DR. G. B. DAVIES

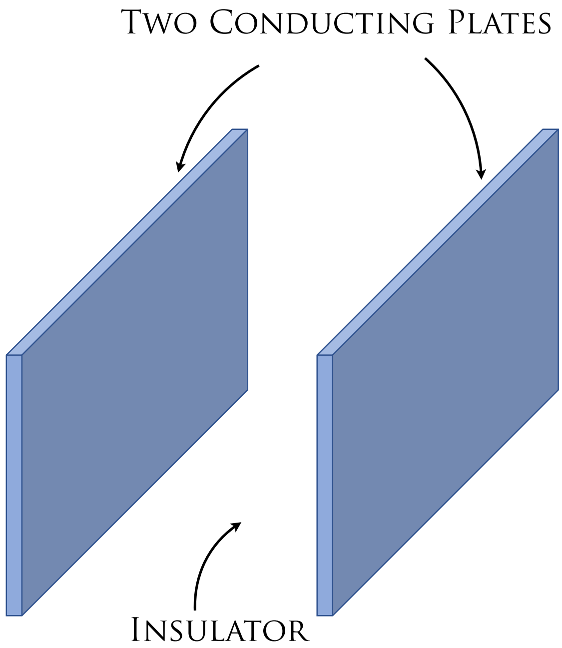
CAPACITANCE

NAME: CLASS:

Contents

1 *Introduction to Capacitors*

Capacitors are very simple electrical components: they are two conducting plates separated by an insulator.

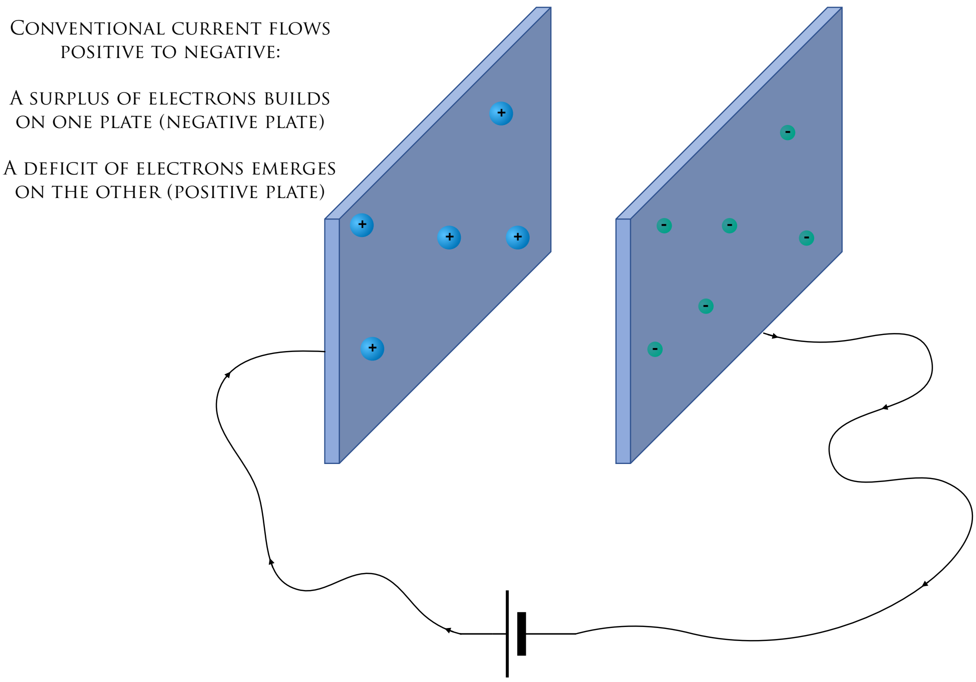


The conducting plates are usually metal, and the insulator separating the plates is often called a "dielectric".

In the very simplest case, you can create a capacitor from two pieces of aluminium foil separated by air, since air is an insulator.

