Capacitors

1. 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 Δt = 0.5 s.
The initial charge on the capacitor is 1000 μC.

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

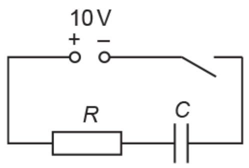
t / s	**Charge Q left on capacitor at time *t* / μC**	**Charge ΔQ decaying in the next 0.5 s / μC**
0	1000	100
0.5	900	
1.0		
1.5		

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

A 700
B 720
C 729
D 800

Your answer [1]

2. 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* × *R* for this circuit?

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

Your answer [1]

3 (a). A student designs an investigation to learn more about an old instrument called a hot wire ammeter. A fine resistance wire stretched between two retort stands sags when heated by the current being measured. This sag is converted into a reading on a non-linear scale.

A current-carrying wire is clamped at each end as shown in Fig. 2.1.

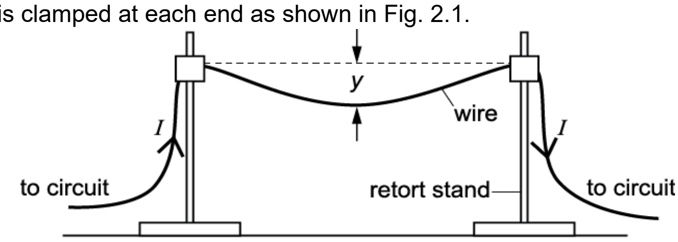


Fig. 2.1

The deflection y at the centre of the wire is measured for various currents I in the wire.
It is suggested that y and I are related by the equation

$$y = aI^b$$

where a and b are constants. This equation can also be written as

$$\lg y = \lg a + b \lg I.$$

A graph is plotted of lg y on the y-axis against lg I on the x-axis. State expressions for the gradient and y-intercept in terms of a and b.

gradient = ...

y-intercept = ...

[1]

(b). For different values of the current I, the vertical deflection y is recorded. A table of results is shown with further columns giving values of lg (I / 10^{-2} A) and lg (y / mm), including the absolute uncertainties.

I / 10^{-2} A	y / mm	lg (I / 10^{-2} A)	lg (y / mm)
50	2.6 ± 0.2		
60	3.4 ± 0.2	1.78	0.53 ± 0.03
70	4.4 ± 0.2	1.85	0.64 ± 0.02
80	5.4 ± 0.2	1.90	0.73 ± 0.02
90	6.6 ± 0.2	1.95	0.82 ± 0.01
95	7.2 ± 0.2	1.98	0.86 ± 0.01

i. Complete the missing values in the table, including the absolute uncertainty for lg (y / mm).

[2]

ii. Fig. 2.2 shows the axes for a graph of lg (y / mm) on the y-axis against lg (I / 10^{-2} A) on the x-axis. The last four points have been plotted including error bars for lg (y / mm). By plotting the two remaining points, complete the graph. Draw a line of best fit.

[2]

