CAPACITANCE
WORKSHEET
A-Level Physics 9702

MJ2024/41/Q6

1 Fig. 6.1 shows a capacitor of capacitance C connected in series with a resistor of resistance R.

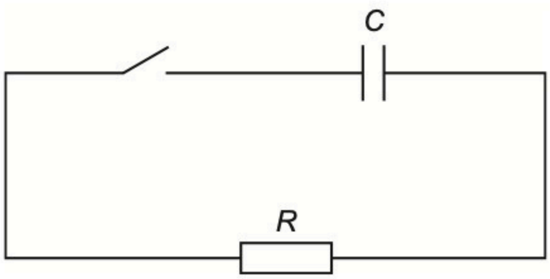

Fig. 6.1

Initially the switch is open and there is a p.d. of 12 V across the capacitor.

At time $t = 0$, the switch is closed so that there is a current I in the resistor.

Fig. 6.2 shows the variation of I with t.

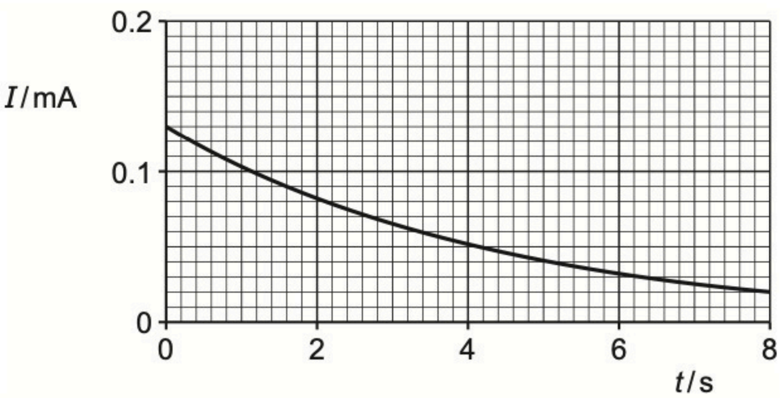

Fig. 6.2

(a) Explain the shape of the line in Fig. 6.2.

....

....

....

....

.... [3]

(b) Use Fig. 6.2 to determine:

(i) resistance R

R = ... Ω [2]

(ii) the time constant τ of the circuit in Fig. 6.1.

τ = ... s [3]

(c) Use your answers in **(b)** to determine capacitance C.

C = ... F [2]

[Total: 10]

2 **(a)** Two capacitors X and Y are connected in series to a power supply of voltage V, as shown in Fig. 6.1.

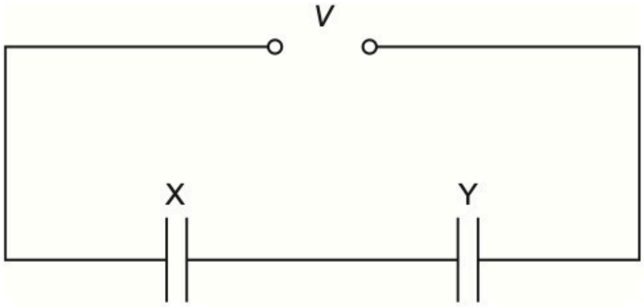

Fig. 6.1

The capacitance of X is C_X and the capacitance of Y is C_Y.

Derive an expression, in terms of C_X and C_Y, for the combined capacitance C_T of the capacitors in this circuit.
Explain your reasoning.

[3]

(b) Two capacitors P and Q are connected in parallel to a power supply of voltage V.
The capacitance of P is 200 μF. The capacitance C_Q of Q can be varied between 0 and 400 μF.
When $C_Q = 0$, the total energy stored in the capacitors is 2.5 mJ.

(i) Show that the supply voltage V is 5.0 V.

[2]

(ii) Calculate the total energy, in mJ, stored in the capacitors when C_Q has its maximum value.

total energy = ... mJ [3]

(iii) On Fig. 6.2, sketch the variation of the total energy E stored in the capacitors with C_Q, as C_Q varies from 0 to 400 μF.

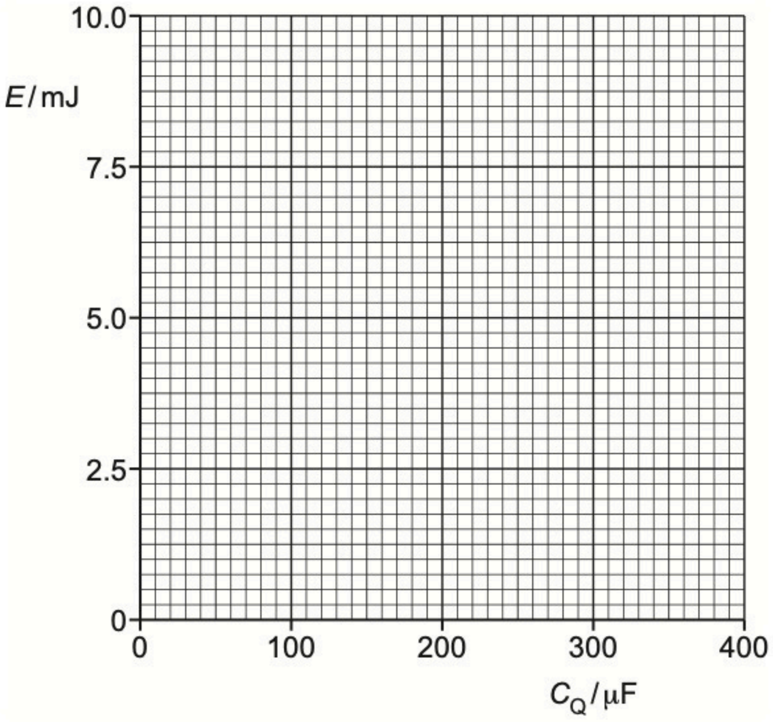

Fig. 6.2

[2]

[Total: 10]

3 **(a)** Three capacitors are connected as shown in Fig. 4.1. **March24/42/Q4**

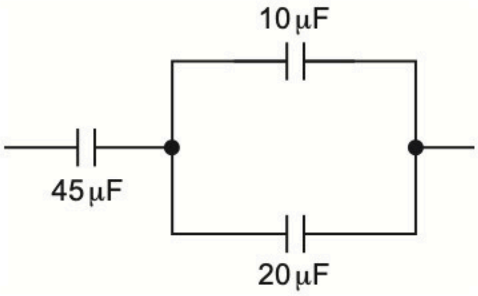

Fig. 4.1

Determine the total capacitance, in μF, of the network of three capacitors.

capacitance = ... μF [2]

(b) A capacitor of capacitance 45 μF is connected to a variable power supply initially set at 8.0 V. The output of the power supply increases so that the potential difference (p.d.) across the capacitor increases to 9.6 V.

Calculate the increase in energy ΔE stored in the capacitor.

ΔE = ... J [2]

4 A capacitor C is charged so that the potential difference (p.d.) V across its terminals is 8.0 V. The capacitor is connected into the circuit of Fig. 6.1.

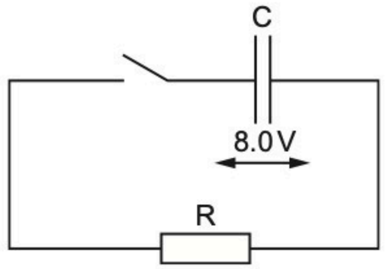

Fig. 6.1

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

(a) Fig. 6.2 shows the variation of V with the charge Q on the plates of capacitor C as the capacitor discharges.

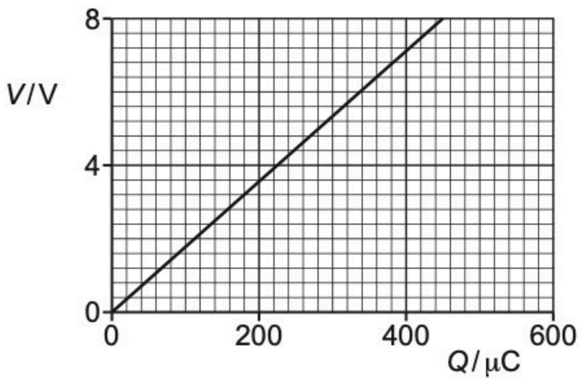

Fig. 6.2

(i) Show that the energy stored in capacitor C at time $t = 0$ is 1.8 mJ.

[2]

(ii) Determine the capacitance of capacitor C. Give a unit with your answer.

capacitance = ... unit .... [2]

(b) Fig. 6.3 shows the variation with t of $-\ln\left(\frac{V}{8.0\,V}\right)$.

