Capacitors Past Questions + Markscheme

Jan 2005

9 This question is about capacitor discharge.

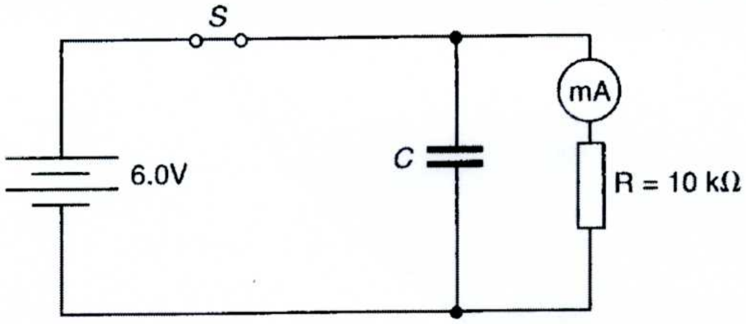
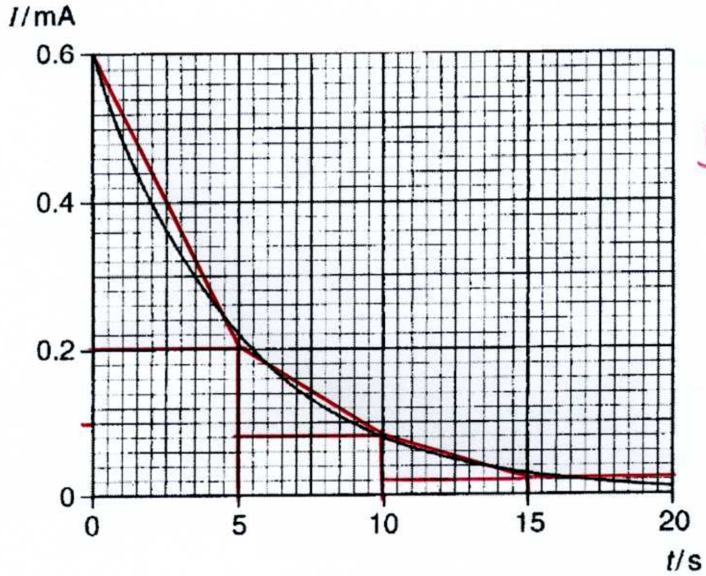


Fig. 9.1

The circuit is set up as shown in Fig. 9.1. Switch *S* is then opened and the capacitor discharges through the resistor. The variation of discharge current *I* with time *t* is shown in Fig. 9.2.



$5 \times \left(\frac{0.4}{2} + 0.2 + \frac{0.12}{2} + 0.08 + \frac{0.06}{2} + 0.02 + \frac{0.02}{2}\right)$

$= 5 \times (0.6) = 3.0$

Fig. 9.2

(a) (i) Explain why the area under the curve represents the initial charge on the capacitor.

Area under curve is $I \times t$ & $Q = It$

[1]

(ii) Show that the initial charge on the capacitor is about 3 mC.

Area under curve = 3 mAs = 3 mC

[2]

(iii) Calculate the value of the capacitance used in the experiment.

$C = Q/V = 3\times10^{-3}/6.0 =$

value of capacitance = 5×10^{-4} unit F [3]

(b) Calculate the energy stored on the capacitor when the switch is closed.

$E = \frac{1}{2}QV = \frac{1}{2} \times 3 \times 10^{-3} \times 6$

energy stored = 9×10^{-3} J [2]

(c) The experiment is repeated. The 10 kΩ resistor is removed and replaced with a 20 kΩ resistor. No other changes are made to the circuit.

