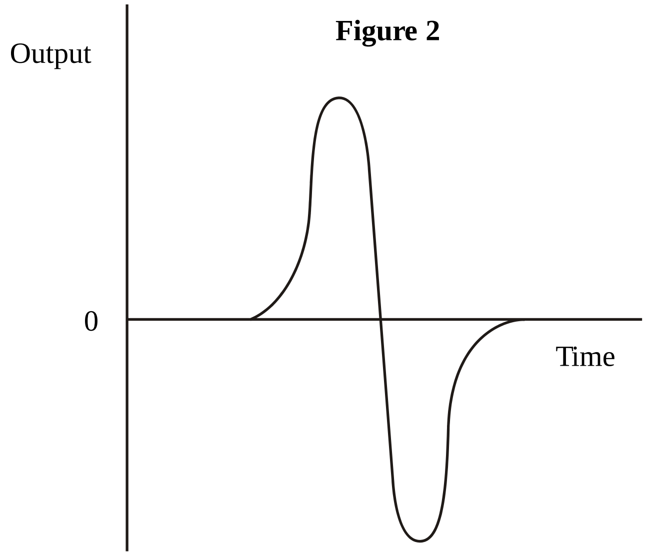


Figure 2



Explain how the output is generated and why it has this shape.

....

....

....

....

....

....

....

....

....

(5)

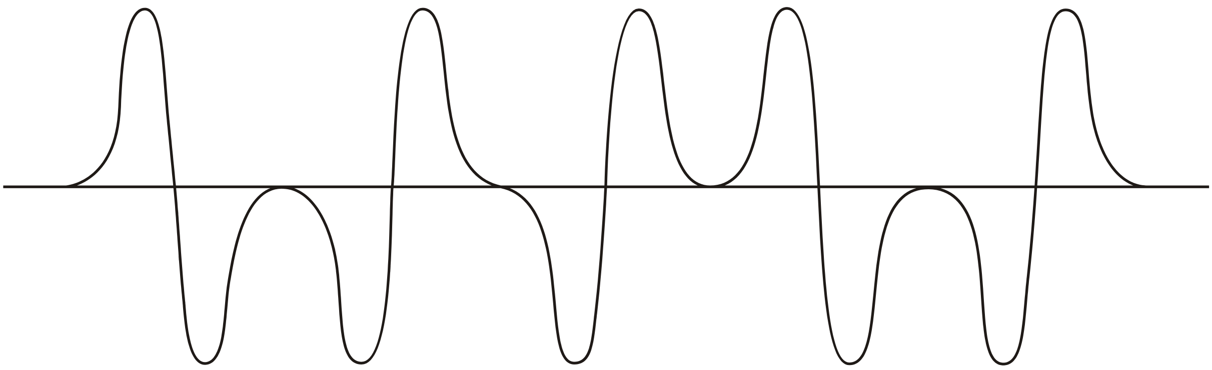
(c) Show that the maximum number of sequences possible with ten magnets (as on this model) is about 1000.

....

....

(1)

(d) The diagram shows an output generated during part of one trial.



Write the number sequence represented by this output. Remember: a north pole facing upwards is interpreted as 1 and a south pole upwards as 0.

....

(1)

(e) A real hard disc spins at very high speeds, making 7200 complete revolutions in one minute. The reading head is following a ring of magnetized regions with diameter 8.9 cm, and the length occupied by each separate magnetized region is 0.83 μm.
Assume that there are no gaps between adjacent magnetized regions. Calculate the rate at which the head is reading bits of data.

....

....

....

....

....

Rate = ...

(3)
(Total 12 marks)

42. (a) State **in words** the formula which gives the electric force between two charged particles.

....

....

....

....

....

(2)

(b) What are the base units of the constant in this formula?

....

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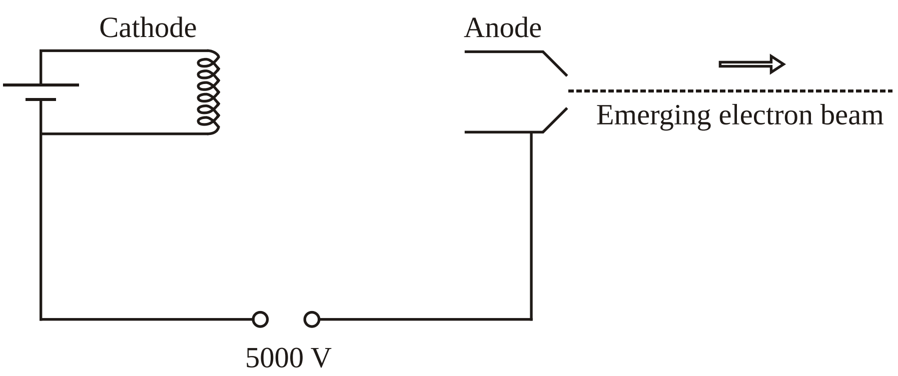
....

....

(3)
(Total 5 marks)

43. Electrons are accelerated from rest from the cathode to the anode of a vacuum tube through a potential difference of 5000 V.

Figure 1



(a) Show that the speed v of an electron as it leaves the anode is approximately 4×10^7 m s^{-1}.

....

....

....

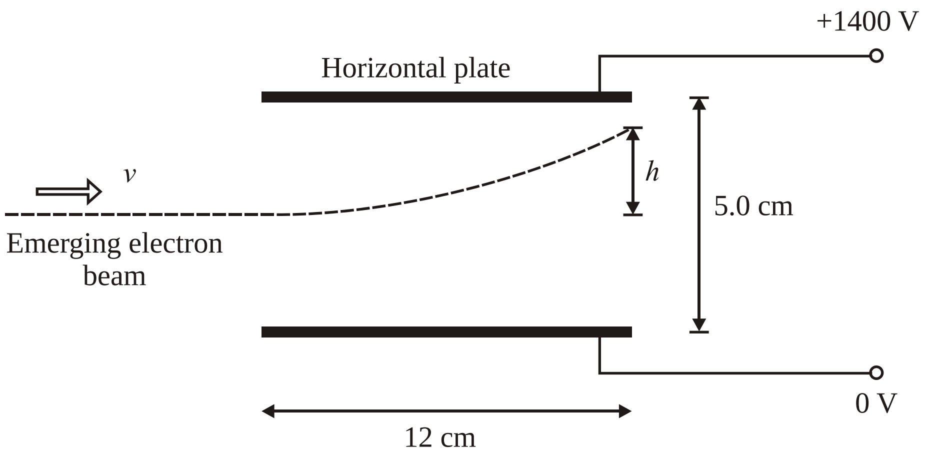
....

....

(3)

(b) The emerging beam of electrons follows a parabolic path as it passes between a pair of horizontal parallel plates 5.0 cm apart with a potential difference of 1400 V between them.

Figure 2



(i) Calculate the strength E of the uniform electric field between the horizontal plates.

....

E = ...

(1)

(ii) Hence determine the force F exerted by this field on each electron.

....

....

F = ...

(1)

(c) An electron experiences an upward acceleration a as it travels between the plates. Its vertical displacement h after a time t is given by

$$h = \frac{1}{2}at^2$$

Calculate the value of h as the electron leaves the plates.

....

....

....

....

....

....

....

....

h = ...

(4)

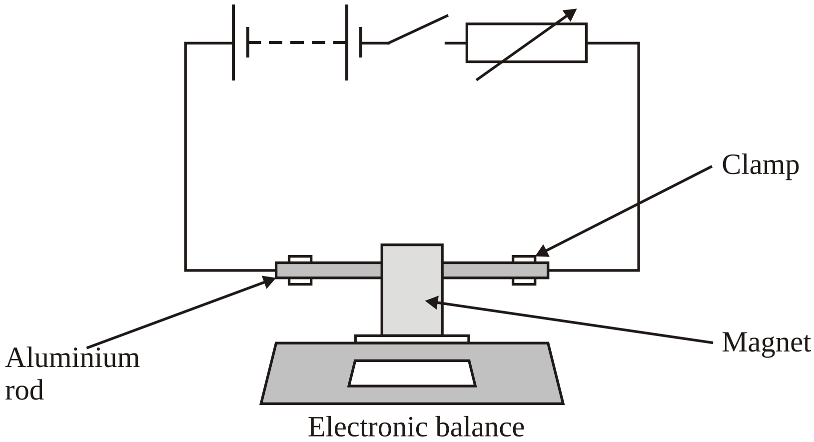
(d) (i) Add to Figure 2 the path that the electron beam would follow if the potential difference between the horizontal plates were decreased. Label this path A.

(1)

(ii) Add to Figure 2 the path that the electron beam would follow if the potential difference between the cathode and the anode were decreased. Label this path B.

(1)
(Total 11 marks)

44. A U-shaped permanent magnet of mass 85.0 g rests on an electronic balance as shown in the diagram. An aluminium rod connected in a circuit is supported between the opposite poles of the magnet so that it is unable to move.



The switch is closed. The reading on the balance increases to 85.4 g.

(a) (i) Calculate the additional force on the magnet when there is current in the circuit.

....

Force = ...

(1)

(ii) Explain how this additional force originates. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

....

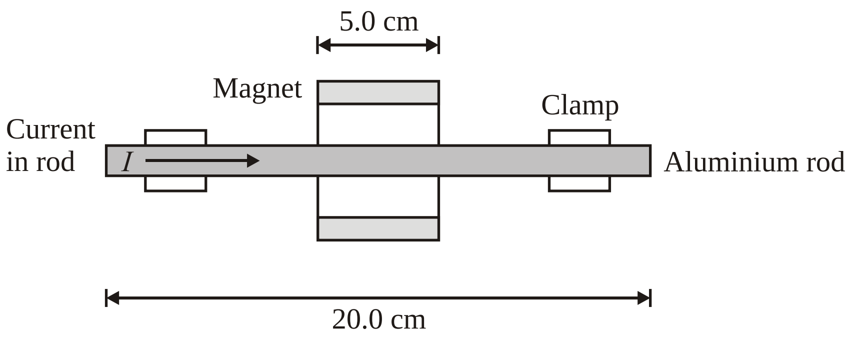
....

(4)

(b) The diagram below shows a plan view of the rod and the poles of the magnet.

(i) On the diagram **label the poles of the magnet** to indicate the direction of field needed to produce a downward force on the magnet.

VIEW AS SEEN FROM ABOVE



(1)

(ii) The rod is 20.0 cm long and the magnet is 5.0 cm wide. The magnetic flux density of the magnet is 30.0 mT. Calculate the current in the rod.

....

....

....

Current = ...

(3)

(iii) The direction of the current is reversed. What would be the new reading on the balance?

....

Balance reading = ...

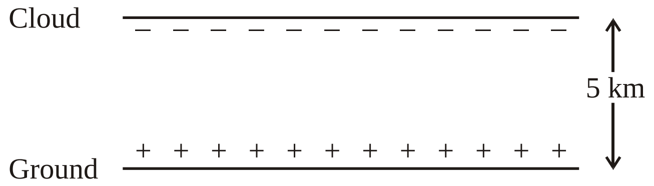
(2)

(Total 11 marks)

45. This is an extract from an article on thunderstorms.

"The electric field required to cause damp air to ionise, as happens in a lightning strike, is 3×10^5 V m^{-1}. When this happens, 40 C of charge passes between the cloud (at a height of 5 km) and the ground. The strike lasts 20 ms, and completely discharges the cloud."

The cloud and the ground below it may be modelled as a capacitor, as in the diagram.



Calculate the voltage between the cloud and the ground when the strike occurs.

....

....

....

Voltage = ...

(2)

Calculate the capacitance between the cloud and the ground.

....

....

....

Capacitance = ...

(2)

Find an approximate value for the resistance of the air between the cloud and the ground during the strike.

....

....

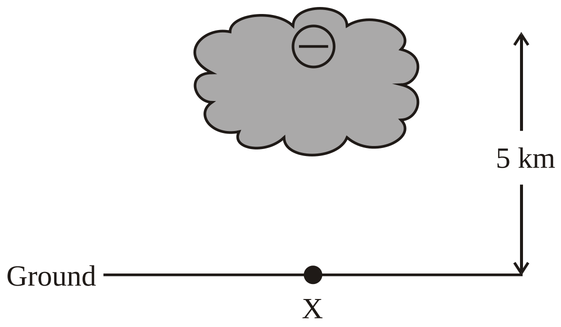
....

Resistance = ...

(2)

A different way of modelling a thunder cloud is to treat the charge of –40 C as a point charge at a height of 5 km, as shown in the diagram below.

Assume in this simple model that the ground has no effect on the field strength or shape.



Using this model,

(i) draw on the shaded area of the diagram the electric field in that region,

(2)

(ii) calculate the value of the electric field this point charge of –40 C would cause at the point X on the ground immediately below it,

....

....

....

Electric field = ...

(2)

(iii) explain why one might expect the lightning strike to begin from the cloud and not from the ground.

....

....

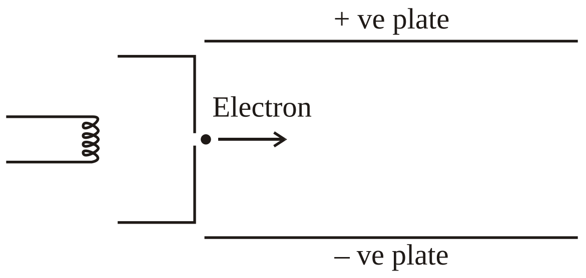
....