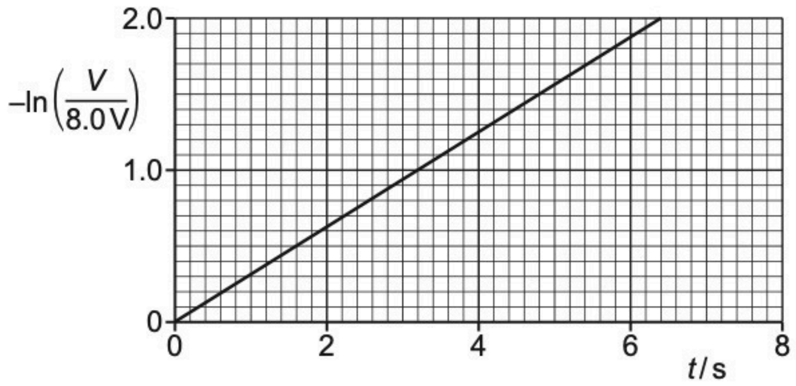

Fig. 6.3

(i) Show that, when t is equal to one time constant, the value of $-\ln\left(\frac{V}{8.0\,V}\right)$ is equal to 1.0.

[2]

(ii) Determine the time constant τ of the circuit in Fig. 6.1.

τ = ... s [1]

(iii) Calculate the resistance of resistor R.

resistance = ... Ω [2]

[Total: 9]

5 Two capacitors A and B are connected into the circuit shown in Fig. 5.1.

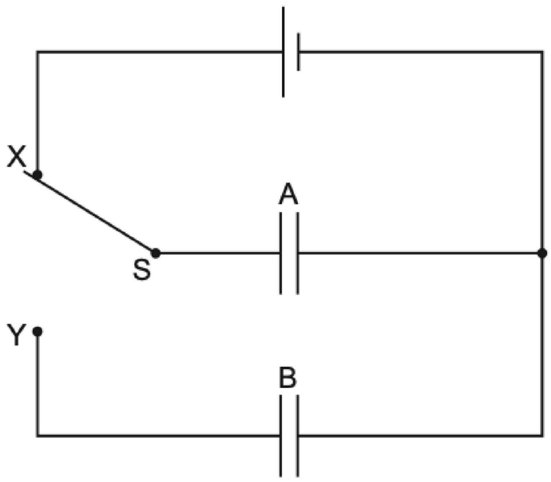

Fig. 5.1

Capacitor A has capacitance C and capacitor B has capacitance $3C$.
The electromotive force (e.m.f.) of the cell is V.
The two-way switch S is initially at position X, and capacitor B is initially uncharged.

(a) State, in terms of V and C, expressions for:

(i) the initial charge Q_A on the plates of capacitor A

Q_A = ... [1]

(ii) the initial energy E_A stored in capacitor A.

E_A = ... [1]

(b) The two-way switch S is now moved to position Y.

(i) State and explain what happens to the charge that was initially on the plates of capacitor A.

....

....

.... [2]

(ii) Show that the final potential difference (p.d.) V_B across capacitor B is given by

$$V_B = \frac{V}{4}.$$

Explain your reasoning.

[3]

(iii) Determine an expression, in terms of V and C, for the decrease ΔE in the total energy that is stored in the capacitors as a result of the change of the position of the switch.

ΔE = ... [2]

[Total: 9]

March23/42/Q5

6 A capacitor, a battery of electromotive force (e.m.f.) 12V, a resistor R and a two-way switch are connected in the circuit shown in Fig. 5.1.

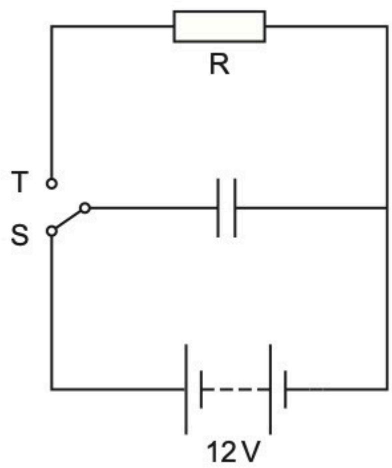

Fig. 5.1

The switch is initially in position S. When the capacitor is fully charged, the switch is moved to position T so that the capacitor discharges. At time t after the switch is moved the charge on the capacitor is Q.

The variation with t of $\ln(Q/\mu C)$ is shown in Fig. 5.2.

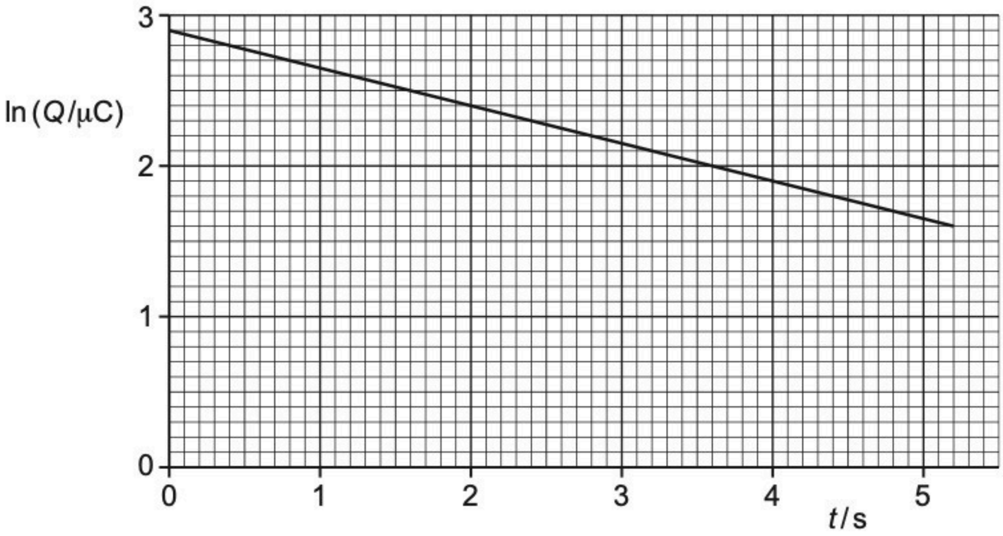

Fig. 5.2

(a) Show that the capacitance of the capacitor is 1.5 μF.

[3]

(b) Determine the resistance of R.

resistance = ... Ω [3]

(c) Calculate the energy stored in the capacitor at time $t = 0$.

energy = ... J [2]

(d) A second identical resistor is now connected in parallel with R.

The switch is initially in position S. When the capacitor is fully charged, the switch is moved to position T so that the capacitor discharges. At time t after the switch is moved the charge on the capacitor is Q.

On Fig. 5.2, sketch a line to show the variation of $\ln(Q/\mu C)$ with t between time $t = 0$ and time $t = 5.0$ s. [2]

[Total: 10]

ON22/41/Q5

Q7 A capacitor of capacitance 470 μF is connected to a battery of electromotive force (e.m.f.) 24 V in the circuit of Fig. 5.1.

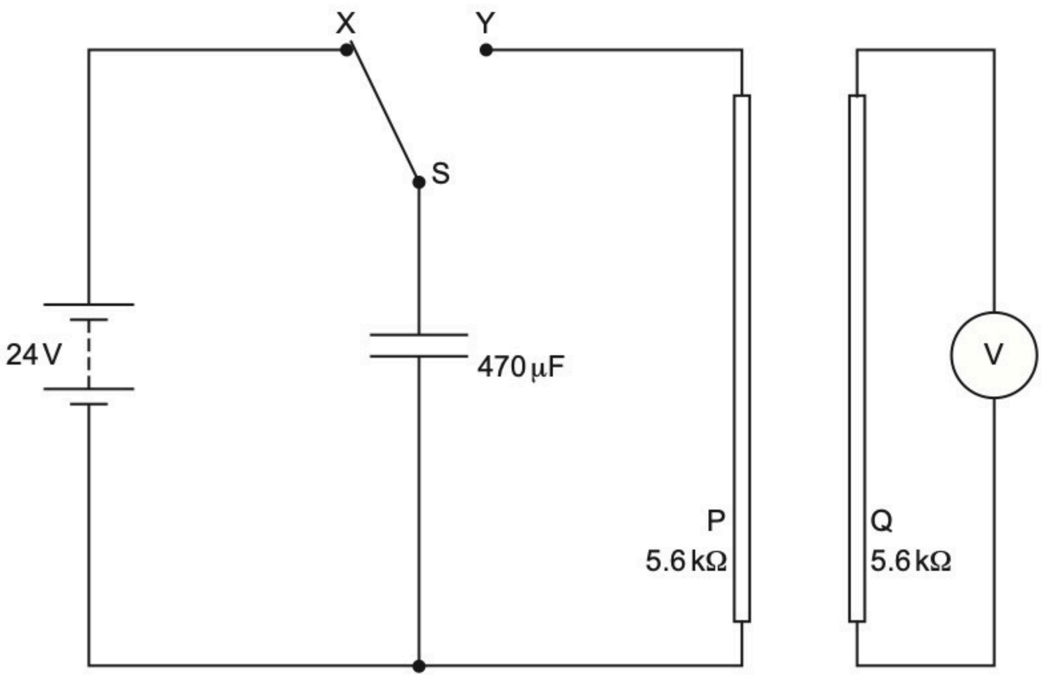

Fig. 5.1

The two-way switch S is initially at position X.