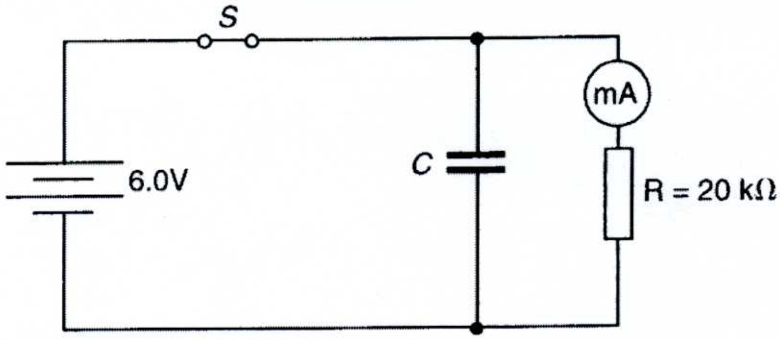
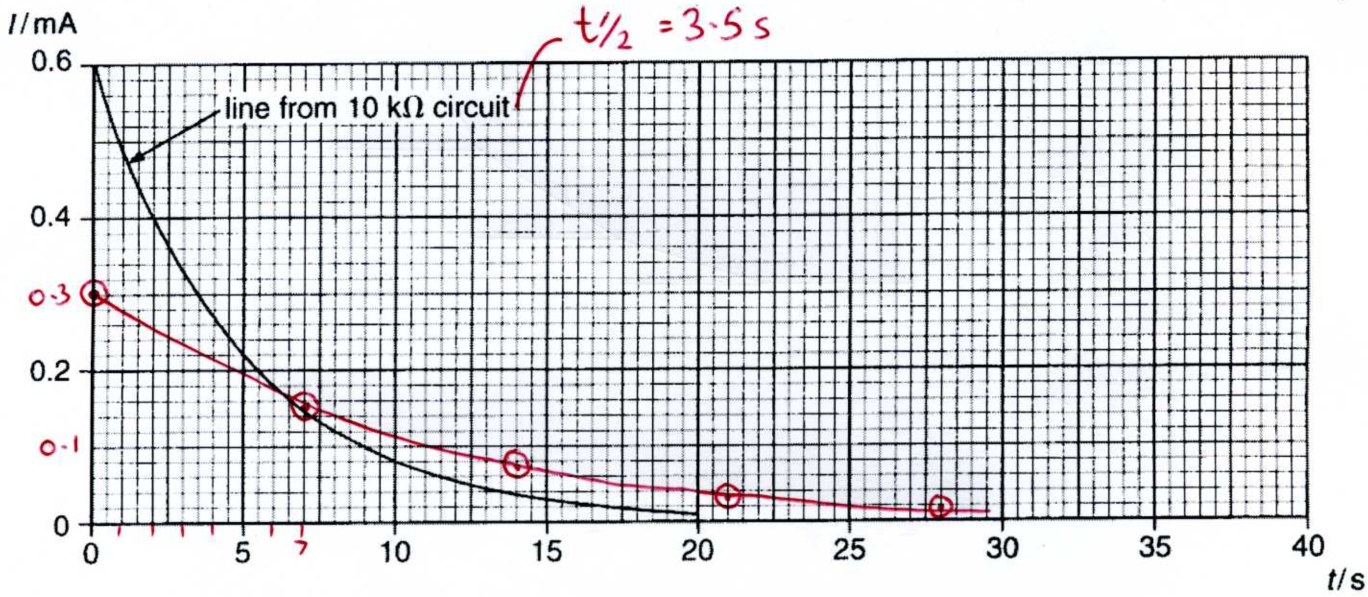


Fig. 9.3

Use the axes on Fig. 9.4 to sketch the graph of current against time for the new circuit.



[3]

Fig. 9.4

[Total: 11]

R is ×2 so I_0 will be half = 0.3 mA

RC is ×2 so time constant / $t_{1/2}$ doubled. to 7s

June 2005

2 The flash unit of a disposable camera contains a 470 μF capacitor. The potential difference across the charged capacitor is 270 V.

(a) Calculate the charge on the capacitor.

$C = Q/V \quad \therefore \quad Q = CV$

$= 470 \times 10^{-6} \times 270$

$= 0.127\,C$

charge on capacitor = 0.127 unit C [3]

(b) Calculate the energy stored on the capacitor.

$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 470 \times 10^{-6} \times 270^2 =$

energy stored on capacitor = 17.1 J [2]

Jan 2007

7 A capacitor stores a charge of 5.6 mC at a p.d. of 12 V.

Calculate the value of the capacitance.

$C = Q/V = \frac{5.6 \times 10^{-3}}{12} =$

capacitance = 4.7×10^{-4} F [2]

7 The 4700 μF capacitor shown in Fig. 7.1 is used as a part of a timing circuit.

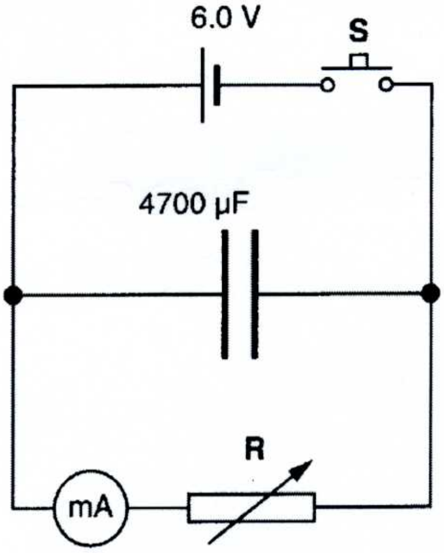


Fig. 7.1

The variable resistor **R** is initially set to a value of 12 kΩ.
The timing sequence is started by closing and opening the switch **S**.

(a) Whilst the switch **S** is closed, calculate

(i) the charge stored by the capacitor

$Q = CV = 4700 \times 10^{-6} \times 6$

charge = 0.028 C [1]

(ii) the energy stored by the capacitor

$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 4700 \times 10^{-6} \times 6^2$

energy = 0.085 J [2]

(iii) the current in **R**.

$I = V/R = 6/12 \times 10^3$

current = 5×10^{-4} unit A [2]

(b) **(i)** Explain why the current will start to decrease as soon as **S** is opened.

[2]

(ii) Show that the time constant τ for this circuit is about 60 s.

$\tau = RC = 12 \times 10^{3} \times 4700 \times 10^{-6} = 56\ s$

[1]

(c) The experiment is repeated with the value of **R** reduced to 6.0 kΩ from its previous value of 12 kΩ. half

State the new values of

(i) the current whilst the switch is closed double

current = 1×10^{-3} A [1]

(ii) the time constant. half

time constant = 28 s [1]

(d) With **R** set at 6.0 kΩ, a student briefly closes the switch **S** every 10 seconds. The voltage across the capacitor varies as shown in Fig. 7.2.