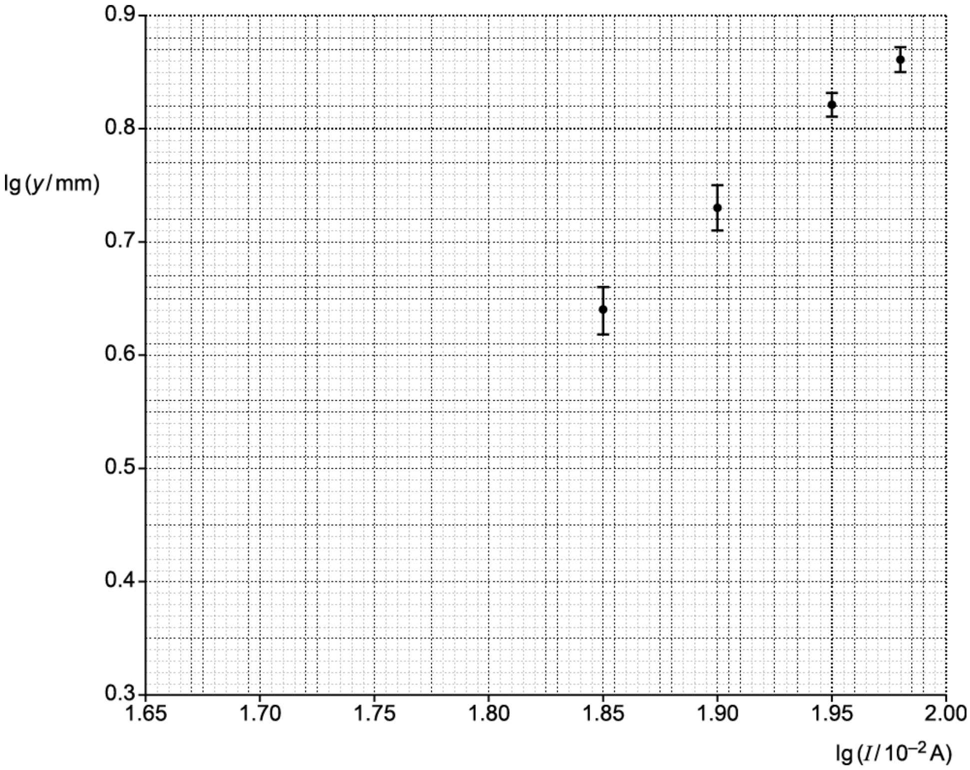


Fig. 2.2

(c).

i. Use the line of best fit through the data points in Fig. 2.2 to determine numerical values of

1 *b*

b = ... **[1]**

2 *a*.

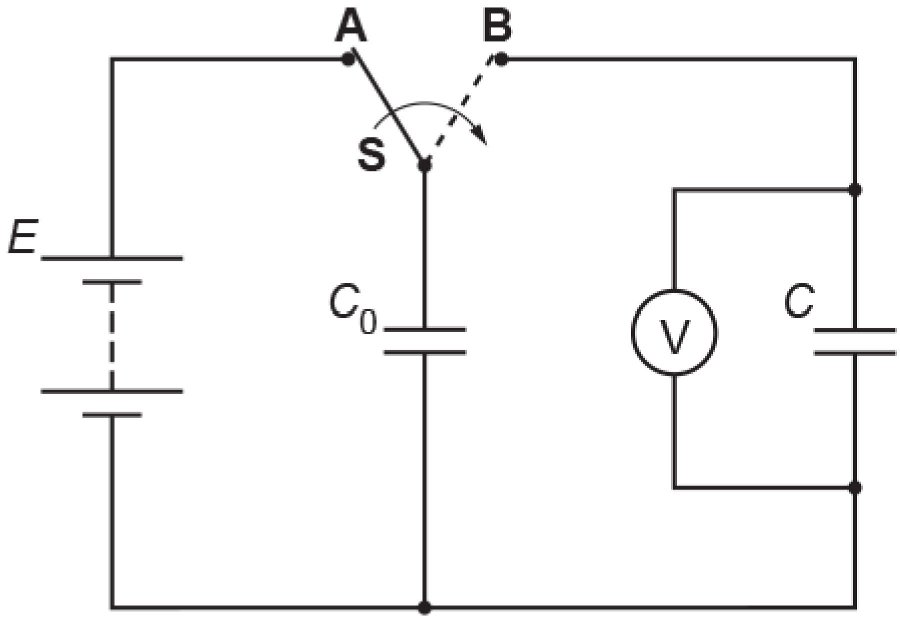
a = ... **[2]**

ii. Determine the absolute uncertainty in the value of *b*.

uncertainty in *b* = ± .... **[2]**

4 (a). 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.

Show that $V = \frac{C_0}{C + C_0} E$.

