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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Capacitors (6.1)

A Level Physics A (H556) · Module 6: Particles and medical physics

26 questions · 169 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions run from the lowest mark tariff to the highest, so similar questions sit together.

Click any row below to jump straight to that question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

26 questions · 169 marks · lowest tariff first

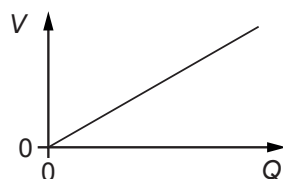


MULTIPLE-CHOICE QUESTIONS

12 questions in this booklet



- 7 The graph below shows the variation of potential difference V with charge Q for a capacitor.



Which row is correct for the gradient of the graph and the area under the graph?

	Gradient of graph	Area under the graph
A	capacitance ⁻¹	work done
B	capacitance ⁻¹	permittivity
C	capacitance	power
D	capacitance	energy

Your answer

[1]

- 8 A capacitor discharges through a resistor. At time $t = 0$, the charge stored by the capacitor is $600\text{ }\mu\text{C}$. The capacitor loses 5.0 % of its charge every second.

What is the charge **left** on the capacitor at time $t = 4.0\text{ s}$?

A $111\text{ }\mu\text{C}$

B $120\text{ }\mu\text{C}$

C $480\text{ }\mu\text{C}$

D $489\text{ }\mu\text{C}$

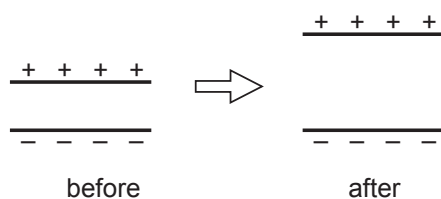
Your answer

[1]

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- 9 Two isolated parallel capacitor plates have an equal and opposite charge. The separation between the plates is doubled. The charge on each plate remains the same but the potential difference between the plates doubles.



Which statement is correct?

- A The capacitance of the capacitor doubles.
- B The energy stored by the capacitor is halved.
- C The permittivity of free space doubles.
- D The electric field strength between the plates remains the same.

Your answer

[1]

8 An isolated metal sphere is charged using a power supply.

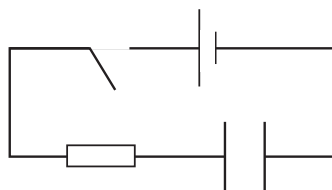
Which single quantity can be used to determine the capacitance of the sphere?

- A** The diameter of the sphere.
- B** The charge on the sphere.
- C** The resistance of the metal.
- D** The e.m.f. of the power supply.

Your answer

[1]

- 9 A capacitor is charged through a resistor.



The cell has e.m.f. 1.50 V and negligible internal resistance.
The capacitor is initially uncharged. The time constant of the circuit is 100 s .
The switch is closed at time $t = 0$.

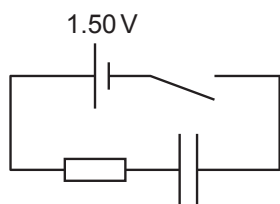
What is the potential difference across the capacitor at time $t = 200\text{ s}$?

- A 0.20 V
- B 0.55 V
- C 0.95 V
- D 1.30 V

Your answer

[1]

13 A capacitor is charged through a resistor.



The cell has electromotive force (e.m.f.) 1.50 V and negligible internal resistance. The time constant of the circuit is 10 s. The switch is closed at time $t = 0$. At time t , the potential difference across the resistor is 0.60 V.

Which expression is correct?

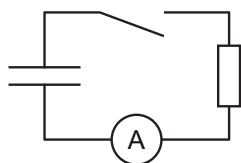
- A $0.60 = 1.50e^{-0.10t}$
- B $0.90 = 1.50e^{-0.10t}$
- C $0.60 = 1.50e^{-10t}$
- D $0.60 = 1.50(1 - e^{-10t})$

Your answer

[1]

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14 A capacitor is discharged through a resistor.



The capacitor is fully charged at time $t = 0$. The time constant of the circuit is 10 s. The switch is closed at time $t = 0$. The current in the resistor is I .

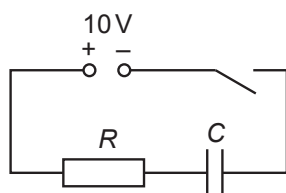
Which row is correct?

	Current I at $t = 0$	Current I at $t = 10\text{ s}$
A	maximum	0
B	maximum	37% of the current at $t = 0$
C	0	63% of the current at $t = \infty$
D	0	37% of the current at $t = \infty$

Your answer

[1]

- 7 The diagram below shows a circuit used to charge a capacitor.



The power supply has electromotive force (e.m.f.) 10 V and negligible internal resistance.

The capacitor has capacitance C and the resistor has resistance R .

The switch is closed at time $t = 0$.

The table below shows potential difference V across the resistor at various values of time t .

V/V	10	6.3	5.0	3.7
t/s	0	2.8	4.2	6.0

What is the product $C \times R$ for this circuit?

- A** 0 s
- B** 2.8 s
- C** 4.2 s
- D** 6.0 s

Your answer

[1]

- 8 A capacitor discharges through a resistor.
At time $t = 0$ the potential difference V across the capacitor is V_0 .
At time $t = 2.0$ s, $V = 0.90 V_0$.

Which statement is **not** correct?

- A** At $t = 4.0$ s, $V = 0.81 V_0$.
B The capacitor is fully discharged after $t = 10$ s.
C The potential difference across the resistor is the same as that for the capacitor.
D The potential difference V decreases exponentially with time t .

Your answer

[1]

- 6 A student is modelling the decay of charge for a capacitor discharging through a resistor using the equation $\frac{\Delta Q}{\Delta t} = -0.2Q$.

The student decides to use $\Delta t = 0.5$ s.

The initial charge on the capacitor is $1000 \mu\text{C}$.

Part of the modelling spreadsheet from the student is shown below.

t/s	Charge Q left on capacitor at time $t/\mu\text{C}$	Charge ΔQ decaying in the next 0.5 s/ μC
0	1000	100
0.5	900	
1.0		
1.5		

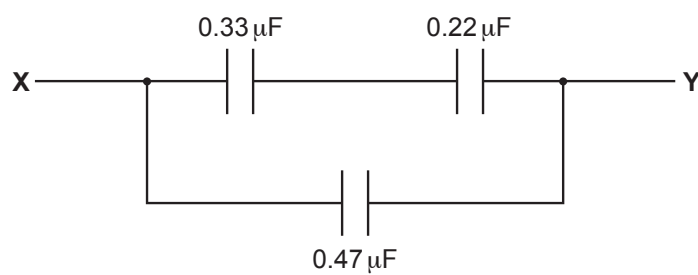
What is the value of Q in μC at $t = 1.5$ s?

- A** 700
B 720
C 729
D 800

Your answer

[1]

- 4 Three capacitors are arranged in a circuit.



The capacitance of each capacitor is shown.

What is the total capacitance between X and Y?

- A $0.25\ \mu\text{F}$
- B $0.60\ \mu\text{F}$
- C $1.02\ \mu\text{F}$
- D $8.0\ \mu\text{F}$

Your answer

[1]

8 A student is using a spreadsheet to model the decay of charge on a capacitor.

They are using the equation $\frac{\Delta Q}{\Delta t} = -\frac{Q}{2.5}$.

The student chooses a time interval of 0.5 s. At time $t = 0.0$ s the charge on the capacitor is $600\,\mu\text{C}$.

Part of the modelling spreadsheet is shown below.

t/s	Charge Q left on capacitor after time $t/\mu\text{C}$	Charge ΔQ decaying in the next $0.5\text{ s}/\mu\text{C}$
0.0	600	120
0.5	480	
1.0		
1.5		
2.0		

What is the charge on the capacitor at $t = 1.5$ s?

- A $130\,\mu\text{C}$
- B $240\,\mu\text{C}$
- C $246\,\mu\text{C}$
- D $307\,\mu\text{C}$

Your answer

[1]

6-MARK QUESTIONS

1 question in this booklet



- 21 (a) A capacitor of capacitance 7.2 pF consists of two parallel metal plates separated by an insulator of thickness 1.2 mm . The area of overlap between the plates is $4.0 \times 10^{-4}\text{ m}^2$. Calculate the permittivity of the insulator between the capacitor plates.

permittivity = ... F m^{-1} [2]

- (b) Fig. 21 shows a circuit.

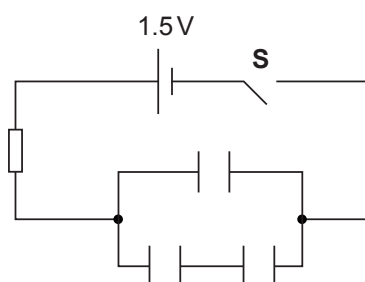


Fig. 21

The capacitance of each capacitor is $1000\text{ }\mu\text{F}$. The resistance of the resistor is $10\text{ k}\Omega$. The cell has e.m.f. 1.5 V and negligible internal resistance.

- (i) Calculate the total capacitance C in the circuit.

$C = \dots\dots\dots \mu\text{F}$ [2]

- (ii) The switch **S** is closed at time $t = 0$. There is zero potential difference across the capacitors at $t = 0$.
Calculate the potential difference V across the resistor at time $t = 12$ s.

$V =$ V [2]

8-MARK QUESTIONS

2 questions in this booklet



22 A student wishes to determine the permittivity ϵ of paper using a capacitor made in the laboratory.

The capacitor consists of two large parallel aluminium plates separated by a very thin sheet of paper.

The capacitor is initially charged to a potential difference V_0 using a battery. The capacitor is then discharged through a fixed resistor of resistance $1.0\text{ M}\Omega$.

The potential difference V across the capacitor after a time t is recorded by a data-logger. The student uses the data to draw the $\ln V$ against t graph shown in Fig. 22.

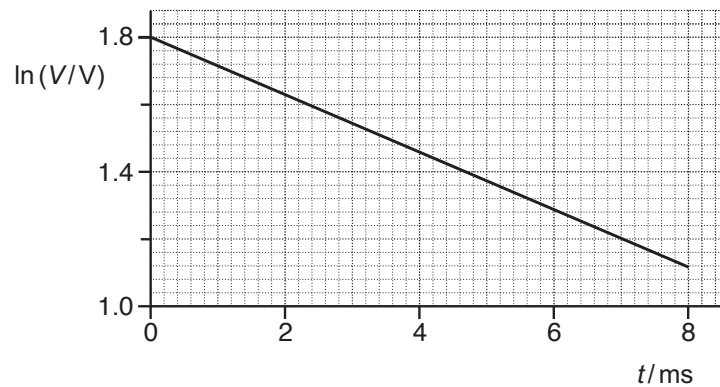


Fig. 22

(a) Show that the magnitude of the gradient of the line shown in Fig. 22 is equal to

$$\frac{1}{CR}$$

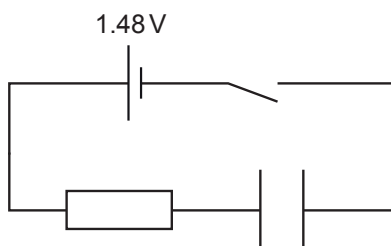
where C is the capacitance of the capacitor and R is the resistance of the resistor.

[2]

(b)* Use Fig. 22 to determine the capacitance C of the capacitor. Describe how the student can then use this value of C to determine a value for ϵ .
In your description, mention any additional measurements required on the capacitor.

[6]

20 (a) The diagram below shows a circuit to charge a capacitor.

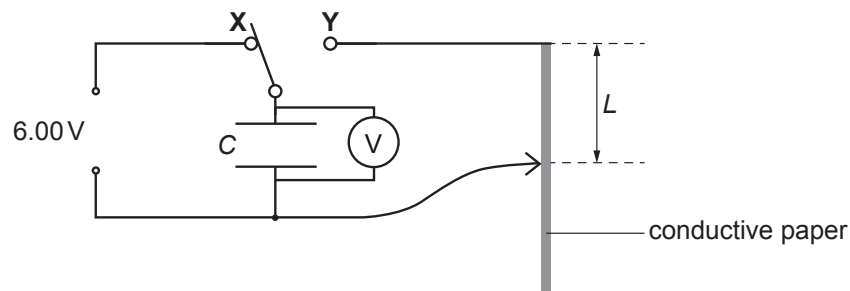


The electromotive force (e.m.f.) E of the cell is 1.48 V and it has negligible internal resistance. The resistance of the resistor is $120\text{ k}\Omega$ and the capacitance of the capacitor is $2000\text{ }\mu\text{F}$. At time $t = 0$ the capacitor is uncharged. The switch is closed at time $t = 0$.

