1 (a) State what is meant by a capacitance of 370 μF

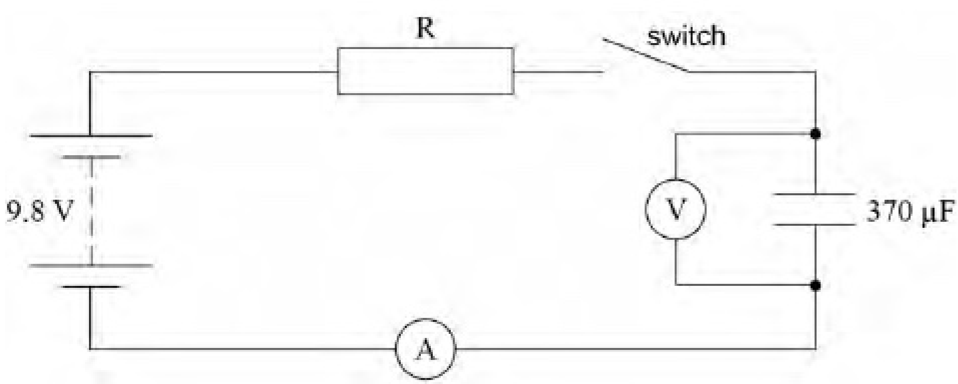
amount of charge stored in coulombs per volt

see youtube walk through

(2)

(b) The charging of a 370 μF capacitor is investigated using the circuit shown in **Figure 1**.
Both meters in the circuit are ideal.

Figure 1



The power supply of emf 9.8V has a negligible internal resistance. The capacitor is initially uncharged. When the switch is closed at time t = 0 charge begins to flow through resistor R. The time constant of the charging circuit is 1.0 s

Calculate the resistance of R.

$T = RC \Rightarrow \frac{1}{370 \times 10^{-6}}$

resistance of R = 2.7×10^{3} Ω

(1)

(c) Identify, with the symbol X on **Figure 2**, the potential difference (pd) across the capacitor when the switch has been closed for 2.0 s

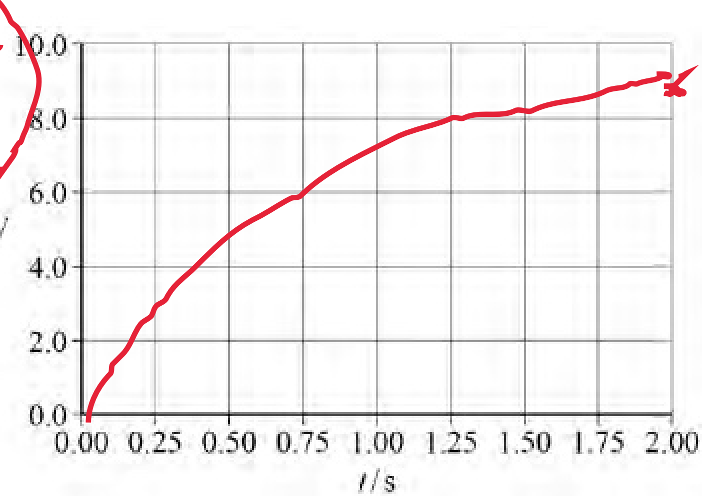
Sketch the graph that shows how the pd varies from $t = 0$ to $t = 2.0$ s

Figure 2

$V = V_0 (1 - e^{-t/RC})$

$V = 9.8 (1 - e^{-2/...})$

$V = 8.5$



(2)

(d) Calculate the time taken for the charging current to fall to half its initial value.

$T_{1/2} = 0.69 RC$

time = 0.69 s

(1)

(e) Calculate the time taken for the charge on the capacitor to reach 3.0 mC

$Q = Q_0 (1 - e^{-t/RC})$

$3 mC$; $CV_0 = 370 \times 10^{-6} \times 9.8 = 3.6 \times 10^{-3} C$

$\frac{Q}{Q_0} - 1 = -e^{-t/RC}$

$1 - \frac{Q}{Q_0} = e^{-t} \Rightarrow \ln\left(1 - \frac{Q}{Q_0}\right) = -t$

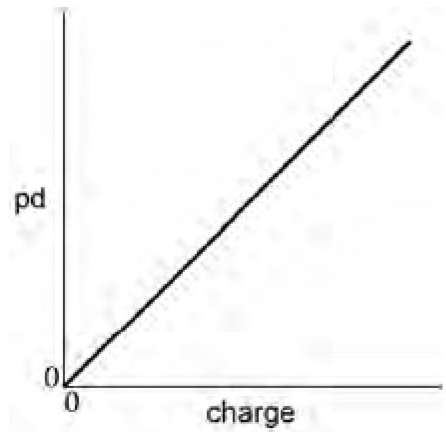
time = ______________________ s

$-1.8 = -t \Rightarrow t = 1.8 s$

(3)

(Total 9 marks)

2 The graph shows the variation of potential difference (pd) with charge for a capacitor while it is charging.



$Q = CV$

$Q \propto V$

$Q = It$ $\propto V$

Which statement can be deduced from the graph?

A The charging current is constant. ⬭ could be....

B The energy stored in the capacitor increases uniformly with time. ⬭ $E = \frac{1}{2}QV$ curve

C The capacitance of the capacitor is constant. ✓ ⬭

D The power supply used to charge the capacitor had a constant terminal pd. ✗ ⬭ – no

(Total 1 mark)

3 The figure below shows a capacitor of capacitance 370 pF. It consists of two parallel metal plates of area 250 cm^2. A sheet of polythene that has a relative permittivity 2.3 completely fills the gap between the plates.

not to scale

(a) Calculate the thickness of the polythene sheet.

