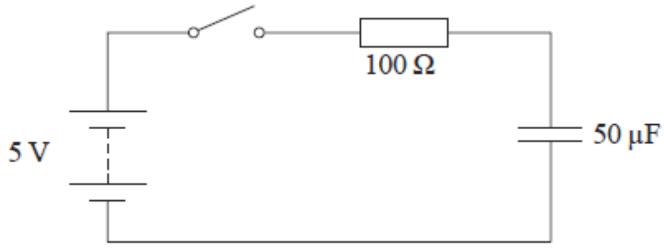
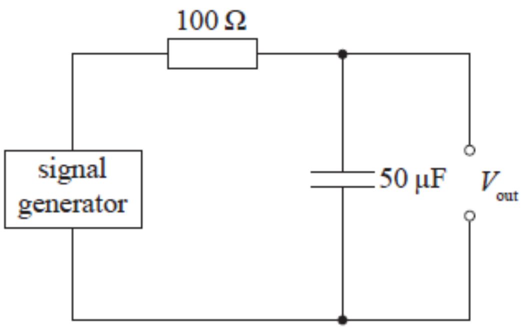
Questions

Q1.

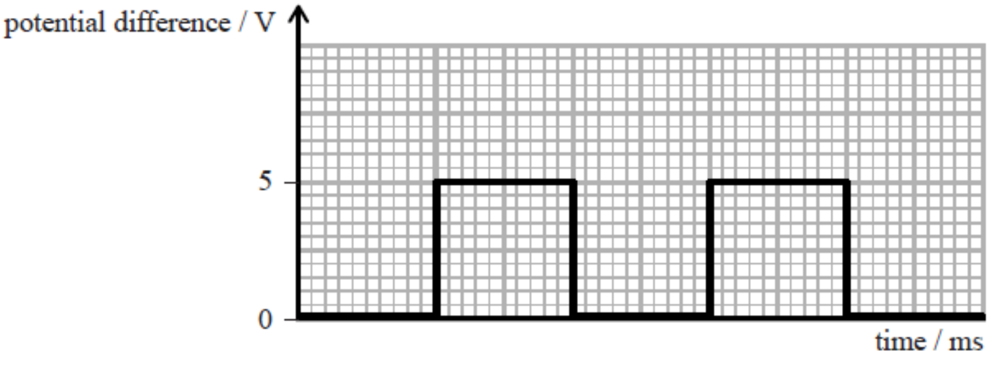
A circuit consists of a battery of e.m.f. 5 V and negligible internal resistance, a switch, a 100 Ω resistor and an uncharged 50 μF capacitor.



The battery and switch are replaced by a signal generator providing a square wave output of peak potential difference 5 V. The signal generator has negligible internal resistance.



The graph shows the square wave output of the signal generator. The frequency of the square wave is 20 Hz.



On the graph add values to the time axis and sketch a graph of the potential difference, V_{out}, across the capacitor for two cycles of the square wave. Assume the capacitor is initially uncharged.

(5)

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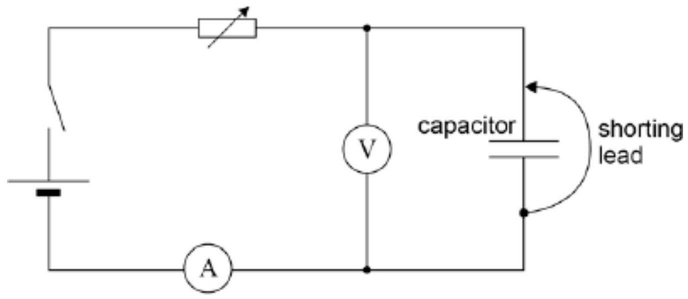
(Total for question = 5 marks)

2 This question is about capacitor charging and discharging.

A student designs an experiment to charge a capacitor using a constant current. The figure below shows the circuit the student designed to allow charge to flow onto a capacitor that has been initially discharged.



The student begins the experiment with the shorting lead connected across the capacitor as in the figure above. The variable resistor is then adjusted to give a suitable ammeter reading. The shorting lead is removed so that the capacitor begins to charge. At the same instant, the stop clock is started.

The student intends to measure the potential difference (pd) across the capacitor at 10 s intervals while adjusting the variable resistor to keep the charging current constant.

The power supply has an emf of 6.0 V and negligible internal resistance. The capacitor has a capacitance of 680 μF. The variable resistor has a maximum resistance of 100 kΩ.

(a) The student chooses a digital voltmeter for the experiment. A digital voltmeter has a very high resistance.

Explain why it is important to use a voltmeter with very high resistance.

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(1)

(b) Suggest **one** advantage of using an analogue ammeter rather than a digital ammeter for this experiment.

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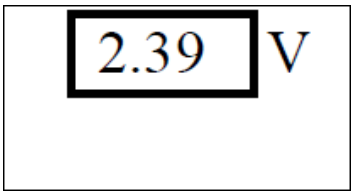
(1)

(c) Suggest a suitable full scale deflection for an analogue ammeter to be used in the experiment.

full scale deflection = ______________________

(2)

(d) The diagram shows the reading on the voltmeter at one instant during the experiment. The manufacturer gives the uncertainty in the meter reading as 2%.



Calculate the absolute uncertainty in this reading.

uncertainty = ______________________V

(1)

(e) Determine the number of different readings the student will be able to take before the capacitor becomes fully charged.

number = ______________________

(3)

(f) The experiment is performed with a capacitor of nominal value 680 μF and a manufacturing tolerance of ± 5 %. In this experiment the charging current is maintained at 65 μA. The data from the experiment produces a straight-line graph for the variation of pd with time. This shows that the pd across the capacitor increases at a rate of 98 mV s^{-1}.

Calculate the capacitance of the capacitor.

capacitance = ____________________ μF

(2)

(g) Deduce whether the capacitor is within the manufacturer's tolerance.