[2]

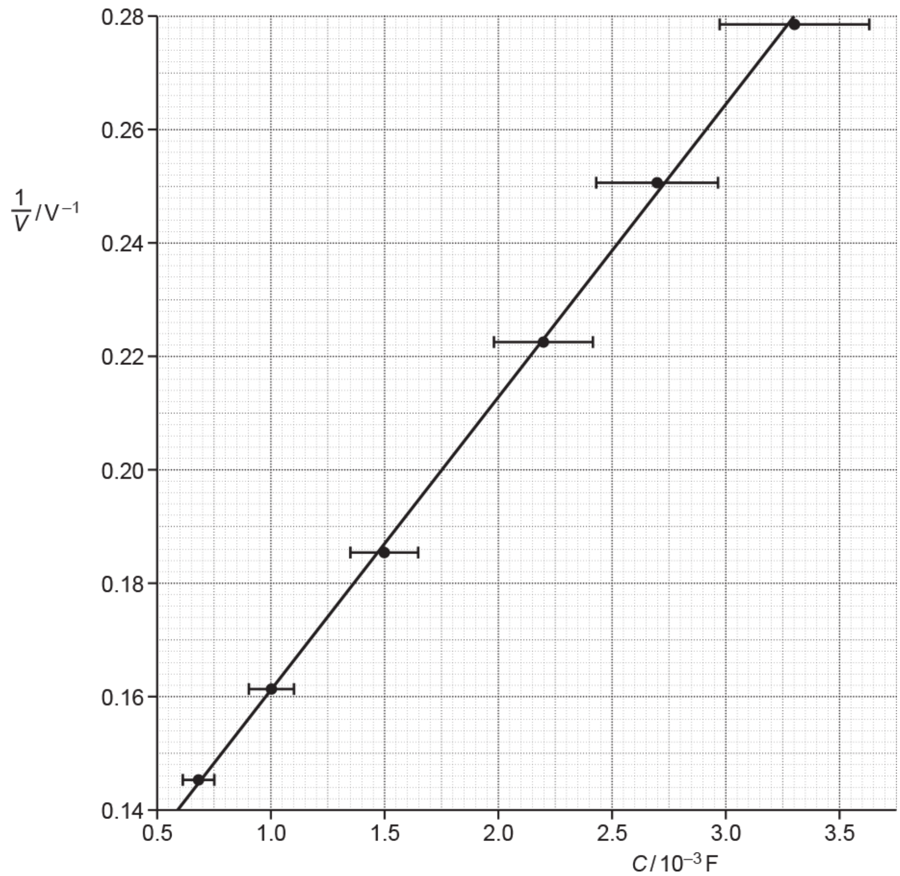
(b). A student wants to determine the values of E and C_0 by repeating the experiment above and measuring the potential difference (p.d.) V for a selection of capacitors of capacitance C.

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]

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 V^{-1} 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 = ... 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 kΩ 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.

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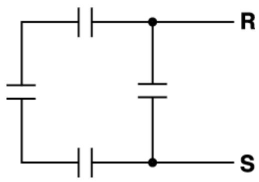
[1]

5. The diagram below shows a circuit connected by a student.



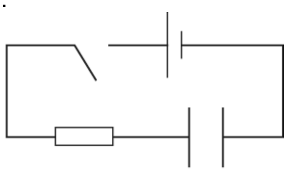
The capacitance of each capacitor is 300 pF.
What is the total capacitance between points **R** and **S**?

A 75 pF
B 230 pF
C 400 pF
D 1200 pF

Your answer

[1]

6. 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 $t = 200$ s?

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

Your answer

[1]

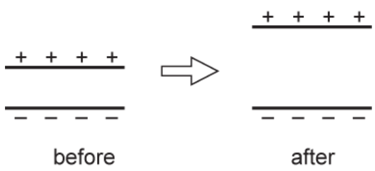
7. A capacitor discharges through a resistor.
At time $t = 0$ the potential difference V across the capacitor is V_0.
At time $t = 2.0$ s, $V = 0.90\ V_0$.

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]

8. 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]

9. A capacitor discharges through a resistor. At time $t = 0$, the charge stored by the capacitor is 600 μC. The capacitor loses 5.0 % of its charge every second.

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

A 111 μC
B 120 μC
C 480 μC
D 489 μC

Your answer [1]

10. A capacitor consists of two parallel plates separated by air. The capacitor is connected across a d.c. supply. The charged capacitor is then disconnected and the separation between the plates is doubled.

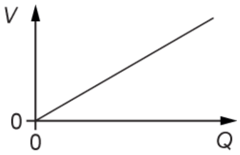
Which statement is correct about the charge stored by the capacitor?