Calculate the time t when the potential difference across the capacitor is 1.00 V .

$t = \dots\dots\dots\text{ s}$ [4]

(b) A capacitor of capacitance C is connected across a strip of conductive paper.



The switch is moved from **X** to **Y**, and the time t for the potential difference across the capacitor to halve is measured.

The time t is given by the expression

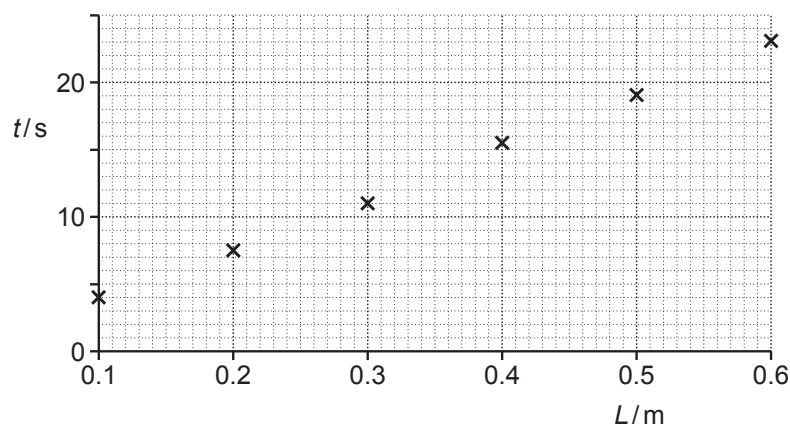
$$t = (Ck \ln 2) \times L$$

where k is the resistance of the conductive paper per unit length and L is the length of the conductive paper.

The value of C is $1.2 \times 10^{-3} \text{ F}$.

In an experiment, L is changed and t measured.

The data points are plotted on a t against L grid as shown below.



Draw a straight line of best fit through the data points, and use the gradient of this line to determine k .

$k = \dots\dots\dots \Omega \text{ m}^{-1}$ [4]



9-MARK QUESTIONS

1 question in this booklet



- 5** Large power stations generate an electrical power of about 1 GW.

Current methods of energy production that use nuclear fusion are unable to produce enough energy for large-scale energy production. A proposed method of controlling nuclear fusion is inertial confinement fusion (ICF). ICF uses a large number of powerful lasers to create the high temperatures required for nuclear fusion to occur.

One ICF experiment uses a network of capacitors to store the energy needed to power the lasers. When the network is fully charged:

- potential difference across the network = 24 kV
- total energy stored in the network = 400 MJ

- (a) (i)** Calculate the total capacitance, C , of the network.

$C = \dots\dots\dots$ F [2]

- (ii)** Explain why the individual capacitors in the network should be connected in parallel in order to produce this total capacitance.

.....
 [1]

- (b)** The total stored energy must be released in a time of less than 1 millisecond.

Explain, using a calculation, why the lasers are powered by the network of capacitors instead of being connected directly to the mains electricity supply.

.....

 [2]

(c) The fusion reaction in the ICF experiment is

deuterium + tritium $\rightarrow$ alpha particle + neutron

Calculate the number of fusion reactions that must occur for the energy released by fusion to be equal to the electrical energy stored in the network of capacitors.

- mass of deuterium = 2.014102 u
- mass of tritium = 3.016049 u
- mass of alpha particle = 4.002603 u
- mass of neutron = 1.008665 u

number of fusion reactions = ... [4]

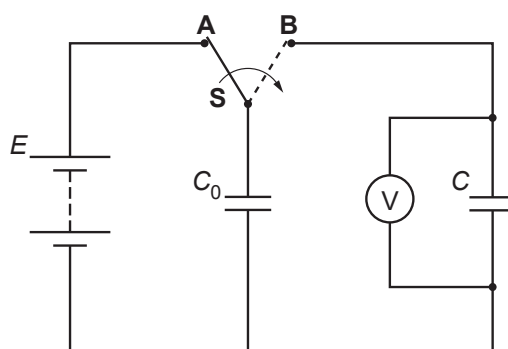
10-MARK QUESTIONS

2 questions in this booklet



- 2 The diagram below shows a circuit containing two capacitors which are both initially uncharged. The battery has e.m.f. E and negligible internal resistance.

The switch **S** is first moved to position **A** until the capacitor of capacitance C_0 is fully charged.



The switch **S** is then moved to position **B**. The initial charge stored by the capacitor of capacitance C_0 is shared between the two capacitors. The final reading on the voltmeter is V .

- (a) Show that $V = \frac{C_0}{C + C_0} E$.

[2]

- (b) A student wants to determine the values of E and C_0 by repeating the experiment above and measuring the potential difference (p.d.) V for a selection of capacitors of capacitance C .

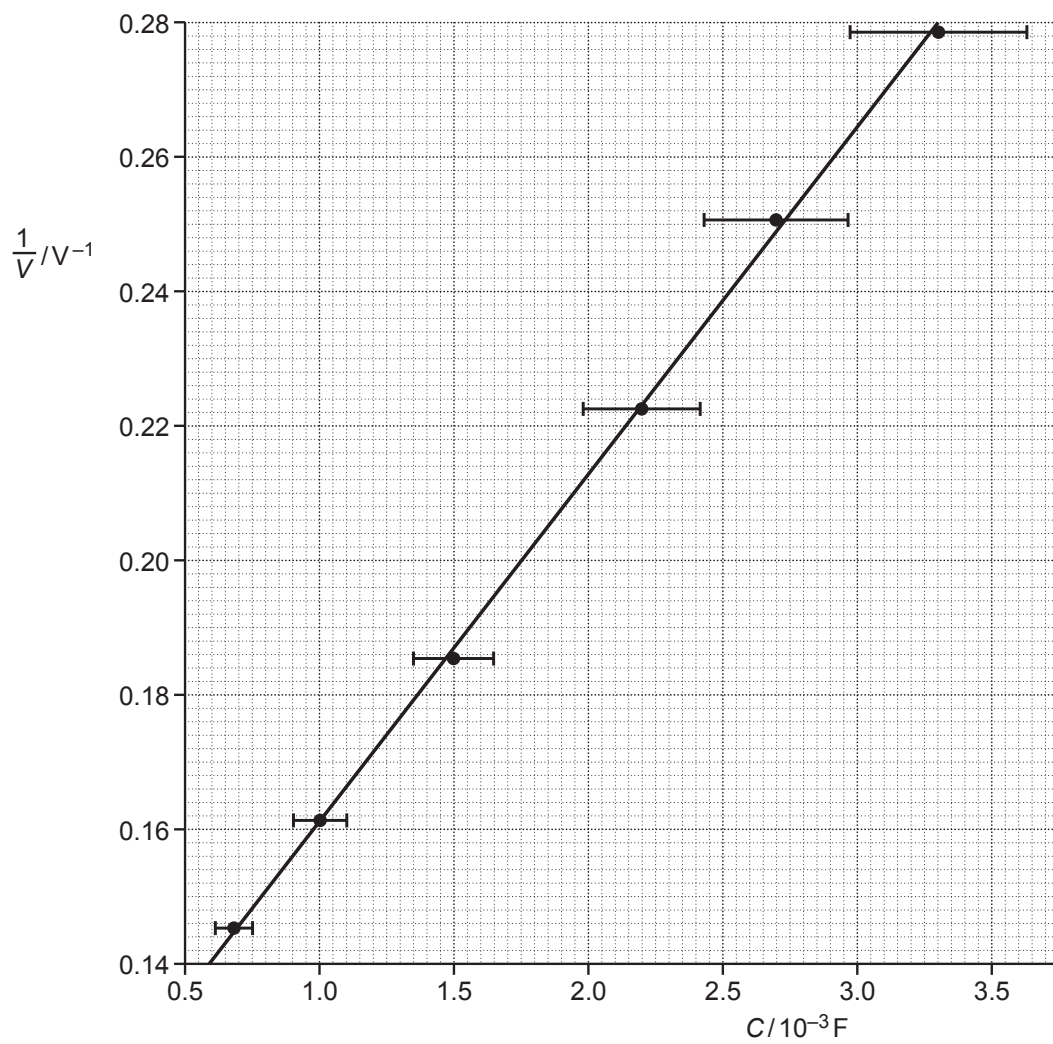
The student decides to plot a graph of $\frac{1}{V}$ against C .

- (i) Use the expression in (a) to show that the graph should be a straight line of gradient $\frac{1}{C_0 E}$ and y-intercept $\frac{1}{E}$.

[1]

Question 2 continues on page 6

- (ii) The data points, error bars and the line of best fit drawn by the student are shown in the graph below.



The gradient of the line of best fit is $51 \text{ V}^{-1} \text{ F}^{-1}$. The value of E is 9.1 V .

Determine the value of C_0 in millifarads (mF). Write your answer to 2 significant figures.

$C_0 = \dots\dots\dots \text{ mF}$ [2]

- (iii) Draw on the graph a straight line of worst fit.

Use this line to determine the absolute uncertainty in your value of C_0 . Write your answer to an appropriate number of significant figures.

absolute uncertainty = ... mF [4]

- (c) The experiment is repeated with a resistor of resistance $10\text{ k}\Omega$ placed in series between **S** and the capacitor of capacitance C_0 .

State with a reason what effect, if any, this would have on the experiment.

.....

 [1]

- 6 (a) Define the **time constant** of a circuit containing a capacitor of capacitance C and a resistor of resistance R .

.....
 [1]

- (b) The capacitor circuit shown in **Fig. 6.1** can be used to smooth oscillating electrical signals.

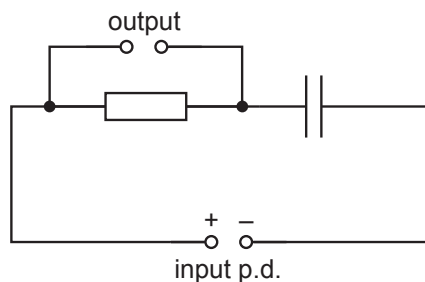


Fig. 6.1

- (i) **Fig. 6.2** shows the input signal of potential difference (p.d.) V against time t .

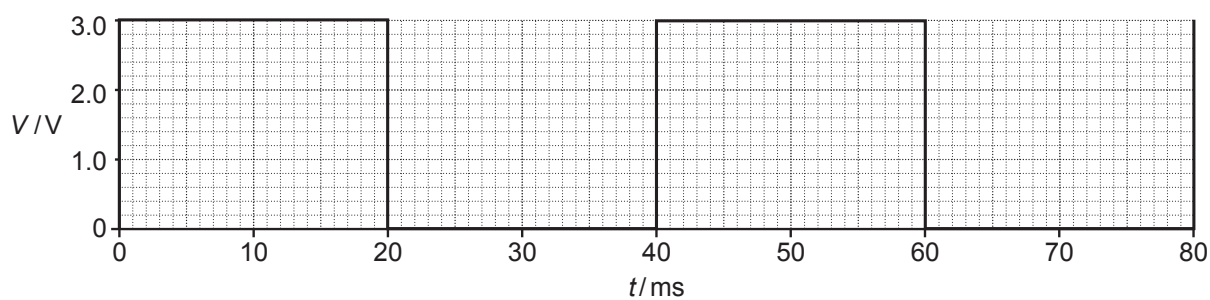


Fig. 6.2

Calculate the frequency f of this input signal.

$f =$ Hz [2]

- (ii) Fig. 6.3 shows the variation of the charge Q on the positive plate of the capacitor with time t .

