7 The capacitor is an electrical component which has the ability or “capacity” to store energy in the form of an electrical charge, producing a potential difference across its plates, much like a small rechargeable battery.

When an electric potential is applied across the terminals of a capacitor, for example when a capacitor is connected across a battery, electrons will move from one of the terminal to the other via the battery. No current flows between the two plates. The current through the source circuit will eventually cease when the electric potential across the capacitor reaches that of the battery. This process is known as charging.

When the capacitor is now attached to a circuit, it will behave like a battery due to the charges accumulated across its terminals. However, unlike a battery, the voltage and current that it produces decreased with time as the charges on its plates is limited. This process is known as discharging.

The ability of the capacitor to store charges is known as capacitance *C*, measured in Farads (F), which is the ratio of the amount of electric charge *Q* stored to the difference in electric potential *V* across it. *C* can therefore be expressed as

$$C = \frac{Q}{V}$$

The parallel plate capacitor is the simplest form of capacitor. It can be constructed using two metal foil plates of surface area *A,* separated at a distance *d* and placed parallel to each other. The two plates are electrically separated either by air or by some form of a good insulating material such as mica, ceramic or plastic as shown in Fig 7.1. This insulating layer is commonly called the dielectric. The dielectric constant ε measures the amount of electric potential energy that the dielectric can store under the influence of an electric field.

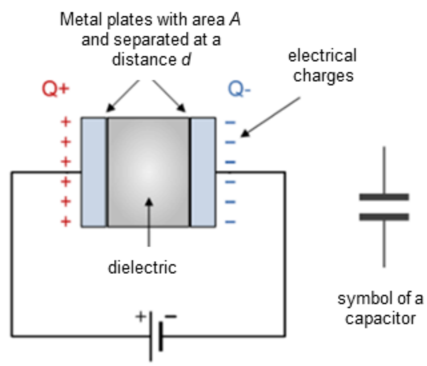

Fig 7.1

C can therefore also be expressed as

$$C = \varepsilon \frac{A}{d}$$

(a) Data comparing the variation of capacitance *C* with the separation between the conducting plates of 4 capacitors is as shown in Fig. 7.2 and Fig 7.3.

	Capacitor			
	W	**X**	**Y**	**Z**
Separation *d* / mm	Capacitance *C* / nF			
0.10	0.103	0.053	0.089	0.124
0.20	0.052	0.027	0.044	0.062
0.30	0.034	0.018		0.041
0.40	0.026	0.013	0.022	0.031