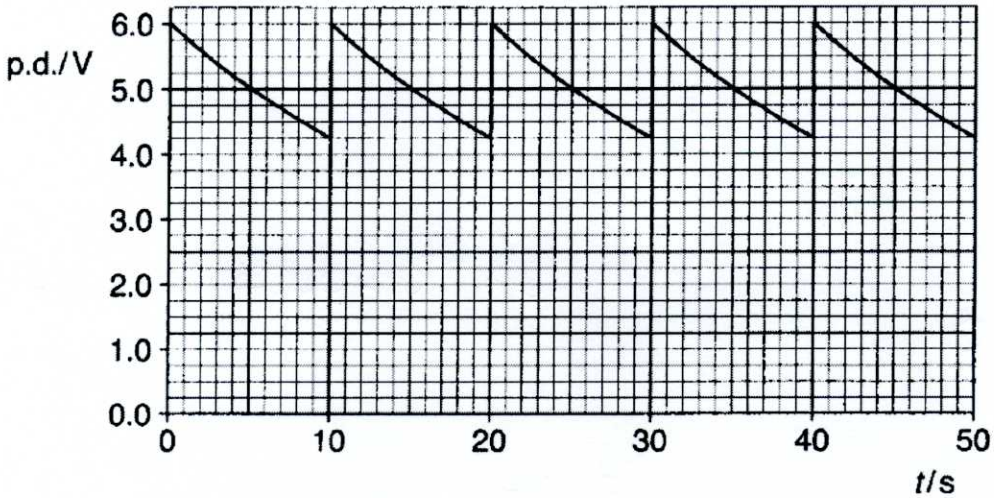


Fig. 7.2

State and explain **two** features of the graph.

feature 1: maximum p.d = 6.0V

explanation: supply p.d is 6.0V

feature 2: p.d only falls to 4.2 V in 10 s

explanation: $V = V_0 e^{-t/RC} = 6e^{-10/28} = 4.2$

[4]

1 Study the circuit in Fig. 1.1.

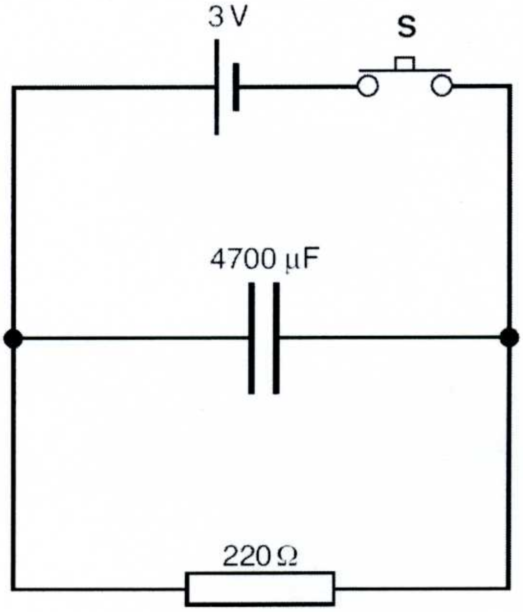


Fig. 1.1

The switch **S** is closed to charge the capacitor. When the switch is opened the capacitor discharges through the resistor.

Here is a list of values:

1.4×10^{-2} 2.1×10^{-2} 1.0 1.4 2.1

Choose from the list the value that is closest to

(a) the time constant τ of the circuit in seconds

$\tau = RC = 4700 \times 10^{-6} \times 220 = 1.0$

value 1.0 s

(b) the charge in coulombs on the capacitor when at a p.d. of 3.0 V

$Q = CV = 4700 \times 10^{-6} \times 3 = 1.4 \times 10^{-2}$

value 1.4×10^{-2} C

(c) the energy stored on the capacitor in joules when at a p.d. of 3.0 V

$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 4700 \times 10^{-6} \times 3^2 = 2.1 \times 10^{-2}$

value 2.1×10^{-2} J

(d) the initial value of the current in ampere when the fully charged capacitor discharges through the resistor.

$I = V/R = 3/220 = 1.4 \times 10^{-2}$

value 1.4×10^{-2} A

[4]

11 This question is about capacitor discharge in the circuit shown in Fig. 11.1.

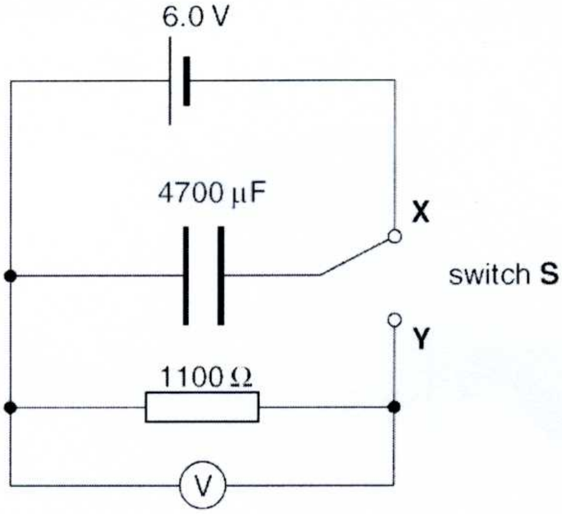


Fig. 11.1

The switch **S** is moved from **X** to **Y**. The capacitor discharges through the 1100 Ω resistor. Fig. 11.2 shows the graph of p.d. against time.