Capacitors store charge and electrical energy

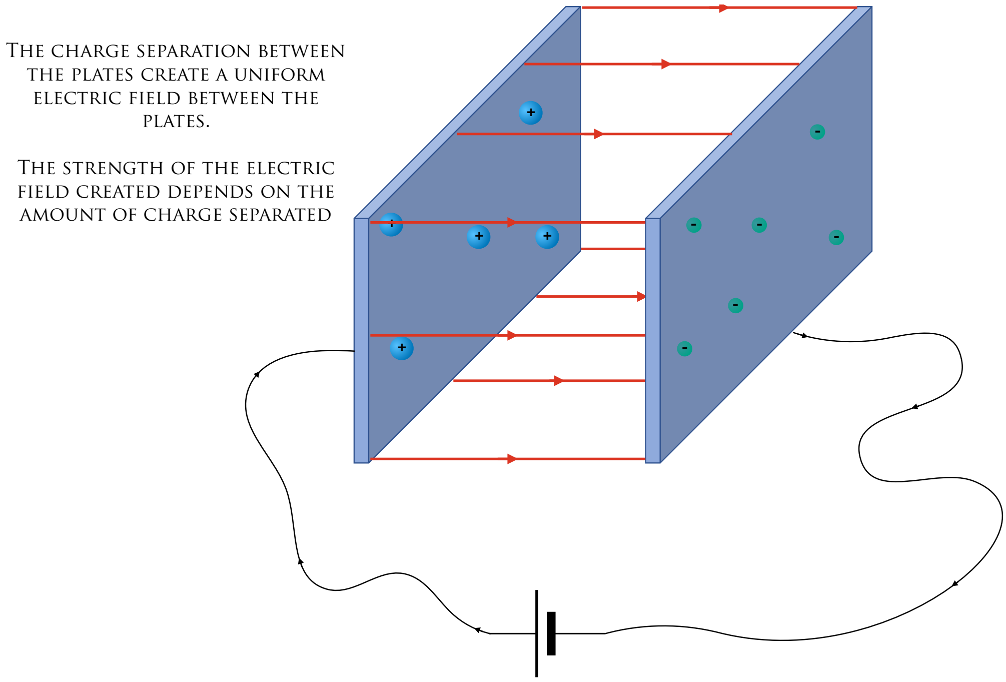
To see how they do this, consider what happens when a capacitor is connected to a battery, as shown in the image below.



The electrons flow from the negative terminal of the battery on to one plate of the capacitor, and electrons leave the other plate of the capacitor, creating a deficit of electrons and hence an overall positive charge.

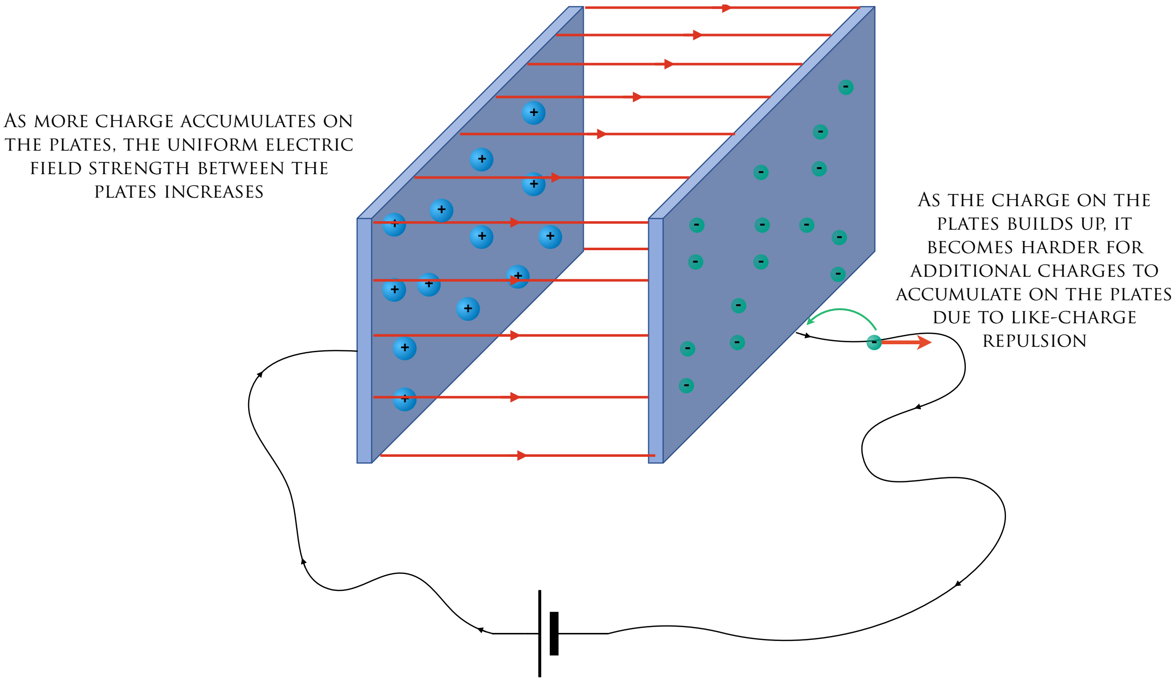
Because there is an **insulator** between the plates, charge cannot flow from one plate to the other.

The charge separation creates a uniform electric field between the plates, as shown below:



As charge builds up, the electric field strength increases.

However, it becomes harder and harder for the battery to give enough energy to charges to move onto the plates and stay there. This is because electrons flowing from the battery are repelled by the electrons on the negative plate of the capacitor.



With these pictures in mind, we define capacitance as follows:

The **capacitance** C of a capacitor tells us how much charge Q it stores when plugged in to a battery of emf V:

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

If a capacitor stores more charge Q for a given potential difference V, it has a higher capacitance than a capacitor that stores less charge Q for a given V.

The unit of capacitance is the **Farad (F)**.