Fig 7.2

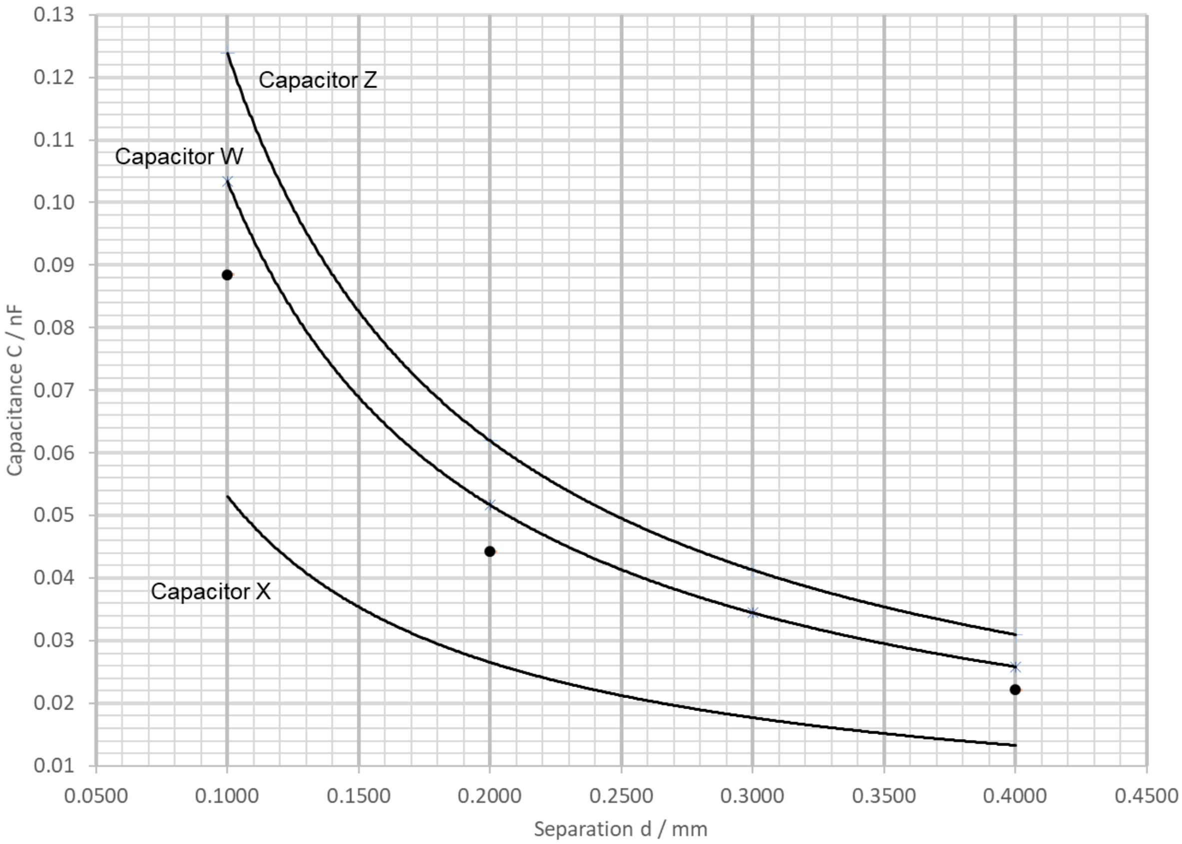

Fig 7.3

(i) Complete Fig 7.2 for Capacitor Y.

[1]

(ii) On Fig 7.3, plot the missing capacitance value for Capacitor Y. Complete Fig 7.3 by drawing the best fit line for Capacitor Y.

[2]

(iii) Using Fig 7.3, determine the value of C for capacitor Z when d = 0.15 mm

C = ………………………… nF [1]

(iv) Hence, given that the area A for Capacitor Z is 1.0×10^{-4} m^2, determine the values of its dielectric constant ε.

ε = ………………………… F m^{-1} [2]

(b) Fig 7.4 shows a setup that can be used to charge a capacitor. An e.m.f source V_s is arranged in series with a resistor R and a capacitor C.

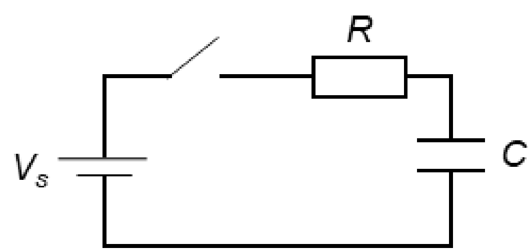

Fig 7.4

When the switch is closed, the voltage across the capacitor V_c can be expressed as

$$V_c = V_s(1 - e^{-t/RC})$$

where t is the time from which the switch is closed.

(i) Explain why after the switch is closed, the current through the resistor will eventually decrease to zero.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

(ii) Hence or otherwise, deduce an expression for the variation with time of the current passing through the resistor I_R.

I_R = ………………………… [1]

(c) When the e.m.f. source is removed from Fig 7.4, the circuit can be used for to discharge a capacitor as shown in Fig 7.5.

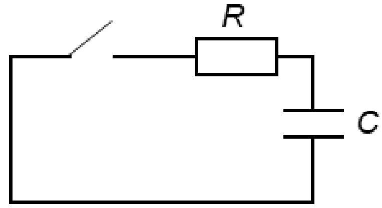

Fig 7.5

When the switch is closed, the voltage across the capacitor V_c can be expressed as

$$V_c = V_o e^{-t/RC}$$

where V_o is the initial voltage across the capacitor while t is the time from which the switch is closed.

(i) Suggest why the voltage across the capacitor decreases *exponentially* during discharge.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

(ii) Despite not being able to maintain a constant voltage output, capacitors are widely used in almost all electronic devices.

State an advantage that the capacitor has over a battery.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………..….......…………….………………………........…………… [1]

(d) A student uses the capacitor to model a signal generator, which sends a signal periodically when switched on. A model of the signal generator is as shown in Fig 7.6 where a 12.0 V battery is placed in series with a variable resistor and a 20.0 μF capacitor. A device is place across the output of the signal generator.