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(1)

(h) The student decides to confirm the value of the capacitance by first determining the time constant of the circuit when the capacitor **discharges** through a **fixed** resistor.

Describe an experiment to do this. Include in your answer:

- a circuit diagram
- an outline of a procedure
- an explanation of how you would use the data to determine the time constant.

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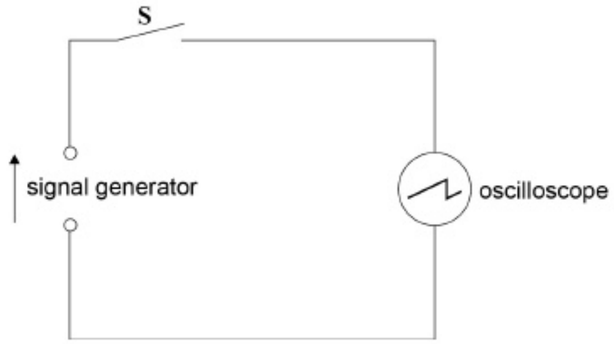
(4)

(Total 15 marks)

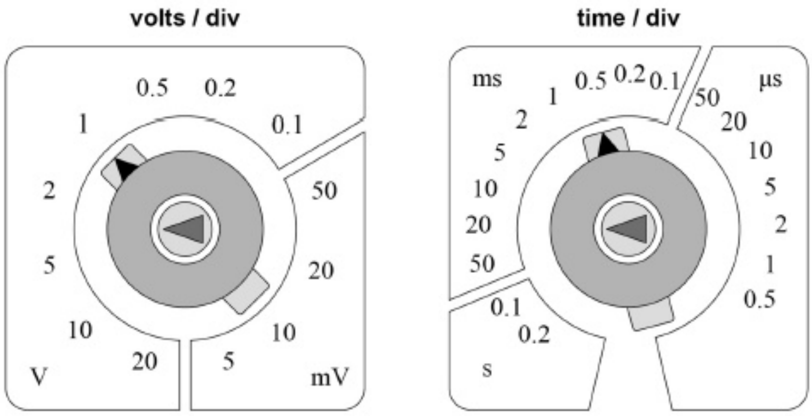
3 A signal generator is connected to an oscilloscope, as shown in **Figure 1**.

Figure 1



The Y-voltage gain and time-base settings of the oscilloscope are shown in **Figure 2**.

Figure 2



When switch **S** is open (off) the oscilloscope displays the waveform shown in **Figure 3**.

When **S** is closed (on) the oscilloscope displays the waveform shown in **Figure 4**.

(a) Determine the peak-to-peak voltage V of the waveform shown in **Figure 4**.

V = ____________________ V

(1)

(b) Determine the frequency f of the waveform shown in **Figure 4**.

f = ____________________ Hz

(2)

Figure 3

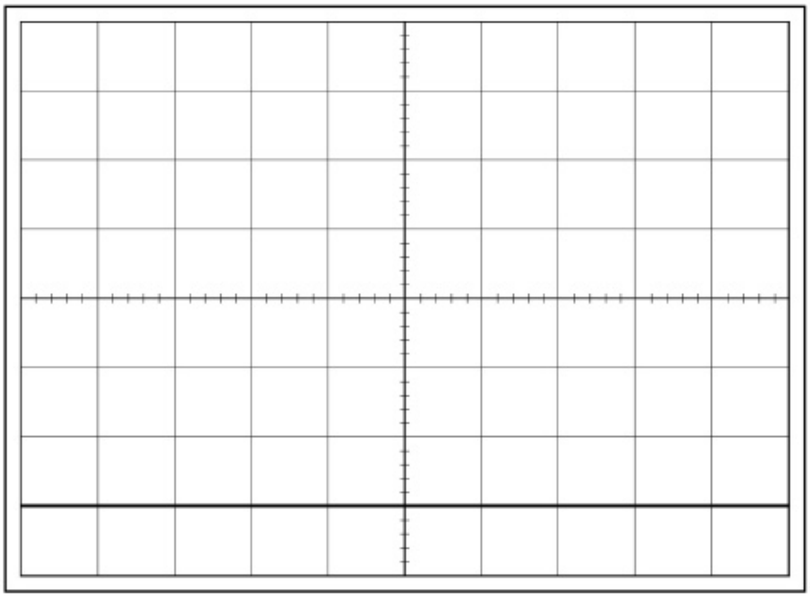
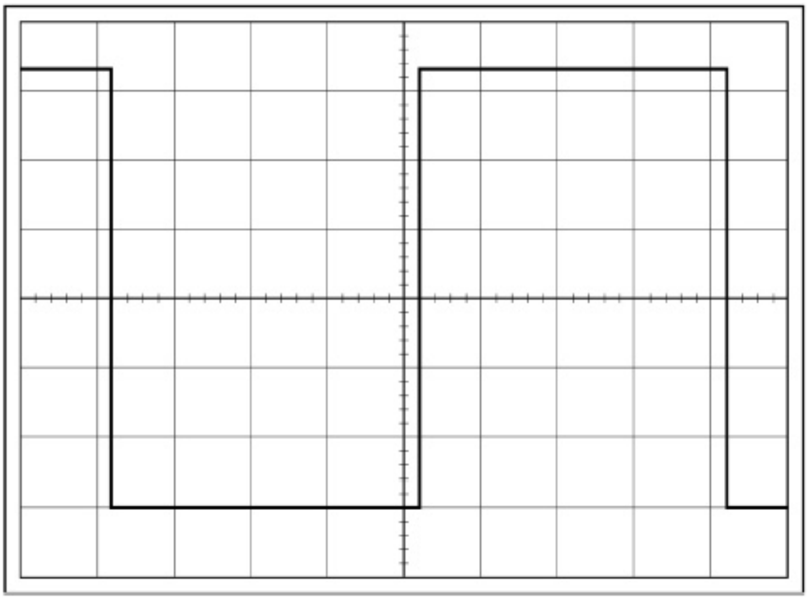
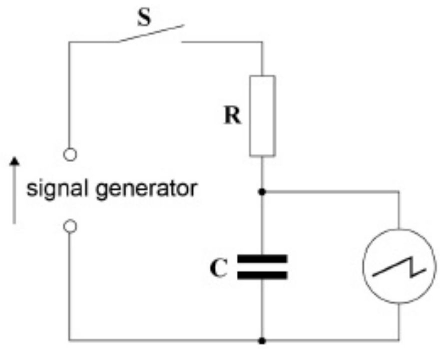


Figure 4



(c) **Figure 5** shows the signal generator connected in series with a resistor **R** and a capacitor **C**.