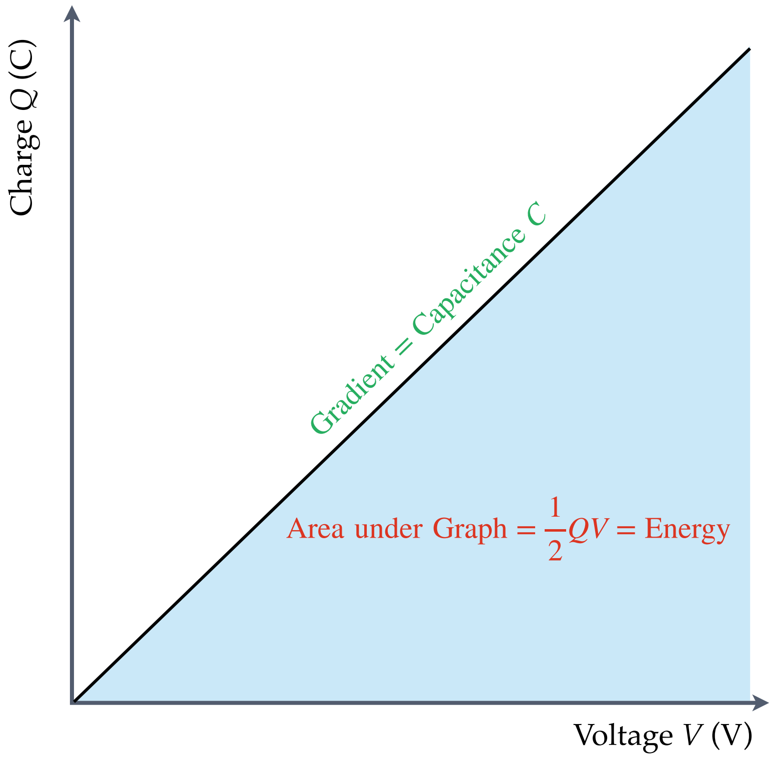
You should be aware that a Farad is a huge unit, and most of the capacitances you will deal with will be in the μF - pF size.

$$\begin{aligned} \mu\text{F} &= 10^{-6}\text{ F} \\ \text{nF} &= 10^{-9}\text{ F} \\ \text{pF} &= 10^{-12}\text{ F} \end{aligned}$$

1.1 Capacitors Store Energy

If we plot a graph of how much charge a capacitor stores as we vary the voltage applied across it, we get a straight line graph with gradient C (since $Q = CV$):

Comparing $Q = CV$ with $y = mx + c$ if we plot Q on the y-axis and V on the x-axis yields $m = C$ and $c = 0$.



The area under the graph is $\frac{1}{2}QV$. Remembering from the electric fields topic, we know that voltage, energy, and charge are related as follows: $V = \frac{E}{Q}$ and so QV gives us an energy. Therefore, the energy stored on a capacitor is:

$$\text{Energy} = \frac{1}{2}QV$$

We can now substitute $Q = CV$ or $V = \frac{Q}{C}$ into this equation to obtain two other common forms of this equation:

$$\text{Energy} = \frac{1}{2}CV^2 \qquad \text{Energy} = \frac{1}{2}\frac{Q^2}{C}$$

Worked Example 1-0 - Simple $Q = CV$ calculations

Q: A capacitor has capacitance 500 μF. Calculate the charge stored on the capacitor when it is connected to a 1.5 V battery.

A: We simply plug the relevant variables in to our capacitance equation:

$$\begin{aligned} Q &= CV \\ &= 500\ \mu\text{F} \times 1.5\ \text{V} \\ &= 750\ \mu\text{C} \end{aligned}$$

Practice Questions 1-1 - Finding RC from discharge graphs

Calculate the charge stored on the following capacitors:

1. A capacitor of capacitance 200 μF is connected to a 6 V battery.
2. A capacitor of capacitance 200 μF is connected to a 9 V battery.

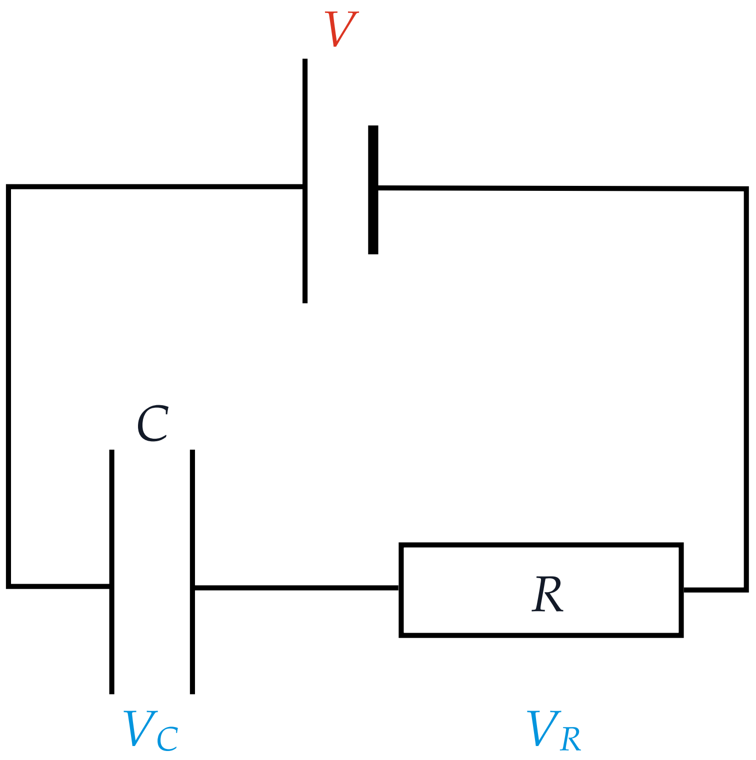
3. A capacitor of capacitance 450 nF is connected to a 3 V battery.