....

(1)

(Total 11 marks)

46. The diagram below illustrates an experiment with electrons. A beam of electrons is created using an electron gun, and deflected using an electric field.



Explain how the electron gun creates a beam of electrons. Add to the diagram if that will help your explanation.

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(4)

The electrons are accelerated from rest through a potential difference of 340 V. Calculate their speed as they leave the gun.

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Speed = ...

(3)

Explain what is meant by the term **electric field.**

....

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(1)

The electric field which deflects the beam is created by applying a potential difference of 2500 V across plates 9.0 cm apart. Show that the vertical acceleration of the electrons due to this field is about 5×10^{15} m s^{-2}.

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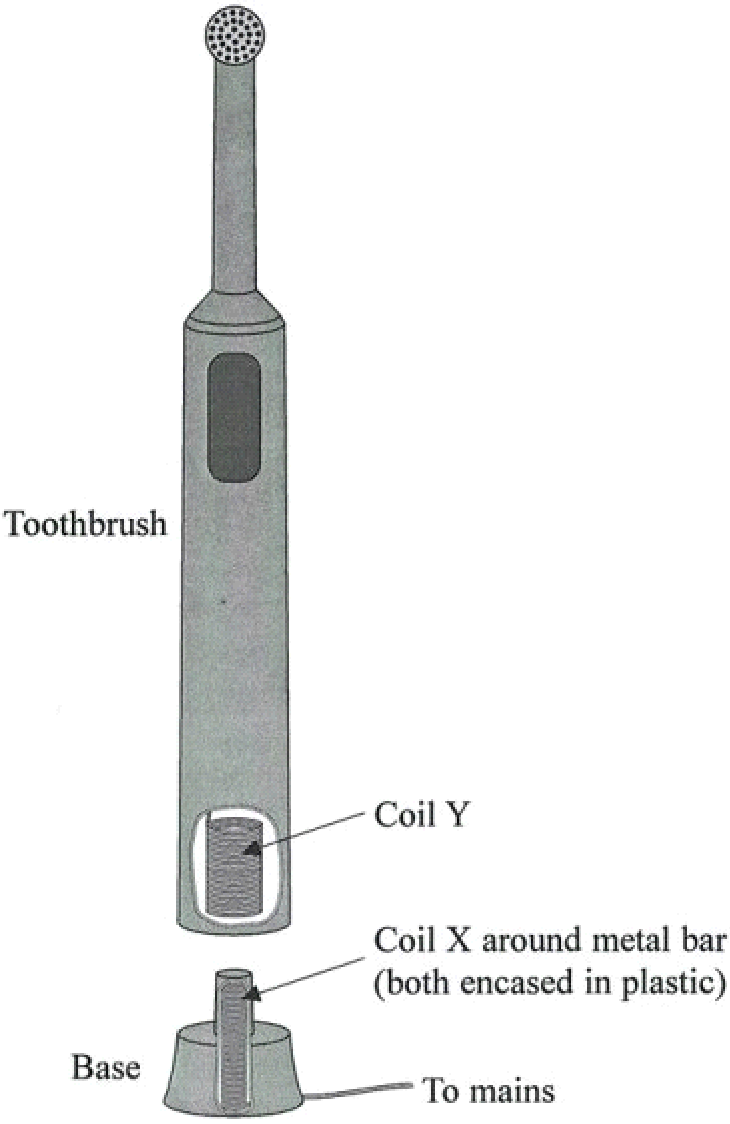
(4)
(Total 12 marks)

47. The diagram shows an electric toothbrush. An electric toothbrush recharges its batteries despite there being no metal contacts between the toothbrush and the base.



(a) State a reason for avoiding metal contacts between the toothbrush and the base.

....

....

(1)

(b) The base, which is connected to an a.c. supply, contains a coil around a metal bar (coil X). The toothbrush contains a second coil (coil Y). When you put the toothbrush on to the base, coil Y goes around the bar and coil X without the two coils making contact.

Explain how this arrangement is able to charge the battery in the toothbrush.

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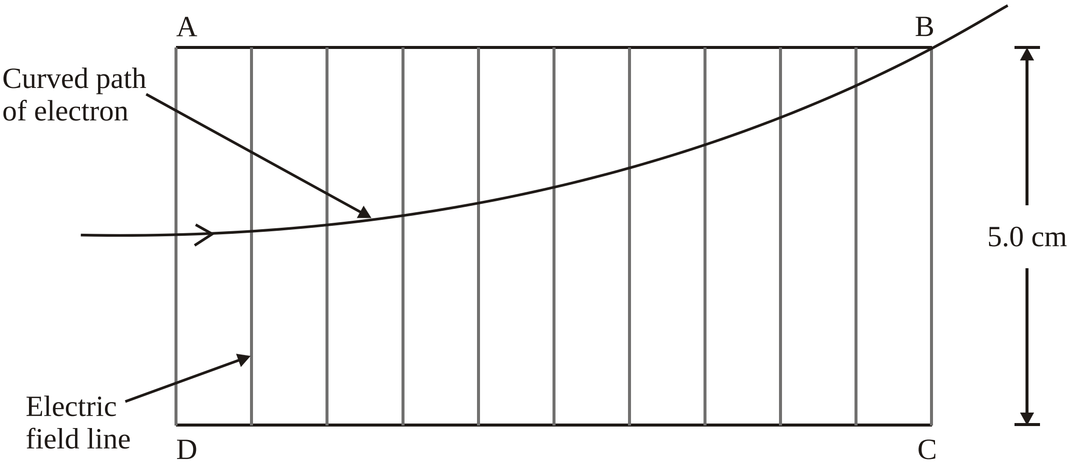
(6)
(Total 7 marks)

48. The diagram shows the path of an electron in a uniform electric field between two parallel conducting plates AB and CD. The electron enters the field at a point midway between A and D. It leaves the field at B.



(a) Mark on the diagram the direction of the electric field lines.

(1)

(b) (i) The conducting plates are 5.0 cm apart and have a potential difference of 250 V between them. Calculate the force on the electron due to the electric field.

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Force = ...

(3)

(ii) State the direction of this force on the electron and explain why it does not affect the horizontal velocity of the electron.

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....

(2)

(c) To leave the electric field at B the electron must enter the field with a speed of 1.30×10^7 m s^{-1}. Calculate the potential difference required to accelerate an electron from rest to this speed.

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....

Potential difference = ...

(3)

(d) A very thin beam of electrons enters a uniform electric field at right angles to the field. The electrons have a range of speeds.

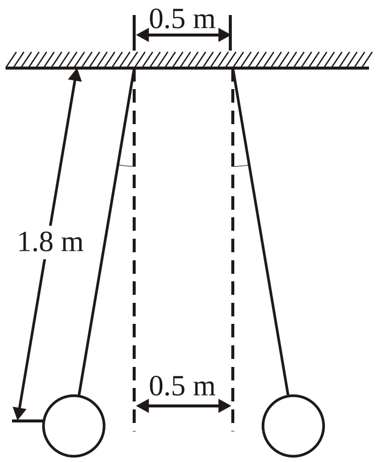
(i) Draw a diagram to show the shape of the beam as it moves through the field.

(ii) On your diagram label which electrons have the fastest speed.

(2)
(Total 11 marks)

49. A student wants to test Coulomb's law, which is about the force between two charged objects.

She plans to hang two balloons on insulated threads, charge them both with equal positive charges, and measure the angles at which they hang away from each other. The dimensions she plans to use in her experiment are shown on the diagram.



She thinks she can make accurate measurements if the balloons hang at an angle of 1.5° or more from the vertical. **Add to the diagram** to show all the forces acting on one of the balloons. Hence show that the minimum charge Q she needs on each balloon must be about 0.1 μC. [Assume that each balloon behaves as though the charge were concentrated at its centre.]

The mass of each balloon = 0.0018 kg.

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(Total 6 marks)

50. Experiments supervised by Rutherford about 100 years ago involved firing alpha particles at thin gold foils. Outline the results of these experiments, and the conclusions scientists drew from them.

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(4)

The relationship between the rate of alpha detection (N) and the angle of scatter (θ) is predicted to be of the form

$$N \propto (\sin \theta/2)^{x}$$

Explain how you would determine x graphically from a set of experimental results for N and θ.

....

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....

(2)

The symbols for an alpha particle and a gold nucleus are given below.

$^{4}_{2}\text{He}$	$^{197}_{79}\text{Au}$
alpha particle	gold nucleus

Explain the meaning of the numbers in the symbol for the gold nucleus.

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(2)

Show that the mass of an alpha particle is about 7×10^{-27} kg.

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....

(1)

In these experiments, an alpha particle may approach a gold nucleus to within a distance of 5×10^{-14} m. Calculate the electric force between them at this separation.

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Force = ...

(3)

(Total 12 marks)

51. The formulae list states:

In a magnetic field $F = Bqv \sin \theta$

Describe the situation to which this equation refers, stating the meaning of each symbol.

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(4)

The formulae list also gives an equation $r = p/BQ$.

Describe the situation modelled by this equation, stating the meaning of the symbol p.

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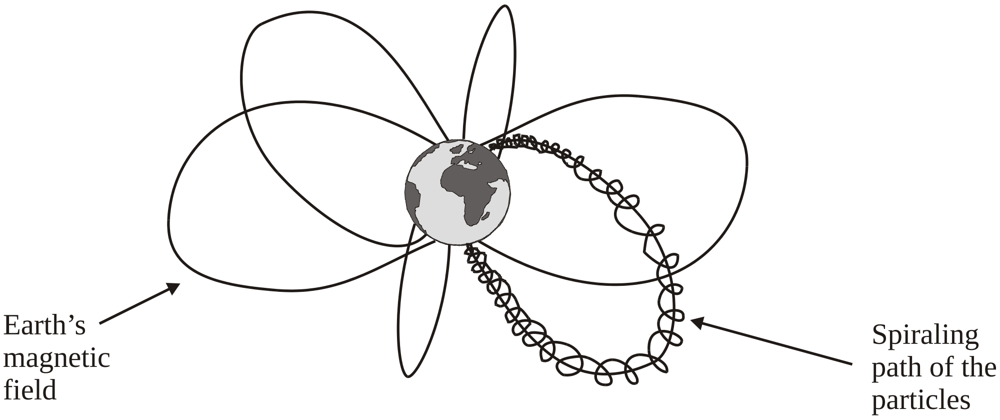
(2)

Particles arriving from the Sun can enter the Earth's magnetic field in such a way that they spiral along towards the North pole as shown in the diagram below. As they near the North pole they give rise to the beautiful Aurora Borealis, or Northern Lights.



Explain why the path of a particle is curved.

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(2)

Explain why the spiralling circular path of a particle decreases in radius as it nears the North Pole.

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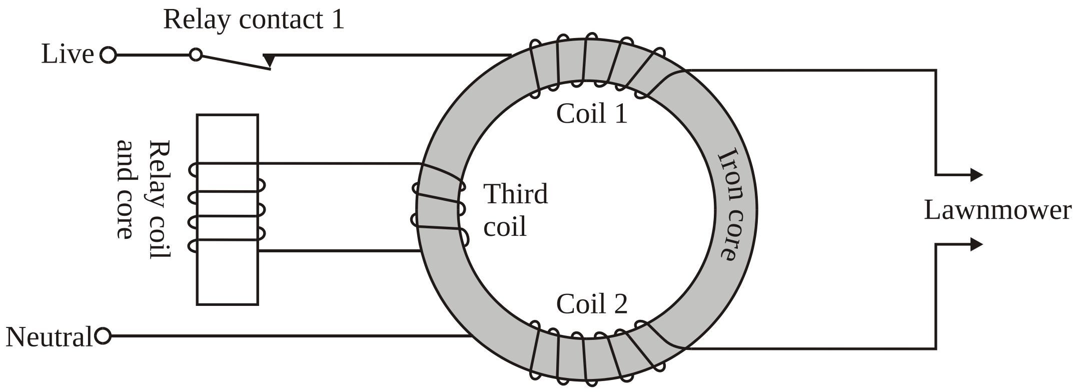
(2)
(Total 10 marks)

52. The diagram shows a device called a Residual Current Circuit Breaker (RCCB). It is designed to protect users of appliances connected to the mains a.c. power supply, e.g. an electric lawnmower.



Explain why, in normal operation, the resultant flux in the iron core due to coils 1 and 2 is zero.

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(2)

If there is a difference in the currents flowing in the live and neutral wires, for example caused by a person coming into contact with a bare wire, the RCCB breaks the circuit. Explain how.

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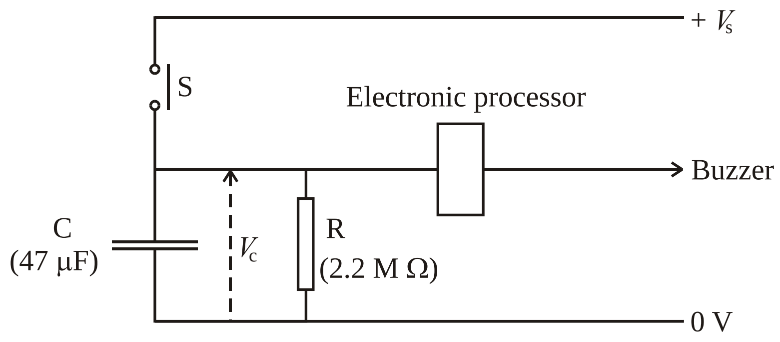
(5)
(Total 7 marks)

53. The diagram shows a simple timing circuit.



The electronic processor operates so that the buzzer sounds when V_c is greater than $\frac{3}{4}V_s$. The switch S is normally open. Explain in detail what happens in the circuit after the switch S is closed for a moment then opened again. Your answer should include an appropriate calculation and a sketch graph.