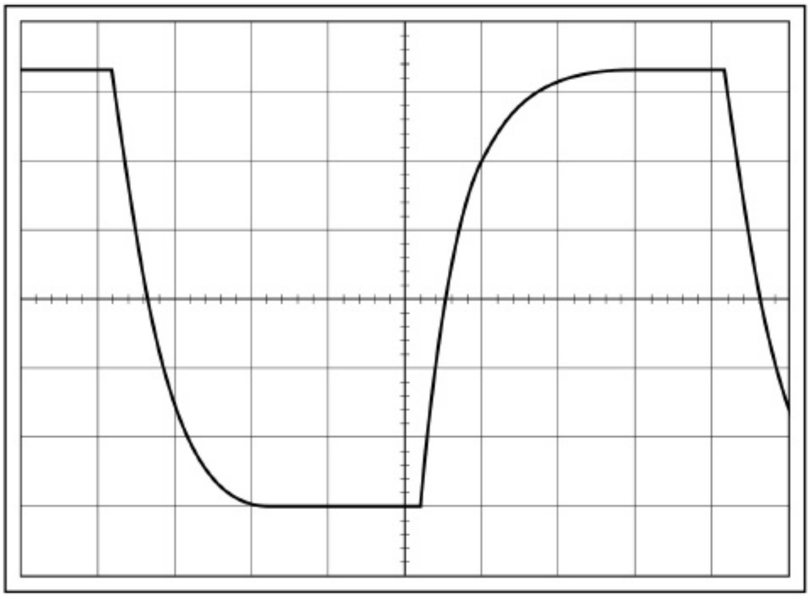
Figure 5



The oscilloscope is connected across the capacitor.
The Y-voltage gain and time-base settings are still the same as shown in **Figure 2**.

When **S** is closed (on) the oscilloscope displays the waveform shown in **Figure 6**.

Figure 6



Determine the time constant of the circuit in **Figure 5**.

time constant = ____________________ s

(2)

(d) A student suggests that setting the time-base to 0.2 ms $division^{-1}$ might reduce uncertainty in the determination of the time constant.

State and explain any possible advantage or disadvantage in making this suggested adjustment.

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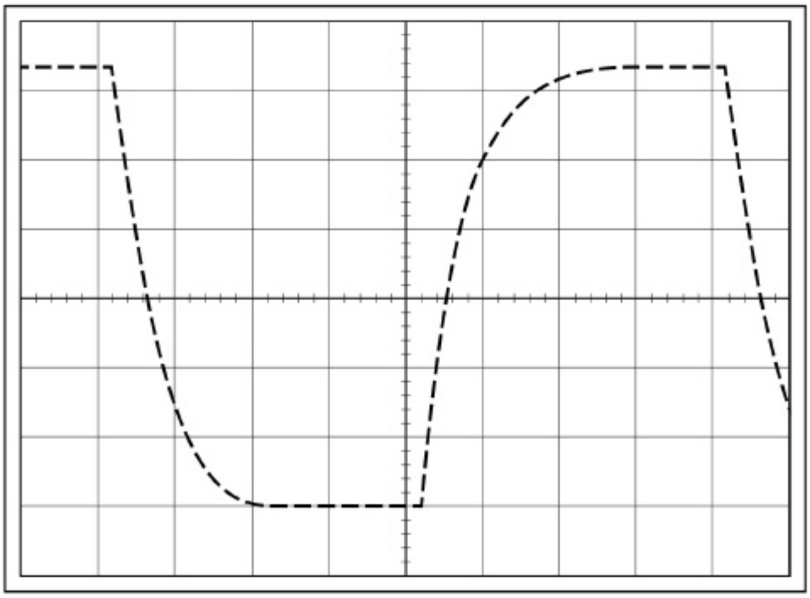
(3)

(e) The student connects an identical resistor in parallel with **R** and uses the oscilloscope to display the waveform across **C**.

Draw on **Figure 7** the waveform you expect the student to see.

The waveform of **Figure 6** is shown as a dashed line to help you show how the waveform changes.

Figure 7



Explain the change in the waveform.

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(2)

(f) **Figure 8a** is a graph of voltage against time showing the output of the signal generator. **Figure 8b** shows the voltage across **C** during the same time interval.

The student interchanges the positions of **R** and **C** and connects the oscilloscope across **R**.

Complete **Figure 8c** to draw the voltage across R during the time interval.