2 *Charging a Capacitor*

In the introduction, we showed that a capacitor stores charge when it is connected to a voltage source such as a battery.

However, we also argued that while initially it was easy for charges to accumulate on the plates, as the charges build up on the plate it becomes more difficult for the battery to push additional charges onto the plates because of like-charge repulsion.

Amazingly, we can derive a mathematical formula that models this situation perfectly and that can tell us the amount of charge Q stored on the plate at any time t after we connect it to a battery.
Consider the circuit in the diagram below.



Charge flows from the battery of $emf = V_B$ to the capacitor plates of a capacitor of capacitance C through the wires. Since wires have resistance, we can pretend the wires have an overall fixed resistance R.

Using Kirchoff's 2nd law or the "emf loop rule" we can derive the following relation:

$$V_B = V_R + V_C$$

This simply tells us that the voltage gained by any charge going across the battery must be lost as the charge passes through the resistor and the capacitor.

Using $V = IR$ for the resistor and $V_C = \frac{Q}{C}$ for the capacitor we now obtain:

$$V_B = IR + \frac{Q}{C}$$

Now we need to remember that current is the rate of flow of charge i.e. $I = \frac{dQ}{dt}$:

$$V_B = \frac{dQ}{dt}R + \frac{Q}{C}$$

This now completes our differential equation that shows how the charge varies with time: we can solve this to find the charge $Q(t)$ on a capacitor at any moment in time.

We use the derivative version rather than $I = \frac{Q}{t}$ because the current is changing the whole time, we need the current at an instant in time, which is what $I = \frac{dQ}{dt}$ gives us

This is a first order differential equation that you learn to solve in further maths, but for the sanity of readers who are not doing further maths, we leave the derivation as optional.

The solution to this differential equation is the following equation:

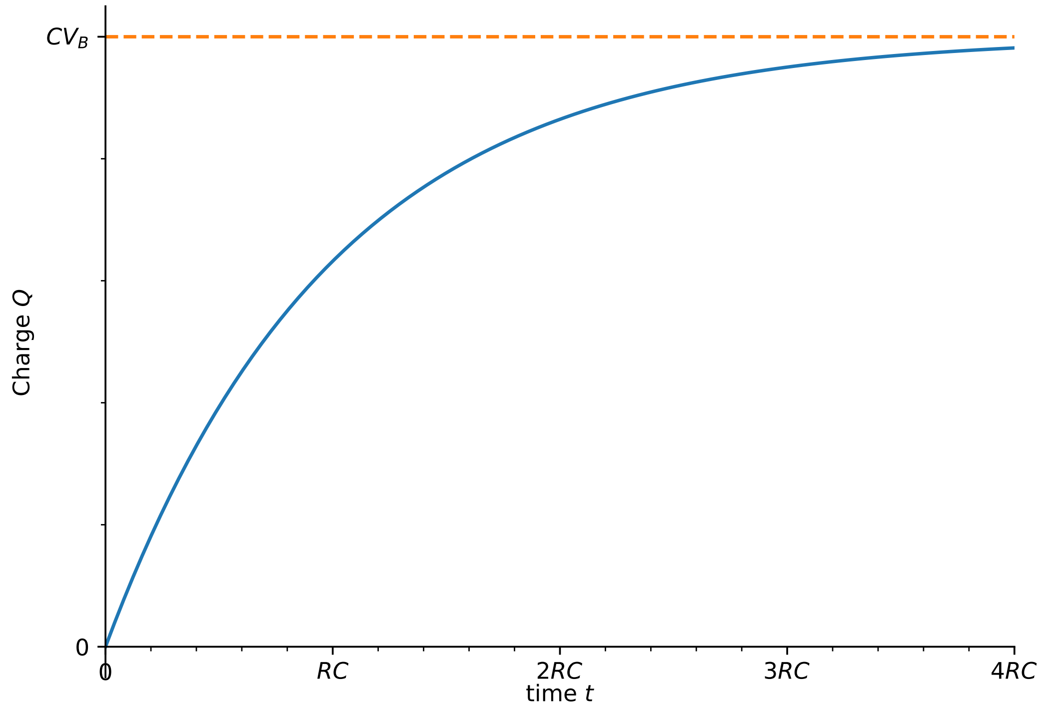
$$Q = CV_B\left(1 - e^{-\frac{t}{RC}}\right)$$

where:

- Q is the charge on the capacitor measured in Coulombs (C).
- C is the capacitance of the capacitor measured in Farads (F).
- t is the time since charging begins measured in seconds (s).
- R is the resistance of the resistor measured in Ohms (Ω).