A The charge is the same.
B The charge doubles.
C The charge halves.
D The charge quarters.

Your answer

[1]

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



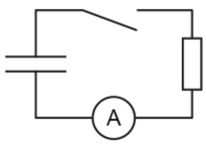
Which row is correct for the gradient of the graph and the area under the graph?

	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]

12. 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.

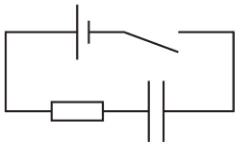
Which row is correct?

	Current I at t = 0	Current I at t = 10 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]

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]**

14. Four capacitors of capacitance 10 μF, 20 μF, 30 μF and 40 μF are connected in **series** to a battery.

Which capacitor has the **largest** potential difference across it?

A 10 μF capacitor
B 20 μF capacitor
C 30 μF capacitor
D 40 μF capacitor

Your answer [ ]

[1]

15 (a). 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.

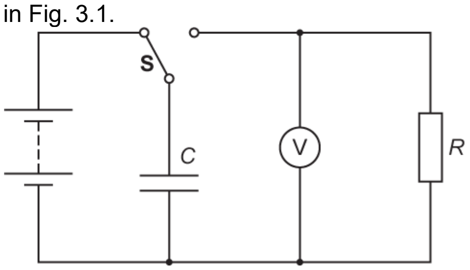


Fig. 3.1

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 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.

The student decides to plot a graph of ln (V / V) 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 s are given in the table below.

***R* / kΩ**	***V* / V**	$\left(\frac{1}{R}\right) / 10^{-6}\ \Omega^{-1}$	**ln (*V* / V)**
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) and its absolute uncertainty in the table above

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[1]

ii. Use the data to complete the graph of Fig. 3.2. Four of the six points have been plotted for you.

[2]

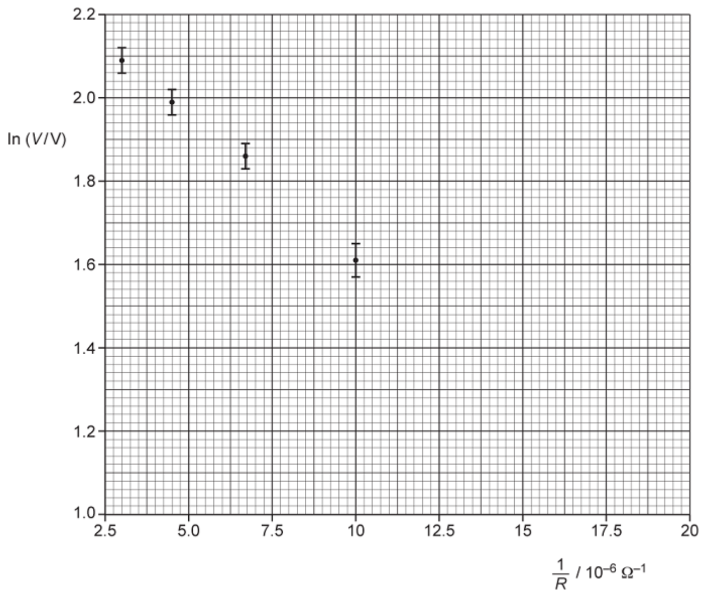


Fig. 3.2

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

C =...................± .... unit .... **[4]**

(c). Determine the value of *R*, in kΩ, for which the capacitor discharges to 10% of its original potential difference in 15.0 s. Show your working.

R = ... kΩ **[2]**

16. Fig. 20.1 shows a capacitor and a switch connected in series to a cell.

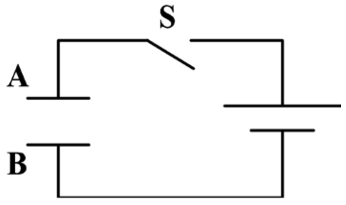


Fig. 20.1

The switch **S** is closed.

Describe and explain how the capacitor plates **A** and **B** acquire opposite charges.