Figure 8a

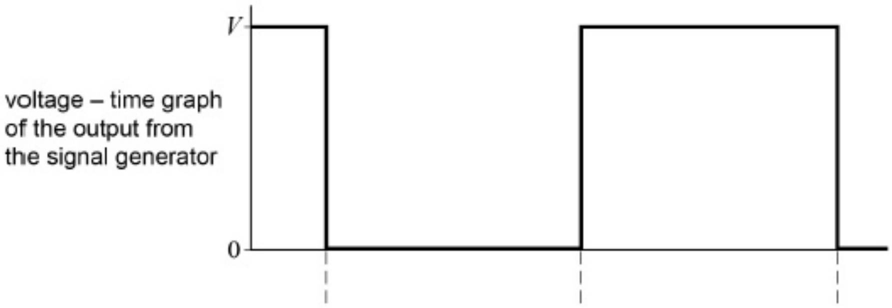


Figure 8b

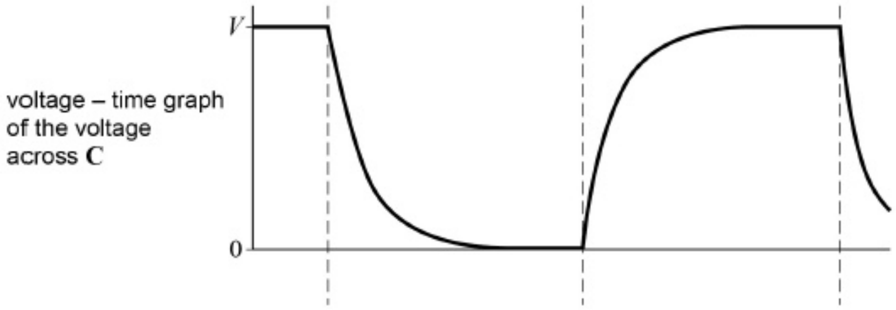
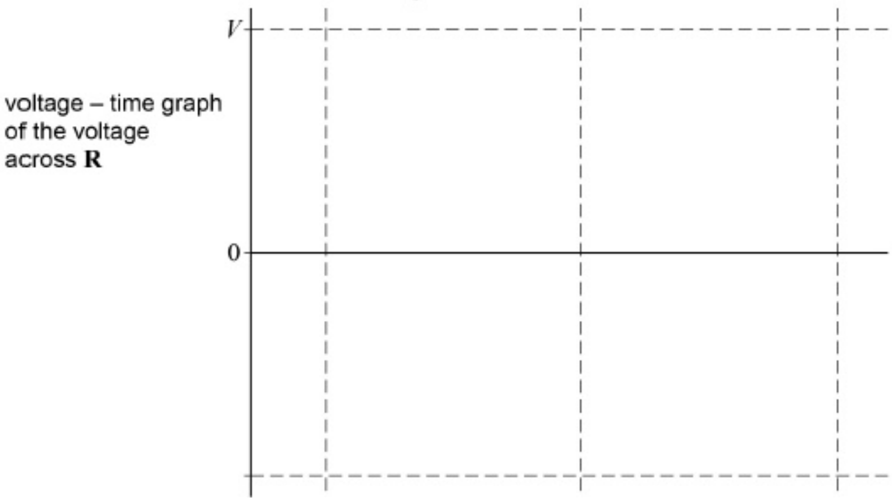


Figure 8c



(2)

(g) State and explain what changes, if any, the student needs to make to the settings of the oscilloscope so the waveform across **R** is fully displayed.

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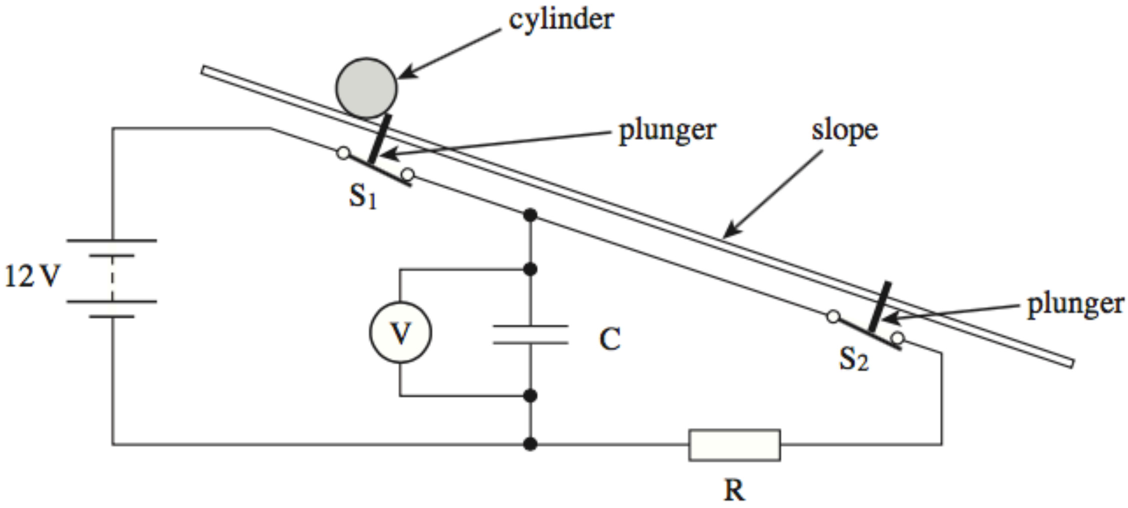
(2)

(Total 14 marks)

A student was required to design an experiment to measure the acceleration of a heavy cylinder as it rolled down an inclined slope of constant gradient. He suggested an arrangement that would make use of a capacitor-resistor discharge circuit to measure the time taken for the cylinder to travel between two points on the slope. The principle of this arrangement is shown in **Figure 2**.

Figure 2



S_1 and S_2 are two switches that would be opened in turn by plungers as the cylinder passed over them. Once opened, the switches would remain open. The cylinder would be released from rest as it opened S_1. The pd across the capacitator would be measured by the voltmeter.

(a) Describe the procedure the student should follow, including the measurements he should make, when using this arrangement. Explain how he should use the measurements taken to calculate the acceleration of the cylinder down the slope.

The quality of your written communication will be assessed in this question.

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(6 marks)

(b) When the student set up his experiment using the arrangement shown in **Figure 2**, he used a 22 μF capacitor, C, and a 200 kΩ resistor, R. In one of his results, the initial pd was 12.0 V and the final pd was 5.8 V. The distance between the plungers was 2.5 m.