P and Q are identical long straight wires, each with a resistance of 5.6 kΩ. These wires are placed near to, and parallel to, each other. Wire Q is connected to a voltmeter.

At time $t = 0$, switch S is moved to position Y so that the capacitor discharges through wire P.

(a) **(i)** Calculate the charge Q_0 on the capacitor at time $t = 0$.

Q_0 = ... C [2]

(ii) Calculate the current I_0 in wire P at time $t = 0$.

I_0 = ... A [1]

(iii) Calculate the time constant τ of the discharge circuit.

τ = ... s [2]

(iv) On Fig. 5.2, sketch a line to show the variation with t of the current I in wire P as the capacitor discharges.

Fig. 5.2

[2]

Q8 A capacitor of capacitance C and a resistor of resistance R are connected as shown in Fig. 6.1.

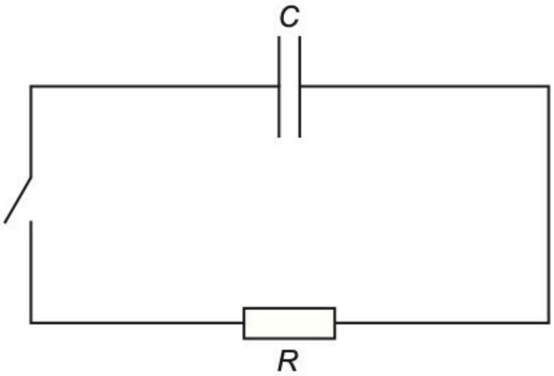

Fig. 6.1

Initially, the capacitor is charged and the switch is open.

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

Fig. 6.2 and Fig. 6.3 show, respectively, the variations with t of the charge Q on the capacitor and the potential difference (p.d.) V across the resistor.

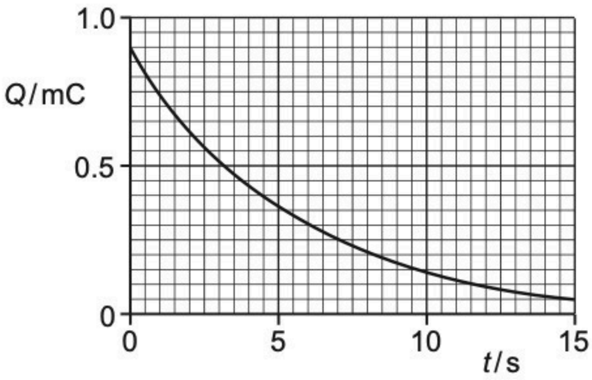

Fig. 6.2

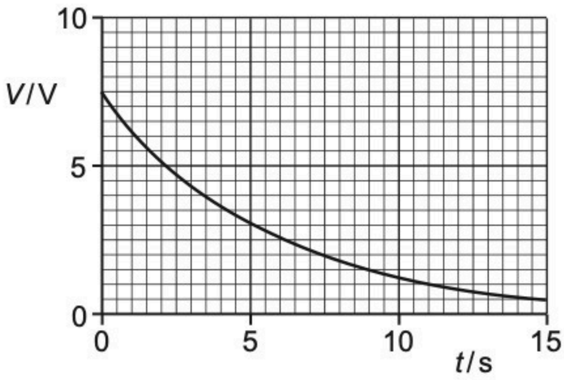

Fig. 6.3

(a) Explain the shape of the line in Fig. 6.3 representing the variation of V with t.

....

....

....

....

.... [3]

(b) Use Fig. 6.2 to show that the time constant of the circuit in Fig. 6.1 is 5.5 s.

[3]

(c) Use Fig. 6.2, Fig. 6.3 and the information in **(b)** to determine:

(i) capacitance C, in μF

C = ... μF [2]

(ii) resistance R, in kΩ.

R = ... kΩ [2]

[Total: 10]

9 **(a)** Define the capacitance of a parallel plate capacitor.

....

....

.... [2]

(b) Two capacitors, of capacitances C_1 and C_2, are connected in parallel to a power supply of electromotive force (e.m.f.) E, as shown in Fig. 5.1.

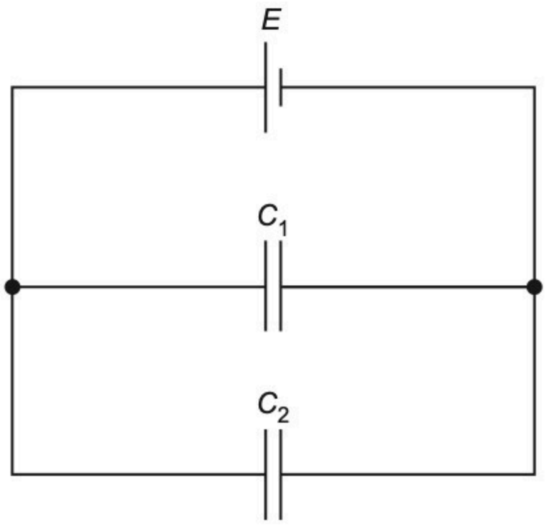

Fig. 5.1

Show that the combined capacitance C_T of the two capacitors is given by

$$C_T = C_1 + C_2.$$

Explain your reasoning. You may draw on Fig. 5.1 if you wish.

[3]

(c) Two capacitors of capacitances 22 μF and 47 μF, and a resistor of resistance 2.7 MΩ, are connected into the circuit of Fig. 5.2.

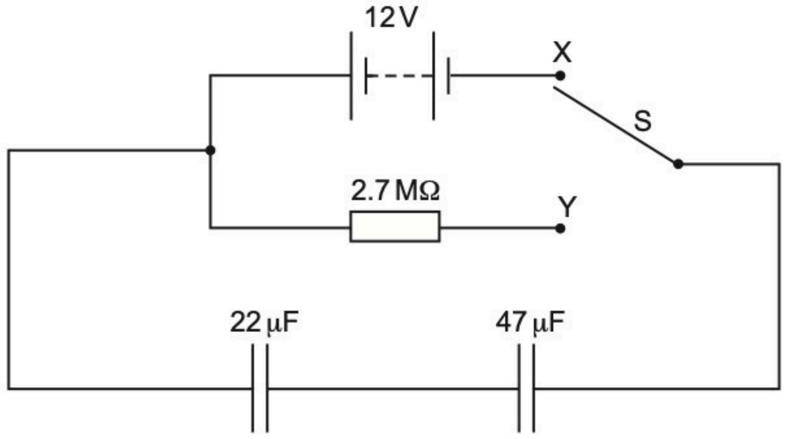

Fig. 5.2

The battery has an e.m.f. of 12 V.

(i) Show that the combined capacitance of the two capacitors is 15 μF.

[1]

(ii) The two-way switch S is initially at position X, so that the capacitors are fully charged.

Use the information in **(c)(i)** to calculate the total energy stored in the two capacitors.

total energy = ... J [2]

(iii) The two-way switch is now moved to position Y.

Determine the time taken for the potential difference (p.d.) across the 22 μF capacitor to become 6.0 V.

time = ... s [3]

[Total: 11]