---

[2]

17. A nucleus of hydrogen-3 ($^{3}_{1}H$) is unstable and it emits a beta-minus particle (electron).

The emitted beta-minus particle enters a region of uniform magnetic field.
Fig. 22.1 shows the path of the particle **before** it enters the magnetic field.

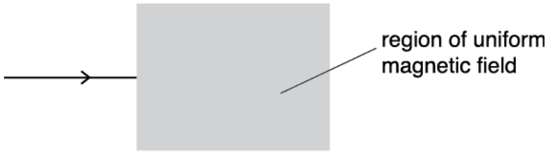


Fig. 22.1

The direction of the magnetic field is into the plane of the paper.
Describe and explain the path of the particle in the magnetic field.

----

[2]

18. 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 MΩ.

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.

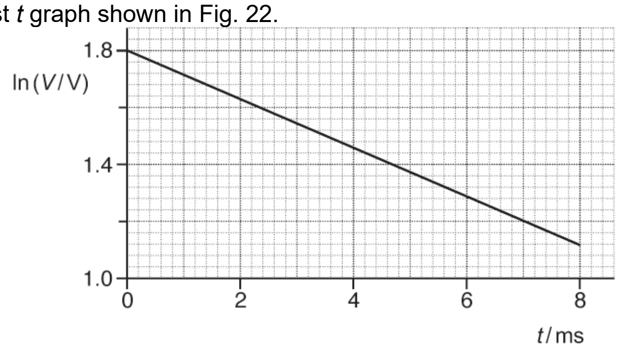


Fig. 22

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]

19. Fig. 20.1 shows a capacitor connected to a power supply.

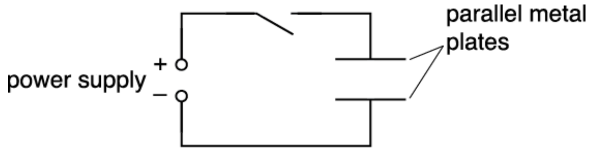


Fig. 20.1

The capacitor consists of two parallel metal plates separated by air.
The switch is closed to charge the capacitor.
The switch is then opened and the separation between the charged plates is **doubled**.
State and explain what happens to the energy stored by the capacitor.

---

[3]

20. Fig. 20.3 shows a capacitor-resistor circuit.

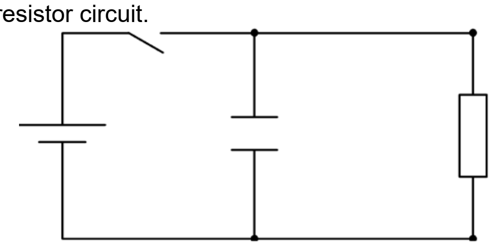


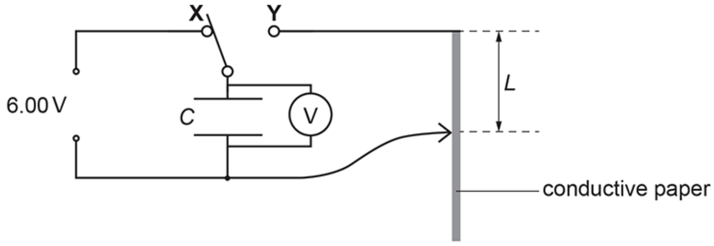
Fig. 20.3

Describe how the time constant of this circuit can be determined experimentally in the laboratory.

---

[3]

21 (a). 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

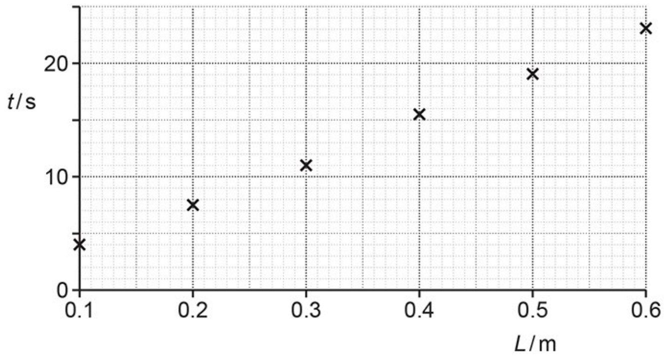
$t = (Ck \ln 2) \times L$

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 1.2×10^{-3} F.