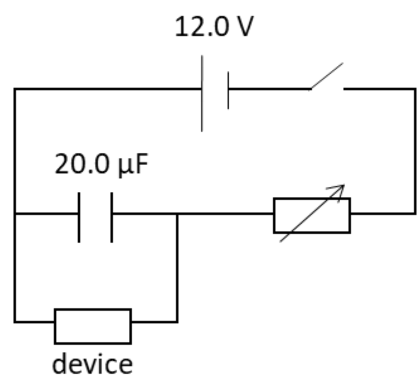

Fig 7.6

The device can be considered to have a very large resistance until the potential difference across it reaches 8.0 V. At 8.0 V, its resistance decreases to a negligible level and allows the capacitor to fully discharge through it almost instantly. The resistance of the variable resistor is initially set to be 5.0 Ω.

(i) Determine the maximum amount of charge that can be stored in the capacitor.

amount of charge = ………………………… C [1]

(ii) When the switch is closed, determine the time taken for the capacitor to reach 8.0 V.

time = ………………………… s [2]

(iii) Hence or otherwise, determine the frequency output of the signal generator.

frequency = ………………………… Hz [1]

(iv) Fig 7.7 shows the variation with time of the voltage across the capacitor as the resistance of the variable resistor is varied over four different values.

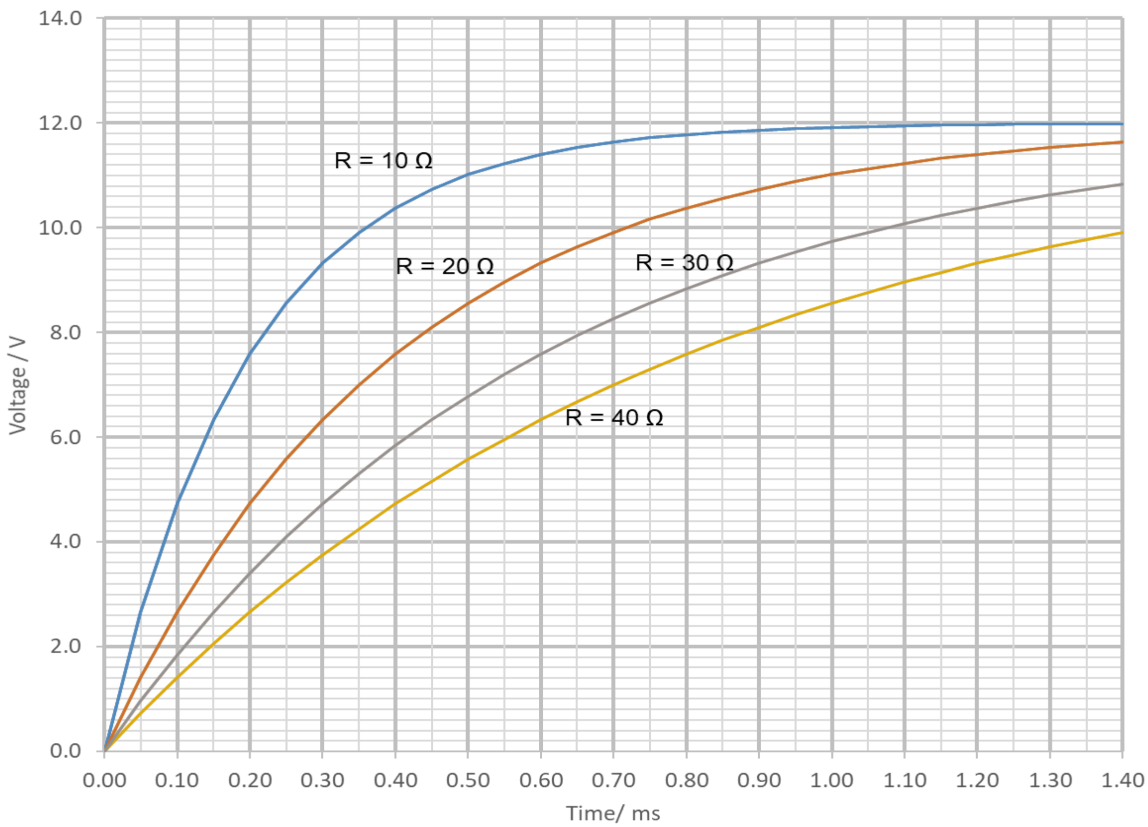

Fig 7.7

1. Using Fig 7.7, explain how the variable resistor can be used to increase the frequency of the signal generator.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

2. If the signal generator is to have a frequency of at least 2 kHz, determine all possible resistance value(s) in Fig. 7.7 that can be used.

resistance = ………………………… Ω [2]

End of Paper