(b) (i) From the student's result, calculate the time taken for the cylinder to reach the second plunger.

answer = ...s

(3 marks)

(b) (ii) What value does this result give for the acceleration of the cylinder down the slope, assuming the acceleration is constant?

answer = ...$m\,s^{-2}$

(2 marks)

A student is investigating the behaviour of a capacitor-resistor circuit as shown in Fig. 1.1.

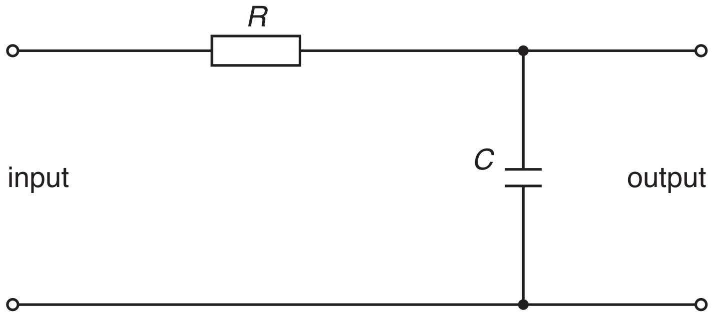


Fig. 1.1

A neon lamp flashes on and off when it is connected across the capacitor with a potential difference V_F across the lamp of approximately 90 V.

The student has a number of unmarked resistors.

It is suggested that the period T of the flashes of the lamp is related to the resistance R of the resistor by the expression

$$T = RCK$$

where C is the capacitance of the capacitor and K is a constant.

The constant K is given by

$$K = \ln\left(\frac{V_i - V_L}{V_i - V_F}\right)$$

where V_i is the potential difference across the input, V_F is the potential difference required to make the lamp flash and V_L is a constant.

Design a laboratory experiment to test the relationship between T and R.
Explain how your results could be used to determine a value for K and V_L.

You should draw a diagram, on page 3, showing the arrangement of your equipment. In your account you should pay particular attention to:

- the procedure to be followed
- the measurements to be taken
- the control of variables
- the analysis of the data
- any safety precautions to be taken.

6 A student is investigating a circuit containing capacitors.

The capacitors are initially uncharged. A capacitor of capacitance Y is charged by connecting it to a power supply. The charge is then shared with another capacitor of capacitance C connected between the terminals P and Q, as shown in Fig. 2.1.

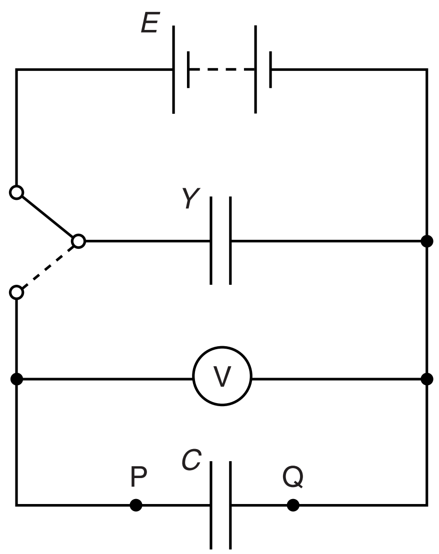


Fig. 2.1

A voltmeter is used to measure the maximum potential difference V between P and Q.

The experiment is repeated by adding additional capacitors, each of capacitance C, in series between P and Q.

The total capacitance X between P and Q may be determined by the equation

$$X = \frac{C}{n}$$

where n is the number of capacitors in series.

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

$$YE = (X + Y)V$$

where E is the e.m.f. of the power supply.

(a) A graph is plotted of $\frac{1}{V}$ on the y-axis against X on the x-axis.

Determine expressions for the gradient and y-intercept.

gradient = ...

y-intercept = ...
[1]

(b) Values of n and V are given in Fig. 2.2.

Data: $C = (2.7 \pm 0.4) \times 10^{-3}$ F

n	V/V	X/ 10^{-3} F	$\frac{1}{V}$ / V^{-1}
1	1.20		
2	1.95		
3	2.35		
4	2.75		
5	2.90		
6	3.05		

Fig. 2.2

Calculate and record values of X/ 10^{-3} F and $\frac{1}{V}$ / V^{-1} in Fig. 2.2.

Include the absolute uncertainties in X. [3]