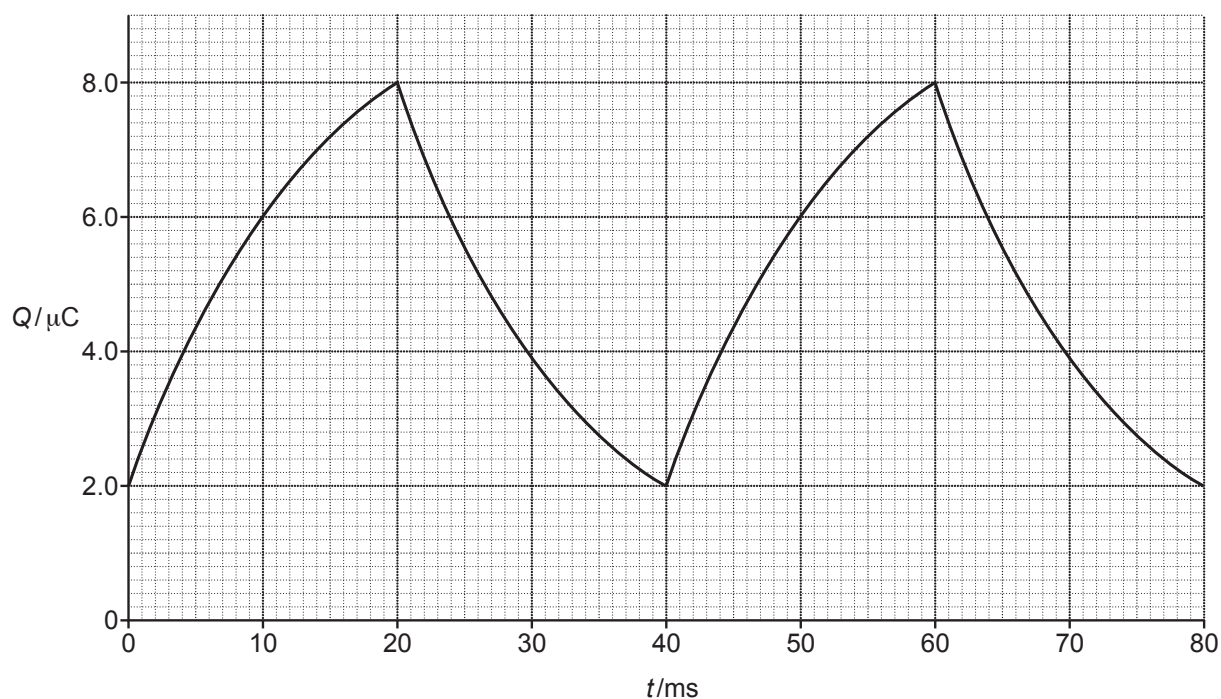


Fig. 6.3

Use a discharging section of the graph in Fig. 6.3 to determine the time constant of the circuit. Give your answer in ms.

time constant = ... ms [2]

- (iii) By drawing a suitable tangent to the graph in Fig. 6.3, calculate the maximum current in the resistor.

maximum current = ... A [2]

- (iv) On Fig. 6.4 below, sketch the variation of the current I in the resistor with time t . Include an appropriate label and scale on the vertical axis.

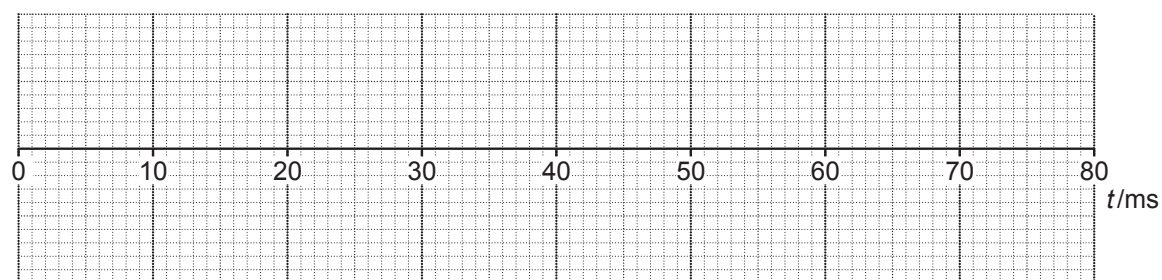


Fig. 6.4

[3]



11-MARK QUESTIONS

2 questions in this booklet



- 3 A student is investigating how the discharge of a capacitor through a resistor depends on the resistance of the resistor.
The equipment is set up as shown in Fig. 3.1.

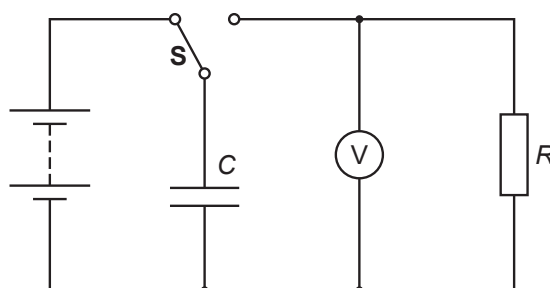


Fig. 3.1

The student charges the capacitor of capacitance C and then discharges it through a resistor of resistance R using switch **S**. After a time $t = 15.0\text{ s}$ the student records the potential difference V across the capacitor. The student repeats this procedure for different values of R .

It is suggested that V and R are related by the equation

$$V = V_0 e^{-\frac{t}{CR}}$$

where V_0 is the initial potential difference across the capacitor and t is the time over which the capacitor has discharged.

- (a) The student decides to plot a graph of $\ln(V/V_0)$ on the y -axis against $\frac{1}{R}$ on the x -axis to obtain a straight line graph. Show that the magnitude of the gradient is equal to $\frac{15}{C}$.

[2]

- (b) Values of R and V at $t = 15.0\text{ s}$ are given in the table below.

$R/\text{k}\Omega$	V/V_0	$\left(\frac{1}{R}\right)/10^{-6}\text{ }\Omega^{-1}$	$\ln(V/V_0)$
56	3.0 ± 0.2	18	
68	3.7 ± 0.2	15	1.31 ± 0.06
100	5.0 ± 0.2	10	1.61 ± 0.04
150	6.4 ± 0.2	6.7	1.86 ± 0.03
220	7.3 ± 0.2	4.5	1.99 ± 0.03
330	8.1 ± 0.2	3.0	2.09 ± 0.03

- (i) Complete the missing value of $\ln(V/V_0)$ and its absolute uncertainty in the table above.

[1]

- (ii) Use the data to complete the graph of Fig. 3.2. Four of the six points have been plotted for you. [2]

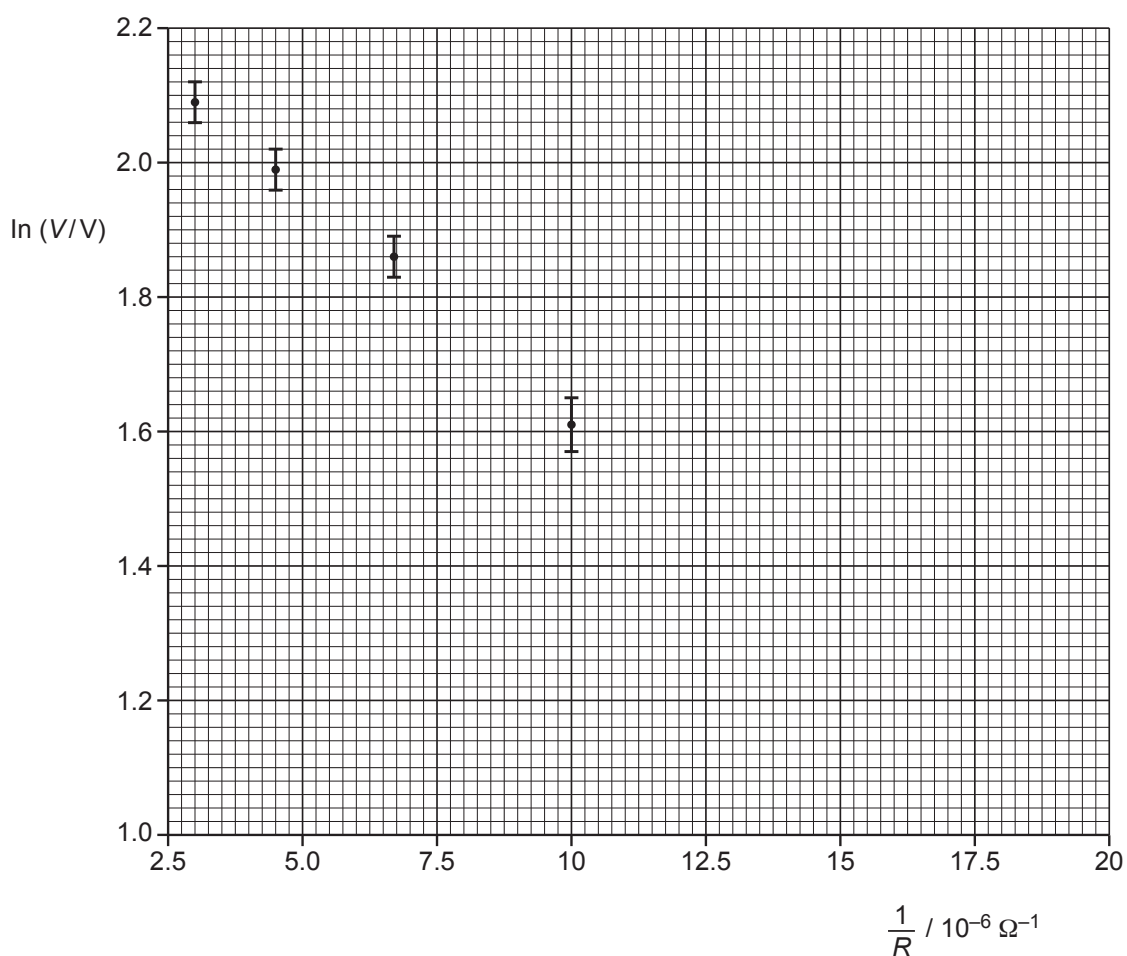


Fig. 3.2

- (iii) Use the graph to determine a value for C . Include the absolute uncertainty and an appropriate unit in your answer.

$C = \dots \pm \dots$ unit $\dots$ [4]

Turn over

- (c) Determine the value of R , in $\text{k}\Omega$, for which the capacitor discharges to 10% of its original potential difference in 15.0 s. Show your working.

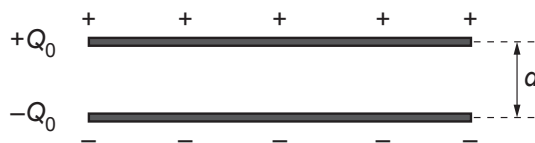
$R = \dots\dots\dots \text{k}\Omega$ [2]

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Question 4 begins on page 10.



22 (a) The diagram below shows a simple capacitor.



The capacitor consists of two horizontal metal plates in a vacuum. The magnitude of the charge on each plate is Q_0 . The potential difference (p.d.) between the plates is V_0 . The capacitor plates have capacitance C_0 . The separation between the plates is d . The energy stored by the capacitor is E_0 .

The top plate is moved vertically upwards. The new separation between the plates is $2d$. The charge on each plate remains the **same**. The energy stored by the capacitor **increases**.

(i) Determine the new:

1 capacitance in terms of C_0

capacitance = ... C_0 [1]

2 p.d. between the plates in terms of V_0

p.d. = ... V_0 [1]

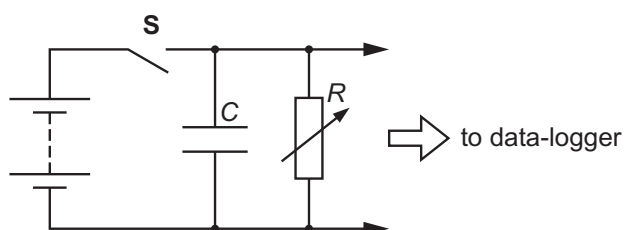
3 energy stored in terms of E_0 .

energy = ... E_0 [1]

(ii) Explain, in terms of forces between the plates, why the energy stored increases.

.....
 [1]

(b) A student discharges a capacitor of capacitance C through a variable resistor of resistance R using the arrangement below.



The capacitor is made from two parallel metal plates separated by a sheet of paper of thickness $8.0 \times 10^{-5} \text{ m}$. The area of overlap between the plates is $3.1 \times 10^{-2} \text{ m}^2$.