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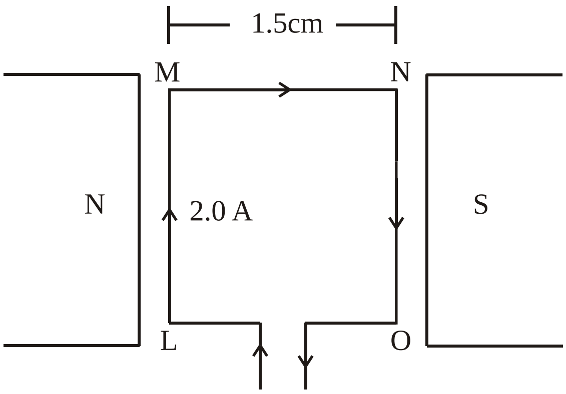
(Total 7 marks)

54. The diagram shows the top view of a square of wire of side 1.5 cm. It is in a uniform magnetic field of flux density 8.0 mT formed between magnetic north and south poles. The current in the wire is 2.0 A



What is the meaning of **uniform** in the phrase uniform magnetic field?

....

....

(1)

Determine the sizes and directions of the electromagnetic forces that act on the sides LM and NO of the square of wire.

....

....

....

....

Force on LM: .... Force on NO: ....

Direction: .... Direction: ....

(3)

Why do no electromagnetic forces act on the sides MN and OL of the square?

....

....

(1)

What effect will the forces acting on LM and NO have on the square of wire?

....

.... **(1)**

The magnetic poles are now moved further apart. Describe and explain what effect, if any, this will have on the magnitudes of the forces produced on LM and NO assuming the current of 2.0 A is unchanged.

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.... **(2)**

(Total 8 marks)

55. The potential difference between the plates of a 220 μF capacitor is 5.0 V.

Calculate the **charge** stored on the capacitor.

....

....

Charge = ... **(2)**

Calculate the **energy** stored by the capacitor.

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Energy = ... **(2)**

Describe how you would show experimentally that the charge stored on a 220 μF capacitor is proportional to the potential difference across the capacitor for a range of potential differences between 0 and 15 V. Your answer should include a circuit diagram.

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(5)
(Total 9 marks)

56. State Lenz's law of electromagnetic induction.

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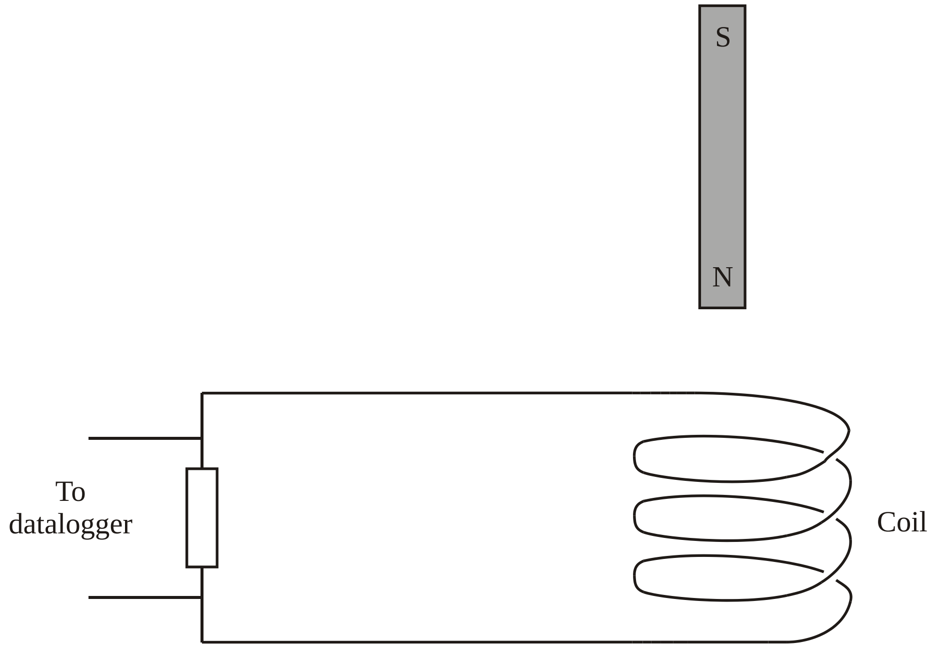
(2)

A bar magnet is dropped from rest through the centre of a coil of wire which is connected to a resistor and datalogger.



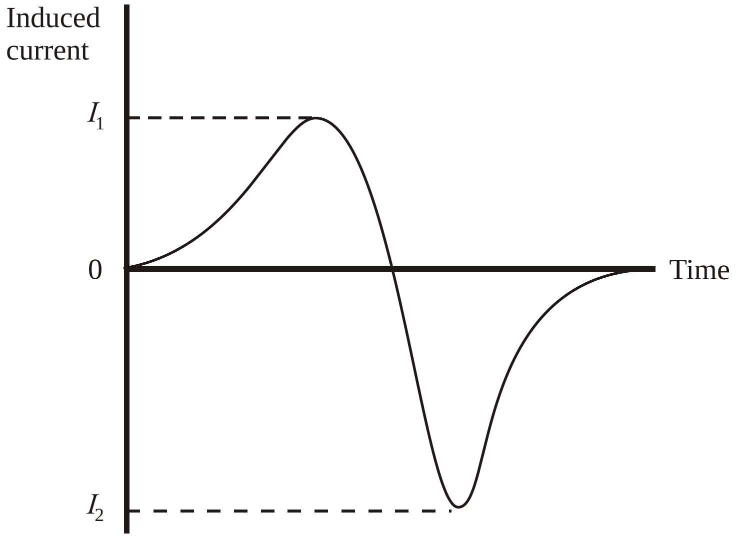
State the induced magnetic polarity on the top side of the coil as the magnet falls towards it.

....

Add an arrow to the wire to show the direction of the induced current as the magnet falls towards the coil.

(2)

The graph shows the variation of induced current in the resistor with time as the magnet falls.



Explain why the magnitude of I_2 is greater than I_1.

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....

(2)
(Total 6 marks)

57. A student is learning about how capacitors work. He uses the circuit shown in Figure 1 to investigate the capacitor C. Letter X labels a connection which he can make to either of the points L or M. Each cell has an e.m.f. of 1.5 V.

Figure 1

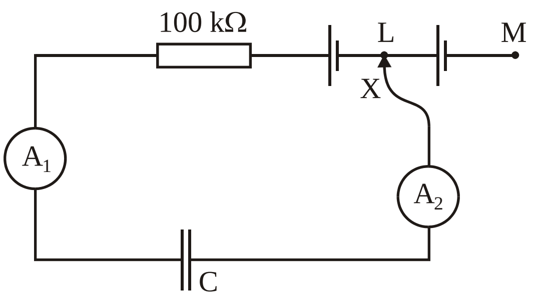
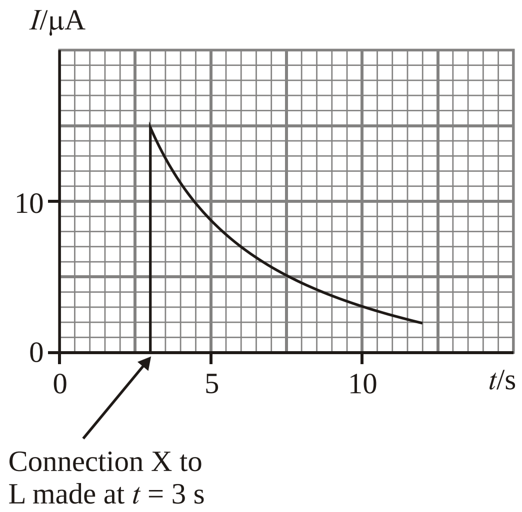


Figure 2



He connects X to L. He sketches how the reading on ammeter 1 varies with time (Figure 2).

Explain in terms of charge what has happened in the circuit.

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(3)

Explain what he would have seen if he had watched ammeter 2.

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(2)

Use his sketch graph (Figure 2) to estimate the charge which has passed through ammeter 1 between the times t = 3 s and t = 10 s.

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....

Charge = ...

(2)

Use the graph and your answer above to estimate the capacitance of the capacitor.

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....

Capacitance = ...

(3)

State and explain what he would observe on each ammeter if he then continued the experiment by moving the connection X from L to M.

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(2)
(Total 12 marks)

58. Faraday's and Lenz's laws are given at the back of this paper as $E = -\mathrm{d}(N\Phi)/\mathrm{d}t$. Explain the meaning of E.

....

....

(2)

Define and explain the meaning of Φ.

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....

(2)

A student does an experiment on electromagnetic braking. She arranges an aluminium disc to spin horizontally as shown in Figure 1. Above the disc she fixes an iron core with a coil around it. She can vary the braking current I_b to this coil.

Figure 1

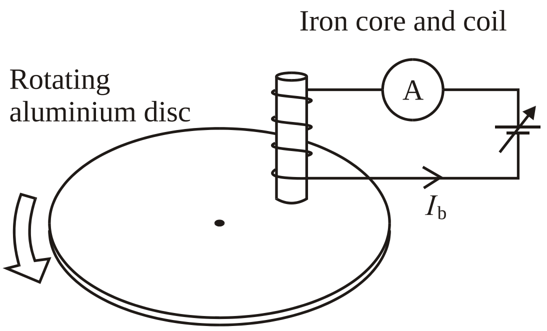
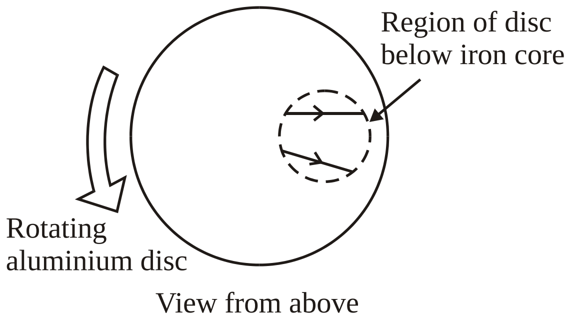


Figure 2



The braking current in the coil causes currents to flow in the rotating aluminium disc. Figure 2 shows the paths of two of these currents in the region of the disc below the iron core.

Add to the diagram to show the complete paths of these two currents.

(1)

Explain

(i) why these currents flow,

....

....

....

(ii) why these currents cause a force tending to slow the disc.

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(3)

The student reasons that the braking effect might be proportional to the square of the braking current I_b. Use appropriate equations to explain her reasoning.

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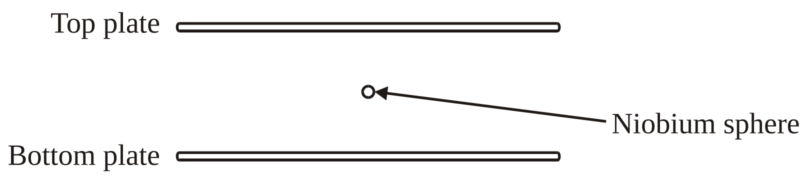
(3)
(Total 11 marks)

59. The diagram shows the apparatus used in an experiment to discover if matter can carry 'fractional charge', that is, charge which is a fraction of the charge on an electron.

A magnetic force is used to keep a niobium sphere stationary between two metal plates.



The sphere carries some electric charge. Once the sphere is stationary, an electric field is applied between the plates. This causes an electric force on the sphere, which causes it to accelerate in a vertical direction. This acceleration is measured. The charge on the sphere can then be calculated.

The electric field is created by applying a potential difference of 2000 V across the plates, with the top plate being positive. The plates are 0.80 cm apart.

Sketch **on the diagram** the pattern of the electric field between the plates.

(2)

Calculate the electric field strength between the plates.

....

....

Electric field strength = ...

(2)

The niobium sphere has mass 1.8×10^{-7} kg. During one experiment its acceleration is 3.0×10^{-7} m s^{-2} upwards. Calculate the magnitude of the charge on the sphere, and state its sign.

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....

Charge = ...

(4)

Explain why it is important for the experiment to be carried out in a vacuum.

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(1)
(Total 9 marks)

60. A current-carrying conductor is situated in a magnetic field. Describe how you could demonstrate that the magnitude of the force on the conductor is directly proportional to the magnitude of the current in it. You may wish to include a diagram in your answer.
You may be awarded a mark for the clarity of your answer.