In an experiment, *L* is changed and t measured.

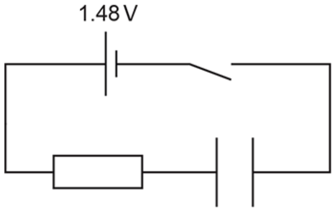
The data points are plotted on a *t* against *L* grid as shown below.



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

k = ... Ω m^{-1} **[4]**

(b). 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 kΩ and the capacitance of the capacitor is 2000 μF.
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 = ... s **[4]**

22 (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 4.0×10^{-4} m^2. Calculate the permittivity of the insulator between the capacitor plates.

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

(b). Fig. 21 shows a circuit.

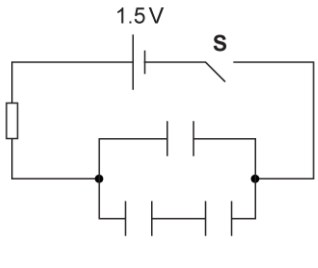


Fig. 21

The capacitance of each capacitor is 1000 μF. The resistance of the resistor is 10 kΩ. The cell has e.m.f. 1.5 V and negligible internal resistance.

i. Calculate the total capacitance *C* in the circuit.

C = ... μF **[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]**

23. Fig. 20.2 shows an arrangement of capacitors connected to a battery.

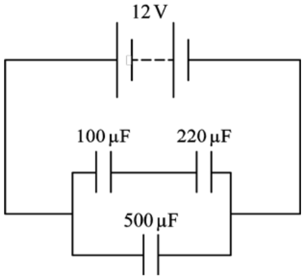


Fig. 20.2

The e.m.f. of the battery is 12 V.

Calculate the total energy E stored by the capacitors in this circuit.

E = ... J **[4]**

24. Fig. 22.1 shows two horizontal metal plates in a vacuum.

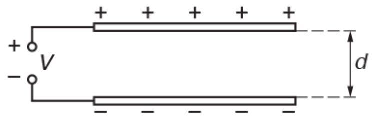


Fig. 22.1

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.

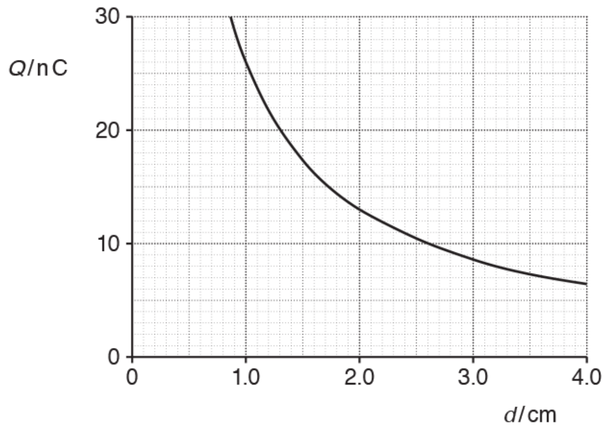


Fig. 22.2

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

Test proposed:

Working:

[2]

ii. Use capacitor equations to show that *Q* is inversely proportional to *d*.

[2]

25 (a). This question is about investigating the charging and discharging of capacitors.

Two students are given the circuit shown in Fig. 6.1. It consists of two resistors and two uncharged capacitors, a 10 V supply and a two-way switch **S**.

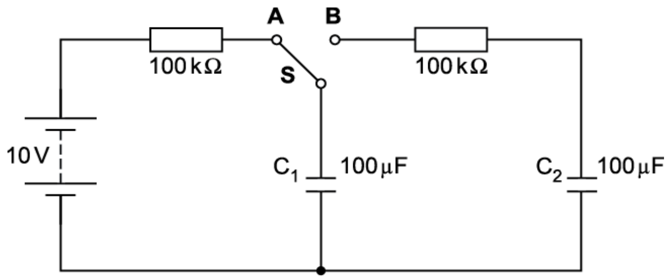


Fig. 6.1

The first student is asked to investigate the charging of the capacitor C_1 when **S** is connected to **A**. She selects an ammeter of range 0 to 100 μA reading to 2 μA and a stopwatch reading to 0.1 s.