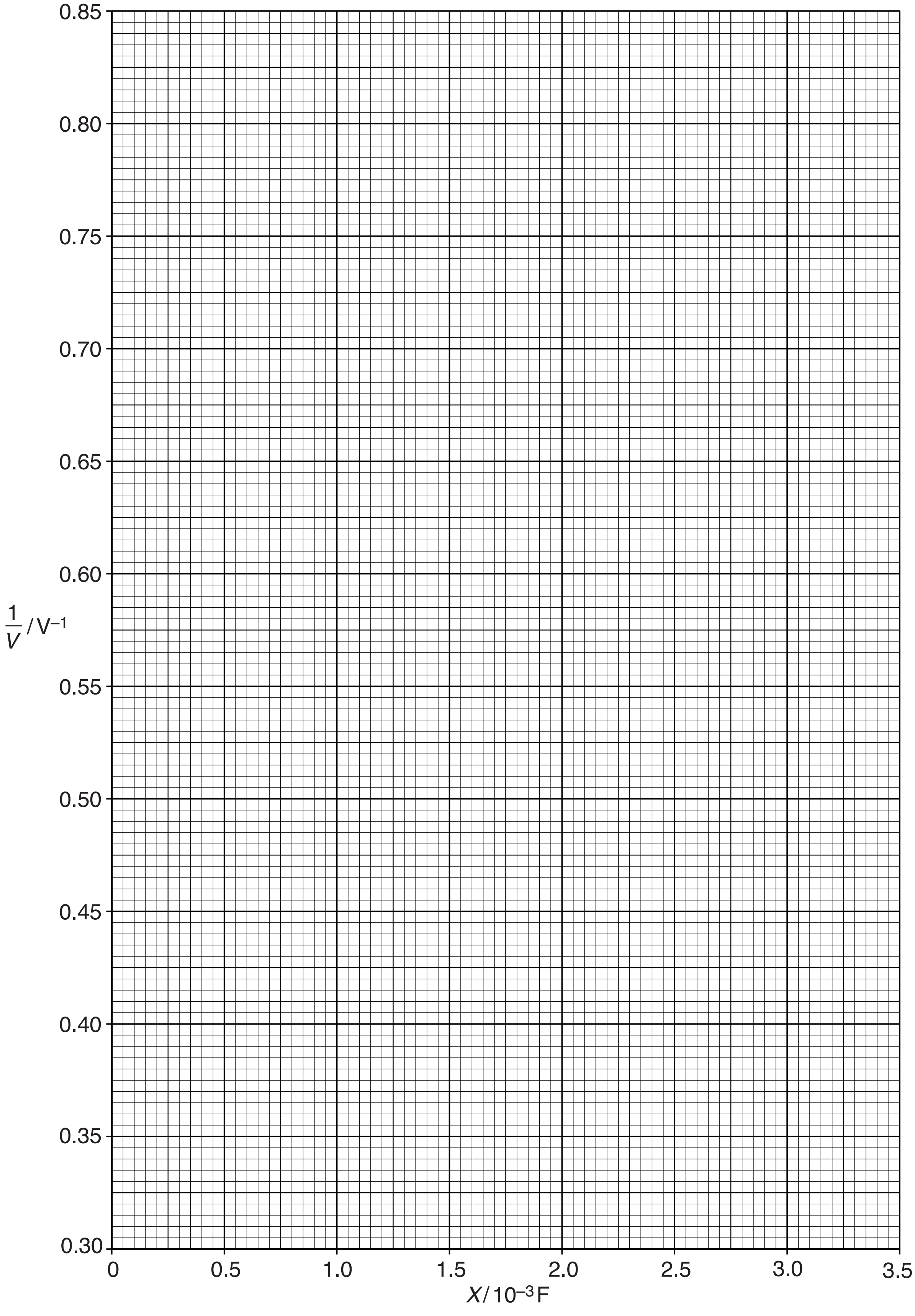
(c) **(i)** Plot a graph of $\frac{1}{V}$ / V^{-1} against X/ 10^{-3} F.

Include error bars for X. [2]

(ii) Draw the straight line of best fit and a worst acceptable straight line on your graph. Both lines should be clearly labelled. [2]

(iii) Determine the gradient of the line of best fit. Include the absolute uncertainty in your answer.

gradient = ... [2]


0.85
0.80
0.75
0.70
0.65
0.60
$\frac{1}{V}$ / V^{-1}
0.55
0.50
0.45
0.40
0.35
0.30
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
X / 10^{-3} F

(iv) Determine the *y*-intercept of the line of best fit. Include the absolute uncertainty in your answer.

y-intercept = ...[2]

(d) **(i)** Using your answers to **(a)**, **(c)(iii)** and **(c)(iv)**, determine the values of *E* and *Y*. Include an appropriate unit for *Y*.

E = ... V

Y = ...
[2]

(ii) Determine the percentage uncertainty in *Y*.

percentage uncertainty in *Y* = ... % [1]

[Total: 15]

7 . A student is investigating the charging of a capacitor. A circuit is set up as shown in Fig. 2.1

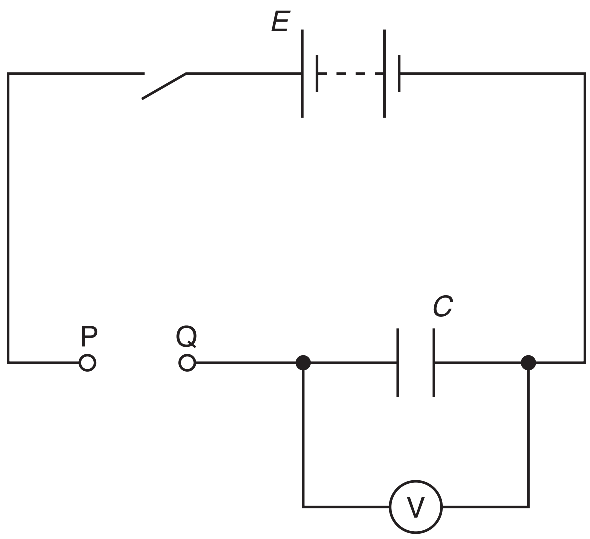


Fig. 2.1

The capacitor is initially discharged. A resistor of resistance *R* is connected between P and Q. When the switch is closed, the time *t* for the voltmeter reading to increase to a specific value *V* is measured. The capacitor is then discharged.

The experiment is repeated with a different number *n* of resistors each of resistance *R* connected in series between P and Q.

It is suggested that *t* and *n* are related by the equation

$$1 - \frac{V}{E} = e^{-\left(\frac{t}{nRC}\right)}$$

where *E* is the electromotive force (e.m.f.) of the power supply and *C* is the capacitance of the capacitor.

(a) A graph is plotted of *t* on the *y*-axis against *nR* on the *x*-axis.