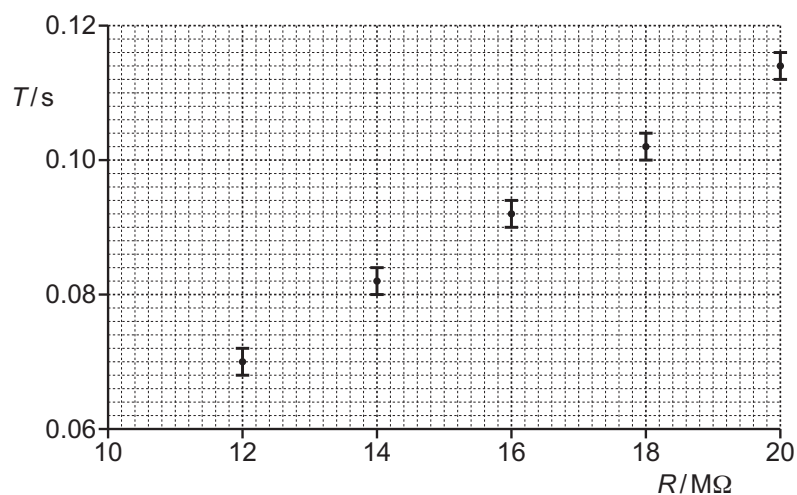
The capacitor is charged fully by closing switch **S**. At time $t = 0$, **S** is opened and the capacitor discharges through the resistor. After $t = T$, the potential difference across the capacitor is halved. The student repeats this for several values of R .

- (i) The student decides to plot T against R to obtain a straight-line graph.

Show that the line has gradient $= C \ln 2$.

[2]

- (ii) The data points plotted by the student are shown below.



- 1 Draw a best-fit straight line through the data points and use the gradient of this line to determine C .

$C = \dots\dots\dots F$ [3]

- 2 Use your answer in (ii)1 to calculate the permittivity ϵ of the paper.

$\epsilon = \dots\dots\dots F m^{-1}$ [2]

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13-MARK QUESTIONS

3 questions in this booklet



3 Fig. 3.1 shows the design of a 'mechanical' torch.

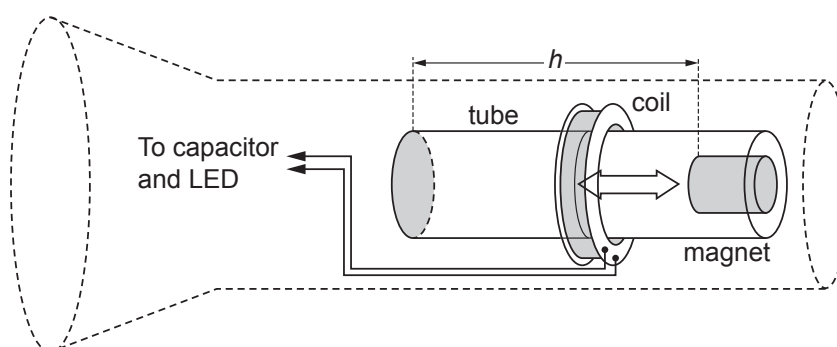


Fig. 3.1

There is no battery in the torch. Instead, when the torch is inverted, the magnet falls a short vertical distance h through the coil of wire, as shown in Fig. 3.2. This induces an electromotive force (e.m.f.) across the ends of the coil. The e.m.f. is used to store charge in a capacitor, which lights a light-emitting diode (LED) when it discharges.

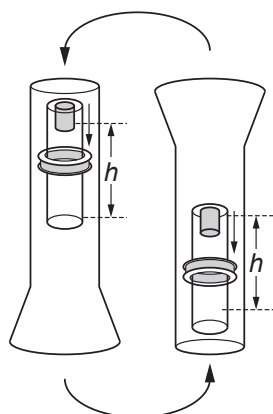


Fig. 3.2

Fig. 3.3 shows the variation with time of the e.m.f. generated as the magnet falls the distance h .

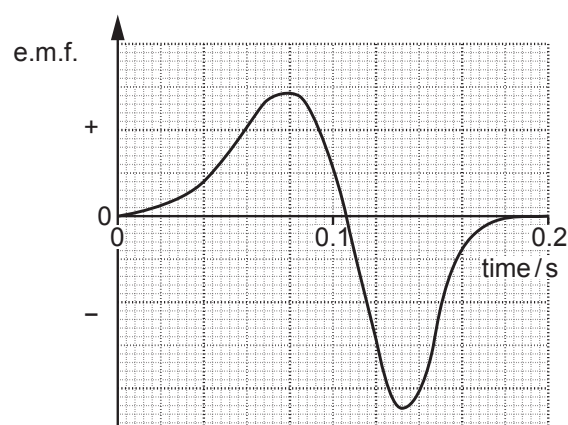


Fig. 3.3

- *(c)** In the torch, the gravitational potential energy of the magnet is converted into electrical energy supplied to the 50 mW LED.

You are asked to investigate whether the efficiency of this energy conversion depends on the number of inversions of the torch.

- Describe how you will make accurate measurements to collect your data. Assume that both the torch and the tube can be opened.
- Explain how you will use the data to reach a conclusion. **[6]**

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Additional answer space if required.

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- 20** In an experiment a circuit is set up so that a capacitor with a resistor in series can be charged and at some later time discharged through the same resistor without changing the positions of the components. This process can be repeated.

The supply has a potential difference (p.d.) 6.0 V d.c.

The capacitor has capacitance $1.0\ \mu\text{F}$.

The resistor has resistance $10\ \text{k}\Omega$.

A voltmeter is used to measure the p.d. across the capacitor.

- (a)** Draw a circuit diagram for this experiment.

[2]

- (b)** Calculate the charge Q stored on the capacitor when it is fully charged.

$Q = \dots\dots\dots\ \text{C}$ [1]

- (c)** Use a calculation to explain why it will not be possible to measure the variation of p.d. across the capacitor with time, using a stop watch.

.....
..... [4]

- (d) State how this experiment can be modified to measure the variation of p.d. across the capacitor with time as the capacitor charges.

.....
 [1]

- (e) The capacitor was completely charged and then discharged to 4.12 V.

- (i) Calculate the time t required for the p.d. across the capacitor to reach 4.12 V when discharging.

$t =$ s [2]

- (ii) Calculate the average rate at which energy is lost by the capacitor as it discharges from 6.0 V to 4.12 V.

average rate at which energy is lost = ... Js^{-1} [3]

22 This question is about lightning.

- (a)** Sheet lightning occurs when there is an electrical discharge between the upper and lower regions of a thunder cloud.

The upper regions are positive and the lower regions are negative.

The thunder cloud can be modelled as an ideal parallel plate capacitor with circular horizontal plates.

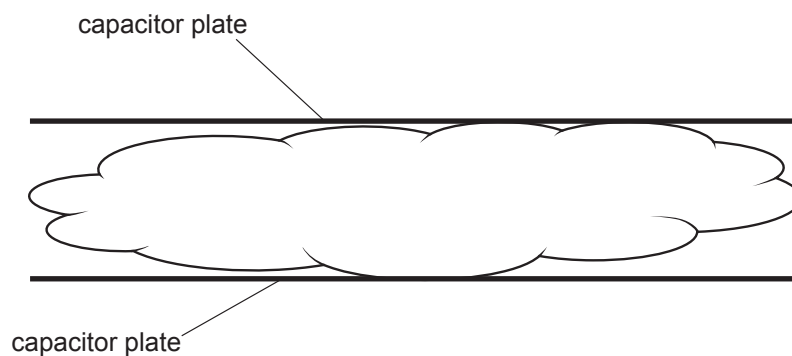
The data for the capacitor comes from the cloud.

Diameter of cloud	24 km
Distance between upper and lower regions	3.2 km
Electric field strength between the regions	$4.0 \times 10^5 \text{ V m}^{-1}$

- (i)** The diagram shows the plates of the model capacitor superimposed on the cloud.

Draw on the diagram to show the electric field lines between capacitor plates.

[2]



- (ii)** Suggest why the actual electric field lines of the cloud would differ from what you have drawn.

.....
 **[1]**

- (iii)** Show that the potential difference (p.d.) V between the plates is about $1 \times 10^9 \text{ V}$.

[1]

- (iv) Calculate the capacitance C of the model capacitor.

Assume the permittivity of the material of the cloud is the same as the permittivity of free space.

$$C = \dots\dots\dots \text{ F [2]}$$

- (v) Calculate the magnitude of the charge Q on one of the plates of the model capacitor.

$$Q = \dots\dots\dots \text{ C [2]}$$

- (b) Fork lightning is an electrical discharge that occurs between the bottom of the cloud and the surface of the Earth.

Another cloud has a charge of 155 C and is at a height of 2.0 km .

The surface of the Earth has an electrical potential V of 0 V .

- (i) Assume the cloud acts as a **point** charge.

Calculate the magnitude of the electrical potential V between the cloud and the surface of the Earth.

$$V = \dots\dots\dots \text{ V [2]}$$

- (ii) A fork lightning strike has a duration of 25 ms . The cloud discharges at a constant rate. The cloud is uncharged after the strike.

Calculate the number of electrons reaching the ground in 1.0 ms .

$$\text{number of electrons in } 1.0 \text{ ms} = \dots\dots\dots \text{ [3]}$$



14-MARK QUESTIONS

1 question in this booklet



- 22 (a) Fig. 22.1 shows two horizontal metal plates in a vacuum.

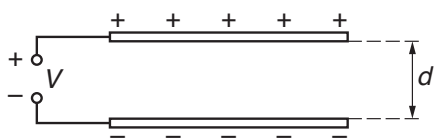


Fig. 22.1

The plates are connected to a power supply. The potential difference V between the plates is constant. The magnitude of the charge on each plate is Q . The separation between the plates is d .

Fig. 22.2 shows the variation with d of the charge Q on the positive plate.

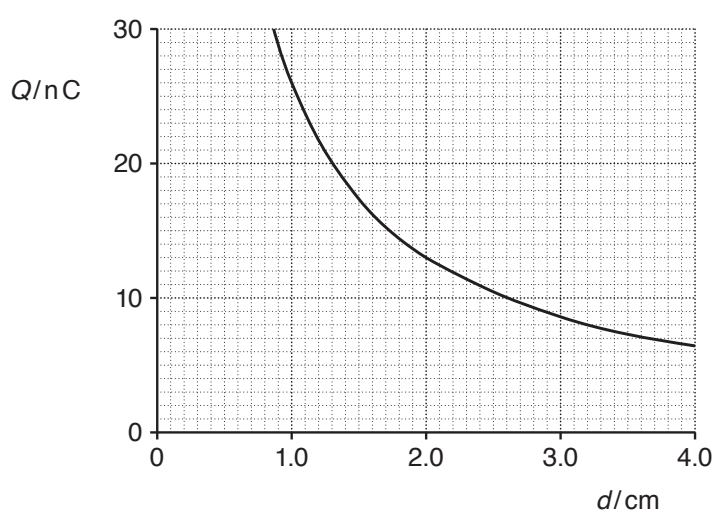


Fig. 22.2

- (i) Use Fig. 22.2 to propose and carry out a test to show that Q is inversely proportional to d .

Test proposed:

.....

Working:

- (ii) Use capacitor equations to show that Q is inversely proportional to d .

[2]

- (b) Fig. 22.3 shows a negatively charged oil drop between two oppositely charged horizontal plates in a vacuum.

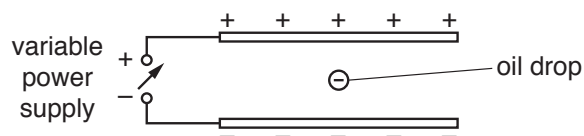


Fig. 22.3

The plates are fixed and connected to a variable power supply. The weight of the oil drop is $1.8 \times 10^{-14} \text{ N}$.

- (i) The power supply is adjusted so that the potential difference between the plates is 200 V when the oil drop becomes **stationary**.

State the magnitude of the vertical electric force F_E acting on the charged oil drop.

$$F_E = \dots\dots\dots \text{ N [1]}$$

- (ii) The potential difference between the plates is now increased to 600 V. The oil drop accelerates upwards.

Calculate the acceleration a of the oil drop.

$$a = \dots\dots\dots \text{ ms}^{-2} \text{ [3]}$$

Question 22 continues on page 26

- (c)* Fig. 22.4 shows an arrangement used by a student to investigate the forces experienced by a small length of charged gold foil placed in a uniform electric field.