10 The variation with potential difference V of the charge Q on one of the plates of a capacitor is shown in Fig. 5.1.

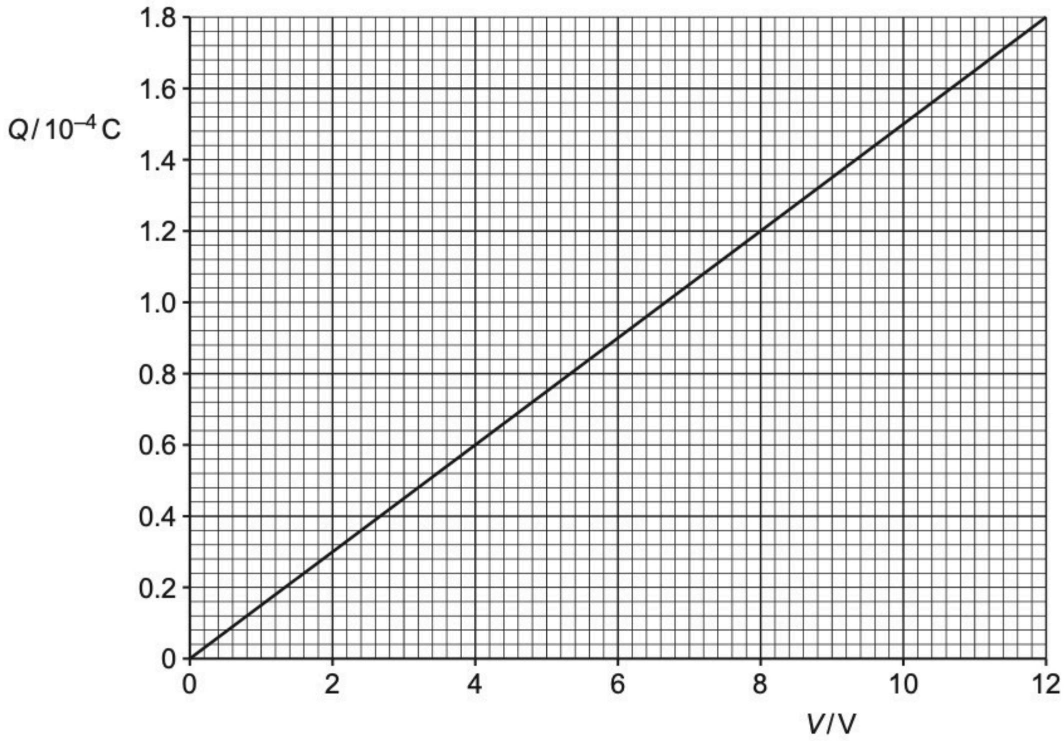

Fig. 5.1

The capacitor is connected to an 8.0 V power supply and two resistors R and S as shown in Fig. 5.2.

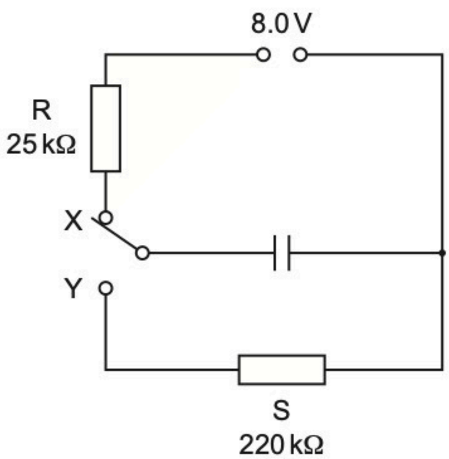

Fig. 5.2

The resistance of R is 25 kΩ and the resistance of S is 220 kΩ.

The switch can be in either position X or position Y.

(a) The switch is in position X so that the capacitor is fully charged.

Calculate the energy E stored in the capacitor.

E = ... J [2]

(b) The switch is now moved to position Y.

(i) Show that the time constant of the discharge circuit is 3.3 s.

[2]

(ii) The fully charged capacitor in **(a)** stores energy E.

Determine the time t taken for the stored energy to decrease from E to $E/9$.

t = ... s [4]

(c) A second identical capacitor is connected in parallel with the first capacitor.

State and explain the change, if any, to the time constant of the discharge circuit.

....

....

.... [2]

[Total: 10]

ON21/41/Q6

11 **(a)** A capacitor consists of two parallel metal plates, separated by air, at a variable distance x apart, as shown in Fig. 6.1. The capacitance C is inversely proportional to x.

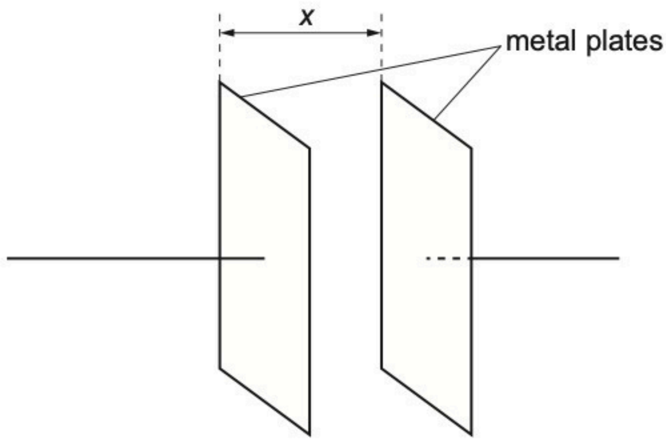

Fig. 6.1

The capacitor is charged by a supply so that there is a potential difference (p.d.) V between the plates.

State expressions, in terms of C and V, for the charge Q on one of the plates and for the energy E stored in the capacitor.

Q = ... E = ... [1]

(b) The charged capacitor in **(a)** is now disconnected from the supply. The plates of the capacitor are initially separated by distance L. They are then moved closer together by a distance D, as shown in Fig. 6.2.

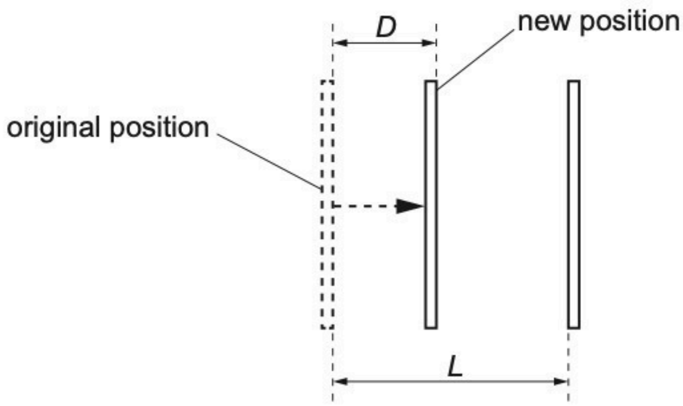

Fig. 6.2

State expressions, in terms of C, V, L and D, for:

(i) the new capacitance C_N

C_N = ... [1]

(ii) the new charge Q_N on one of the plates

Q_N = ... [1]

(iii) the new p.d. V_N between the plates.

V_N = ... [1]

(c) Explain whether reducing the separation of the plates in **(b)** results in an increase or decrease in the energy stored in the capacitor.

....

....

.... [1]

[Total: 5]

12 (a) State what is meant by the *capacitance* of a parallel plate capacitor. **MJ21/41/Q7**

....

....

.... [2]

(b) A capacitor of capacitance C is connected into the circuit shown in Fig. 7.1.

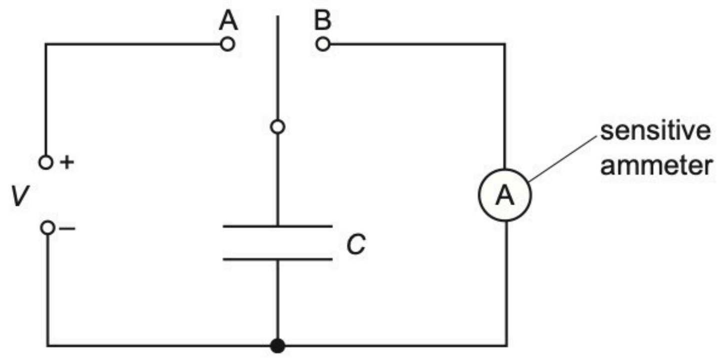

Fig. 7.1

When the two-way switch is in position A, the capacitor is charged so that the potential difference across it is V.
The switch moves to position B and the capacitor fully discharges through the sensitive ammeter.

The switch moves repeatedly between A and B so that the capacitor charges and then discharges with frequency f.

(i) Show that the average current I in the ammeter is given by the expression

$$I = fCV.$$

[2]

(ii) For a potential difference V of 150 V and a frequency f of 60 Hz, the average current in the ammeter is 4.8 μA.

Calculate the capacitance, in pF, of the capacitor.

capacitance = ... pF [2]

(c) A second capacitor, having the same capacitance as the capacitor in **(b)**, is connected into the circuit of Fig. 7.1. The two capacitors are connected in series.

State and explain the new reading on the ammeter.

new reading = ... μA

....

....

.... [3]

[Total: 9]

13 **(a)** Two flat metal plates are held a small distance apart by means of insulating pads, as shown in Fig. 6.1.

MJ21/42/Q6

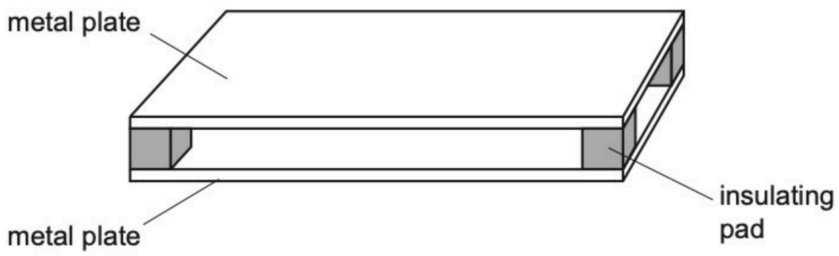

Fig. 6.1

Explain how the plates could act as a capacitor.

....

....

.... [2]

(b) The arrangement in Fig. 6.1 has capacitance *C*.
The arrangement is connected into the circuit of Fig. 6.2.