Discuss whether she has made a sensible choice of equipment for this experiment.

---

[4]

(b). A student is asked to investigate the change of potential difference (voltage) *V* with time *t* across each capacitor from the instant that **S** is moved from **A** to **B**.

i. Explain why the final potential difference across each capacitor is 5.0 V.

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[2]

ii. Predict the outcome of the experiment by sketching **two** graphs on Fig. 6.2 to display the results that the student should obtain for each capacitor. Label them C_1 and C_2.

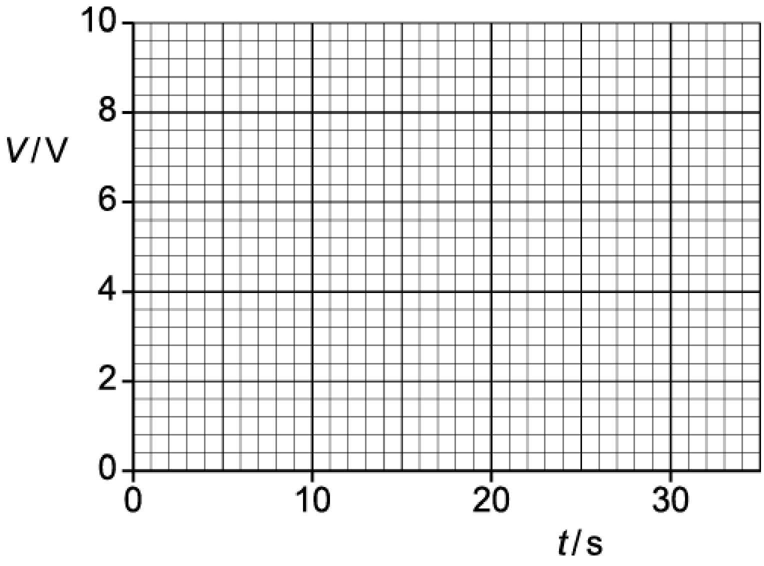

Fig. 6.2

[3]

26. 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 MΩ.

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.

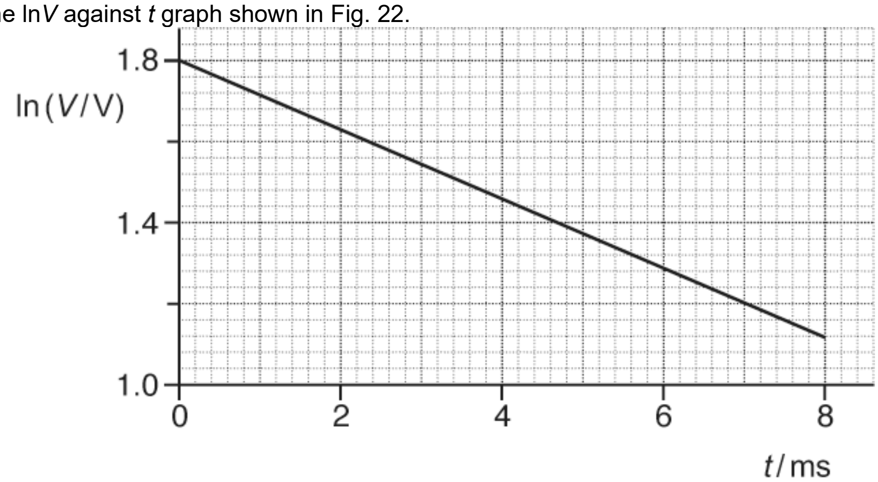

Fig. 22

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]

27. A student is carrying out an experiment in the laboratory to determine the capacitance C of a capacitor. Fig. 20.2 shows the circuit used by the student.

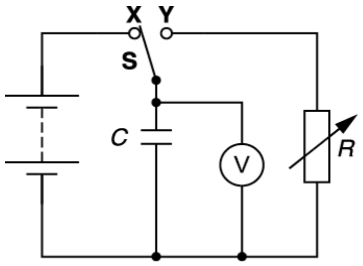

Fig. 20.2

The switch **S** is first connected to **X** to charge the capacitor. The switch is then moved to **Y** at time $t = 0$. The time T taken for the potential difference V across the capacitor to halve is determined for different values of resistance R.

i. Fig. 20.3 shows the graph of T against R as plotted by the student.