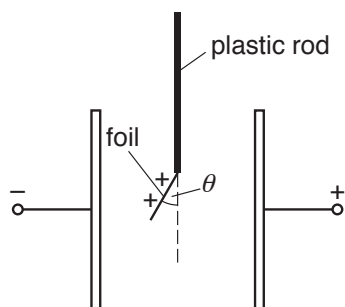


Fig. 22.4

The two vertical metal plates are connected to a high-voltage supply.

The foil is given a positive charge by briefly touching it to the positive plate.

The angle θ made with the vertical by the foil in the electric field is given by the expression

$$\tan \theta = \frac{qE}{W}$$

where q is the charge on the foil, E is the electric field strength between the plates and W is the weight of the foil.

The angle θ can be determined by taking photographs with the camera of a mobile phone.

Describe how the student can safely conduct an experiment to investigate the relationship between θ and E .

Identify any variables that must be controlled.

[6]

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Additional answer space if required.

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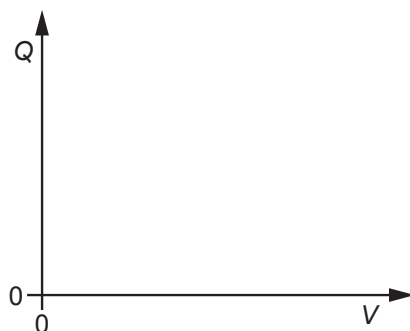
15-MARK QUESTIONS

1 question in this booklet



22

- (a) Sketch a graph showing how the charge Q stored on a capacitor varies with the potential difference V across it.

**[1]**

- (b) Describe how to use your graph to calculate the energy stored by the capacitor.

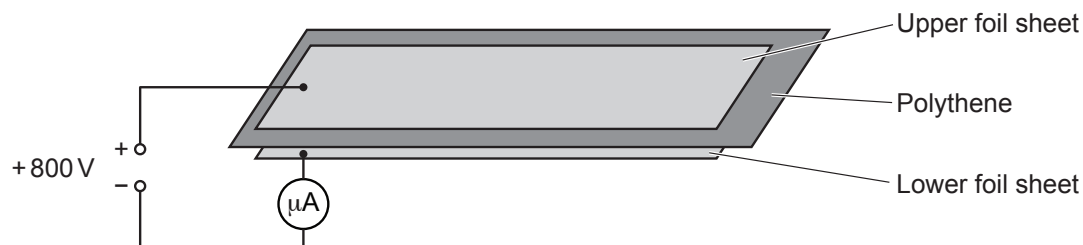
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..... **[2]**

- (c) A teacher has built a model capacitor using sheets of aluminium and polythene. They use the model capacitor to measure the thickness of the polythene.

The foil sheets are rectangular, 30 cm wide and 50 cm long. The polythene sheet is larger to avoid the edges of the foil coming into contact with each other.



The power supply is switched on. The model capacitor is charged to 800 V in a time of 1.8 s.

The average current from the power supply during this time is $2.6 \mu\text{A}$.

The polythene has relative permittivity 2.3.

- (i) Calculate the thickness, d , of the polythene in mm.

$d = \dots\dots\dots$ mm [3]

- (ii) Suggest how the experiment should be carried out in order to get a set of accurate and precise results.

.....

 [3]

(d)* A student creates a spreadsheet to model the discharge of a different capacitor through a resistor.

Fig. 22.1a shows part of the spreadsheet and some important values used in the modelling process.

Fig. 22.1a

	A	B	C
1	t/s	$Q/\mu\text{C}$	$\Delta Q/\mu\text{C}$
2	0.0	200.00	−9.67
3	0.5	190.33	−9.20
4	1.0	128.03	−8.76
5	1.5	121.84	−8.33
6	2.0	115.94	−7.93
7	2.5	110.34	−7.55
8	3.0	148.55	−7.18
9	3.5	141.37	−6.84
10	4.0	134.53	−6.51
11	4.5	128.03	−6.19
12	5.0	121.84	−5.89
13	5.5	115.94	−5.61
14	6.0	110.34	−5.34
15			
16			
17			
18			
19			
20			
21			

time interval, $\Delta t = 0.5\text{ s}$

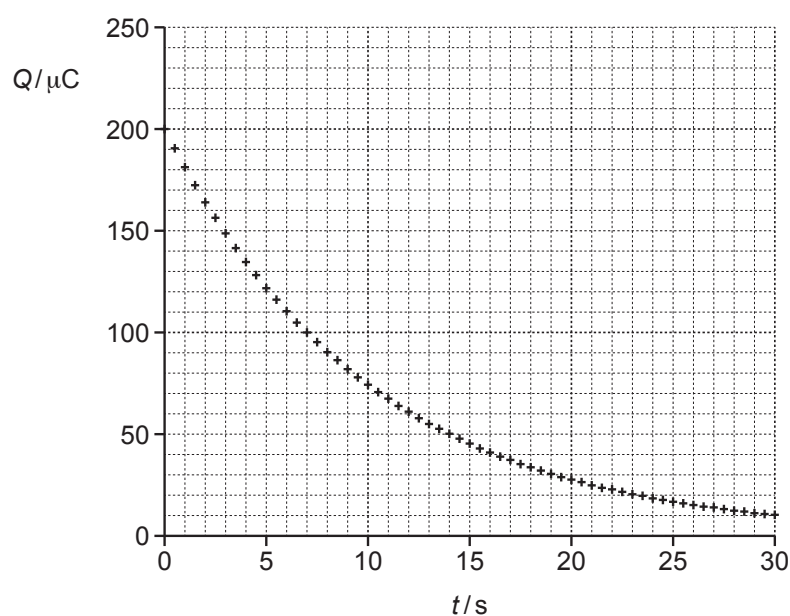
initial charge, $Q_0 = 200\text{ }\mu\text{C}$

capacitance of capacitor, $C = 22\text{ }\mu\text{F}$

resistance of resistor, $R = 470\text{ k}\Omega$

Fig. 22.1b shows a plot of the values of t and Q from the spreadsheet.

Fig. 22.1b



Use the data in Fig. 22.1a and Fig. 22.1b to describe how the student

- would calculate the values in columns **A**, **B** and **C** in the spreadsheet
- could confirm by calculation that the spreadsheet correctly models the discharge of the real capacitor.

[6]

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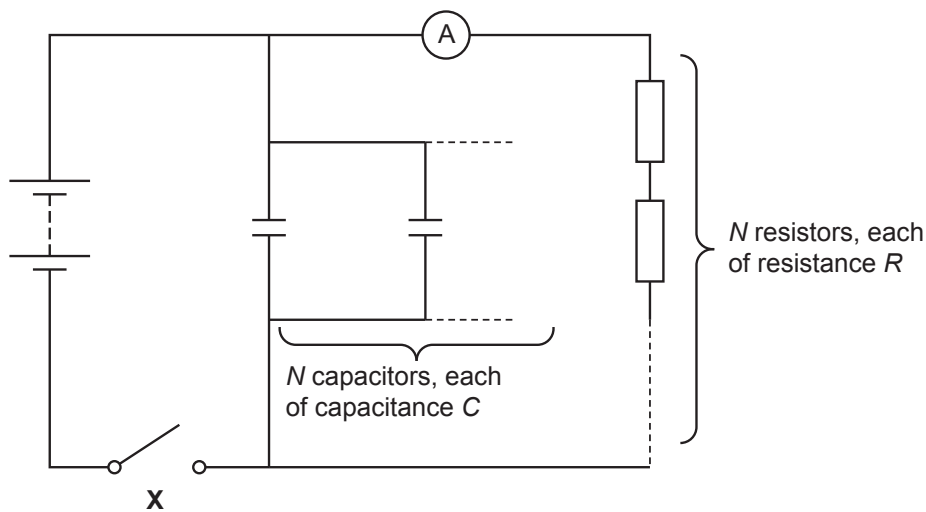


16-MARK QUESTIONS

1 question in this booklet



2 A group of students investigate the circuit shown in the figure below.



There are N capacitors, each of capacitance C , connected in parallel.

There are N resistors, each of resistance R , connected in series.

Initially, the students close the switch **X**. They then note the reading on the ammeter.

The students then open the switch. They record the time T for the reading on the ammeter to fall to half of its initial value.

The table below shows the students' results.

N	T/s			
	1	2	3	Mean
1	14.7	14.1	14.3	
2	50.3	49.6	50.1	
3	126.6	126.3	125.2	126.0
4	224.4	224.3	225.9	224.9
5	356.1	354.3	345.6	352.0
6	500.4	512.7	499.5	504.2

(a) Show that $T = (\ln 2)N^2RC$.

[2]

(b) The students write in their lab books, "Our data is precise".

Evaluate this statement.

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..... [2]

Question 2 continues on page 6

(c) The results table is repeated below.

Complete the last column for $N = 1$ and $N = 2$ in the table below.

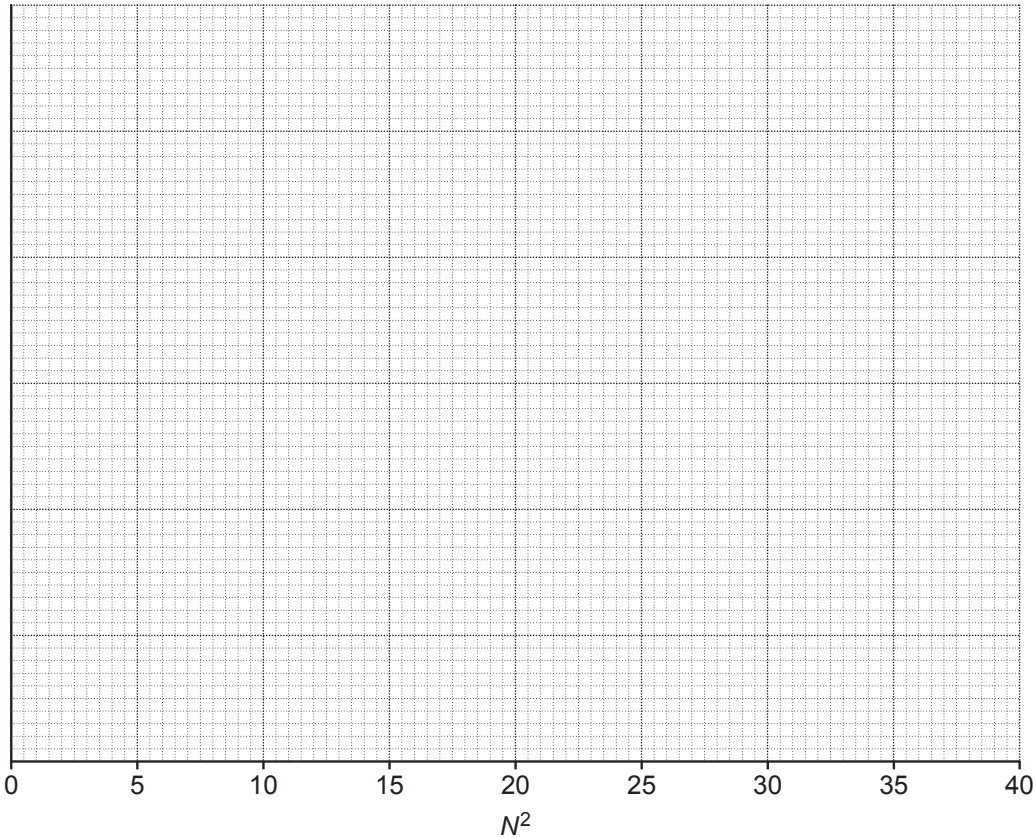
N	T/s			
	1	2	3	Mean
1	14.7	14.1	14.3	
2	50.3	49.6	50.1	
3	126.6	126.3	125.2	126.0
4	224.4	224.3	225.9	224.9
5	356.1	354.3	345.6	352.0
6	500.4	512.7	499.5	504.2

[1]

(d) The students begin to plot a graph of T (y-axis) against N^2 (x-axis).

(i) Complete the graph below and plot the 6 results from the table. You are **not** expected to include error bars.

[4]



(ii) Draw a straight line of best fit on the graph. [1]

(iii) Calculate the gradient of the straight line of best fit.

gradient = ... s [2]

(iv) The value of C is known to be $1000\ \mu\text{F} \pm 5\%$.