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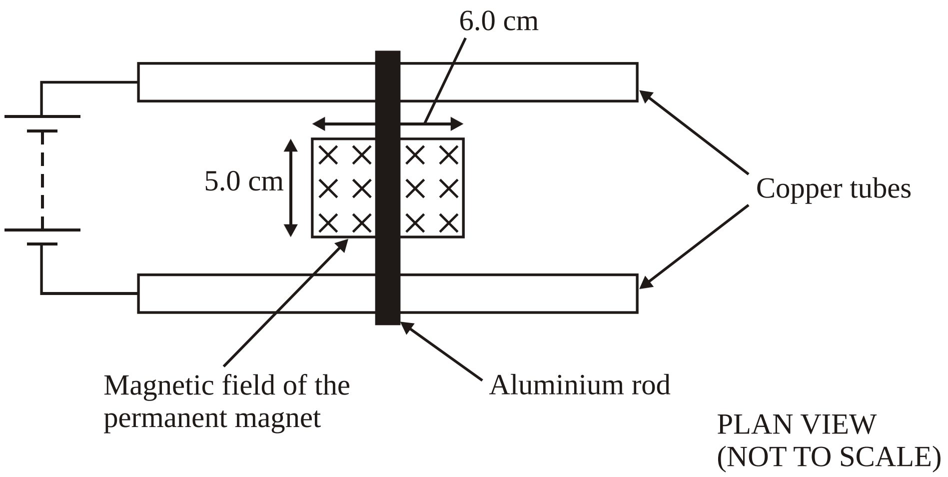
(4)

An aluminium rod of mass 50 g is placed across two parallel horizontal copper tubes which are connected to a low voltage supply. The aluminium rod lies across the centre of and perpendicular to the uniform magnetic field of a permanent magnet as shown in the diagram.

The magnetic field acts over a region measuring 6.0 cm × 5.0 cm.



The magnetic flux density of the field between the poles is 0.20 T. Calculate the initial acceleration of the rod, assuming that it slides without rolling, when the current in the rod is 4.5 A.

....

....

....

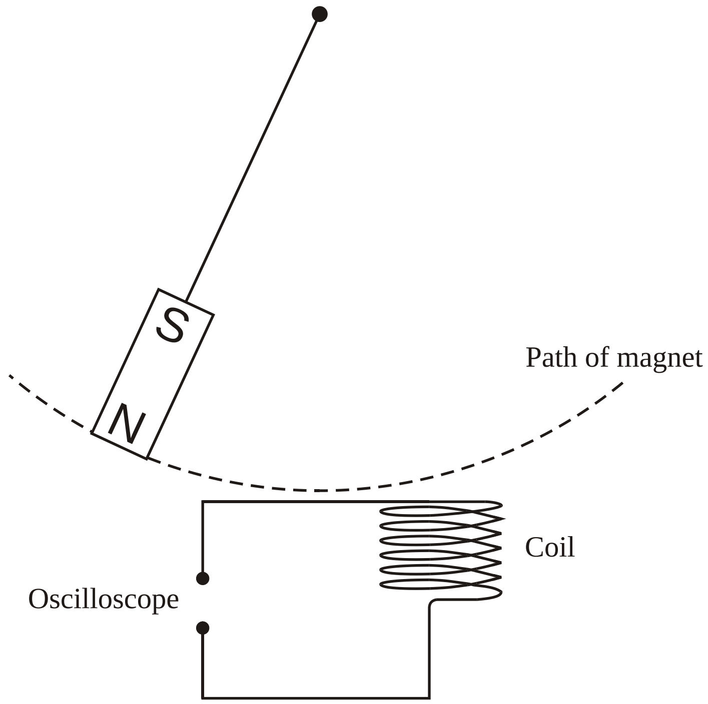
....

Initial acceleration = ...

(4)

(Total 8 marks)

61. A bar magnet is suspended above a vertical coil of wire. It is then displaced to one side and released such that it oscillates above the coil as shown in the diagram. The coil of wire has its ends connected to an oscilloscope.



Explain why an e.m.f. is induced across the ends of the coil.

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....

(2)

By considering Lenz's law, label with an X on the diagram each position of the magnet at which the induced e.m.f. changes polarity.

(2)

The maximum induced e.m.f. is 3.0 mV. Calculate the rate of change of flux needed to induce this e.m.f. in a coil of 500 turns.

....

....

....

Rate of change of flux = ...

(2)

State three changes that could be made to the apparatus in order to increase the maximum induced e.m.f.

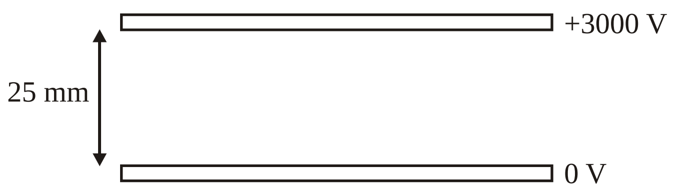
1 ....

2 ....

3 ....

(3)
(Total 9 marks)

62. The diagram shows two parallel plates with a potential difference of 3000 V applied across them. The plates are in a vacuum.



On the diagram sketch the electric field pattern in the region between the plates.

(2)

On the same diagram sketch and label two equipotential lines.

(1)

The plates are 25 mm apart. Show that the force experienced by an electron just above the bottom plate is about 2×10^{-14} N.

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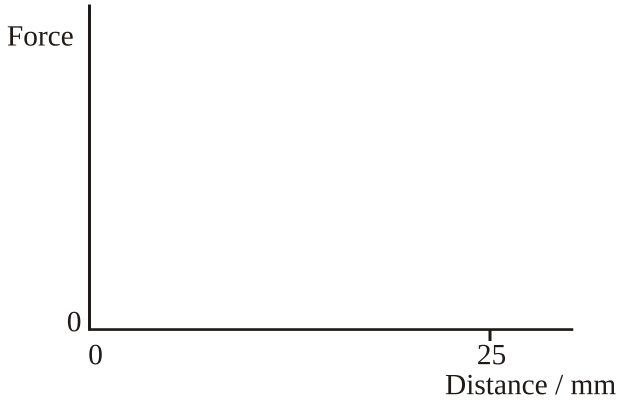
....

(3)

Complete the graph to show how the force on the electron varies with the distance of the electron from the bottom plate.



(2)

This force causes the electron to accelerate.

The electron is initially at rest in contact with the bottom plate when the potential difference is applied. Calculate its speed as it reaches the upper plate.

....

....

....

....

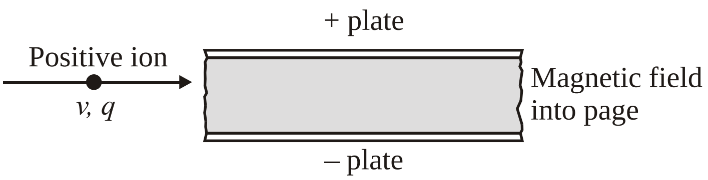
....

Speed = ...

(3)

(Total 11 marks)

63. Particle physics often involves passing beams of particles through electric and/or magnetic fields. The diagram illustrates a beam of positive ions, each with charge q and travelling at speed v, entering a region containing both an electric field of strength E and a magnetic field of flux density B. The electric field acts between the parallel plates. The magnetic field acts into the page.



The electric field causes a force on an ion when it is between the plates. State a formula for the magnitude of this force.

....

(1)

In which direction does this force act?

....

(1)

The magnetic field causes a force on the ion in the opposite direction to the force from the electric field.

With a suitable combination of values of υ, E and B, the electric and magnetic forces balance and each ion will travel straight through the region without changing direction. Calculate the value of υ for an ion to travel straight through the region if $E = 1.2 \times 10^4$ N C^{-1} and $B = 0.40$ T.

....

....

....

υ = ...

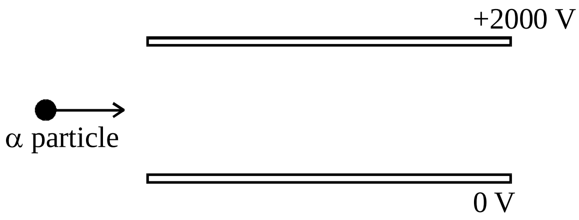
(3)

Explain why ignoring the effect of gravity on the ion is justified.

....

(2)
(Total 7 marks)

64. The diagram shows a high-speed alpha particle entering the space between two charged plates in a vacuum.



Add to the diagram the subsequent path of the alpha particle as it passes between the plates and well beyond them.

(3)

The gap between the plates is 10 mm. Calculate the magnitude of the electric force on the alpha particle as it passes between the plates.

....

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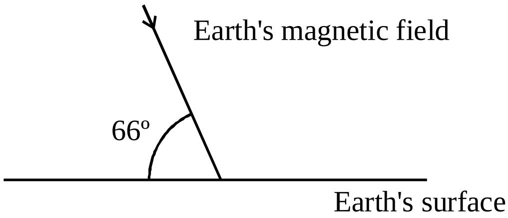
....

Electric force = ...

(3)
(Total 6 marks)

65. In London the Earth’s magnetic field has a magnetic flux density of 4.8×10^{-5} T at 66 to the horizontal as shown in the diagram.



Calculate the magnitude of the horizontal component of the Earth’s magnetic field in London.

....

....

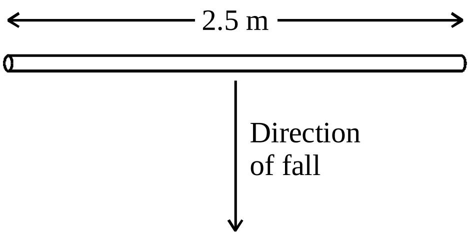
Horizontal component = ...

(2)

For a conductor of length I moving at a speed i) perpendicular to a field of flux density *B*, the induced voltage V between the ends of the conductor is given by

$$V = Bl\upsilon$$

A metal scaffolding pole falls from rest off a high building. The pole is aligned horizontally in an east-west direction. The Earth’s magnetic field lines at this point lie in a north-south direction.



Calculate the induced voltage across the pole 2.0 s after it started to fall.

....

....

....

Induced voltage = ...

(3)

What would be the induced voltage after 2.0 s if the pole were aligned in a north-south direction? explain your answer.

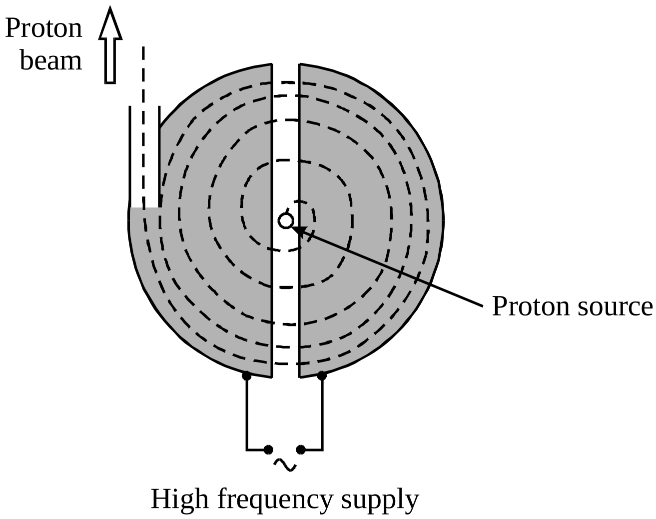
....

....

....

(2)
(Total 7 marks)

66. The simplified diagram shows the ‘dees’ of a cyclotron connected to a high frequency alternating supply. The dashed line shows the path of an accelerated proton. In the shaded region a uniform magnetic field *B* of flux density 0.80 T acts upwards out of the paper.



(i) Explain why the magnetic field must be upwards out of the paper when accelerating protons.

(ii) By considering a proton of mass m and charge e (1.6 × 10^{-19} C) moving in a circle of radius r in the cyclotron, show that the time t taken to complete one semicircle is given by

$$t = \frac{\pi m}{Be}$$

(5)

(iii) Describe how the energy of the proton is increased in a cyclotron. Give one reason why the energy cannot be increased indefinitely. You may be awarded a mark for the clarity of your answer.

(4)

(iv) Show that the gain in energy of a proton accelerated through a potential difference of 12 kV is about 2 × 10^{-15} J.

(v) The kinetic energy of a proton circling at a radius *r* can be expressed as

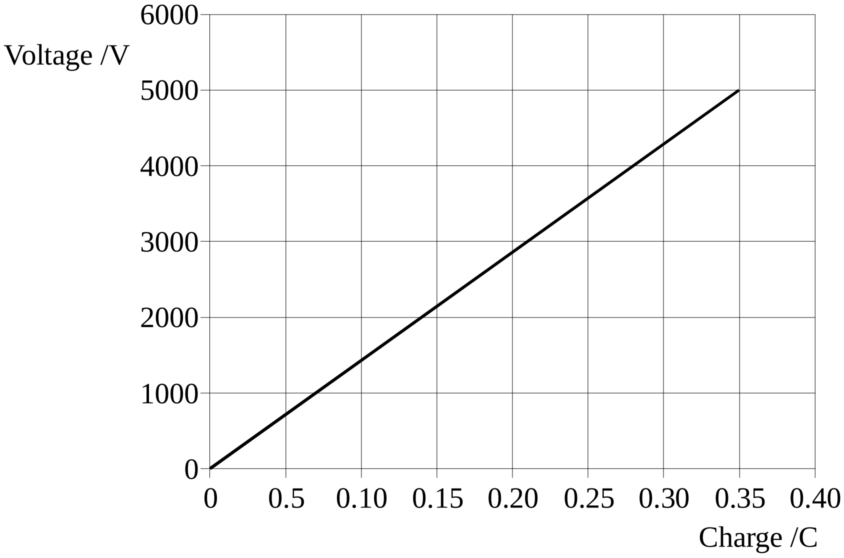
$$\text{k.e.} = \frac{B^2 e^2 r^2}{2m}$$

Calculate the radius of the circle in which a proton will be moving after being accelerated 850 times across a potential difference of 12 kV.