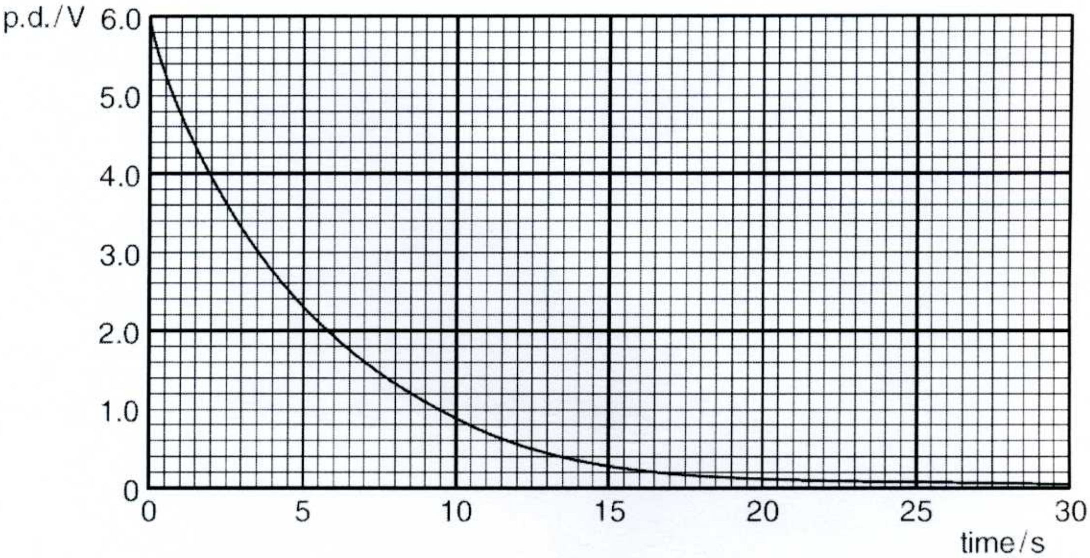


Fig. 11.2

(a) Use information from the diagram and the graph to show that

(i) the initial charge on the capacitor is about 0.03 C

$Q = CV = 4700 \times 10^{-6} \times 6$

$= 0{\cdot}028\ C$

[1]

(ii) the initial rate of discharge is about 5 mA

$I = V/R = 6/1100 = 5{\cdot}5 \times 10^{-3}\ A$

$= 5{\cdot}5\ mA$

[1]

(iii) the time constant of the circuit is about 5 s.

$\tau = RC = 1100 \times 4700 \times 10^{-6}$

$= 5{\cdot}2\ s$

[1]

(b) Explain why the rate of fall of voltage is proportional to the rate of fall of charge and hence proportional to the current in the circuit.

$C = Q/V$ ~~XXXXXXXXXXXXXXXXX~~ V is proportional to Q and dQ/dt the rate of fall of charge is the current in the circuit $I = dQ/dt$.

[2]

(c) A series of models of the discharge are considered.

(i) In the simplest model the current is assumed to remain constant at its initial value throughout the discharge. Show that this model predicts that the capacitor would fully discharge in time RC.

$I = Q/t \quad \therefore \quad t = Q/I = \frac{CV}{V/R}$

$t = CV \times \frac{R}{V} = RC$

[2]

(ii) A better model calculates the change of charge ΔQ in successive time intervals Δt using the equation $\Delta Q = -\frac{Q}{RC}\Delta t.$

Fig. 11.3 shows the graph produced when Δt is set at 4.0 s.

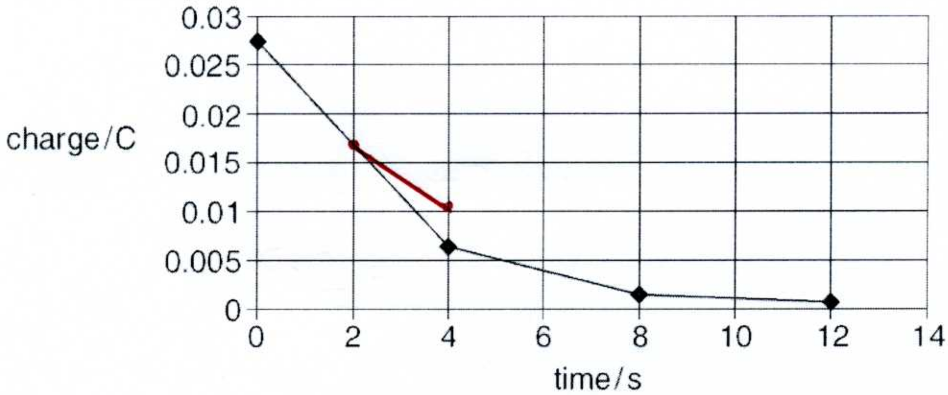


Fig. 11.3

To improve the model Δt is reduced to 2.0 s. This graph gives the charge remaining at 2.0 s as 0.017 C. Use this value to show that the loss of charge during the next two seconds will be about 6.5×10^{-3} C.

$\Delta Q = -\frac{Q}{RC}\Delta t = \frac{-0.017}{5.2} \times 2.0 = \underline{6.5 \times 10^{-3}\ C}$

[1]

(iii) Draw a line on the graph in Fig. 11.3 to represent the loss of charge from the capacitor between 2.0 s and 4.0 s.