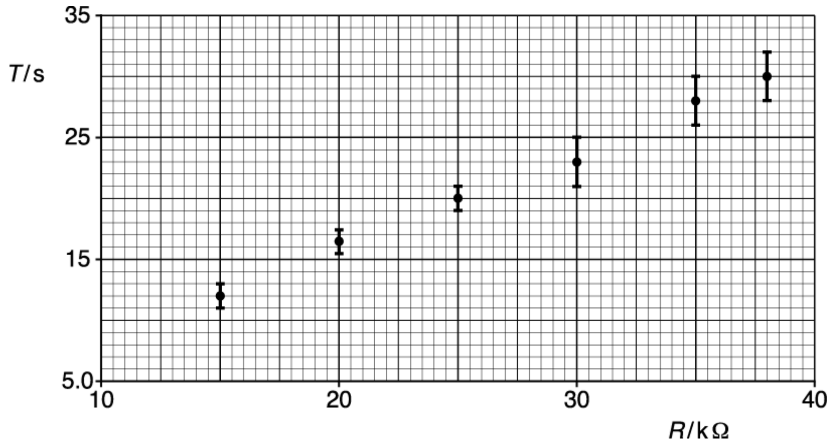

Fig. 20.3

1 Draw a straight line of best fit.

[1]

2 Use $V = V_0e^{-t/CR}$ to show that $T = -\ln(0.5)CR$.

[2]

3 Determine a value for the capacitance C.

C = ... F **[3]**

ii. Describe, without doing any calculations, how you can use Fig. 20.3 to determine the percentage uncertainty in C.

---

[2]

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

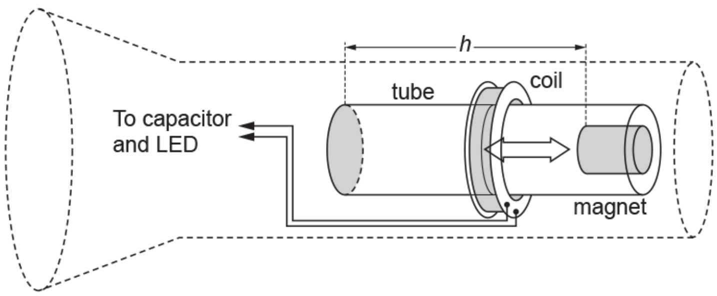

Fig. 3.1

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.

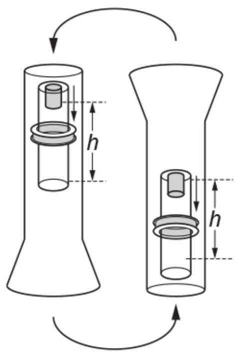

Fig. 3.2

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

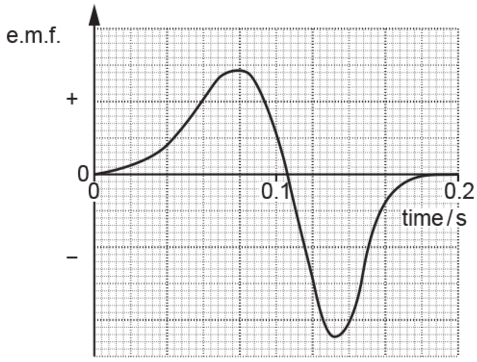

Fig. 3.3

When the torch is inverted, the pulses of e.m.f. shown in Fig. 3.3 cause a capacitor of capacitance 0.12 F to become charged.
Each positive **and** each negative pulse adds 9.0×10^{-3} C to the charge stored in the capacitor.

i. The torch is inverted 80 times.
Calculate the total energy stored in the capacitor.

total energy = ... J **[3]**

ii. When the torch is switched on, the energy stored in the capacitor lights a 50 mW LED.
Estimate the time for which the LED lights.

time = ... s **[1]**

END OF QUESTION PAPER