The constant RC has units of time - strangely - and we will discuss this in detail in a later section.

Plotting a graph of this equation yields the following graph:



It is interesting to consider the limiting case in which the capacitor is charging for infinite time:

$$\lim_{t\to\infty} Q = CV_B\left(1 - e^{-\frac{t}{RC}}\right) = CV_B$$

This is where the capacitor equation

$$Q = CV$$

originates. It tells us how much charge is stored on the capacitor for a given voltage applied across the capacitor. Note now then that the equation is strictly only true when the capacitor has been charging for infinite time, but in practice we reach very close to this value in a short amount of time.

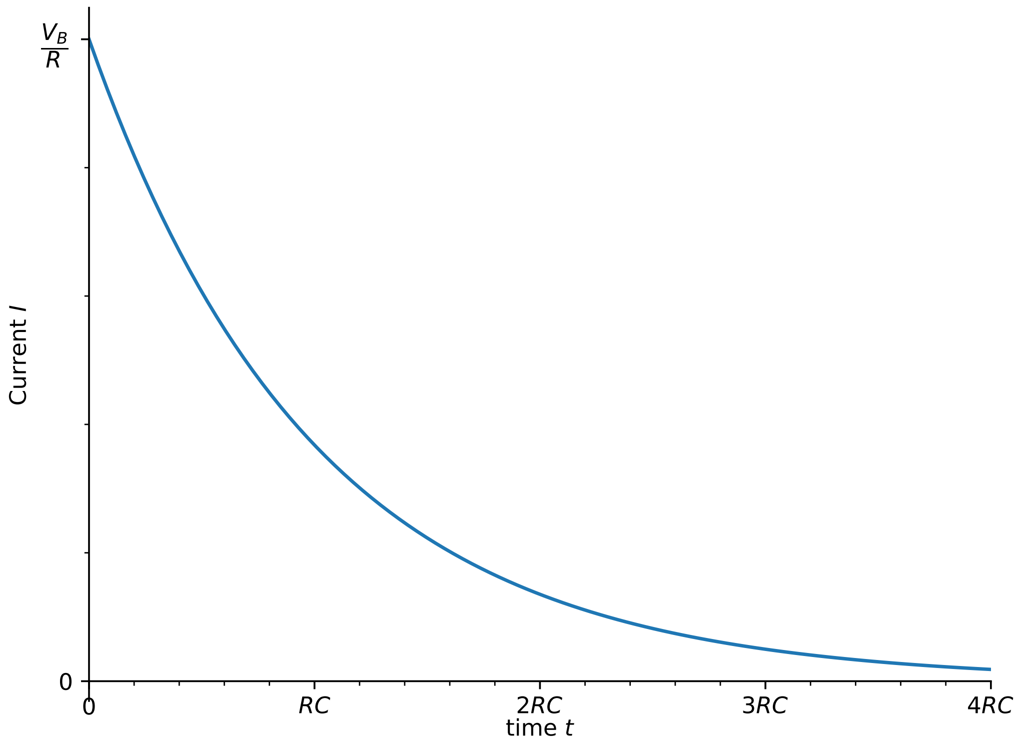
$e^{-\frac{t}{RC}} = \frac{1}{e^{\frac{t}{RC}}}$. As $t \to \infty$ $e^t \to \infty$ and so $\frac{1}{e^t} \to 0$

To understand how the current behaves as a function of time, we differentiate our charging equation with respect to t:

$$\begin{aligned} Q &= CV_B\left(1 - e^{-\frac{t}{RC}}\right) \\ \implies \frac{dQ}{dt} &= CV_B \times -\frac{1}{RC}e^{-\frac{t}{RC}} \\ \implies I &= \frac{V_B}{R}e^{-\frac{t}{RC}} \end{aligned}$$

This shows that the current flowing in the capacitor circuit is initially just $\frac{V_B}{R}$, as expected, but that as time progresses the current decreases, which makes intuitive sense.

Plotting a graph of this equation yields the following graph:



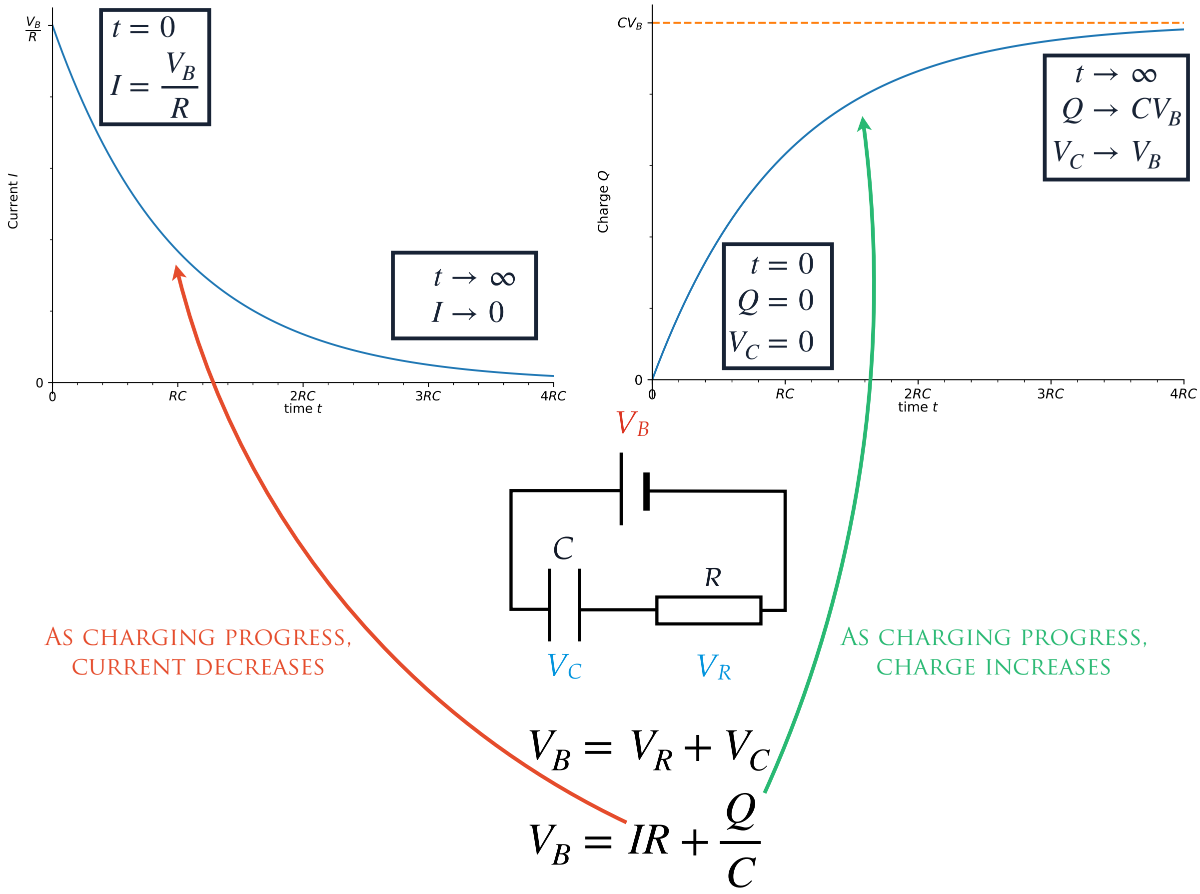
It is worthwhile to take a step back and consider why capacitors display this behaviour:

1. Initially, the capacitor plates are uncharged, and the battery does little work moving charges on to the plates. This results in a high initial current.

2. As more charge builds up on the plates, the repulsion between like charges increases, and adding each successive charge becomes more and more difficult. The current decreases during this process.

3. Eventually, the plates are "full" or "saturated" with charge and adding another charge becomes extremely difficult. The current is essentially 0 and the charge on the capacitor is $Q = CV$.

The following graph summarises the behaviour of a capacitor as it charges:



2.1 Optional: Derivation of the Capacitor Charging Equation

To solve this differential equation, we need to "separate" the differential equation and get all the Q terms on one side and all the t terms on the other so we can integrate:

We need an equation of the form $\int f(Q)\, dQ = \int f(t) dt$

$$\frac{V_B}{R} - \frac{Q}{RC} = \frac{dQ}{dt}$$
$$\int dt = \int \frac{1}{\frac{V_B}{R} - \frac{Q}{RC}} dQ$$

To solve the integral on the right hand side we need to use a substitution. The easiest substitution to use is simply:

$$u = \frac{V_B}{R} - \frac{Q}{RC}$$
$$\implies du = -\frac{1}{RC}\, dQ$$
$$\implies dQ = -RC\, du$$

which allows us to transform our previous integral to:

$$
\begin{aligned}
\int dt =& \int \frac{1}{\frac{V_B}{R} - \frac{Q}{RC}} \, dQ \\
\implies \int dt =& -RC \int \frac{1}{u} \, du \\
t + c =& \; -RC \ln u \\
t + c =& \; -RC \ln \left(\frac{V_B}{R} - \frac{Q}{RC} \right)
\end{aligned}
$$

From here, we are home and dry and simply need to solve for Q:

$$
\begin{aligned}
t + c =& \; -RC \ln \left(\frac{V_B}{R} - \frac{Q}{RC} \right) \\
\implies -\frac{t}{RC} + C =& \; \ln \left(\frac{V_B}{R} - \frac{Q}{RC} \right) \\
\implies e^{-\frac{t}{RC} + C} =& \; \frac{V_B}{R} - \frac{Q}{RC} \\
\implies \frac{Q}{RC} =& \; \frac{V_B}{R} - Ae^{-\frac{t}{RC}} \\
\implies Q =& \; RC \left(\frac{V_B}{R} - Ae^{-\frac{t}{RC}} \right)
\end{aligned}
$$

To fully solve this equation, we need find the value of the constant A. We can do this by using *initial conditions*, or in other words known values of Q and t. We note that there is no charge on the capacitor just as we start charging it $Q = 0$ at $t = 0$