$C = 370 \times 10^{-12}$ F

$A = 250 cm^2$

$1000 cm^2 = 1 m^2$

$A = 0.025$

$C = \frac{A\varepsilon_0\varepsilon_r}{d}$

$d = \frac{A\varepsilon_0\varepsilon_r}{C}$

$d = \frac{2.5 \times 10^{-2} \times 8.85 \times 10^{-12} \times 2.3}{370 \times 10^{-12}}$

thickness = 1.4×10^{-3} m

(2)

(b) The capacitor is charged so that there is a potential difference of 35 V between the plates. The charge on the capacitor is then 13 nC and the energy stored is 0.23 μJ.

The supply is now disconnected and the polythene sheet is pulled out from between the plates without discharging or altering the separation of the plates.

Show that the potential difference between the plates increases to about 80 V.

all fixed but ε_r from $2.3 \rightarrow 1$

$V = 35V$ $\quad Q = 13\,nC$ (will be fixed) $\quad E = 0.23\,\mu J$ $\quad$ $C = \frac{A\varepsilon_0\varepsilon_r}{d}$

$C_{new} = \frac{370 \times 10^{-12} F}{2.3} = 161\,pF$ $\quad \frac{Q}{C} = V$ $\quad C \propto \varepsilon_r$

$\therefore V$ up $2.3 \Rightarrow V = 35 \times 2.3 = 80.5\,V$

(2)

(c) Calculate the energy that is now stored by the capacitor.

$E = \frac{1}{2}CV^2$ or $\frac{1}{2}QV$

energy stored = 0.52 μJ

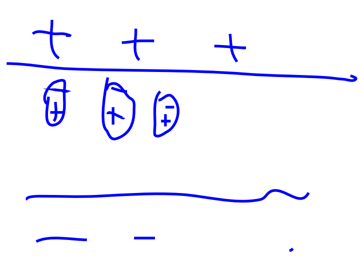
(2)

(d) Explain why there is an increase in the energy stored by the capacitor when the polythene sheet is pulled out from between the plates.

Molecules in dielectric line up when in between plates.
You have to do work on the cap. when moving out plate

(2)

(Total 8 marks)



Mark schemes

1 (a) (Refers to a capacitor that) stores/holds/changes by 370 μC of charge ✓

For every (1) volt/volt change (of pd across its plates) ✓

OR

Reference to charge to pd OR charge to voltage ratio ✓ includes units C or coulomb and V or volt ✓

"Unit of pd" is no substitute for using volt and "unit of charge" is no substitute for coulomb.

However the alternative marking could give a single mark for 370×10^{-6} units of charge per unit of pd.

An equation may contribute towards the first mark but only if the symbols are identified. A second mark can be given if the units are identified.

Ignore poor phrasing like 'per unit volt passing through'.

2

(b) (Using time constant = RC)

($R = 1.0 / 370 \times 10^{-6}$)

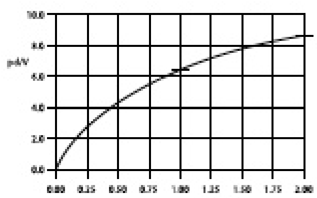
$R = 2.7 \times 10^{3}$ (Ω) ✓

Check that the unit on answer line has not been altered.

1

(c) First mark for marking a cross at 2 s and 8.5 V (by eye) ✓

Second mark for graph starting at the origin and having a decreasing gradient ie not reaching horizontal ✓



Cross must be in the bottom half but not on the 8.0 V major grid line or exactly half way up (9.0 V).

If a series of plotting crosses are given only consider the one placed at 2 s for the first mark.

2

(d) (Using $T½ = 0.69\,RC = 0.69 \times 1.0$)

$T½ = 0.69$ (s) ✓

1 sig fig is not acceptable

1

(e) (Use of $Q = Q_0(1 - e^{-\frac{t}{RC}}) = CV_0(1 - e^{-\frac{t}{RC}})$)

Mark for max charge = CV_0 which may come from substitution or seeing $3.6(2) \times 10^{-3}$ C ✓

$3.0 \times 10^{-3} = 370 \times 10^{-6} \times 9.8\ (1 - e^{-t})$ ✓

Mark for substitution ($0.8274 = (1 - e^{-t})$ so $e^t = 1/0.173 = 5.79$)

t = 1.7 s or 1.8 s ✓

OR

Voltage $V = Q/C = 3 \times 10^{-3} / 370 \times 10^{-6}$
= 8.1(1) V ✓

(Substitute into $V = V_0(1 - e^{-\frac{t}{RC}})$)

$8.1 = 9.8\ (1 - e^{-t})$ ✓

t = 1.7 s or 1.8 s ✓

Alternative mark scheme uses the voltage as proportional to the charge.

Do not allow use of the graph for 2nd mark and 3rd mark.

An answer only gains only the last mark.

Evidence of working must be shown which shows substitution into a $(1 - e^{-t})$ form of the equation.

3

[9]

2 **C**

[1]

3 (a) $d = \frac{8.9\times10^{-12}\times2.3\times250\times10^{-4}}{370\times10^{-12}}$ ✓

1.4×10^{-3} m (1.4 (1.38) mm)✓

Data substitution – condone incorrect powers of 10 for C and A ✓

2

(b) New capacitance = 161 pF✓

New V = 0.13 nC / 161pF = 81 V✓

2

(c) Energy stored = $\frac{1}{2} \times 161 \times 10^{-12} \times 81^2$ ✓

0.53 μJ✓

2

(d) Energy increases because:

In the polar dielectric molecules align in the field with positive charged end toward the negative plate (or WTTE).✓

Work is done on the capacitor separating the positively charged surface of the dielectric from the negatively charged plate (or vice versa).✓

2

[8]