$0.017 - 6.5 \times 10^{-3} = 0.0105\ C \approx 0.01\ C$

[1]

(iv) Explain why reducing the time interval Δt leads to a more accurate model of the discharge.

The rate of decay is updated more frequently
(It is held constant for shorter time intervals)

[1]

June 2008

3 Here are some data about a capacitor

capacitance = 470 μF

p.d. across fully charged capacitor = 12 V.

(a) Show that the charge on the capacitor is about 5.6 mC.

$C = Q/V \quad \therefore \quad Q = CV = 470 \times 10^{-6} \times 12$

$= \underline{5.64 \times 10^{-3}\ C}$

[1]

The capacitor is discharged through a resistor. After three seconds the p.d. across the capacitor has fallen to 10 V.

(b) Show that a charge of about 0.9 mC passes through the resistor as the p.d. across the capacitor falls to 10 V.

At 10 V $\quad Q = 470 \times 10^{-6} \times 10 = 4.70 \times 10^{-3}\ C$

$5.64 \times 10^{-3} - 4.7 \times 10^{-3} = \underline{9.4 \times 10^{-4}\ C} \approx 0.9\ mC$

[2]

(c) The average current in the resistor as the p.d. across the capacitor falls from 12 V to 10 V is about 0.3 mA.

Explain why 0.3 mA is an **average** value.

The current is the rate of dischage and this falls as Q falls because $dQ/dt \propto Q$

[1]

Jan 2010

9 Calculate the energy stored on a 4700 μF capacitor when a p.d. of 9.0 V is applied across it.

$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 4700 \times 10^{-6} \times 9^2$

energy stored = 0.19 J .... J **[2]**

11 A student is experimenting with capacitors. He has two capacitors available, one of capacitance 1000 μF and one of unknown value. He connects the circuit shown in Fig 11.1 and closes the switch **S**.

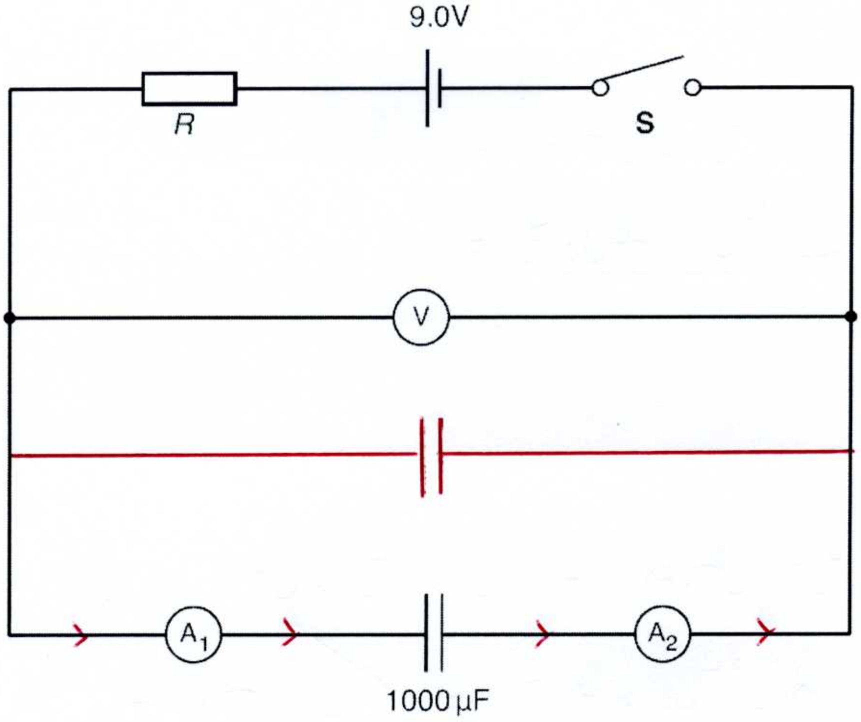


Fig. 11.1

(a) **(i)** State the current in ammeter A_1 when the current in ammeter A_2 is + 0.5 mA.

sign and magnitude of current = ...+ 0.5...... mA **[1]**

(ii) Calculate the charge on the 1000 μF capacitor when the potential difference across the capacitor is 9.0 V.

$Q = CV = 1000 \times 10^{-6} \times 9 =$

charge = ...9×10^{-3}...... C **[2]**

(b) The switch **S** is now opened again. The high-resistance voltmeter reading remains at 9.0 V. The student connects the uncharged capacitor of unknown value in parallel with the charged 1000 μF capacitor.

(i) Draw on Fig. 11.1 to show the second capacitor connected in the circuit. **[1]**

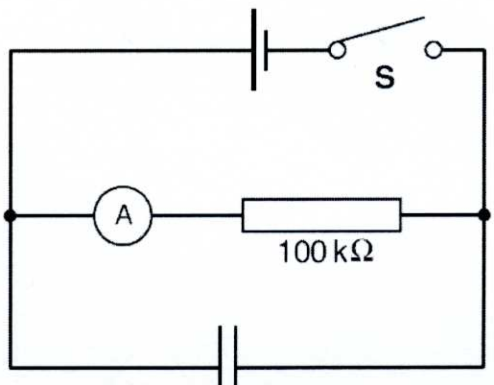
When the second capacitor has been connected the student notices that the voltmeter reading has dropped to half its previous value.