Use your gradient value from (iii) to find a value for R , in units of $\text{k}\Omega$, including an **absolute** uncertainty.

$R = \dots \pm \dots \text{k}\Omega$ [2]

(e) Following the investigation, the students discovered that the sixth $1000\ \mu\text{F}$ capacitor connected to the circuit was actually two $470\ \mu\text{F}$ capacitors connected in parallel.

(i) State the type of error caused by this mistake.

..... [1]

(ii) Explain the effect that this error would have had on the calculated value of R .

.....

 [1]

MARK SCHEMES

official OCR mark schemes



7	A	1	
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8	D	1	
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9	D	1	
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8	A		1	
---	---	--	---	--



9	D		1	
---	---	--	---	--



13	A	1	
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14	B	1	
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7	D	1	
---	---	---	--



8	B	1	
---	---	---	--



6	C	1	
—	—	—	



4	B	1	
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8	D	1	
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Question	Answer	Mark	Comments
21 (a)	$\epsilon = 7.2 \times 10^{-12} \times 1.2 \times 10^{-3} / 4.0 \times 10^{-4}$ permittivity = 2.2×10^{-11} (F m ⁻¹)	C1 A1	Allow any subject Allow ϵ_0 instead of ϵ Note answer to 3 sf is 2.16×10^{-11} (F m ⁻¹) Allow 1 mark for bald 2.4; relative permittivity calculated
(b) (i)	capacitance of two capacitors in series = 500 (μF) $C = 1000 + 500$ $C = 1500$ (μF)	C1 A1	
(ii)	$V = 1.5 \times e^{-12/15}$ $V = 0.67$ (V)	C1 A1	Possible ecf from (i) Allow 1 mark for 0.83 V, $V = 1.5[1 - e^{-12/15}]$ used
	Total	6	

22	(a)	$(V = V_0 e^{-t/CR}) \quad \ln(V/V_0) = -t/CR \quad \text{or} \quad \ln V = \ln V_0 - t/CR$ $\ln V = \ln V_0 - t/CR \quad \text{and} \quad y = mx + c \quad / \quad \text{gradient} = -1/CR$	B1 B1	Note the minus sign is necessary
	(b)*	Level 3 (5–6 marks) Clear description and correct value of C <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Clear description and some correct working OR Some description and correct value for C <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Some description OR Some working <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit	B1 × 6	Indicative scientific points may include: Description • $C = \epsilon A/d$ • A = area (of overlap) and d = separation. • Use ruler to measure the side / radius / diameter (and hence the area A) • Ensure total overlap of plates. • Measure the thickness / d of paper using micrometer / (vernier) caliper. • Take several readings of thickness and determine an average value for d Calculation of capacitance • gradient ≈ 85 • $C \approx 1.2 \times 10^{-8}$ (F)
		Total	8	

20	(a)	$(CR =) 2000 \times 10^{-6} \times 120 \times 10^3$ $1.00 = 1.48 \times [1 - e^{-t/240}]$ or $0.48 = 1.48e^{-t/240}$ $(t =) -240 \times \ln(0.48/1.48)$ $t = 270$ (s)	C1 C1 C1 A1	$CR = 240$ (s) Special case: 94 (s) for use of discharging equation. Max 2 marks
	(b)	Line of best fit drawn through the data points Gradient = 38 $(Ck\ln 2 = \text{gradient})$ $1.2 \times 10^{-3} \times k \times \ln 2 = 38$ $k = 4.6 \times 10^4$ ($\Omega \text{ m}^{-1}$)	B1 C1 C1 A1	Allow ± 2 . Not calculated through use of a single point. Possible ECF from incorrect gradient Note: gradient of 40 gives 4.8×10^4 and gradient of 36 gives 4.3×10^4
		Total	8	

5	(a)	(i)	$(W = \frac{1}{2} C V^2 \text{ so})$ $400 \times 10^6 = 0.5 \times C \times (24 \times 10^3)^2$ C = 1.4 (F)	C1 A1	Allow $W = \frac{1}{2} Q V$ and $C = Q / V$ $(Q = 3.3 \times 10^4 \text{ (C) so})$ $C = Q / V = 3.3 \times 10^4 / 24 \times 10^3$
		(ii)	(putting capacitors in parallel) increases the total capacitance ORA	B1	Allow $C_T = C_1 + C_2 + \dots$ or capacitors add together (in parallel) Ignore capacitors in parallel can store more charge/energy
	(b)		power $\approx 400 \times 10^6 / 10^{-3} = 4.0 \times 10^{11} \text{ (W)}$ power required is equivalent to output of ≈ 400 power stations or time taken for power station to release stored energy $= 400 \times 10^6 / 10^9 = 0.40 \text{ s}$ 0.4s is (much) longer than 1 ms	M1 A1 (M1) (A1)	Allow ECF (a)(i) for incorrect POT in 400GW Allow this is <u>much</u> more than could be provided by one power station or $4.0 \times 10^{11} \text{ (W)} \gg 1 \text{ GW}$ Ignore comments about household supply Allow ECF (a)(i) for incorrect POT in 400GW Allow it would take more time / too long



5	(c)	(mass defect in u =) $(2.014102 + 3.016049 - 4.002603 - 1.008665) \text{ u}$ $(= 0.018883 \text{ u})$ (mass defect in kg =) $0.018883 \times 1.661 \times 10^{-27}$ $(= 3.1365 \times 10^{-29})$ (energy per fusion reaction in J = mc^2 =) $3.1365 \times 10^{-29} \times (3.00 \times 10^8)^2$ $(= 2.82 \times 10^{-12})$ (number of fusion reactions = $\frac{\text{energy needed}}{\text{energy per fusion reaction}} =$ $400 \times 10^6 / 2.82 \times 10^{-12} =$) 1.4×10^{20}	Allow ECF for mass defect throughout unless XP C1 Mark is for correct working leading to the answer. Answer does not need to be calculated but 0.018883 u (not just 0.018883) implies C1 Allow negative answer C1 Mark is for substituting $u = 1.661 \times 10^{-27} \text{ (kg)}$, seen anywhere in the working Allow 1.66×10^{-27} or 1.67×10^{-27} for 1.661×10^{-27} Answer need not be calculated but 3.1365×10^{-29} implies first two C1 marks C1 Mark is for multiplying mass defect by $(3.00 \times 10^8)^2$, seen anywhere in the working Answer need not be calculated but 2.82×10^{-12} implies all three C1 marks A1 Ignore unit if given Allow ECF (a)(i) or (b) for incorrect POT in 400GW Note for markers: calculation in kg $3.34542 + 5.00966 - 6.64832 - 1.67539 (\times 10^{-27})$ $= (8.35508 - 8.32372) \times 10^{-27} (= 3.136 \times 10^{-29} \text{ kg})$ Note for markers: calculation in J $3.01088 + 4.50869 - 5.98349 - 1.50785 (\times 10^{-10})$ $= (7.51957 - 7.49134) \times 10^{-10} (= 2.82 \times 10^{-12} \text{ J})$
		Total	9

2	(a)		(initial charge) $Q = EC_0$ or (Q conserved so final) $Q = V(C + C_0)$ (as capacitors are in parallel) <u>so</u> $EC_0 = V(C + C_0)$ (and hence $V = C_0 E / (C + C_0)$)	M1	At least one correct expression for Q for first mark
				A1	The two correct expressions equated for the second mark
	(b)	(i)	$1/V = 1/E + C/EC_0$ (and compare to $y = c + mx$)	B1	Mark is for rearrangement into linear equation
		(ii)	$1/EC_0 = 51 = 1/(9.1 C_0)$ giving $C_0 = 1/(51 \times 9.1) \text{ F}$ $C_0 = 2.2 \text{ (mF)}$	B1 B1	$C_0 = 2.1547 \times 10^{-3} \text{ F}$ Answer must be correct, rounded correctly and given in mF Candidate's answer must be given to 2 SF
		(iii)	(at least) one correct worst fit line drawn gradient calculated correctly using a large triangle uncertainty = $C_0 - 1/(\text{wfl gradient} \times 9.1)$ uncertainty given is to the same number of decimal places as C_0	B1 B1 B1 B1	Top and bottom points chosen must be from opposite extremes of uncertainty limits, accurate to within half a small square $\Delta x \geq 1.5 \times 10^{-3}$; expect 59 ± 1 or 44 ± 1 (or 0.059 or 0.044); allow ECF from poorly drawn line; readings must be accurate to within half a small square ECF from b(ii) ; expect uncertainty of up to 0.4 (mF) ECF from b(ii) If no value for C_0 given in b(ii) , allow any answer given to 1dp
	(c)		Only effect is to slow the charging and/or discharging (of capacitor(s)) <u>and so</u> the final charges are unchanged / the values for V are unchanged / the graph is unchanged / the gradient is unchanged / there is no effect on the experiment (results)	B1	Allow and so the experiment takes longer
			Total	10	

Question	Answer	Marks	Guidance
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6	(a)		time taken for current (or charge or voltage) to fall to $1/e$ of <u>its initial value</u>	B1	Not capacitance Not to fall <u>by</u> (a factor of) $1/e$ Allow to decrease <u>to</u> 37% of its initial value Allow to decrease <u>by</u> 63% Ignore time constant = CR
	(b)	(i)	$f (= 1/T) = 1 / (40 \times 10^{-3})$ $f = 25$ (Hz)	B1 B1	Allow $f = 1/T$ and $T = 40 \times 10^{-3}$ (s)
		(ii)	EITHER Calculation of Q_0 / e time constant (read from graph) = 14 (ms) OR Use of $Q = Q_0 e^{-t/CR}$ time constant = 14 (ms)	C1 A1 (C1) (A1)	Allow any initial value of charge e.g. $8.0 / e = 2.9$ (μC) or $37\% \times 8.0 = 3.0$ (μC) Allow 14 ± 1 (ms) e.g. $2.0 = 8.0 e^{-0.02/CR}$ gives $CR = 0.02 / \ln 4$ Using the decay equation may incur two POT errors
		(iii)	tangent drawn to graph <u>at steepest part of curve</u> maximum current in range 5.0×10^{-4} to 7.0×10^{-4} (A)	M1 A1	Judge by eye, no daylight between curve and tangent Allow a negative answer Allow answer to 1sf



Question			Answer	Marks	Guidance
6	(b)	(iv)	vertical axis labelled as current with the correct unit and at least one positive and one negative scale marking and scale should allow for their maximum current to be plotted exponential decay of current in each section sign of current alternates at 20, 40, 60 and 80 ms	B1 M1 A1	For example I / mA , $I (\text{mA})$, $I / 10^{-4} \text{ A}$, current in mA etc All scale markings shown must be correct Allow any curve with a decreasing gradient in each section Ignore value of minimum current but not zero Ignore sign of current for this marking point All curves should start at the correct maximum current value. However, If B1 mark has not been scored, allow any value of maximum current as long as it remains consistent across all four sections
			Total	10	



Question	Answer	Mark	Guidance
3 (a)	Take $\ln$ to give $\ln V = -(t/C).1/R + \ln V_0$ gradient (m) = $(-t/C)$ where $t = 15$	M1 A1	allow $\ln(V/V_0) = -(t/C).1/R$
(b) (i)	1.10 ± 0.07	B1	value plus uncertainty required for the mark
(ii)	two points plotted correctly to within $\frac{1}{2}$ small square on x-axis; line of best fit	B1 B1	ignore accuracy of length of error bar; ecf bi value or both worst acceptable lines drawn
(iii)	gradient ($= 15/C$) = 6.6×10^4 ; $C = 15 / 6.6 \times 10^4 = 2.3 \times 10^{-4}$ (F) worst acceptable straight line drawn $(C) \pm 0.3 \times 10^{-4}$ F	C1 A1 B1 B1	accept 6.4 to 6.8 ignore power of 10 accept $2.3 \pm 0.1 \times 10^{-4}$ allow ecf for the point calculated incorrectly in b(ii) ; steepest or shallowest possible line that passes through <u>all</u> the error bars; should pass from top of top error bar to bottom of bottom error bar or bottom of top error bar to top of bottom error bar allow e.g. $(C) \pm 0.2 \times 10^{-4}$; allow value of C to 4 SF but N.B. the uncertainty and the value of C must be to the same number of decimal places allow $230 \pm 30 \mu\text{F}$ etc allow equivalent unit including $\text{s } \Omega^{-1}$, C V^{-1} , A s V^{-1}
(c)	$\ln(0.1) = -15/RC$ or $R = -15/C \ln(0.1)$ or $R = 0.65/C$ $R = 0.65/2.3 \times 10^{-4}$ giving $R = 28 \text{ k}\Omega$	C1 A1	$\ln(0.1) = -2.30$ ecf (b)(iii)
Total		11	