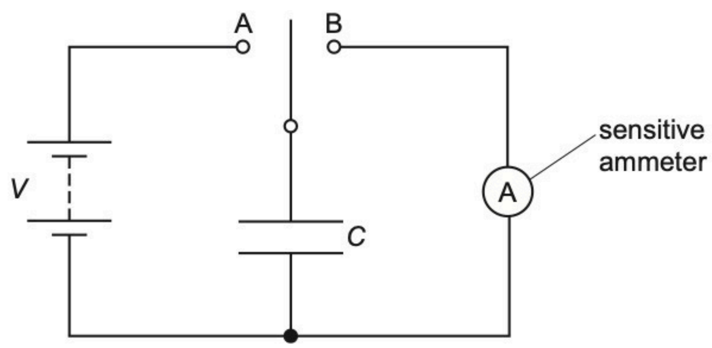

Fig. 6.2

When the two-way switch is moved to position A, the capacitor is charged so that the potential difference across it is V. When the switch moves to position B, the capacitor fully discharges through the sensitive ammeter.

The switch moves repeatedly between A and B so that the capacitor charges and then discharges with frequency f.

(i) Show that the average current I in the ammeter is given by

$$I = CVf.$$

[2]

(ii) For a potential difference V of 180 V and a frequency f of switching of 50 Hz, the average current I in the ammeter is 2.5 μA.

Calculate the capacitance, in pF, of the parallel plates.

capacitance = ... pF [2]

(c) A second capacitor is connected into the circuit of Fig. 6.2.
The two capacitors are connected in parallel.

State and explain the change, if any, in the average current in the ammeter.

....

....

.... [2]

[Total: 8]

14 **(a)** **(i)** Define the *capacitance* of a parallel plate capacitor.

....

....

.... [2]

(ii) State **three** functions of capacitors in electrical circuits.

1. ....

2. ....

3. ....
[3]

(b) A student has available four capacitors, each of capacitance 24 μF.

The capacitors are connected as shown in Fig. 6.1.

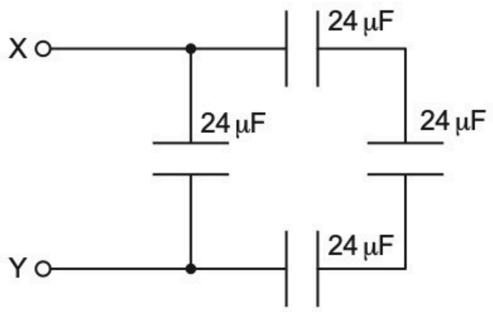

Fig. 6.1

Calculate the combined capacitance between the terminals X and Y.

capacitance = ... μF [2]

[Total: 7]

ON20/42/Q6

15 **(a)** **(i)** Define the *capacitance* of a parallel plate capacitor.

....

....

.... [2]

(ii) State **three** functions of capacitors in electrical circuits.

1. ....

2. ....

3. ....

[3]

(b) A student has available **three** capacitors, each of capacitance 12 μF.

Draw diagrams, one in each case, to show how the student connects the capacitors to give a combined capacitance between the terminals of:

(i) 18 μF

[1]

(ii) 8 μF.

[1]

[Total: 7]

16 **(a)** State **two** different functions of capacitors in electrical circuits.

1. ....

....

2. ....

.... [2]

(b) Three uncharged capacitors of capacitances C_1, C_2 and C_3 are connected in series with a battery of electromotive force (e.m.f.) E and a switch, as shown in Fig. 6.1.

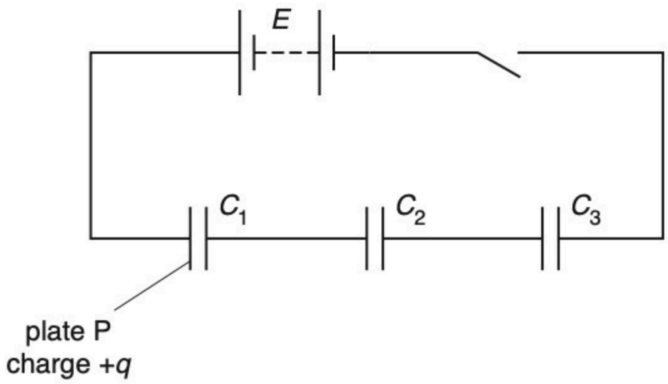

Fig. 6.1

When the switch is closed, there is a charge $+q$ on plate P of the capacitor of capacitance C_1.

Show that the combined capacitance C of the three capacitors is given by the expression

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

[3]

(c) A student has available four capacitors, each of capacitance 20 μF.

Draw circuit diagrams, one in each case, to show how the student may connect some or all of the capacitors to produce a combined capacitance of:

(i) 60 μF

[1]

(ii) 15 μF.

[1]

[Total: 7]

March19/42/Q6

Q17 **(a)** Define the *capacitance* of a parallel-plate capacitor.

....

....

.... [2]

(b) A student has three capacitors. Two of the capacitors have a capacitance of 4.0 μF and one has a capacitance of 8.0 μF.

Draw labelled circuit diagrams, one in each case, to show how the three capacitors may be connected to give a total capacitance of:

(i) 1.6 μF

[1]

(ii) 10 μF.

[1]

(c) A capacitor C of capacitance 47 μF is connected across the output terminals of a bridge rectifier, as shown in Fig. 6.1.

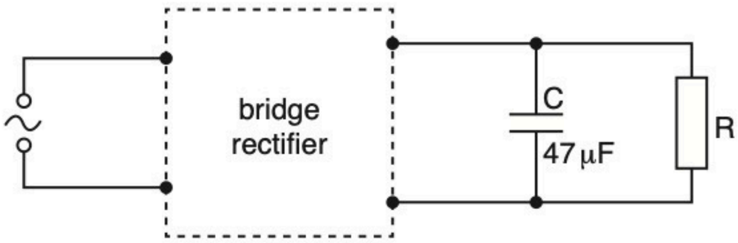

Fig. 6.1

The variation with time *t* of the potential difference *V* across the resistor R is shown in Fig. 6.2.

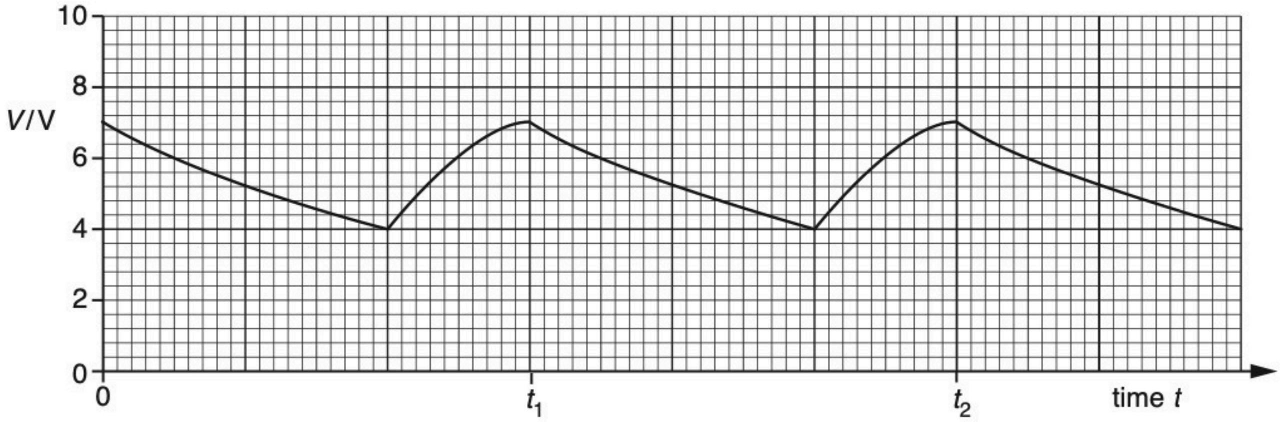

Fig. 6.2

Use data from Fig. 6.2 to determine the energy transfer from the capacitor C to the resistor R between time t_1 and time t_2.

energy = ... J [3]

[Total: 7]

MJ18/41/Q7

18 **(a)** Explain what is meant by the *capacitance* of a parallel plate capacitor.

....

....

....

....[3]

(b) A parallel plate capacitor C is connected into the circuit shown in Fig. 7.1.

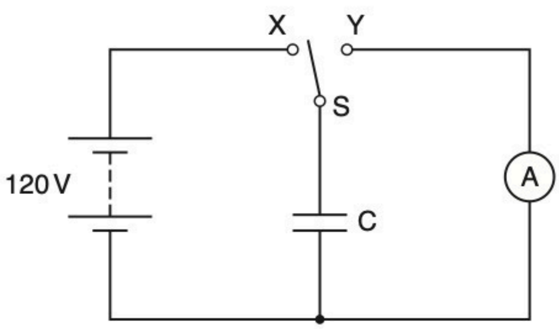

Fig. 7.1

When switch S is at position X, the battery of electromotive force 120 V and negligible internal resistance is connected to capacitor C.
When switch S is at position Y, the capacitor C is discharged through the sensitive ammeter.