Determine an expression for the gradient.

gradient = ... [1]

(b) Values of *n* and *t* are given in Fig. 2.2.
Each resistor has a resistance *R* of 4.7 kΩ ± 10%.

n	*t* / s	
1	15.8	
2	34.8	
3	50.8	
4	66.8	
5	83.8	
6	97.2	

Fig. 2.2

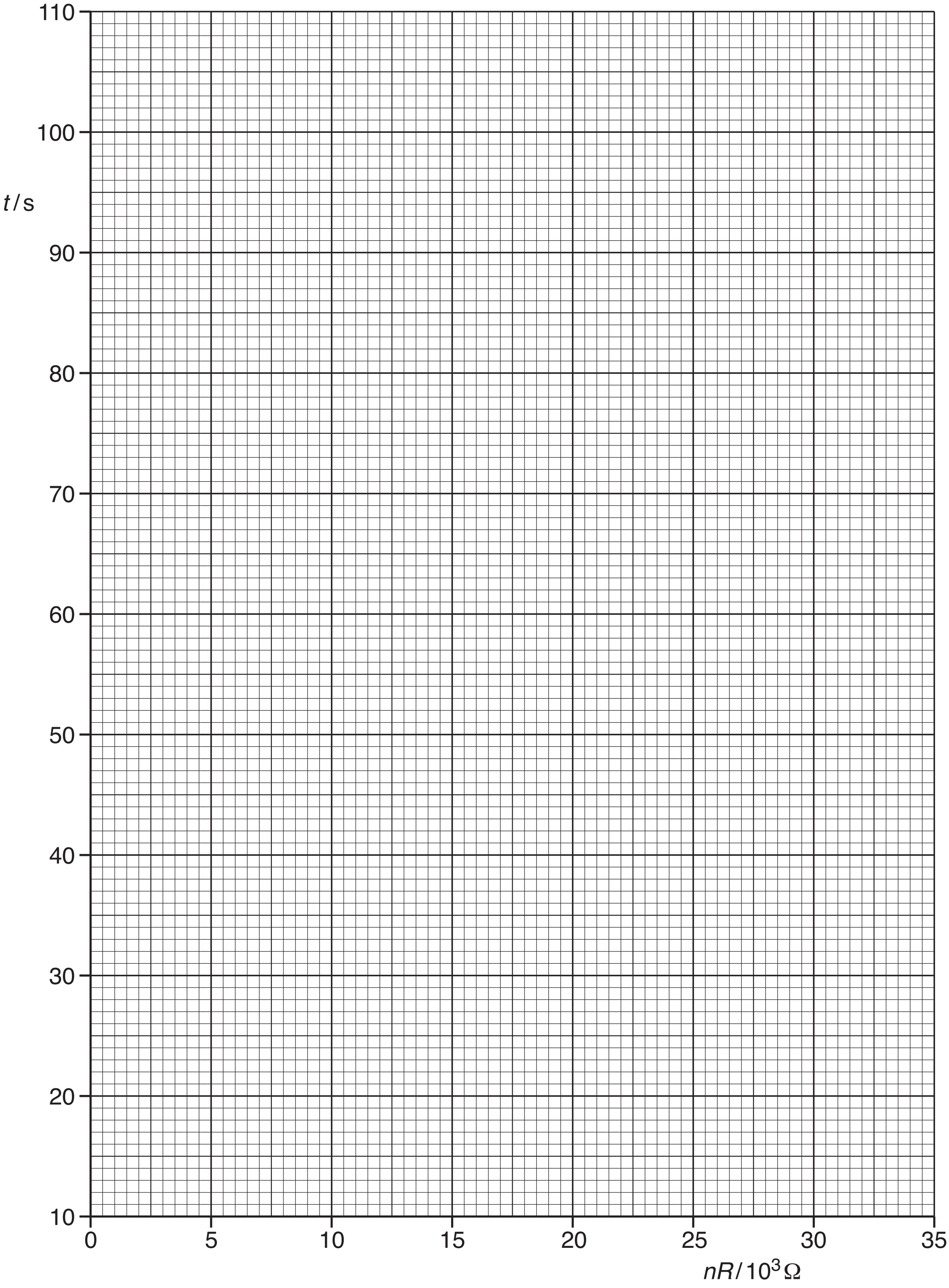
Calculate and record values of $nR/10^3\,\Omega$ in Fig. 2.2.
Include the absolute uncertainties in *nR*. [2]

(c) **(i)** Plot a graph of *t*/s against $nR/10^3\,\Omega$.
Include error bars for *nR*. [2]

(ii) Draw the straight line of best fit and a worst acceptable straight line on your graph. Both lines should be clearly labelled. [2]

(iii) Determine the gradient of the line of best fit. Include the absolute uncertainty in your answer.

gradient = ... [2]



110
100
t / s
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
nR / 10³ Ω

(d) **(i)** Using your answers to **(a)** and **(c)(iii)**, determine the value of *C*. Include an appropriate unit.

Data: $E = 5.0\,\text{V}$
$V = 4.0\,\text{V}$

C = ... [3]

(ii) Determine the percentage uncertainty in *C*.

percentage uncertainty in *C* = ... % [1]

(e) The experiment is repeated using the same capacitor. Determine the resistance *K* of the single resistor that is required so that the time for the voltmeter reading to reach 90% of the e.m.f. of the power supply is 5.0 minutes. Include the absolute uncertainty in your answer.

K = ... Ω [2]

[Total: 15]

8 A student investigates the discharge of a capacitor through a resistor using the circuit shown in Fig. 2.1.

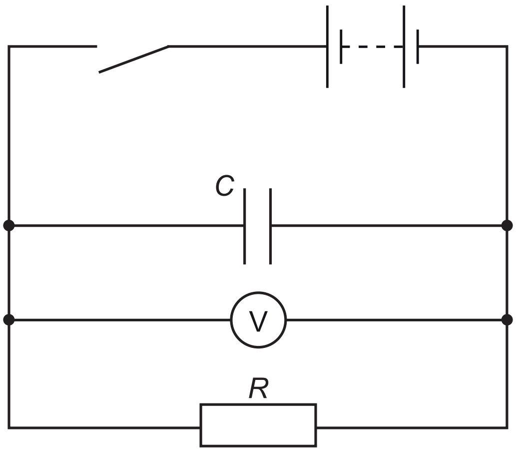


Fig. 2.1

The student initially closes the switch and charges the capacitor. The switch is then opened and a stop-watch is started. The capacitor discharges through the resistor. At time *t* the potential difference *V* across the capacitor is measured.