H556/03

Mark Scheme

June 2017

Question	Answer	Marks	Guidance
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22	(a)	(i)1	0.5 (C_0)	B1	Allow $\frac{1}{2}$
		(i)2	2 (V_0)	B1	Ignore working No ecf
		(i)3	2 (E_0)	B1	Ignore working No ecf
		(ii)	Work done against <u>attractive</u> forces	B1	Allow WD for work done
	(b)	(i)	Evidence of use of $V = V_0 e^{-t/CR}$ leading to $\ln(\frac{1}{2}) = -T/CR$ or $\ln 2 = T/CR$ $T = C \ln 2 \times R$ compared with $y = mx$ with gradient = $C \ln 2$	M1 A1	Must see exponential decay as starting point (allow Q for V) Allow t for T Allow x for V and x_0 for V_0 Not $T/R = \text{gradient}$
		(ii)1	Best-fit line drawn correctly gradient = $5.4 (\times 10^{-9})$ $C = (\text{gradient} / \ln 2) = 7.8 \times 10^{-9} \text{ (F)}$	B1 B1 B1	Note line must pass through all (vertical part of) error-bars. If more than one line drawn, all lines must pass through all error-bars (1/2 square tolerance). Allow $\pm 0.2 (\times 10^{-9})$ Ignore POT Ecf from incorrect gradient, but penalise POT error here
		(ii)2	$7.8 \times 10^{-9} = \frac{\epsilon \times 3.1 \times 10^{-2}}{8.0 \times 10^{-5}}$ $\epsilon = 2.0 \times 10^{-11} \text{ (F m}^{-1}\text{)}$	C1 A1	Possible ECF from (b)(ii)1 Allow 1 mark if final answer is relative permittivity correctly calculated (ϵ divided by 8.85×10^{-12})
			Total	11	

3	(a)	• (Induced) e.m.f. is caused by a change in (magnetic) flux (linkage) / (Induced) e.m.f. is proportional (or equal to) the <u>rate</u> of change of (magnetic) flux (linkage) • The peaks are inverse / e.m.f. changes from positive to negative because: the rate of change of magnetic flux linking the coil changes sign or the flux (linkage) increases and then decreases or description in terms of Lenz's law as seen by coil to conserve energy • The e.m.f. becomes zero because: the (rate of) change of magnetic flux is zero when the magnet is in the middle of the coil • The second peak has a larger negative amplitude because: the <u>rate</u> of change of flux linkage is greater (when the magnet leaves the coil compared to when it enters) • The pulses have different widths because: the second Δt is shorter (since magnet accelerates) or areas under curves must be the same (because total change of flux linkage is the same on entering and leaving coil) / area under curve = $V\Delta t = N\Delta\phi$ (so bigger V leads to smaller Δt)	B1 x 3 Maximum 3 marks from 4 marking points. Not voltage or p.d. or current for e.m.f. Accept 'cutting of field lines by coil' for 'change in flux' <u>Answers to any of the last three points must link clearly to the correct graph characteristic</u> Allow the North (or South) pole first approaches then recedes Ignore magnet approaches then recedes / field increases then decreases Not torch is inverted Allow no field lines are being cut Allow the magnet is accelerating / is travelling faster when it exits the coil
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H556/03			Mark Scheme		June 2019
Question			Answer	Marks	Guidance
	(b)	(i)	$Q = 9.0 \times 10^{-3} \times 2 \times 80 = 1.44 \text{ (C)}$ $W = (Q^2/2C =) 1.44^2/2 \times 0.12$ $W = 8.6(4) \text{ (J)}$	C1 C1 A1	ECF for incorrect Q e.g. 2/3 for use of $Q = 0.72\text{(C)}$ giving $W = 2.2\text{(J)}$
		(ii)	$(W = Pt \text{ so } 8.6 = 0.050t)$ $t = 8.6/0.050 = 170 \text{ (s)}$	A1	ECF (b)(i) for incorrect W
	(c)		see page 14	B1 x 6	
			Total	13	



H556/03			Mark Scheme		June 2019
Question			Answer	Marks	Guidance
3	(c)		Level 3 (5 - 6 marks) Clear determination of input energy, procedure and analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.</i> Level 2 (3 – 4 marks) Clear determination of input energy and procedure, but no analysis or Clear analysis but limited determination of input energy and/or limited procedure or Attempted determination of input energy, basic procedure, and an attempt at analysis <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) A limited selection from the scientific points worthy of credit. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. Candidates can gain full credit for investigating the efficiency of either: Method 1(M1): GPE ($nmg h$) to energy conversion in LED (Pt) or Method 2(M2): GPE ($nmg h$) to energy stored in capacitor ($\frac{1}{2}CV^2$ or $\frac{1}{2}Q^2/C$) <u>L1 maximum for any answers which do not use GPE as input energy</u> Indicative scientific points may include: Determination of input energy - record the number of inversions, n (use electronic / top pan balance to) measure mass of magnet m (use mm ruler to) measure tube length l_t and magnet length l_m - calculate $h = l_t - l_m$ - calculate (GPE =) $nmg h$ Procedure - invert torch n times (with torch switched off) - make sure that the magnet falls the full height h between inversions - M1 switch torch on and (use stopwatch to 0.1 s to) measure time t taken until LED goes out (use video with timer for greater accuracy) - M1 use a darkened room or view LED through tube - M2 (use voltmeter across capacitor to) measure final p.d. V_f - M2 (with coulombmeter) measure final charge Q_f stored by capacitor - repeat experiment for different n Analysis of efficiency - M1 calculate $W = Pt$ where $P = 50$ mW - M2 calculate $W = \frac{1}{2}CV_f^2$ or $\frac{1}{2}Q_f^2/C$ - calculate efficiency = $W/nmg h$ - compare efficiency values for different n - plot suitable graph e.g. efficiency against n / W against $nmg h$ - plot t against n (M1) / V^2 or Q^2 against n (M2) with justification - discuss shape / gradient of graph



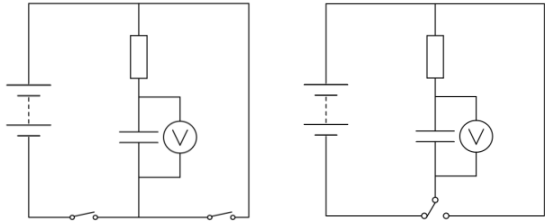
H556/03

Mark Scheme

June 2019

Question	Answer	Marks	Guidance
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20	(a)	Circuit showing (6V) supply in series with a capacitor and resistor, with a voltmeter in parallel with the capacitor. Switch/switches allowing discharging of the capacitor through the resistor.	B1 No labels required. ALLOW any suitable symbol for d.c. supply B1 ALLOW this mark if resistor and capacitor in parallel if switch will allow the discharge Examples of correct circuit for both marks e.g. 
	(b)	Charge = $1.0 \times 10^{-6} \times 6.0 = \mathbf{6.0 \times 10^{-6}}$ (C)	A1 ALLOW correct answer to 1 significant figure
	(c)	(CR =) $1 \times 10^{-6} \times 10 \times 10^3$ CR / Time constant / $\tau = 0.010$ (s) Time constant / τ is time taken to fall to 1/e (37%) of initial value The time it takes to record the variation of pd / the capacitor to discharge is far less than (human) <u>reaction time</u> OR	C1 ALLOW POT error for capacitance if same as in (b) A1 ALLOW 1sf ALLOW t for τ B1 NOT fallen <u>by</u> 37% B1

Question			Answer	Mark	Guidance
			$V = V_0 e^{-\left(\frac{t}{CR}\right)}$ to give $0.6 = 6.0 e^{-\left(\frac{t}{1.0 \times 10^{-6} \times 10 \times 10^3}\right)}$ $t = 0.023 \text{ (s)}$ 0.6 is the voltage when it has fallen to 10% of the initial voltage The time it takes to record the variation of pd / for the capacitor to discharge is far less than human <u>reaction time</u> OR $V = V_0 e^{-\left(\frac{t}{CR}\right)}$ to give $V = 6.0 e^{-\left(\frac{0.02}{1.0 \times 10^{-6} \times 10 \times 10^3}\right)}$ $V = 0.81 \text{ V}$ 0.02 s is a very short amount of time The time it takes to record the variation of pd / for the capacitor to discharge is far less than human <u>reaction time</u>	(C1) (A1) (B1) (B1) (C1) (A1) (B1) (B1)	Substitution into exponential decay equation to fall to a value of V less than $0.9V_0$ ($<5.4\text{V}$). ALLOW calculation in log form e.g $\ln 0.6 = \ln 6.0 - t/0.01$ Justification/explanation for using a given voltage Substitution into exponential decay equation with a time less than 0.1s ($t < 0.1\text{s}$). ALLOW calculation in log form $\ln V = \ln 6.0 - 0.02/0.01$ Justification/explanation for using a given time
	(d)		Use an oscilloscope / data logger with a voltmeter probe	B1	ALLOW connect a voltmeter to a datalogger
	(e)	(i)	$V = V_0 e^{-\left(\frac{t}{CR}\right)}$ to give $4.12 = 6.0 e^{-\left(\frac{t}{1.0 \times 10^{-6} \times 10 \times 10^3}\right)}$ $= 3.76 \times 10^{-3} \text{ (s)}$	C1 A1	ALLOW in terms of logs eg $\ln 4.12 = \ln 6.0 - \frac{t}{0.01}$ Correct to at least 2 significant figures IGNORE minus sign in final answer



Question			Answer	Mark	Guidance
		(ii)	Change in energy = $\frac{1}{2} CV_1^2 - \frac{1}{2} CV_2^2$ $= (\frac{1}{2} \times 1 \times 10^{-6} \times 6^2) - (\frac{1}{2} \times 1 \times 10^{-6} \times 4.12^2) = 9.5 \times 10^{-6} \text{ (J)}$ rate = $9.5 \times 10^{-6} / 3.76 \times 10^{-3}$ $= \mathbf{2.53 \times 10^{-3} \text{ (Js}^{-1}\text{)}}$	C1 C1 A1	 ALLOW POT error from (e)(i) Ecf from (e)(i) Correct to at least 2 significant figures

22	(a)	(i) At least 4 equidistant parallel vertical (straight) lines With arrows pointing downwards	B1 B1	By eye Ignore field lines outside of plates At least one line must touch top and bottom plate At least one arrow, and all arrows given must be correct
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Question			Answer	Mark	Guidance
		(ii)	The top and the bottom of the clouds will not be parallel / will be uneven	B1	Allow uneven charge distribution / charge density Allow the field is non-uniform Allow the cloud is a non-uniform shape Ignore cloud has non uniform density
		(iii)	$(V = Ed) = 4.0 \times 10^5 \times 3.2 \times 10^3 = 1.3 \times 10^9 \text{ (V)}$	B1	Values of E , d with correct powers of 10 and correct evaluation must be seen to at least 2sf (1.28) Ignore unit
		(iv)	$C = \left(\frac{\epsilon_0 A}{d} \right) = \frac{8.85 \times 10^{-12} \times \pi \times (12 \times 10^3)^2}{3.2 \times 10^3}$ $C = 1.3 \times 10^{-6} \text{ (F)}$	C1 A1	All values (including ϵ_0) substituted correctly Correct evaluation to at least 2sf (1.25×10^{-6}) Note: use of $C = 4\pi\epsilon_0 R$ (leading to 1.3×10^{-6} is XP)
		(v)	$Q (= CV) = 1.25 \times 10^{-6} \times 1.28 \times 10^9$ $Q = 1600 \text{ (C)}$	C1 A1	Ecf from (a)(iii) and (a)(iv) Correct evaluation to at least 2sf Allow 2sf answer of 1700 C for 2sf values used in calculation Allow answer of 1250C for p.d. value of 1×10^9
	(b)	(i)	$V = \frac{Q}{4\pi\epsilon_0 r}$ $V = \frac{155}{(4\pi \times 8.85 \times 10^{-12} \times 2 \times 10^3)}$	C1	All values substituted correctly