(4)
(Total 13 marks)

67. To restore a regular heart rhythm to a patient in an emergency, paramedics can use a machine called a defibrillator. The defibrillator uses a capacitor to store energy at a voltage of several thousand volts. Conducting ‘paddles’ are placed on either side of the patient’s chest, and a short pulse of current flows between them when the capacitor is discharged.

The graph below shows voltage against charge for the capacitor used in a defibrillator.



With reference to the graph, show that the energy stored in a capacitor is given by the formula $W = \frac{1}{2}QV$.

....

....

....

....

(2)

Calculate the energy stored by the capacitor when charged to 5000 V.

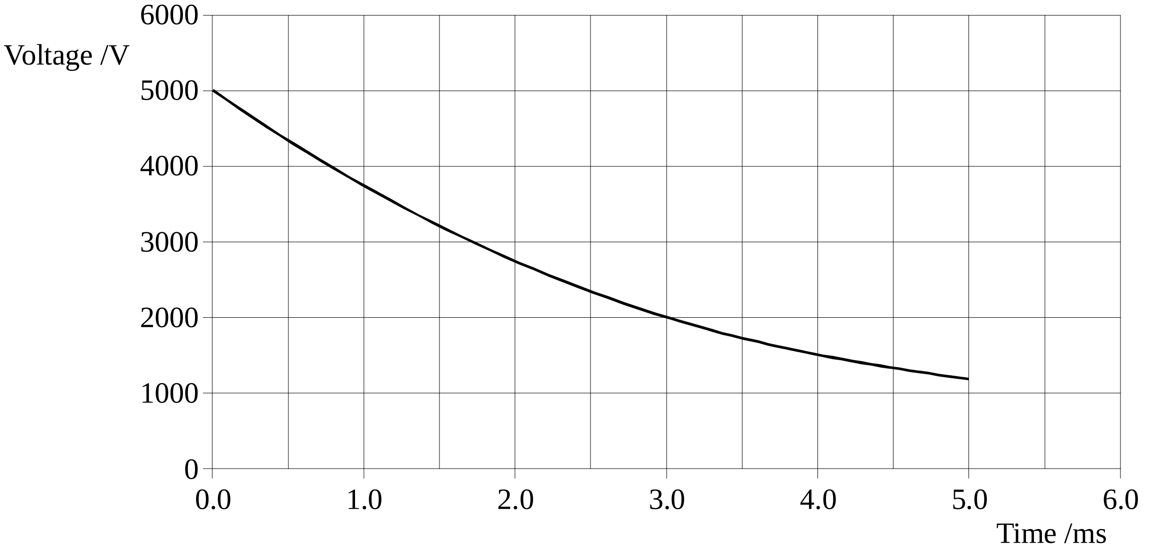
....

....

Energy = ...

(1)

The graph below shows how voltage varies with time as the capacitor's discharged across a test circuit that has a resistance equivalent to that of the patient's chest.



Use the graph to find the time constant for the circuit.

....

....

Time constant = ...

(2)

The total resistance of the circuit, including the paddles and chest, is 47 Ω. Calculate the capacitance of the capacitor.

....

....

Capacitance = ...

(2)

The energy delivered to the patient's chest is selected by the operator from these settings: 50 J, 180 J, 380 J. This is achieved inside the machine electronically, by allowing the discharge to proceed for an appropriate length of time.

On one particular setting, the discharge lasts for 2.0 ms. Calculate the energy left in the capacitor at this time.

....

....

....

(2)

Some energy loss occurs and roughly 60% of the energy leaving the capacitor during the discharge actually goes into the patient. Find which setting the operator has selected.

....

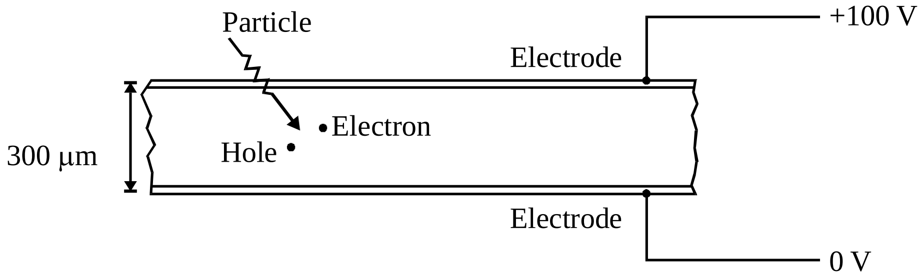
....

Energy setting = ...

(2)

(Total 11 marks)

68. One type of particle detector at CERN consists of a thin wafer of silicon. On both sides of the wafer are aluminium electrodes, with a voltage of 100 V across them. The electrodes are 300 μm apart. When a particle enters the wafer, it creates an electron/hole pair as shown (a hole acts like a positive electron).



Electric field = ...

(2)

Calculate the force due to this field on an electron in the wafer.

....

....

Force = ...

(2)

Indicate on the diagram the direction of this force on the free electron shown. Explain why the force has this direction.

....

....

....

(2)

The hole can move in the direction of the electric field, provided that it can gain enough energy from the field to move it from one atom to the next. The distance between atoms is 2.8×10^{-10} m. Calculate how much energy the hole gains in moving this distance in the direction of the field.

....

....

Energy = ...

(2)

(Total 8 marks)

69. The dynamo torch, Figure 1, is operated by successive squeezes of the handle. These cause a permanent magnet to rotate within a fixed coil of wires, see Figure 2. Harder squeezes rotate the magnet faster.

Figure 1

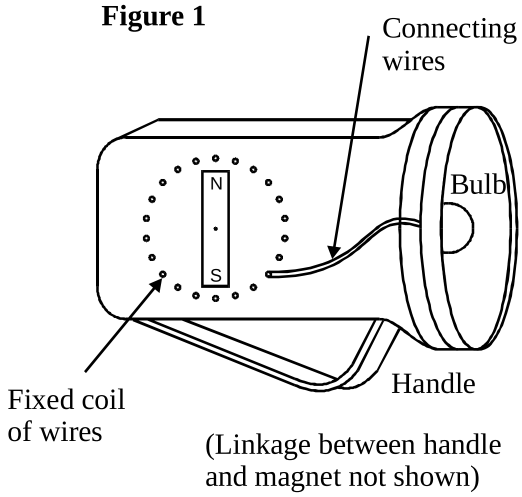
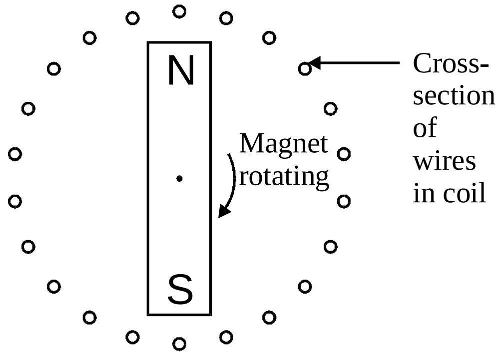


Figure 2



On Figure 2 sketch the field of the permanent magnet.

Discuss the physics of how the torch works and the factors which affect the brightness of the bulb.

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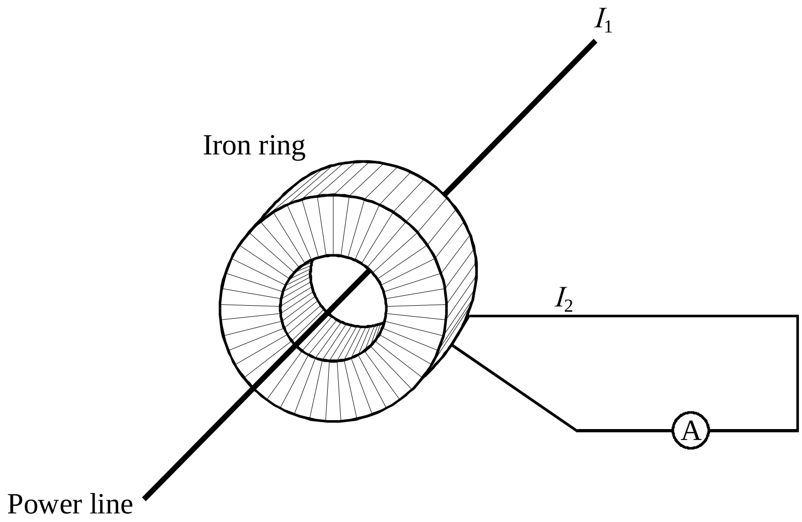
(Total 6 marks)

70. A large current such as that in a power station or power line (e.g. 2000 A) is hard to measure using a conventional meter simply connected in series. The usual technique makes use of the fact that this current is alternating. A ring of iron is clamped round the wire whose current (I_1 in the diagram) is to be measured. A coil with 1000 turns is wound round the iron. An induced current flows in this coil; by measuring this current (I_2) with a conventional meter, it is possible to calculate the value of I_1.



Suggest a reason why it is difficult to measure a large current with a conventional meter in series in the circuit.

....

....

....

(1)

Explain how the alternating current I_1 causes the current I_2.

....

....

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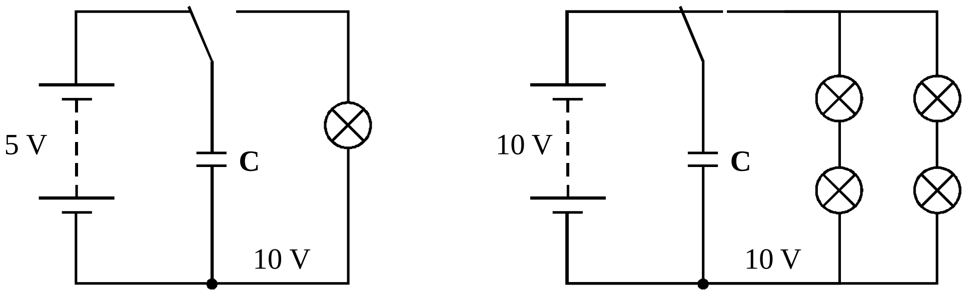
....

....

(4)
(Total 5 marks)

71. A student has four identical lamps. She connects up circuit 1. Using 5 V the lamp flashes briefly when the switch is moved from left to right. She then connects up circuit 2. Using 10 V with this arrangement, each of the four lamps gives a similar flash to the lamp in circuit 1.



Circuit 1　　　　Circuit 2

Discuss the physics of what the student has observed.

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(6)
(Total 6 marks)

72. State Faraday's law of electromagnetic induction.

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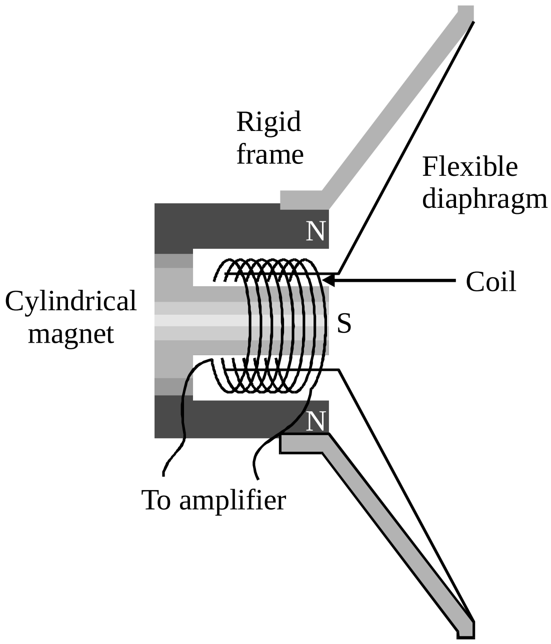
....

(2)

Microphones convert longitudinal sound waves into electrical signals, which can be amplified. One type of microphone consists of a flexible diaphragm connected to a coil of wire, which is near a cylindrical magnet.



Describe how sound waves are converted into electrical signals. You may be awarded a mark for the clarity of your answer.

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(4)
(Total 6 marks)

73. A defibrillator is a machine that is used to correct irregular heartbeats by passing a large current through the heart for a short time. The machine uses a 6000 V supply to charge a capacitor of capacitance 20 μF. The capacitor is then discharged through the metal electrodes (defibrillator paddles) which have been placed on the chest of the patient.

Calculate the charge on the capacitor plates when charged to 6000 V.

....

Charge = ...

(2)

Calculate the energy stored in the capacitor.

....

....

Energy = ...

(2)

When the capacitor is discharged, there is an initial current of 40 A through the patient.

Calculate the electrical resistance of the body tissue between the metal electrodes of the paddles.

....

....

Resistance = ...

(1)

Assuming a constant discharge rate of 40 A, calculate how long it would take to discharge the capacitor.

....

....

....

....

Time = ...

(2)

In practice the time for discharge is longer than this calculated time. Suggest a reason for this

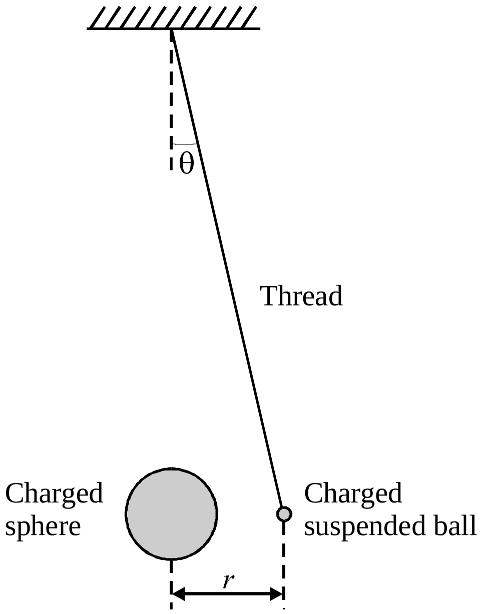
....