The switch vibrates so that it is first in position X, then moves to position Y and then back to position X fifty times each second.

The current recorded on the ammeter is 4.5 μA.

Determine

(i) the charge, in coulomb, passing through the ammeter in 1.0 s,

charge = ... C [1]

(ii) the charge on one plate of the capacitor, each time that it is charged,

charge = ... C [1]

(iii) the capacitance of capacitor C.

capacitance = ... F [2]

[1]

(c) A second capacitor, having a capacitance equal to that of capacitor C, is now placed in series with C.

Suggest and explain the effect on the current recorded on the ammeter.

....

....

....[2]

[Total: 9]

19 **(a)** Explain what is meant by the *capacitance* of a parallel plate capacitor. **MJ18/42/Q6**

....

....

....

....[3]

(b) Three parallel plate capacitors each have a capacitance of 6.0 μF.

Draw circuit diagrams, one in each case, to show how the capacitors may be connected together to give a combined capacitance of

(i) 9.0 μF,

[1]

(ii) 4.0 μF.

[1]

(c) Two capacitors of capacitances 3.0 μF and 2.0 μF are connected in series with a battery of electromotive force (e.m.f.) 8.0 V, as shown in Fig. 6.1.

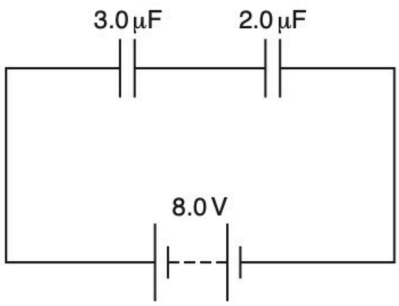

Fig. 6.1

(i) Calculate the combined capacitance of the capacitors.

capacitance = ... μF [1]

(ii) Use your answer in **(i)** to determine, for the capacitor of capacitance 3.0 μF,

1. the charge on one plate of the capacitor,

charge = ... μC

2. the energy stored in the capacitor.

energy = ... J
[4]

[Total: 10]

20 Two capacitors P and Q, each of capacitance C, are connected in series with a battery of e.m.f. 9.0 V, as shown in Fig. 6.1.

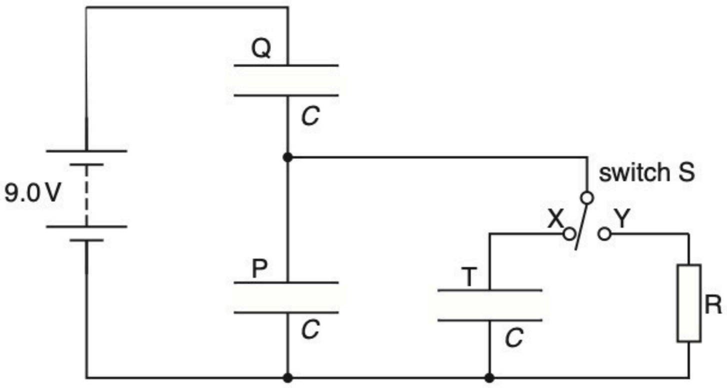

Fig. 6.1

A switch S is used to connect either a third capacitor T, also of capacitance C, or a resistor R, in parallel with capacitor P.

(a) Switch S is in position X.

Calculate

(i) the combined capacitance, in terms of C, of the three capacitors,

capacitance = ... [2]

(ii) the potential difference across capacitor Q. Explain your working.

potential difference = ... V [2]

(b) Switch S is now moved to position Y.
State what happens to the potential difference across capacitor P and across capacitor Q.

capacitor P: ....

....

....

capacitor Q: ....

....

....
[4]

[Total: 8]

MJ17/42/Q7

21 A capacitor consists of two parallel metal plates, separated by an insulator, as shown in Fig. 7.1.

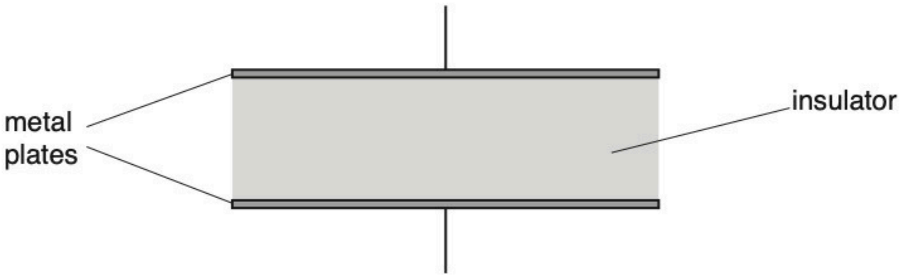

Fig. 7.1

(a) Suggest why, when the capacitor is connected across the terminals of a battery, the capacitor stores energy, not charge.

....

....

....[2]

(b) Define the *capacitance* of the capacitor.

....

....

....[2]

(c) The capacitor is charged so that the potential difference between its plates is V_0.
The capacitor is then connected across a resistor for a short time. It is then disconnected.
The energy stored in the capacitor is reduced to $\frac{1}{16}$ of its initial value.

Determine, in terms of V_0, the potential difference across the capacitor.

potential difference = ...[2]

[Total: 6]

22 **(a)** **(i)** Define *capacitance*. **ON16/42/Q7**

....

....[1]

(ii) Use the expression for the electric potential due to a point charge to show that an isolated metal sphere of diameter 25 cm has a capacitance of 1.4×10^{-11} F.

[2]

(b) Three capacitors of capacitances 2.0 μF, 3.0 μF and 4.0 μF are connected as shown in Fig. 7.1 to a battery of e.m.f. 9.0 V.

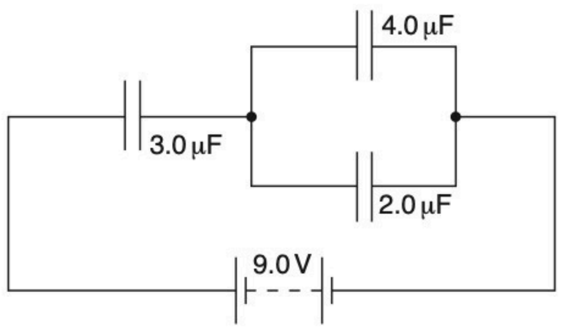

Fig. 7.1

Determine

(i) the combined capacitance of the three capacitors,

capacitance = ... μF [1]

(ii) the potential difference across the capacitor of capacitance 3.0 μF,

potential difference = ... V [2]

(iii) the positive charge stored on the capacitor of capacitance 2.0 μF.

charge = ... μC [2]

[Total: 8]

23 **(a)** State two uses of capacitors in electrical circuits, other than for the smoothing of direct current.

1. ....

2. .... [2]

(b) The combined capacitance between terminals A and B of the arrangement shown in Fig. 7.1 is 4.0 μF.

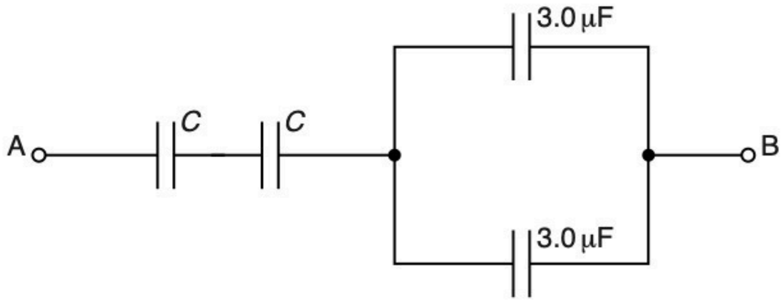

Fig. 7.1

Two capacitors each have capacitance *C* and the remaining capacitors each have capacitance 3.0 μF.

The potential difference (p.d.) between terminals A and B is 12 V.

(i) Determine the capacitance *C*.