Question			Answer	Mark	Guidance
			$= 7.0 \times 10^8 \text{ (V)}$	A1	Correct answer to at least 2sf (6.97)
		(ii)	Either $(I =) 155 / 25 \times 10^{-3} = (6200 \text{ A})$ $n = 6200 / 1.6 \times 10^{-19} = 3.88 \times 10^{22}$ $n \text{ (in 1ms)} = 3.88 \times 10^{22} \times 10^{-3} = 3.9 \times 10^{19}$ Or $(\text{Charge flow}) = 155/25 = (6.2 \text{ C ms}^{-1})$ $n = 6.2 / 1.6 \times 10^{-19}$ $n = 3.9 \times 10^{19}$	C1 C1 A1 (C1) (C1) (A1)	Ignore units throughout although penalise any unit on answer line Correct evaluation to at least 2sf (3.88) Correct evaluation to at least 2sf (3.88)

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22	(a)	(i)	$Qd = \text{constant}$ At least two pairs of values substituted to show that $Qd = \text{constant}$	C1 Allow straight-line graph of Q against $1/d$ passes through the origin Allow as d increases by a given factor (e.g. doubles) then Q decreases by the same factor (e.g. halves) A1 Allow numbers that show when d doubles then Q halves Ignore prefixes and POT errors
		(ii)	$Q = VC$ and $C = \frac{\epsilon_0 A}{d}$ Hence $Q = \frac{V\epsilon_0 A}{d}$ (and $Q \propto \frac{1}{d}$)	C1 Allow ϵ A1 Note Q , or Q/V must be the subject here Allow $Q \propto C$ and $C \propto \frac{1}{d}$
	(b)	(i)	$1.8 \times 10^{-14} \text{ (N)}$	B1 Ignore sign
		(ii)	$(F_E =) 3 \times 1.8 \times 10^{-14} \text{ (N)}$ or $(F_E =) 5.4 \times 10^{-14} \text{ (N)}$ or $(\text{mass} =) \frac{1.8 \times 10^{-14}}{g}$ $(\text{resultant force} = 3.6 \times 10^{-14} \text{ N})$ $(a =) \frac{3.6 \times 10^{-14}}{(1.8 \times 10^{-14}/g)}$ $a = 20 \text{ (m s}^{-2}\text{)}$	C1 Note this mark is for either electric force on the oil drop or the calculating the mass of the oil drop Allow for ECF from (b)(i) C1 A1 Allow $g = 9.8$, but not $g = 10$ Note answer to 3SF is 19.6 Allow 2 marks for $a = 2g$ Note a bald answer of 20 will score 3 marks, if however, we see evidence for $g = 10$, then maximum score will be 2 mark



Question			Answer	Marks	Guidance
	(c)*		Level 3 (5–6 marks) Clear description and at least two from control of variables <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and at least one from control of variables <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Any description but no control of variables or Limited mention of control of variable(s) <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 × 6	Use level of response annotations in RM Assessor Indicative scientific points may include: Description • $E = V/d$ • Voltmeter used to measure p.d. • Ruler used to measure separation d plates • Plastic rod held in a stand • Safety: Do not touch the terminals of high-voltage supply / (positive) plate • Vary d or V to change E • θ determined for each value of E • Experiment repeated for several values of E • Sensible techniques used to determine θ, e.g. use a protractor • Plot $\tan \theta$ against E or $\tan \theta$ against $1/d$ graph • Straight line through origin (expected) Control of variables • Charge q kept constant (ignore method) • Method for keeping q constant (e.g. same V for the (positive) plate, use separate constant voltage supply, etc) • Use the same foil / keep W the same • Keep d or V constant • Foil in between plates (where the field is uniform) • Draught-free room • Do the experiment quickly to avoid leakage of charge
			Total	14	



22	(a)	Straight line through origin	A1	Judge line and origin by eye
22	(b)	Calculate the area underneath the line (As energy stored =) $\frac{1}{2} QV$ OR Area between the origin and the charged voltage / maximum charge	M1 A1	ALLOW drawn on graph if area is clear ALLOW area up to end of their line
22	(c) (i)	$Q = I \times t = 2.6 \times 10^{-6} \times 1.8 = (4.68 \times 10^{-6} \text{ C})$ $C = Q / V = 4.68 \times 10^{-6} / 800 = (5.85 \times 10^{-9} \text{ F})$ $C = \epsilon A / d = \epsilon_0 \epsilon_r A / d$ giving $d = (8.85 \times 10^{-12} \times 2.3 \times 30 \times 10^{-2} \times 50 \times 10^{-2}) / 5.9 \times 10^{-9}$ $= 0.52 \text{ (mm)}$	C1 C1 A1	Evaluation of C implies first two marks Correct to at least 2 significant figures (0.522mm)
22	(c) (ii)	A modification to the apparatus/method to allow a relevant value to be measured to a greater resolution / to be more accurate	B1	e.g. ruler with greater resolution for length measurements (digital) voltmeter/ammeter with greater resolution Include a resistor to increase the time for charging Datalogger / oscilloscope to measure time / voltage

Question		Answer	Mark	Guidance
		Repeat with change to: sheets / voltage / area And average (or plot a graph) to reduce uncertainty	B1 B1	ALLOW random error for uncertainty IGNORE human error
22	(d)	Level 3 (5–6 marks) Clear description of both how the values in each column are calculated, and how calculation can confirm that the spreadsheet models correctly. There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated. Level 2 (3–4 marks) Clear description of how the values in each column are calculated OR clear description of how calculation can confirm that the spreadsheet models correctly OR some description of both how the values in each column are calculated and some description of how calculation can confirm that the spreadsheet models correctly		Indicative points may include: Expect to see in one part of the description the use of the formula $\Delta Q/\Delta t = -Q/CR$ Calculation of time constant gives $CR = 22 \times 10^{-6} \times 470 \times 10^3 = 10.34 \text{ s}$ Column calculation Column A: Times determined by the Δt value Increments of Δt Formula: $A_3 = A_2 + \Delta t$ etc Column B: Charge decreases, starting with the Q_0 value The decrease is dependent on the previous value Formula: $B_{10} = B_9 + C_9$ etc Or by calculation from $Q = Q_0 \exp(-t/CR)$ Column C: Represents change in charge in each time interval Amount of decrease of charge decreases as time increases

Question	Answer	Mark	Guidance
	There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.		Formula: $C2 = B3 - B2$ etc Formula: $C2 = (B2 \times 0.5) / (CR)$ etc $\Delta Q / \Delta t = - \Delta t \times Q / CR$ Calculation to confirm correct modelling Use of $\Delta Q / \Delta t = - Q / CR$ to demonstrate correct values in columns B and C. (e.g. for row 10, $Q = Q_0 \exp(-t/CR) = 200 \times 10^{-6} \exp(-4.0 / (22 \times 10^{-6} \times 470 \times 10^3)) = 136 \text{ mC}$ and comparison with table value Determination of time constant from graph (e.g. 37% of 200 = 74mC, time at 74mC is approximately 10s, with comparison to calculated value (10.34 s)
	Level 1 (1–2 marks) Limited description of how the values in each column are calculated OR limited description of how calculation can confirm that the spreadsheet models correctly There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.		
	0 marks No response or no response worthy of credit.		

2	(a)	$x = x_0 e^{-t/RC}$ or $\frac{x_0}{2} = x_0 e^{-T/RC}$ and (total) resistance = NR and (total) capacitance = NC $\frac{1}{2} = e^{-\frac{T}{NR \times NC}}$ with clear steps leading to $T = (\ln 2)N^2 RC$	M1 Allow $x = x_0 e^{-T/RC}$ Allow any letter for x except N Allow τ for RC Not $x = x_0 (1 - e^{-t/RC})$ Not $R_T C_T = N^2 CR$ alone but allow $R_T C_T = NR \times NC$ A1 Intermediate working must be shown in full e.g. $\ln \frac{1}{2} = -\frac{T}{NR \times NC}$ so $\frac{T}{NR \times NC} = \ln 2$ Do not allow incorrect negative signs in working or in answer																												
	(b)	a measurement is precise if repeat readings are closely clustered (or reverse argument) quantitative data used to support their conclusion	B1 Allow if there is a small spread (of results about the mean value) / small range / small uncertainties (or small error bars on graph) Ignore comments about number of sig figs B1 Either range, absolute or % error calculated correctly for at least one stated value of N <table border="1"> <thead> <tr> <th>N</th><th>Range /s</th><th>abs unc/s)</th><th>%unc</th></tr> </thead> <tbody> <tr> <td>1</td><td>0.6</td><td>+/- 0.3</td><td>2.1 or 4.2</td></tr> <tr> <td>2</td><td>0.7</td><td>+/- 0.4</td><td>0.8 1.6</td></tr> <tr> <td>3</td><td>1.4</td><td>+/- 0.7</td><td>0.6 1.2</td></tr> <tr> <td>4</td><td>1.6</td><td>+/- 0.8</td><td>0.4 0.8</td></tr> <tr> <td>5</td><td>10.5</td><td>+/- 5.3</td><td>1.5 3.0</td></tr> <tr> <td>6</td><td>13.2</td><td>+/- 6.6</td><td>1.3 2.6</td></tr> </tbody> </table>	N	Range /s	abs unc/s)	%unc	1	0.6	+/- 0.3	2.1 or 4.2	2	0.7	+/- 0.4	0.8 1.6	3	1.4	+/- 0.7	0.6 1.2	4	1.6	+/- 0.8	0.4 0.8	5	10.5	+/- 5.3	1.5 3.0	6	13.2	+/- 6.6	1.3 2.6
N	Range /s	abs unc/s)	%unc																												
1	0.6	+/- 0.3	2.1 or 4.2																												
2	0.7	+/- 0.4	0.8 1.6																												
3	1.4	+/- 0.7	0.6 1.2																												
4	1.6	+/- 0.8	0.4 0.8																												
5	10.5	+/- 5.3	1.5 3.0																												
6	13.2	+/- 6.6	1.3 2.6																												

Question		Answer	Mark	Guidance
2	(c)	14.4 <u>and</u> 50.0	B1	Both values given to 1dp Mark entries in first table (on page 4) only if second table (on page 6) is left blank
	(d)	(i)		
		y-axis labelled " T / s "	B1	Allow suitable equivalent e.g. T (s), Time in secs
		y-axis scale completed correctly	B1	Scales markings of 100, 200, 300, 400 and 500 every 2 cm
		all six x-co-ordinates correctly plotted	M1	Check at 1, 4, 9, 16, 25 and 36; $\pm\frac{1}{2}$ small square tolerance.
		all six data points plotted accurately	A1	Check visually by fit to bfl; $\pm\frac{1}{2}$ small square tolerance. ECF candidate's values for $N = 1$ and 2
		(ii)		
		suitable best fit line	B1	There must be an even scatter of points above and below the line
2	(d)	(iii)		
		evidence of use of at least half of the width of the drawn line	B1	Evidenced by triangle drawn on graph or by Δx in working for gradient



Question			Answer	Mark	Guidance
			Gradient =14 (s)	B1	Correct line should have $\Delta x \geq 17.5$ Allow any answer between 13 and 15(s) ECF candidate's own best fit line
		(iv)	$R = \frac{\text{gradient}}{C \ln 2}$ Value of R is in the range 19 – 22 (kΩ) uncertainty is 5% of R with value given to same number of dp as R	B1 B1	For reference, R in kΩ = $\frac{\text{gradient value in d(iii)}}{0.69}$ ECF candidate's gradient value in d(iii) Allow answer given in Ohms if unit clearly stated Allow answer given to 1sf i.e. 20 (kΩ) Expect 1 (kΩ) Allow to more than 1 s.f. but uncertainty <u>must</u> be given to same number of d.p. as candidate's value for R If answer given in Ohms, allow uncertainty also given in Ohms to same number of d.p. as R
	(e)	(i)	systematic	B1	
		(ii)	(smaller T value for N = 6 so)		
			smaller gradient and therefore smaller R value	B1	Ignore references to smaller or bigger C
			Total	16	