....

....

(1)
(Total 8 marks)

74. One practical arrangement for verifying Coulomb's law is to use a lightweight, negatively-charged, freely-suspended ball. It is repelled by the negative charge on a larger sphere that is held near it, on an insulated support. The small angle of deflection θ is then measured.



Draw a free-body force diagram for the suspended ball.

(3)

The weight of the ball is W. Show that the force of repulsion F on the suspended ball is given by

$$F = W \tan \theta$$

....

....

....

....

....

(2)

A student takes several sets of readings by moving the larger sphere towards the suspended ball in order to increase the mutual force of repulsion between them. He measures the angle of deflection θ and the separation distance r in each case. He then calculates the magnitude of the force F.

Here are some of his results.

Force $F/10^{-3}$ N			142	568
Distance $r/10^{-3}$ m	36.0	27.0	18.0	9.0

Calculate the values that you would expect the student to have obtained for the missing forces, assuming that Coulomb's law was obeyed.

....

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Write your answers in the table.

(4)

Suggest why, in practice, it was necessary for the student to take measurements quickly using this arrangement.

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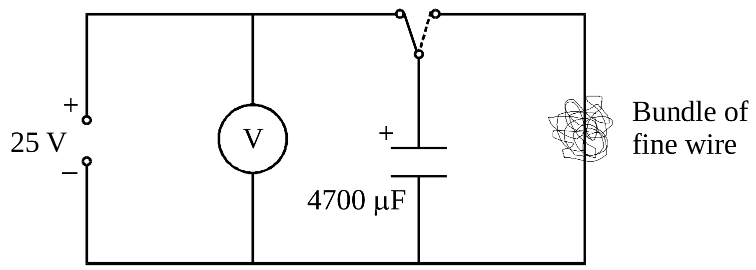
(1)
(Total 10 marks)

75. (i) A 4700 μF capacitor is charged to 25 V and discharged through a tightly wound bundle of fine insulated wire.

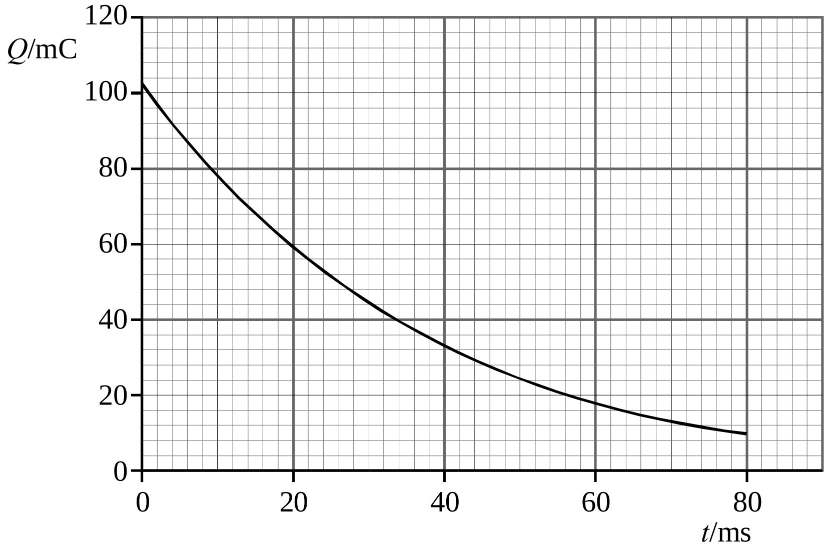


Calculate the energy dissipated in the wire.

Explain why it would be difficult to use this arrangement to demonstrate that $W_c \propto V^2$ for a range of potential differences up to about 50 V. You may be awarded a mark for the clarity of your answer.

(6)

(ii) The graph shows how the charge on the capacitor varies with time as it discharges.

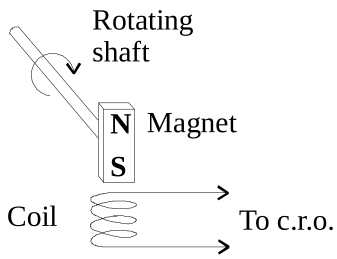


State what name is given to this shape of graph and name another physical phenomenon which gives rise to graphs of this shape.

Showing your working, determine a value for the resistance of the bundle of wire.

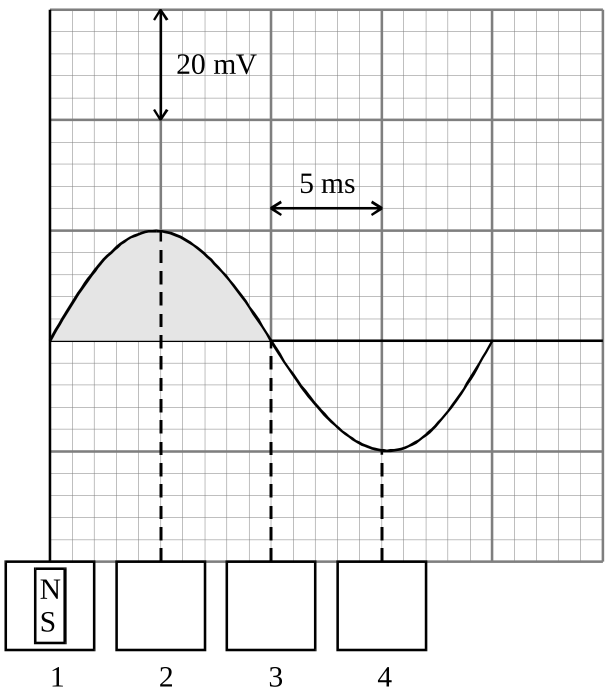
(6)
(Total 12 marks)

76. In order to monitor the performance of a motor, it is necessary to measure its rate of rotation. A simple sensor consists of a small bar magnet attached to the output shaft of the motor. A coil of wire is placed so that the magnet rotates close to it as shown below.



The voltage induced across the coil is displayed on a c.r.o. (cathode ray oscilloscope). The c.r.o. screen is shown below.

Figure i



Explain how the movement of the magnet produces the voltage shown. As part of your explanation, fill in the three empty boxes (2, 3 and 4) below figure (i) to show the corresponding positions of the magnet.

....

....

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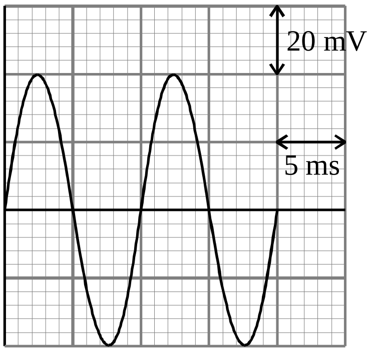
....

(4)

The rotation rate of the shaft is now doubled. The c.r.o. settings are not changed. This produces the c.r.o screen shown below.

Figure ii



Explain the differences between figure (i) and figure (ii).

....

....

....

....

(3)

The shaded area in figure (i) is equal to

2 × (number of turns on coil) × (flux at one end of magnet)

The coil has 240 turns. Show that the flux at each end of the magnet is about 3×10^{-7} Wb.

....

....

....

....

....

(3)

The dimensions of the end of the bar magnet are 1.0 cm × 0.5 cm. Calculate an approximate value for the magnetic flux density at the end of the bar magnet.

....

....

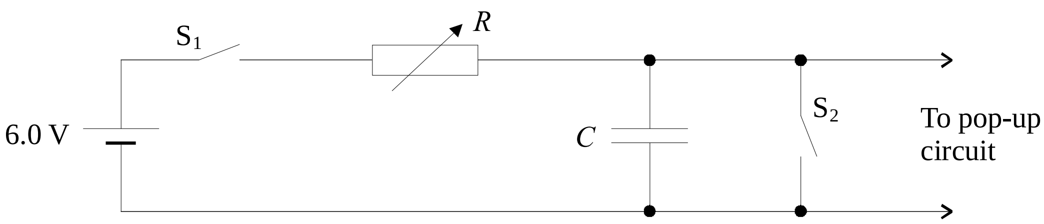
....

Magnetic flux density = ...

(2)

(Total 12 marks)

77. The timer on an electric toaster uses a resistor-capacitor circuit. When the bread is lowered, switch S_1 is closed and the capacitor *C* starts to charge up. When the voltage across it reaches 4.0 V, another circuit is activated which makes the toast pop up, and at the same time switch S_1 is opened and switch S_1 is closed for a few seconds (to discharge the capacitor). The resistor *R* can be varied. The capacitance $C = 100\ \mu F$.



Calculate the energy stored in the capacitor when the voltage across it reaches 4.0 V.

....

....

....

Energy stored = ...

(2)

Which parts of this circuit will transfer this energy to the surroundings at the end of the toasting cycle?

....

....

(1)

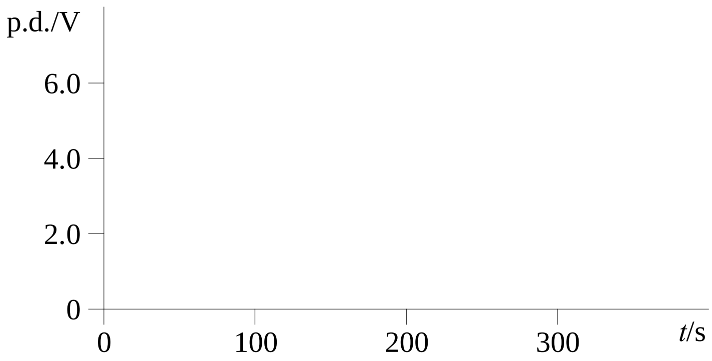
Discuss whether this energy transfer process may damage the toaster.

....

....

(1)

The toaster is set so that switch S_1 opens after 200 s. Complete the graph below to show how the voltage across the capacitor will vary with time from the moment (at t = 0 s) when S_1 is closed.



(3)

By estimating the time constant for the circuit, calculate an approximate value for R when C = 100 μF.

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....

....

R = ...

(2)

Discuss the effect of increasing the resistance, *R*.

....

....

....

....

(2)
(Total 11 marks)

78. There have been several space missions experimenting with tethered satellites. In a 1992 mission, the tethered satellite was connected to the shuttle Atlantis by a long, conducting cable, the satellite being in the higher orbit. As the shuttle orbited through the Earth's magnetic field, an e.m.f. was induced in the conducting cable.

The shuttle, cable and satellite were all moving through the ionosphere, which contains many charmed particles. The charged particles were able to complete a circuit, allowing a current to flow through the cable. One result of this current was that the orbit height of the shuttle, cable and satellite gradually became less.

Explain

(a) the origin of the induced e.m.f.,

(b) the reduction in the orbit height due to the flow of current.

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(Total 5 marks)

79. State the relationship between current and charge

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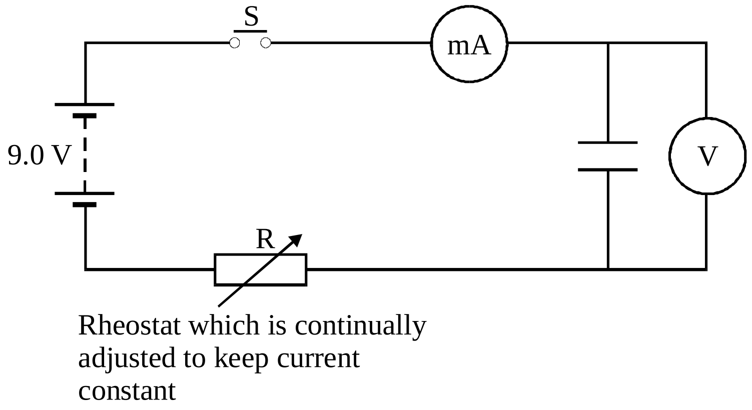
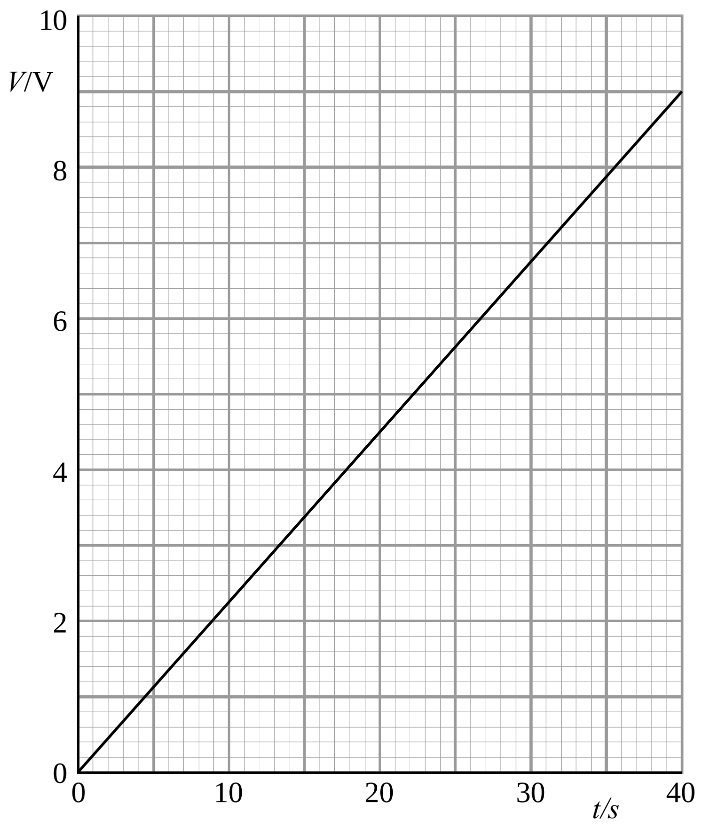
(1)

Two students are studying the charging of a capacitor using the circuit shown. The voltmeter has a very high resistance.