(ii) Deduce the capacitance of the second capacitor explaining your reasoning carefully.

Reasoning: As half the charge has left the capacitor the second must be the same as the first. *

capacitance = 1000 μF **[2]**

(c) The student now connects the 1000 μF capacitor into the circuit shown in Fig. 11.2. Switch **S** is closed briefly and then opened again.



* or $Q = CV$ If V halves then C must double.

Fig. 11.2

(i) Show that when the switch is opened the initial current in the resistor is 9×10^{-5} A.

$$I = V/R = \frac{9}{100 \times 10^3} = 9 \times 10^{-5}\ \text{A}$$

[1]

(ii) Show that the current in the resistor falls to less than 3.5×10^{-5} A after the switch has been opened for 100 s.

$$RC = 1000 \times 10^{-6} \times 100 \times 10^3 = 100\ \text{s}$$

$$I = I_0 e^{-t/RC} = 9 \times 10^{-5} e^{-100/100}$$

[2]

$$= 9 \times 10^{-5}/e = 3.3 \times 10^{-5}\ \text{A}$$

[Total: 9]

10 This question is about capacitor discharge.

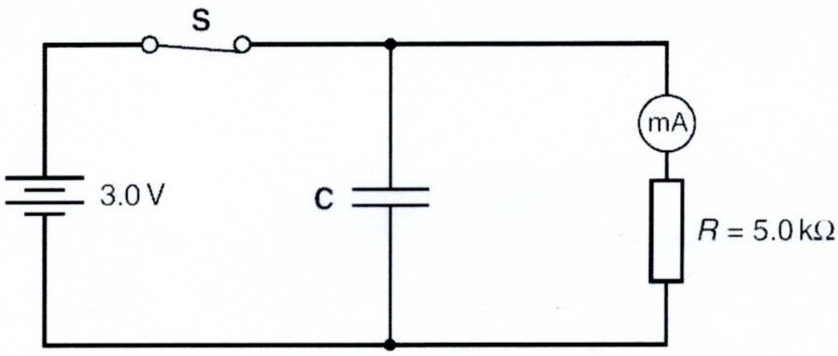


Fig. 10.1

The circuit is set up as shown in Fig. 10.1. Switch **S** is then opened and the capacitor discharges through the resistor. The variation of discharge current I with time t is shown in Fig. 10.2.

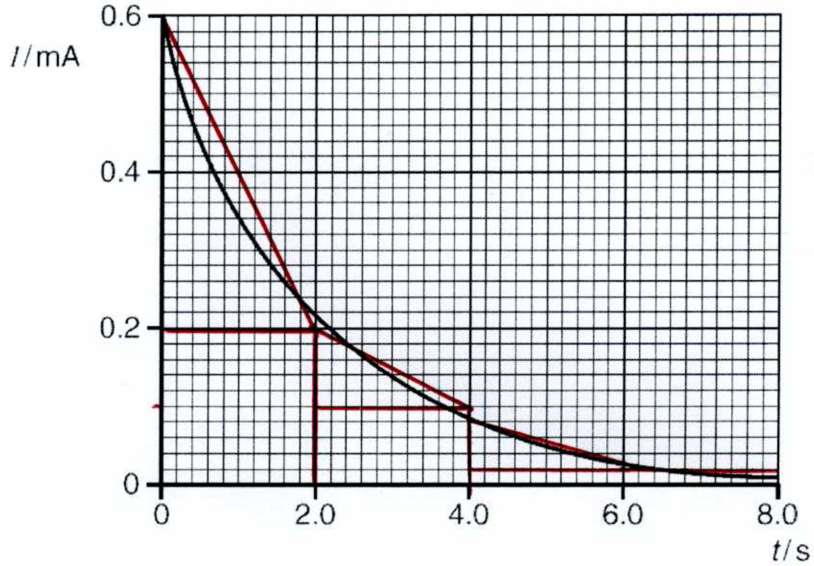


Fig. 10.2

(a) (i) Explain why the area under the curve represents the **initial** charge on the capacitor.

Area under curve is $I \times t$ and $Q = It$

+ The graph shows almost complete discharge **[2]**

(ii) Show that the initial charge on the capacitor is about 1 mC.

Area under graph =

[2]

$$2 \times \left(\left(0.2 + \frac{0.4}{2}\right) + \left(0.1 + \frac{0.1}{2}\right) + \left(\frac{0.06}{2} + 0.02\right) + 0.02 \right)$$

$$= 2 \times 0.62 = \underline{1.2\,\text{mC}}$$

(iii) Calculate the value of the capacitance used in the experiment.

$C = Q/V = 1.2\times10^{-3}/3.0$ or $400\mu F$

value of capacitance = 4×10^{-4} unit F **[3]**

(b) Calculate the energy stored on the capacitor when the switch is closed.