C = ... μF [2]

(ii) Calculate the magnitude of the total positive charge transferred to the arrangement.

charge = ... μC [2]

(iii) Use your answer in **(ii)** to state the magnitude of the charge on one plate of

1. a capacitor of capacitance *C*,

charge = ... μC

2. a capacitor of capacitance 3.0 μF.

charge = ... μC
[2]

[Total: 8]

Question	Answer	Marks
1 a)	• p.d. across capacitor proportional to charge on capacitor • p.d. across capacitor = p.d. across resistor • current in resistor proportional to p.d. across resistor • current in resistor = rate of decrease of charge on capacitor *Any two points, 1 mark each*	B2
	charge proportional to current so rate of decrease of current decreases as current decreases (therefore exponential shape)	B1
1)(i)	$R = V / I$ $= 12 / (0.13 \times 10^{-3})$	C1
	$= 9.2 \times 10^{4}\ \Omega$	A1
1)(ii)	correct read-off of at least one pair of values for I and t	C1
	attempted read-off of t when $I = 0.048$ mA **or** substitution of a correct pair of values of I and t into $I = 0.13 \exp(-t / \tau)$	C1
	$\tau = 4.3$ s	A1
1 c)	$\tau = RC$	C1
	$C = \tau / R = 4.3 / (9.2 \times 10^{4})$ $= 4.7 \times 10^{-5}$ F	A1

2 ;(a)	equal charge on both capacitors	B1
	$V_X + V_Y = V$	M1
	$(Q / C_X) + (Q / C_Y) = (Q / C_T)$ <u>leading to</u> $(1 / C_X) + (1 / C_Y) = (1 / C_T)$ **or** $(V_X / Q) + (V_Y / Q) = (V / Q)$ <u>leading to</u> $(1 / C_X) + (1 / C_Y) = (1 / C_T)$	A1
2 (b)(i)	$E = ½CV^2$	C1
	$V = \sqrt{[(2 \times 2.5 \times 10^{-3}) / (200 \times 10^{-6})]} = 5.0$ V	A1
2 b)(ii)	total capacitance = 600 μF	C1
	$E = ½ \times 600 \times 10^{-6} \times 5.0^2$ $(= 7.5 \times 10^{-3}$ J)	C1
	= 7.5 mJ	A1
2 b)(iii)	line with positive gradient starting at (0, 2.5)	B1
	straight line passing through (400, 7.5)	B1

3 a)	combined capacitance of parallel capacitors = 30 (μF)	C1
	total capacitance $= (1 / 45 + 1 / 30)^{-1}$ = 18 μF	A1
3 b)	$E = ½CV^2$	C1
	$\Delta E = ½ \times 45 \times 10^{-6} (9.6^2 - 8.0^2)$ $= 6.3 \times 10^{-4}$ J	A1

4 (a)(i)	energy stored = area under graph	C1
	$= ½ \times 450 \times 10^{-6} \times 8.0 = 1.8 \times 10^{-3}$ J **or** 1.8 mJ	A1
4 (a)(ii)	$C = Q / V$ **or** $E = ½CV^2$	C1
	$C = (450 \times 10^{-6}) / 8.0$ **or** $(2 \times 1.8 \times 10^{-3}) / 8.0^2$ $= 5.6 \times 10^{-5}$ F	A1
4 (b)(i)	$V = V_0 \exp(-t / RC)$ **and** $\tau = RC$	C1
	$V = V_0 \exp(-t / \tau)$ $V_0 = 8.0$ V, and at one time constant, $t = \tau$ $V / 8.0 = \exp(-\tau / \tau)$, so $\ln(V / 8.0) = -1.0$ **or** $-\ln(V / 8.0) = 1.0$	A1
4 (b)(ii)	[t read from graph at $-\ln(V / 8.0) = 1.0$]: $\tau = 3.2$ s	A1
4 (b)(iii)	$\tau = RC$	C1
	$R = 3.2 / (5.6 \times 10^{-5})$ $= 5.7 \times 10^4\ \Omega$	A1

5 (a)(i)	$Q_A = CV$	A1
5 (a)(ii)	$E_A = ½CV^2$	A1
5 (b)(i)	some of the charge transfers to (the plates of) capacitor B	B1
	transfer is because the p.d.s across the capacitors are not equal **or** transfer stops when the p.d.s across the capacitors become equal	B1
5 (b)(ii)	$V_A = V_B$	M1
	charge on A + charge on B = CV	M1
	$CV_B + 3CV_B = CV$ leading to $V_B = V / 4$	A1
	or	
	$C_T = 4C$	**(M1)**
	$Q_T = CV$	**(M1)**
	$V_B = CV / 4C = V / 4$	**(A1)**
5 (b)(iii)	$\Delta E = ½CV^2 - nCV^2$, where n is a multiple that is less than ½ **or** total final energy $= ½ \times 4C \times (V / 4)^2$ $= ⅛CV^2$	C1
	$\Delta E = ½CV^2 - ⅛CV^2$ $= ⅜CV^2$	A1

6	a)	from graph ln $Q = 2.9$ (so $Q = 18.2\,\mu C$)	**B1**
		$C = Q / V$	**C1**
		$= 18.2 / 12 = 1.5\,\mu F$	**A1**
6	b)	gradient = –0.25	**C1**
		gradient = $-1 / RC$	**C1**
		$R = 1 / (0.25 \times 1.5 \times 10^{-6})$ $= 2.7 \times 10^{6}\,\Omega$	**A1**
		or $\frac{Q}{Q_0} = e^{-t/CR}$ **or** $\ln Q - \ln Q_0 = \frac{-t}{CR}$	**(C1)**
		e.g. $\frac{4.95}{18.2} = e^{-5.2/(1.5\times10^{-6}R)}$ **or** $1.6 - 2.9 = 5.2 / (1.5 \times 10^{-6}R)$	**(C1)**
		$R = 2.7 \times 10^{6}\Omega$	**(A1)**
6	c)	$W = ½\,QV$	**C1**
		$= ½ \times 18.2 \times 10^{-6} \times 12$ $= 1.1 \times 10^{-4}$ J	**A1**
		or $W = ½\,CV^2$	**(C1)**
		$= ½ \times 1.5 \times 10^{-6} \times 12^2$ $= 1.1 \times 10^{-4}$ J	**(A1)**
		or $W = ½\,Q^2 / C$	**(C1)**
		$= ½ \times (18.2 \times 10^{-6})^2 / 1.5 \times 10^{-6}$ $= 1.1 \times 10^{-4}$ J	**(A1)**
6	d)	straight line with different negative gradient starting from (0, 2.9)	**M1**
		straight line between $t = 0$ and at least $t = 5.0$ s with twice the gradient of the original line	**A1**

7	a)(i)	$Q = CV$	**C1**
		$Q_0 = 24 \times 470 \times 10^{-6}$ $= 0.011$ C	**A1**
7	a)(ii)	$I_0 = 24 / 5600$ $= 4.3 \times 10^{-3}$ A	**A1**
7	a)(iii)	$\tau = RC$	**C1**
		$= 5600 \times 470 \times 10^{-6}$ $= 2.6$ s	**A1**
7	a)(iv)	line with negative gradient throughout passing through (0, I_0)	**B1**
		exponential decay curve asymptotic to t-axis	**B1**

8 a)	• p.d. across resistor = p.d. across capacitor • current (in resistor) proportional to p.d. across it • current causes capacitor to lose charge • charge (on capacitor) proportional to p.d. so p.d. decreases *Any two points, 1 mark each*	B2
	rate of change of p.d. decreases as p.d. decreases	B1
8 b)	Q_0 = 0.90 mC **and** at t = one time constant, $Q = Q_0$ exp (–1)	B1
	at t = one time constant, Q = 0.90 exp (–1) = 0.33 mC	M1
	evidence of graph reading: when Q = 0.33 mC, t = 5.5 s	A1
	or	
	evidence of two correct sets of readings for Q and t from the graph	(B1)
	correct substitution of Q and t values into $Q_2 = Q_1 \exp[(t_1 - t_2)/\tau]$	(M1)
	calculation to give τ = 5.5 s	(A1)
	or	
	read-off of half-life as 3.75 s	(B1)
	use of $Q = Q_0 \exp(-t/\tau)$ to show that τ = half-life / ln 2	(M1)
	τ = 3.75 / ln 2 = 5.4 s	(A1)
8 b)	**or**	
	tangent drawn on Q–t graph and value of Q at exact same time as tangent read from graph	(M1)
	gradient of tangent correctly calculated	(A1)
	τ = Q / gradient used to correctly calculate a value for τ as 5.5 s	(A1)
8 c)(i)	$C = Q/V$	C1
	$= [(0.90 \times 10^{-3}) / 7.5] = 1.2 \times 10^{-4}$ C = 120 μF	A1
8 c)(ii)	$R = \tau / C$	C1
	$= 5.5 / (1.2 \times 10^{-4})$ (= 45 800 Ω) = 46 kΩ	A1
9 a)	charge / potential (difference)	M1
	charge is charge on one plate, <u>and</u> potential is p.d. across the plates	A1
9 b)	p.d. across both capacitors = E	B1
	$Q_T = Q_1 + Q_2$	B1
	$C_TE = C_1E + C_2E$ hence $C_T = C_1 + C_2$	B1
9 c)(i)	$[(1/22) + (1/47)]^{-1}$ = 15 μF	A1
9 c)(ii)	energy = $\frac{1}{2}CV^2$	C1
	$= \frac{1}{2} \times 15 \times 10^{-6} \times 12^2$ $= 1.1 \times 10^{-3}$ J	A1
9 c)(iii)	initial p.d. (across 22 μF) = 12 × (15 / 22) = 8.2 V **or** final p.d. across both capacitors = 6.0 × (22 / 15) = 8.8 V	C1
	$V = V_0 \exp[-t/(2.7 \times 10^6 \times 15 \times 10^{-6})]$	C1
	$6.0 = 8.2 \exp[-t/(2.7 \times 10^6 \times 15 \times 10^{-6})]$ **or** $8.8 = 12 \exp[-t/(2.7 \times 10^6 \times 15 \times 10^{-6})]$ t = 13 s	A1