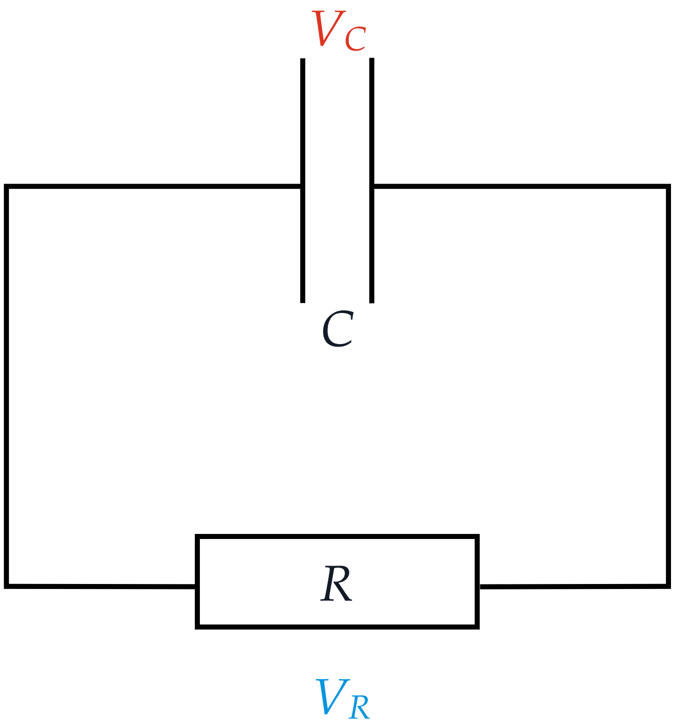
$$
\begin{aligned}
Q =& \; RC \left(\frac{V_B}{R} - Ae^{-\frac{-}{RC}} \right) \\
\implies 0 =& \; RC \left(\frac{V_B}{R} - Ae^{-\frac{0}{RC}} \right) \\
\implies A =& \; \frac{V_B}{R}
\end{aligned}
$$

Plugging this back into our equation gives:

$$
\begin{aligned}
Q =& \; RC \left(\frac{V_B}{R} - Ae^{-\frac{t}{RC}} \right) \\
\implies Q =& \; RC \left(\frac{V_B}{R} - \frac{V_B}{R} e^{-\frac{t}{RC}} \right) \\
\implies Q =& \; RC \frac{V_B}{R} \left(1 - e^{-\frac{t}{RC}} \right) \\
\implies Q =& \; CV_B \left(1 - e^{-\frac{t}{RC}} \right)
\end{aligned}
$$

3 *Discharging a Capacitor*

Once we have fully charged a capacitor such that the charge stored on it is $Q = CV_B$, we can unhook the battery and let the capacitor discharge through a resistor as in the following circuit:



Using Kirchoff's 2nd law again, we obtain:

$$V_C = V_R$$

In other words, all the energy gained by the charges stored on the capacitor is lost as they flow through the resistor. Using $V = IR$ and $I = \frac{dQ}{dt}$ we can re-write this equation as follows:

$$\begin{aligned} V_C &= IR \\ \implies \frac{Q}{C} &= IR \\ \implies \frac{Q}{C} &= -\frac{dQ}{dt}R \end{aligned}$$

This differential equation is much easier to solve than the charging equation, and you have to know the derivation. For now, let's focus on the solution of this differential equation:

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

noindent We can get to alternative forms of this equation in terms of the voltage and the current using $Q = CV$:

$$\begin{aligned} \implies Q &= Q_0 e^{-\frac{t}{RC}} \\ \implies CV &= CV_0 e^{-\frac{t}{RC}} \\ \implies V &= V_0 e^{-\frac{t}{RC}} \end{aligned}$$

and $V = IR$

$$\implies V = V_0 e^{-\frac{t}{RC}}$$
$$\implies IR = I_0 R e^{-\frac{t}{RC}}$$
$$\implies I = I_0 e^{-\frac{t}{RC}}$$