It is suggested that *V* and *t* are related by the equation

$$V = \left(\frac{Q_0}{C}\right)e^{-\left(\frac{t}{RC}\right)}$$

where Q_0 is the charge of the fully charged capacitor, *C* is the capacitance of the capacitor and *R* is the resistance of the resistor.

(a) A graph is plotted of ln *V* on the *y*-axis against *t* on the *x*-axis.

Determine expressions for the gradient and *y*-intercept.

gradient = ...

y-intercept = ...

[1]

(b) Values of *t* and *V* are given in Table 2.1.

Table 2.1

t / s	*V* / V	ln (*V* / V)
0	6.2 ± 0.2	
6	4.6 ± 0.2	
12	3.4 ± 0.2	
18	2.6 ± 0.2	
24	2.0 ± 0.2	
30	1.4 ± 0.2	

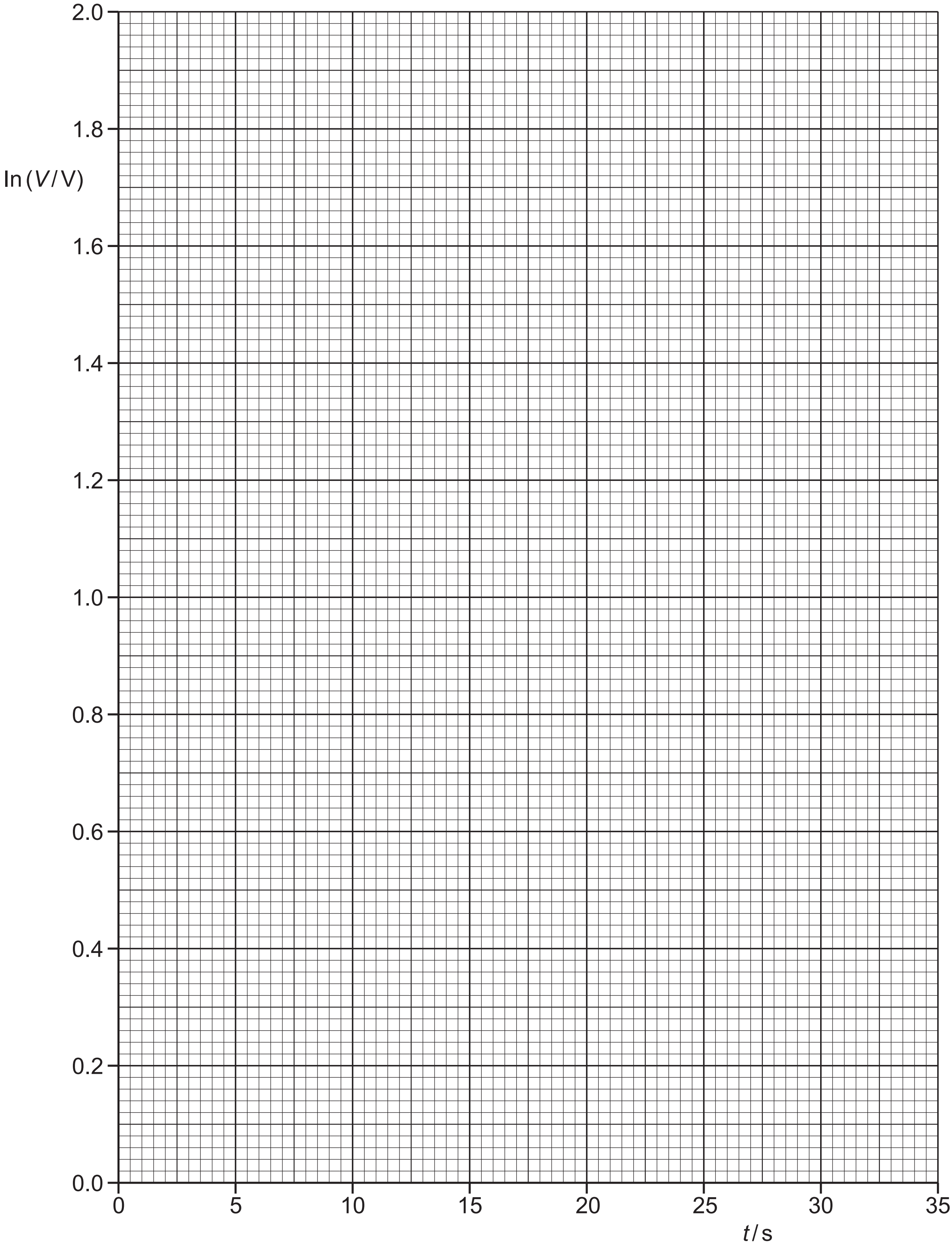
Calculate and record values of ln (*V* / V) in Table 2.1.
Include the absolute uncertainties in ln (*V* / V). [2]

(c) **(i)** Plot a graph of ln (*V* / V) against *t* / s.
Include error bars for ln (*V* / V). [2]

(ii) Draw the straight line of best fit and a worst acceptable straight line on your graph. Both lines should be clearly labelled. [2]

(iii) Determine the gradient of the line of best fit. Include the absolute uncertainty in your answer.

gradient = ... [2]


2.0
1.8
ln (V / V)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
t / s

(iv) Determine the y-intercept of the line of best fit. Do **not** include the absolute uncertainty in your answer.

y-intercept = ... [1]

(d) **(i)** Using your answers to **(a)**, **(c)(iii)** and **(c)(iv)**, determine values of C and Q_0. Include appropriate units.

Data: $R = 39\,\text{k}\Omega$

C = ...

Q_0 = ...
[3]

(ii) The percentage uncertainty in the value of R is 5%.

Determine the absolute uncertainty in C.

absolute uncertainty in C = ... [1]

(e) Using your results, determine the value of V when the time t is 1.0 minute.

V = ... V [1]

[Total: 15]