$E = \frac{1}{2}CV^2 = \frac{1}{2}\times 4\times10^{-4}\times 3^2 =$

energy stored = 1.8×10^{-3} J **[2]**

(c) The experiment is repeated. The 5.0 kΩ resistor is replaced with a 10 kΩ resistor. No other changes are made to the circuit.

double

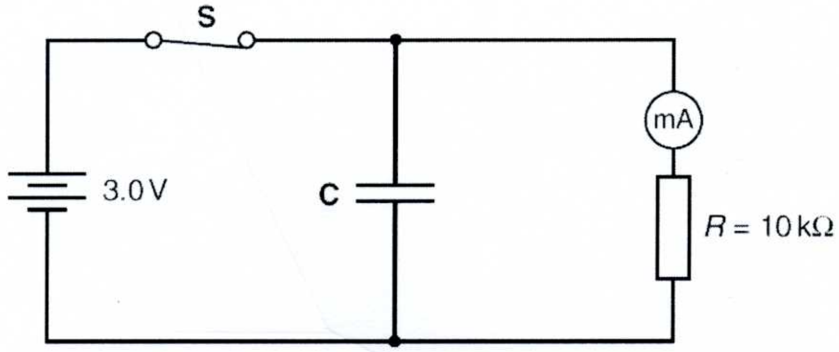
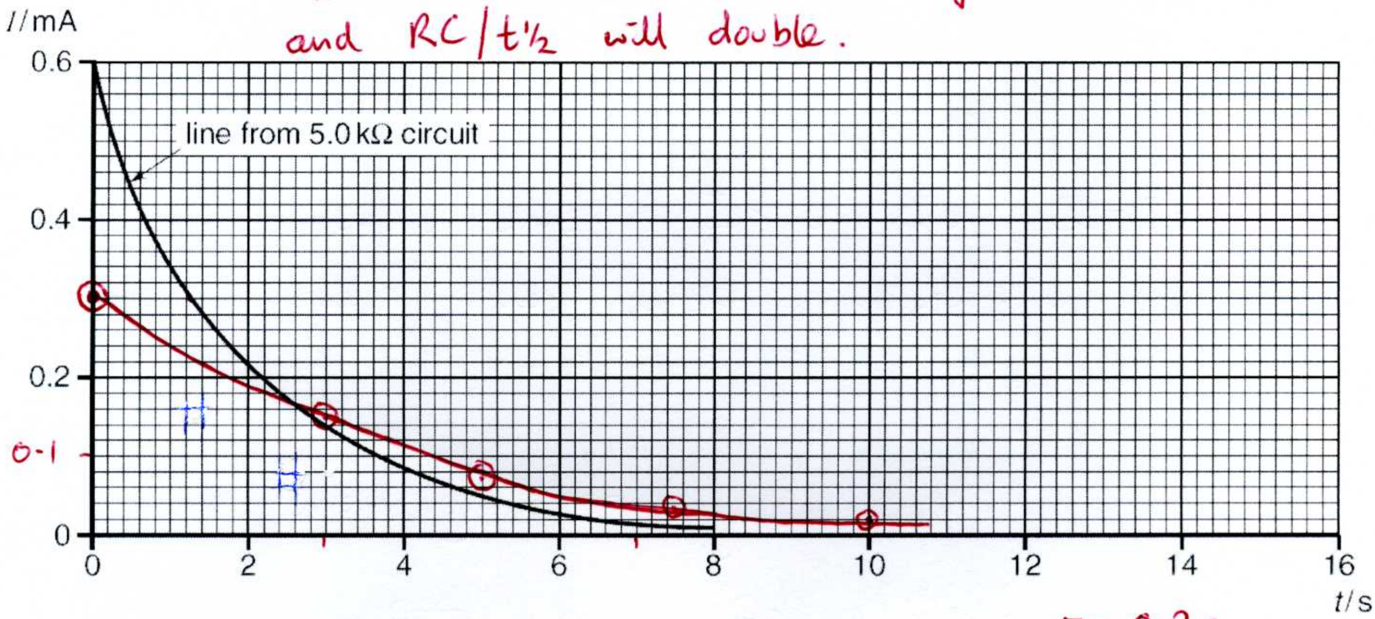


Fig. 10.3

Use the axes on Fig. 10.4 to sketch the graph of current against time for the circuit of Fig. 10.3.

As R is double I_0 will half to 0.3 mA and RC / $t_{1/2}$ will double.



□ = 0.2 s

Fig. 10.4

$t_{1/2} \approx 1.25$ s

new $t_{1/2} = 2.5$ s

[3]

[Total: 12]

9a (I)	Q = I t argument ✓/ dimensions argument	1	
a(ii)	Counting squares ✓gives answer in range 2.5 – 3.5 mC✓	2	Other methods acceptable
a(iii)	C =Q/V = $2.8 \times 10^{-3}/6$✓ = 4.7×10^{-4} ✓F✓ 5×10^{-4} F if paper value used. (If 1/3 used for RC proportion answer is 5.5×10^{-4} F)	3	µF fine. Other methods acceptable
b	E = ½ Q V = ½ x 2.8×10^{-3} x 6 ✓= 8.4×10^{-3} J ✓ (ecf)	2	Other methods acceptable.
c	y intercept 0.3 mA ✓ time constant✓ shallower curve✓ (valid method)	3	0.11 mA at 10 s or 0.15 at 7 s. accept displaced curve.