10 5(a)	(energy stored =) area under line or ½ QV $= \frac{1}{2} \times 8.0 \times 1.2 \times 10^{-4}$	C1
	$= \mathbf{4.8 \times 10^{-4}}$ J	A1
10 (b)(i)	(τ=) RC	C1
	(τ=) $220 \times 10^3 \times (1.2 \times 10^{-4}/8.0)$ = **3.3** s	A1
10 b)(ii)	$E \propto V^2$	C1
	(so time to) $V_o / 3$ $V = V_o e^{-t/RC}$	C1
	$\frac{V_o}{3} = V_o e^{-t/3.3}$ $\frac{1}{3} = e^{-t/3.3}$	C1
	t = 3.6 s	A1
10 5(c)	(total) capacitance is doubled	M1
	time constant is doubled	A1

11 5(a)	$Q = CV$ **and** $E = \frac{1}{2}CV^2$	B1
11 (b)(i)	$C_N = CL / (L - D)$	B1
11 b)(ii)	(charge is unchanged by moving the plates so) $Q_N = CV$	B1
11 b)(iii)	$V_N = Q_N / C_N$ $= (CV) / [CL / (L - D)]$ $= V(L - D) / L$	B1
11 5(c)	oppositely charged plates attract, so energy stored decreases	B1

12 7(a)	charge / potential	M1
	charge is on one plate, potential is p.d. between the plates	A1
12 (b)(i)	$I = Q / t$	M1
	charge = CV <u>and</u> time = $1 / f$ leading to $I = fCV$	A1
12 b)(ii)	$4.8 \times 10^{-6} = 150 \times 60 \times C$	C1
	C = 530 pF	A1
12 7(c)	(total) capacitance is halved	B1
	charge (for each cycle/discharge) is halved **or** since f and V are constant, current is proportional to capacitance	B1
	current = 2.4 μA	B1

13	6(a)	potential difference applied between the plates	M1
		causes charge separation (between the plates) **or** causes energy to be stored (between the plates)	A1
13	(b)(i)	$I = Q / t$	M1
		clear substitution of $Q = CV$ and $f = 1 / t$, leading to $I = fCV$	A1
13	(b)(ii)	$2.5 \times 10^{-6} = 50 \times C \times 180$	C1
		C = 280 pF	A1
13	6(c)	(total) capacitance increases	B1
		greater charge (for each cycle/discharge) so greater (average) current **or** V and f are constant so (average) current increases **or** I is (directly) proportional to C so (average) current increases	B1

14	(a)(i)	charge per unit potential (difference)	M1
		charge on one plate <u>and</u> potential difference across the plates	A1
14	a)(ii)	any three points from: • smoothing • timing/(time) delay • tuning • oscillator • blocking d.c. • surge protection • temporary power supply	B3
14	6(b)	(capacitors in series have combined capacitance =) 8 μF	C1
		capacitance = 8 + 24 = 32 μF	A1

15	(a)(i)	charge per unit potential (difference)	M1
		charge on one plate and potential difference between the plates	A1
15	a)(ii)	any three points from: • smoothing • timing/(time) delaying • tuning • oscillator • blocking d.c. • surge protection • temporary power supply	B3
15	(b)(i)	parallel combination of two in series and a single capacitor	B1
15	b)(ii)	one capacitor in series with two in parallel	B1

16	3(a)	Any valid two points e.g.: • to store (electrical) energy • smoothing/reduce ripple (on direct voltages/currents) • to block d.c. • timing/time delay (circuits) • in oscillator (circuits) • in tuning (circuits) • to prevent arcing/sparks	B2
16	3(b)	clear indication of equal charge on each capacitor	B1
		$E = V_1 + V_2 + V_3$ **and** $V = Q / C$	M1
		completion of algebra leading to $1 / C = 1 / C_1 + 1 / C_2 + 1 / C_3$	A1
16	(c)(i)	three capacitors connected in parallel	B1
16	(c)(ii)	parallel combination of three capacitors connected in series with one capacitor	B1

17	6(a)	charge / potential (difference)	M1
		charge on one plate, p.d. between the plates	A1
17	(b)(i)	all three capacitors connected in series	B1
17	(b)(ii)	8 (μF) in parallel with the two 4 (μF) capacitors connected in series	B1
17	6(c)	discharge from 7.0 V to 4.0 V	C1
		Either energy = ½CV^2 *or* energy = ½ QV and $C = Q / V$	C1
		energy = ½ × 47 × 10^{-6} × ($7^2 - 4^2$) = 7.8 × 10^{-4} J	A1

18	(a)	(capacitance =) charge / potential	M1
		charge is (numerically equal to) charge on one plate	A1
		potential is potential difference between plates	A1
18	b)(i)	4.5 × 10^{-6} C	A1
18	ı)(ii)	9.0 × 10^{-8} C	A1
18	ı)(iii)	capacitance = (9.0 × 10^{-8}) / 120	C1
		= 7.5 × 10^{-10} F	A1
18	(c)	total capacitance is halved	B1
		current is halved	B1

19	(a)	capacitance = charge / potential	M1
		charge is (numerically equal to) charge on one plate	A1
		potential is potential difference between plates	A1
19	(b)(i)	two in series, in parallel with the other (correct symbols)	A1
19	(b)(ii)	two in parallel connected to one in series (correct symbols)	A1
19	¡(c)(i)	capacitance = 1.2 ∝F	A1
19	(c)(ii)	**1.** $Q = CV$	C1
		= 1.2 × 8.0 = 9.6 ∝C	A1
		2. $E = ½QV$ **and** $V = Q / C$ **or** $E = ½CV^2$ **and** $V = Q / C$ **or** $E = ½Q^2 / C$	C1
		E = ½ (9.6 × 10^{-6})^2 / (3.0 × 10^{-6}) = 1.5 × 10^{-5} J	A1

20	¡(a)(i)	1 / T = 1 / (2C) + 1 / C	C1
		T = ⅔C **or** 0.67C	A1
20	(a)(ii)	same charge on Q as on combination	B1
		so p.d. is 6.0 V	B1
20	¡(b)	P: p.d. will decrease (from 3.0 V)	B1
		to zero	B1
		Q: p.d. will increase (from 6.0 V)	B1
		to 9.0 V	B1

21	(a)	equal and opposite charges on the plates so no resultant charge	**B1**
		+ve and –ve charges separated so energy stored	**B1**
21	(b)	charge / potential difference	**M1**
		reference to charge on one plate and p.d. between plates	**A1**
21	(c)	energy = ½ CV^2 **or** energy = ½ QV **and** $C = Q / V$	**C1**
		$(1 / 16) \times ½ CV_0^2 = ½ CV^2$ $V = ¼ V_0$	**A1**

22 **(a)** **(i)** charge / potential (difference) or charge per (unit) potential (difference) B1 [1]

(ii) ($V = Q / 4\pi\varepsilon_0 r$ and $C = Q / V$)

for sphere, C (= Q / V) = $4\pi\varepsilon_0 r$ C1

$C = 4\pi \times 8.85 \times 10^{-12} \times 12.5 \times 10^{-2} = 1.4 \times 10^{-11}$ F A1 [2]

(b) **(i)** $1 / C_T = 1 / 3.0 + 1 / 6.0$

$C_T = 2.0\,\mu$F A1 [1]

(ii) total charge = charge on 3.0 μF capacitor = 2.0 (μ) × 9.0 = 18 (μC) C1

potential difference = Q / C = 18 (μ)C / 3.0 (μ)F = 6.0 V A1 [2]

or

argument based on equal charges:

$3.0 \times V = 6.0 \times (9.0 - V)$ (C1)

$V = 6.0$ V (A1)

(iii) potential difference (= 9.0 – 6.0) = 3.0 V C1

charge (= 3.0 × 2.0 (μ)) = 6.0 μC A1 [2]

23 **(a)** e.g. storing energy
blocking d.c.
in oscillator circuits
in tuning circuits
in timing circuits

any two B2 [2]

(b) **(i)** $1 / 6 + 1 / C + 1 / C = 1 / 4$ C1

$C = 24\,\mu$F A1 [2]

(ii) $Q = CV$
$= 4.0 \times 10^{-6} \times 12$ C1

= 48 μC A1 [2]

(iii) **1.** 48 μC A1

2. 24 μC A1 [2]