The capacitor is initially uncharged. At time zero, one student closes switch S. She watches the milliammeter and continually adjusts the rheostat R so that there is a constant current in the circuit. Her partner records the voltage across the capacitor at regular intervals of time. The graph below shows how this voltage changes with time.



Explain why the graph is a straight line.

....

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(2)

The capacitance used was 4700 μF. Use the graph to determine the charging current.

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....

....

....

Current =..

(3)

In order to keep the current constant, did the student have to increase or decrease the resistance of the rheostat as time passed? Explain your answer.

....

....

....

....

(3)

The students repeat the experiment, with the capacitor initially uncharged. The initial current is the same as before, but this time the first student forgets to adjust the rheostat and leaves it at a fixed value. Draw a second graph on the same axes to show qualitatively how the voltage across the capacitor will now change with time.

(2)
(Total 11 marks)

80. A beam of electrons is directed at a target. They are accelerated from rest through 12 cm in a uniform electric field of strength 7.5×10^5 N C^{-1}.

Calculate the potential difference through which the electrons are accelerated.

....

....

Potential difference = ...

Calculate the maximum kinetic energy in joules of one of these electrons.

....

....

Maximum kinetic energy = ...

(4)

Calculate the maximum speed of one of these electrons.

....

....

....

Maximum speed = ...

(2)

Draw a diagram to represent the electric field close to an isolated electron.

(2)
(Total 8 marks)

81. A metal framed window is 1.3 m high and 0.7 m wide. It pivots about a vertical edge and faces due south.

Calculate the magnetic flux through the closed window. (Horizontal component of the Earth's magnetic field = 20 μT. Vertical component of the Earth's magnetic field = 50 μT.)

....

....

....

Flux =......................................

(2)

The window is opened through an angle of 90° in a time of 0.80 s. Calculate the average e.m.f. induced.

....

....

....

e.m.f. =..

(2)

State and explain the effect on the induced e.m.f. of converting the window to a sliding mechanism for opening.

....

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....

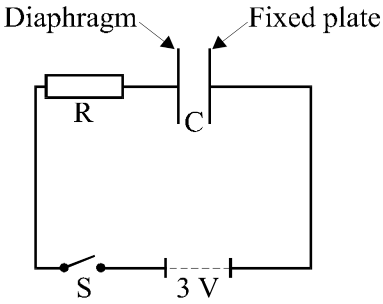
....

....

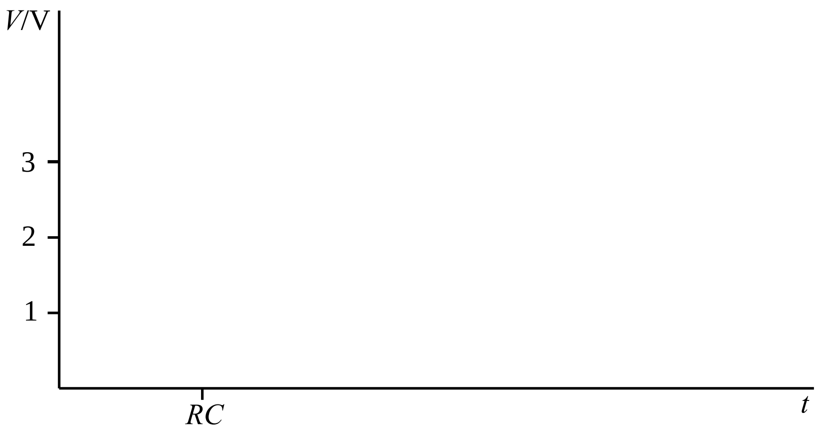
(2)
(Total 6 marks)

82. Most types of microphone detect sound because the sound waves cause a diaphragm to vibrate. In one type of microphone this diaphragm forms one plate of a parallel plate capacitor. As the diaphragm plate moves. the capacitance chances. Moving the plates closer together increases the capacitance. Moving the plates further apart reduces the capacitance.

This effect is used to produce the electrical signal. The circuit shown below consists of a 3 V supply, an **uncharged** capacitor microphone C. a resistor R. and a switch S.



The switch S is closed. Sketch a graph of the voltage across the capacitor microphone against time. Assume that the capacitor microphone is not detecting any sound.



(3)

Explain why movement of the diaphragm causes a potential difference (the signal) across R.

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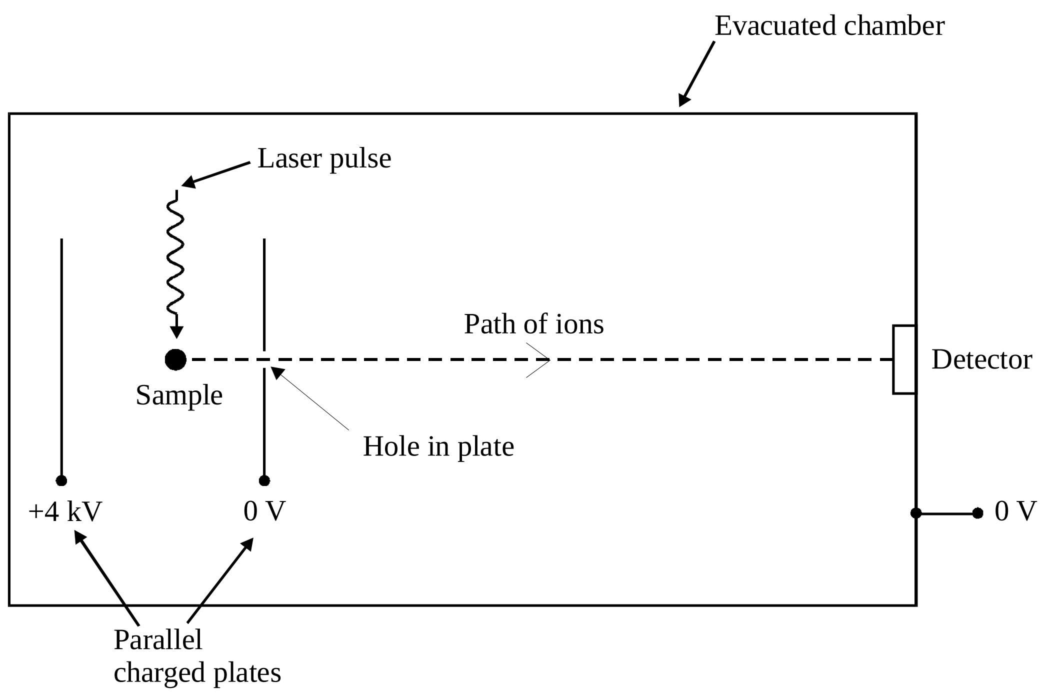
(4)
(Total 7 marks)

83. A mass spectrometer is used to determine the relative amounts of ions of different masses in a sample of material.

A diagram of a new type of mass spectrometer is shown below. In this mass spectrometer, a very short pulse of laser light is directed at the sample of material, which becomes ionised. Each ion has a charge of $+1.6 \times 10^{-19}$ C. This happens **mid-way** between a pair of parallel charged plates.

The time the ion takes to reach the detector depends on its mass. Thus the material in the original sample can be analysed.

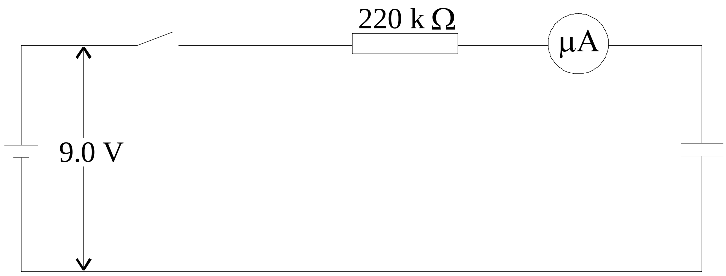


Describe the movement of an ion from the sample to the detector. Hence explain why the time an ion takes to reach the detector depends on its mass. You should include relevant equations.

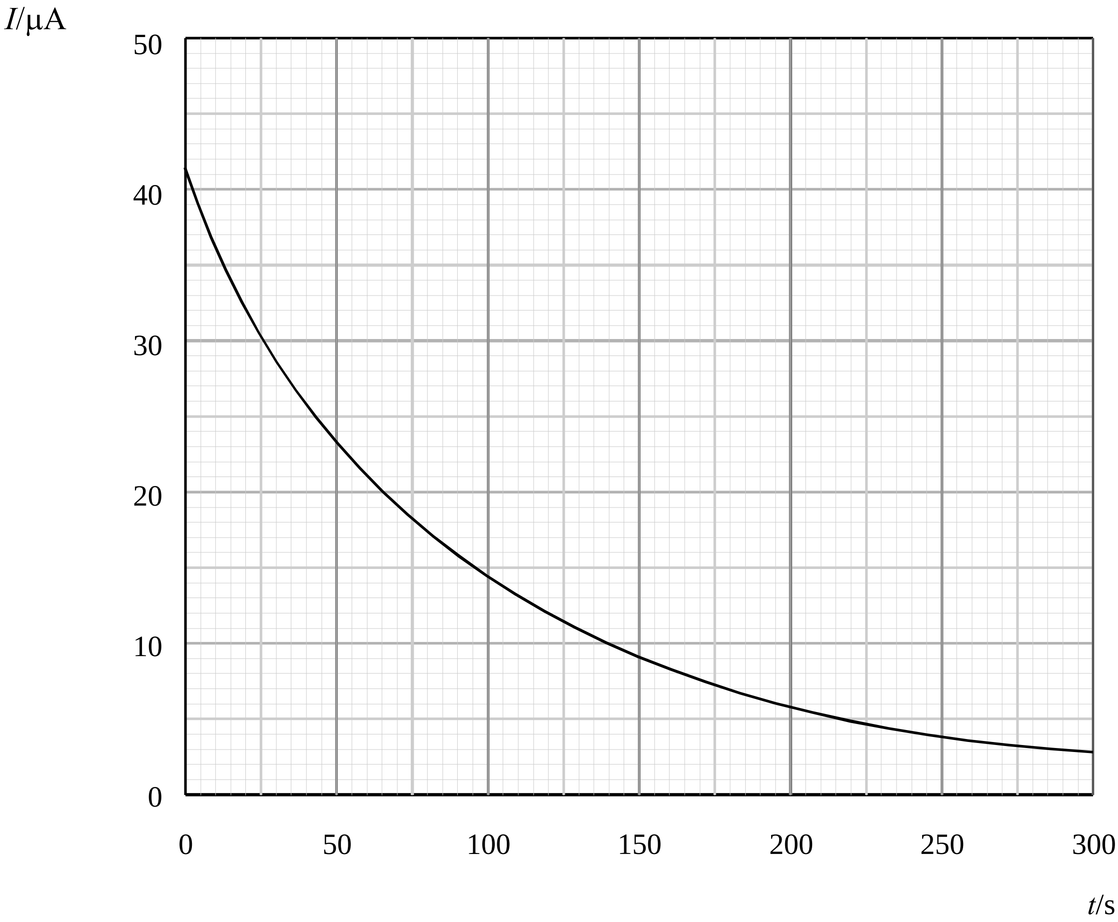
(Allow one lined page)

(Total 7 marks)

84. A student assembles the circuit shown in which the switch is initially open and the capacitor uncharged.



He closes the switch and reads the microammeter at regular intervals of time. The battery maintains a steady p.d. of 9.0 V throughout. The graph shows how the current *I* varies with the time *t* since the switch was closed.



Use the graph to estimate the total charge delivered to the capacitor.

....

....

....

Charge =...

(3)

Estimate its capacitance.

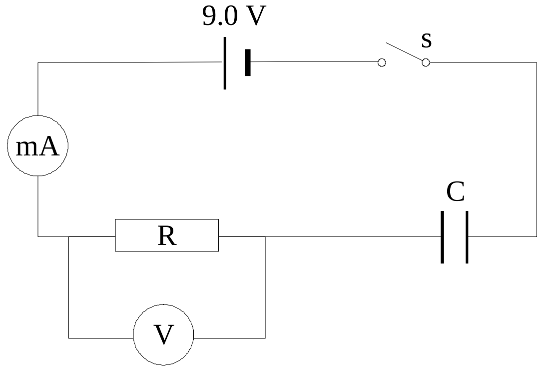
....

....