2 a	Q = CV = 470 x 10^{-6} x 270 ✓ = 0.13 ✓ C ✓	3	Lose one mark (over whole question) for power of ten error in capacitance. Bare answer for calculation worth two marks if correct.
2b	E = ½ QV = ½ x 0.13 x 270 ✓ = 18 J ✓ (or 17 if 0.127 C used)	2	Or E = ½ CV^2 = 17 J

7		C = 5.6×10^{-3}/ 12 ✓ = 4.7×10^{-4}✓ F	2	No sf penalty Don't accept 4.6

7a (i)	Q = 4700 x 10^{-6} x 6 = 0.028 C ✓	1	
(ii)	E = ½ x 0.028 x 6 ✓= 0.084 J ✓ ecf	2	0.085 to 2sf
(iii)	I = 6/ 12 000 ✓ = 0.5 mA ✓	2	Or 5×10^{-4} A (0.5 A gains one mark)
b (i)	As charge leaves, V on capacitor decreases ✓. Therefore, lower V across resistor✓ and lower I through resistor. AW	2	Can gain second mark through V = IR
(ii)	Time constant = 12000 x 4700 x 10^{-6} ✓ = 56 s	1	
c (i)	1 mA or ecf ✓	1	UNIT PENALTY once in c(i) and (ii)
(ii)	28 s ✓ UNIT PENALTY once in c(i) and (ii)	1	
(d)	Sensible feature✓ linked to correct explanation ✓ Sensible feature✓ linked to correct explanation✓ (Look for following features: sudden rise, slow fall, peak pd of 6V, 10 s period, curved discharge, minimum 4.2/4.25/4.4 V.) Accept exponential nature of discharge as an explanation. Look at feature and explanation together.	2 2	e.g. falling to given value of charge linked to time constant. Vertical line at 10 s intervals linked to recharging through low resistance.

1 a	1.0 ✓	1	Accept 1.03
b	1.4×10^{-2}✓	1	Accept 0.014(1)
c	2.1×10^{-2}✓	1	Accept 0.021(15)
d	1.4×10^{-2}✓	1	Accept 0.0136

11			Own answer or method
(a) (i)	Q = 4700 x 10^{-6} x 6✓ = 0.028 C	1	
(a) (ii)	I = V/R = 6/1100✓ = 5.5 mA	1	Or by clear graphical method
(a) (iii)	T = 4700 x 10^{-6} x 1100✓ = 5.2 s	1	

(b)	V is proportional to Q ✓, rate of fall of charge = current✓	2	Other arguments possible
c(i)	Use of *t* = *Q/I* (or rearranged) ✓ Correct substitution of *Q* = *CV* and *R* = *V/I*✓	2	Accept numerical arguments
(ii)	Loss of charge = (-0.017/5.2) x 2.0✓ = 6.5(4) x 10^{-3} C	1	
(iii)	Line from (2.0, 0.017) to (4.0, 0.01) by eye ✓	1	
(iv)	Holds rate of decay constant for smaller time period /closer to continuous change ✓	1	No ecf

3(a)	Q = 470 x 10^{-6} x 12 ✓ = 5.6(4) mC	**1**	Check correct power of ten
3(b)	Q = 470 x 10^{-6} x 10 = 4.7 mC ✓ ΔQ = 5.6 – 4.7 ✓ mC = 0.9 mC	**1** **1**	Or $\Delta Q = C\Delta V$ or implicit✓ Correct evaluation✓
3(c)	**Rate** of flow of charge/discharge or current **falls** (with time) ✓ AW	**1**	Beware experimental error explanations Accept $I = V/R$ and V falls $I = \Delta Q/\Delta t$ not sufficient

9	E = ½ x 4700 x 10^{-6} x 9.0^2 ✓ = 0.19 J✓	2	1.9 x 10^5 one mark 1.9 x 10^2 one mark

11(a)i (ii)	+0.5 ✓ Q = 1000 x 10^{-6} x 9.0✓ = 9 x 10^{-3} C. ✓	1 2	
(b)(i) (ii)	Correctly connected in parallel ✓ Half the charge has left original capacitor✓ (therefore) both capacitors have same value (as p.d. across each is the same in parallel) AW✓	1 2	Many ways to explain this. Use of total capacitance = 2000 μF is a valid method.
c(i) (ii)	I = V/R = 9/100 000 ✓= 9 x 10^{-5} A RC = 100 s. ✓After 100s I = 0.37 x 9 x 10^{-5} = 3.3 x 10^{-5} ✓	1 2	(100 kΩ OK) Need full argument Or use $I = I_o e^{-t/RC}$ M ✓E✓

10	**(a)**		Idea of charge = current x time ✓	2	
		(i)	Area under curve gives charge, and the area shows (almost) complete discharge ✓		
		(ii)	Counting squares/ other clear method✓. Answer in range 1.1 – 1.5 mC✓	2	
		(iii)	1.5 x 10^{-3} / 3.0✓ = 500✓ μF✓	3	Ecf. Using 1 mC gives 330 μF. CV^{-1} acceptable for unit if correct.
	(b)		E = ½ 500 x 10^{-6} x 3^2 ✓=2.3 x 10^{-3} ✓J	2	Ecf, range at standardisation
	(c)		Line starts at 0.3 mA✓, τ twice original (by eye) ✓, smooth curve✓	3 **Total** **12**	Starting at 0.6 mA but everything else correct worth 2