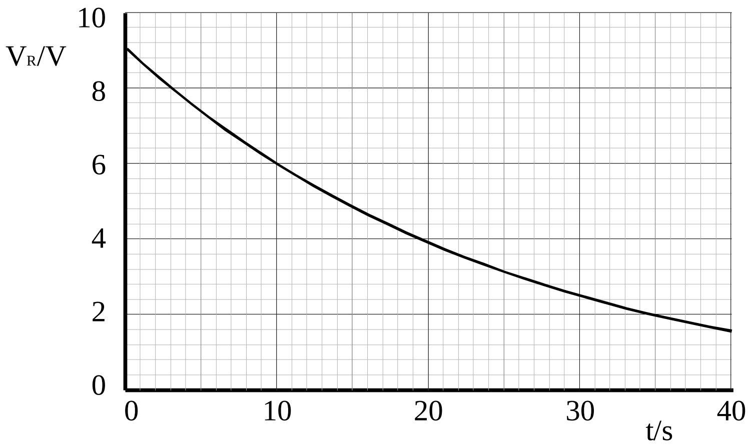
Capacitance =.......................................

(2)
(Total 5 marks)

85. A circuit is set up as shown in the diagram



At t = 0 switch S is closed. Readings of the potential difference across the resistor are taken at regular intervals and the graph shown is obtained.



Use the graph to estimate the time constant for this circuit.

....

....

....

....

....

Time constant =..

(2)

The initial current I_0 = 0. 19 mA.

Calculate the resistance of resistor **R** and hence the capacitance of the capacitor **C**.

....

....

Resistance =...

....

....

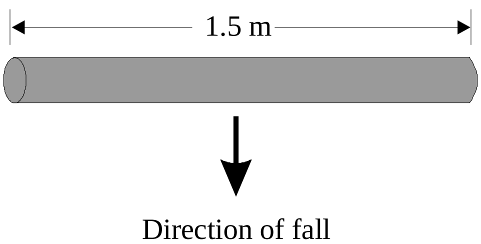
Capacitance =..

(3)

Add to the graph a line showing how the potential difference across the capacitor varies with time over the same period.

(2)
(Total 7 marks)

86. A horizontal metal rod, 1.5 m long, is aligned in an E ↔ W direction and dropped from rest from the top of a high building.



Calculate the e.m.f. induced across the falling rod 2.5 s after release. The horizontal component of the Earth's magnetic field = 2.0×10^{-5} T.

....

....

....

....

e.m.f. =.......................................

(3)

Explain briefly why the magnitude of the vertical component of the Earth's magnetic field is not required in this calculation.

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....

....

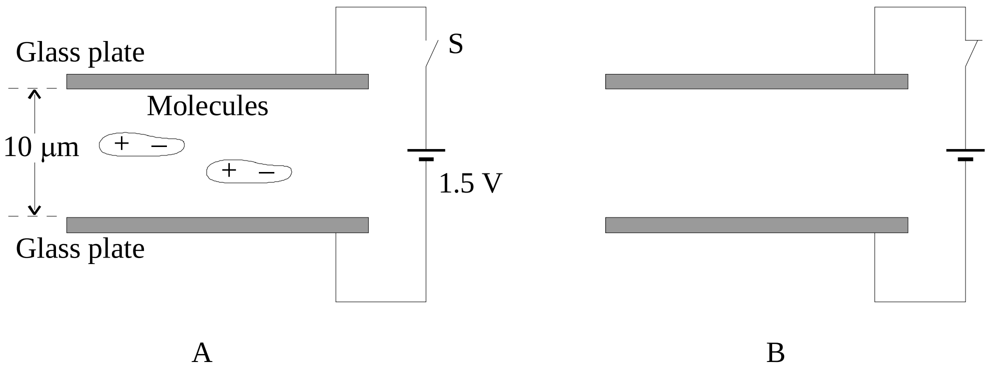
....

....

(2)
(Total 5 marks)

87. Liquid crystal (LC) displays are found in digital watches and calculators. The display is made from two parallel pieces of glass separated by 1.0×10^{-5}m with liquid crystal molecules between them. The glass is coated with conducting material.

The LC molecules have a permanent dipole - that is, they are positive at one end of the molecule and negative at the other. The normal state of these molecules is to be aligned parallel with the glass surfaces as in diagram A. If a voltage of 1.5 V is applied as shown, the molecules align with the electric field.



On diagram A, show the forces acting on the molecule as the switch S is closed.

(1)

Explain why the molecules align with the field.

....

....

....

....

(2)

On diagram B, draw field lines to represent the electric field in the central region of the plates.

(2)

Calculate the strength of the electric field.

…………………………………………………………………………………………………

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…………………………………………………………………………………………………

Field strength = …………………………

(2)
(Total 7 marks)

88. Rahal is choosing a capacitor to use in an electronics project. From a catalogue she finds this information about the range of capacitors for sale

Catalogue letter	Capacitance/μF	Maximum voltage/V
U	15000	16
V	33000	16
W	68000	16
X	220	400
Y	470	400
Z	1000	400

Which of the six capacitors above can store the greatest amount of energy? Justify your answer.

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(3)

The actual value of the capacitor Rahal will receive may be different from the value the catalogue states. The manufacturer guarantees that the maximum percentage difference below/above the catalogue value will be –10% / +50%. Rahal orders one of the 400 V 1000 μF capacitors. Within what range will its actual value lie?

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(2)

When a capacitor is charged (with a p.d. across it), there is always a little current through the "insulator" between the plates - that is, the insulator is never perfect.

This current depends on the p.d. and the capacitor value. The catalogue says "Maximum leakage current 0.003 μA per μF per V".

The next three questions are about one of the 16 V 68 000 μF capacitors which is initially fully charged.

(i) Calculate the charge it stores initially.

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……………………………………………………………………………………………

Charge = ………………………….

(1)

(ii) Show that the value of the maximum leakage current is about 3000 μA.

……………………………………………………………………………………………

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……………………………………………………………………………………………

(2)

(iii) Make an estimate of the time it would take for this capacitor to discharge fully by leakage.
Set out your reasoning clearly.

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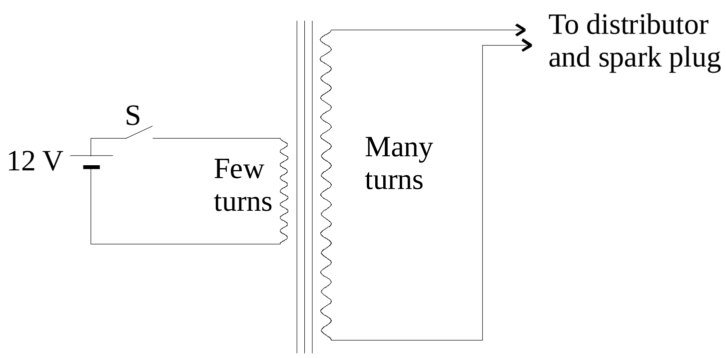
(2)
(Total 10 marks)

89. The ignition system in a car requires 25000 V to be applied to the spark plug to produce a spark in the combustion chamber. This voltage is produced from the car's 12 V d.c. electric supply by using a type of transformer usually called the "ignition coil". A circuit diagram of such a coil is shown below.



In order to generate a pulse of high voltage at the spark plug, the switch S must be closed for a short period and then opened quickly.

Use Faraday’s law to explain why a large voltage is generated in the secondary circuit when the switch is opened.

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…………………………………………………………………………………………………

…………………………………………………………………………………………………

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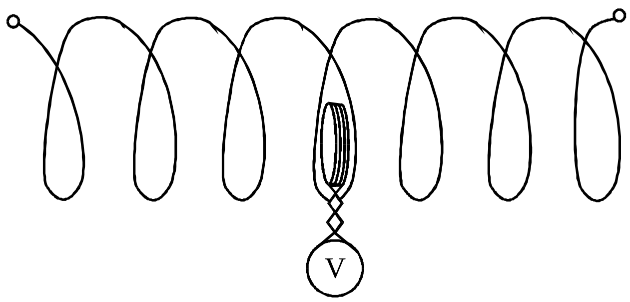
(Total 6 marks)

90. A small solenoid is placed at the centre of the large solenoid as shown. The small solenoid is connected to a digital voltmeter.



State what would be observed on the *voltmeter* when each of the following operations is carried out consecutively.

(a) A battery is connected across the large solenoid.

....

....

(b) The battery is disconnected.

....

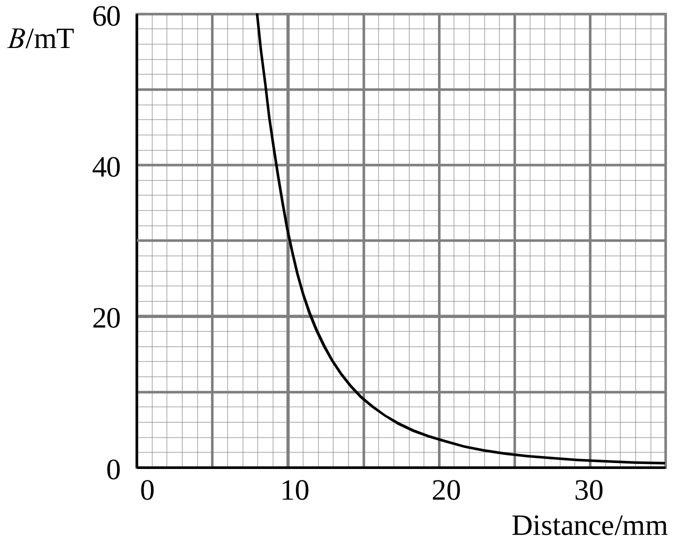
(c) A very low frequency alternating supply is connected across the large solenoid.

....

....

(5)
(Total 7 marks)

91. Magnetic flux density *B* varies with distance beyond one end of a large bar magnet as shown on the graph below.



A circular loop of wire of cross–sectional area 16 cm^2 is placed a few centimetres beyond the end of the bar magnet. The axis of the loop is aligned with the axis of the magnet.

Calculate the total magnetic flux through the loop when it is 30 mm from the end of the magnet.

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Magnetic flux =...

Calculate the total magnetic flux through the loop when it is 10 mm from the end of the magnet.

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Magnetic flux =...

(3)

The loop of wire is moved towards the magnet from the 30 mm position to the 10 mm position so that a steady e.m.f. of 15 μV is induced in it. Calculate the average speed of movement of the loop.

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Speed =.......................

(3)

In what way would the speed of the loop have to be changed while moving towards the magnet between these two positions in order to maintain a steady e.m.f.?

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(1)
(Total 7 marks)

92. State Lenz's law of electromagnetic induction

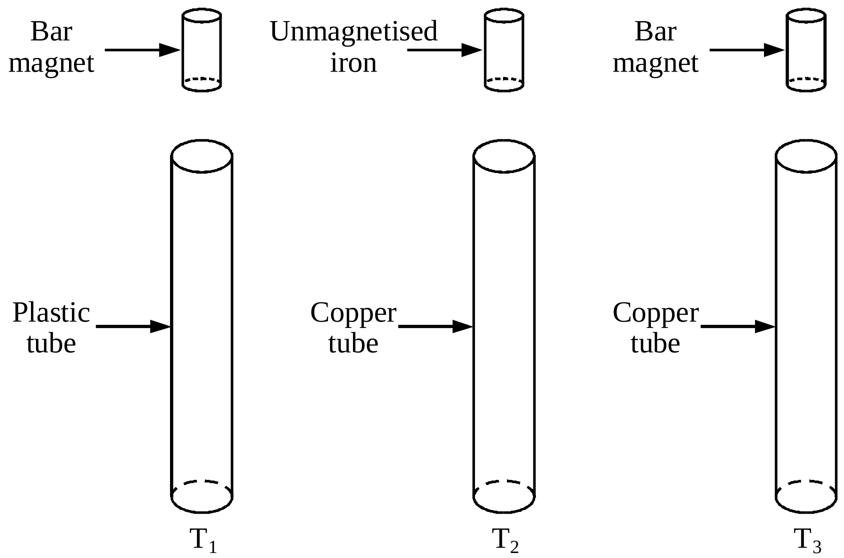
....

....

....

(2)

An exhibit at a science centre consists of three apparently identical vertical tubes, T_1, T_2 and T_3, each about 2 m long. With the tubes are three apparently identical small cylinders, one to each tube.



When the cylinders are dropped down the tubes those in ~T, and ~T2 reach the bottom in less than I second, while that in ~T3 takes a few seconds.

Explain why the cylinder in T_3 takes longer to reach the bottom of the tube than the cylinder in T_1

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(5)

Explain why the cylinder in T_2 takes the same time to reach the bottom as the cylinder in T_1

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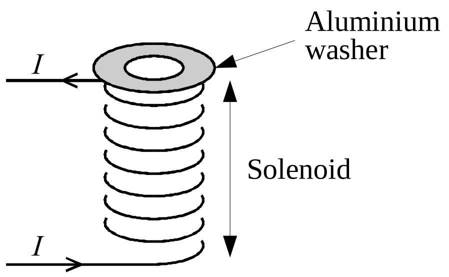
....

....

(2)
(Total 9 marks)

93. A light aluminium washer rests on the end of a solenoid as shown in the diagram.



A large direct current is switched on in the solenoid. Explain why the washer jumps and immediately falls back.

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(Total 5 marks)

94. Define capacitance.

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(2)

An uncharged capacitor of 200 μF is connected in series with a 470 kΩ resistor, a 1.50 V cell and a switch. Draw a circuit diagram of this arrangement.

(1)

Calculate the maximum current that flows.

....

....

Current ....

(2)

Sketch a graph of voltage against charge for your capacitor as it charges. Indicate on the graph the energy stored when the capacitor is fully charged.

(4)

Calculate the energy stored in the fully-charged capacitor.

....

....

Energy = ...

(2)
(Total 11 marks)