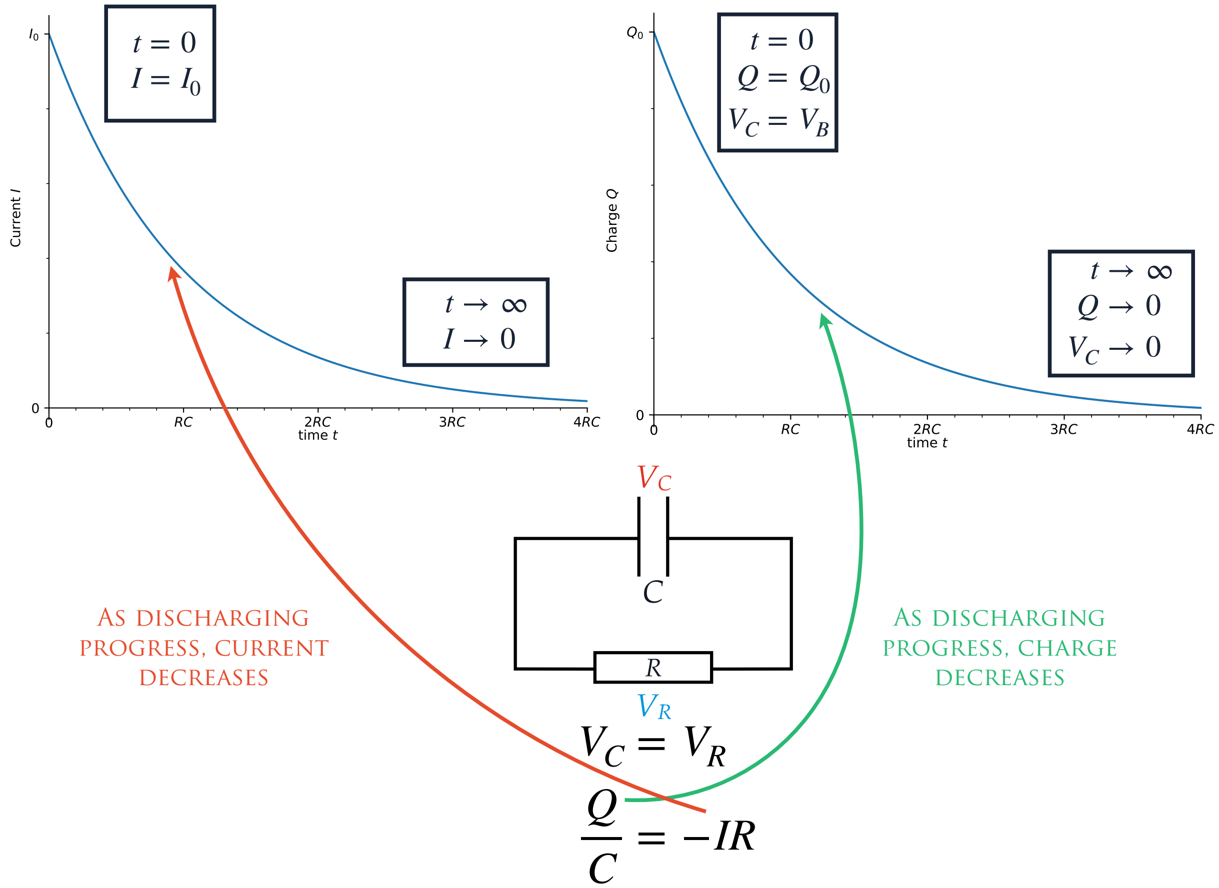
We could equally well have achieved this expression by differentiating the Q equation:

$$Q = Q_0 e^{-\frac{t}{RC}}$$
$$\implies I = \frac{dQ}{dt} = \frac{dQ_0}{dt} e^{-\frac{t}{RC}}$$
$$\implies I = I_0 e^{-\frac{t}{RC}}$$

To summarise:

$$V = V_0 e^{-\frac{t}{RC}} \qquad I = I_0 e^{-\frac{t}{RC}}$$

In other words, the voltage across a capacitor and the current flowing around the circuit follow the same behaviour as the discharging of the capacitor.



1. Initially, the capacitor plates are fully charged, creating a strong uniform electric field between the plates and hence a high potential difference (voltage V).

2. Charge flows off the plate at a fast rate, due to the high potential difference, leading to a large current.

3. As more and more charge leaves the plate, the voltage V across the plates decreases and reduces the "driving force" of the current, and so the current decreases and less charge leaves the plate each second.

4. Eventually, so much charge has left the plates and the potential difference so small that changes in charge, current, and voltage each second are relatively small.

3.1 *Derivation of the discharging equation*

Mercifully, the differential equation resulting from the discharge equation is much easier to solve than the charging equation:

$$\begin{aligned}
V_C &= IR \\
\implies \frac{Q}{C} &= IR \\
\implies \frac{Q}{C} &= -\frac{dQ}{dt}R \\
\implies \frac{Q}{RC} &= -\frac{dQ}{dt} \\
\implies -\frac{1}{RC}\int dt &= \int \frac{1}{Q}\, dQ \\
\implies -\frac{t}{RC} + c &= \ln Q \\
\implies Q &= e^{-\frac{t}{RC}+c} \\
\implies Q &= Ae^{-\frac{t}{RC}}
\end{aligned}$$

Using the fact that at $t = 0$ the charge on the capacitor is just the initial charge $Q(0) = Q_0 = A$

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

Unlike the charging equation, you are expected to know and understand this equation:

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

4 *The time constant* $\tau = RC$

It is curious that the product of resistance R and capacitance C has units of seconds:

$$\begin{aligned}
RC &= \frac{V}{I} \times \frac{Q}{V} \\
\implies RC &= \frac{V}{\frac{Q}{t}} \times \frac{Q}{V} \\
&= \frac{Vt}{Q} \times \frac{Q}{V} \\
\implies RC &= t
\end{aligned}$$

We know this must be true because we can only exponentiate unitless numbers i.e. x must be unitless e^x and since we had $e^{-\frac{t}{RC}}$ the only way $\frac{t}{RC}$ can be unitless is if RC has dimensions of time.

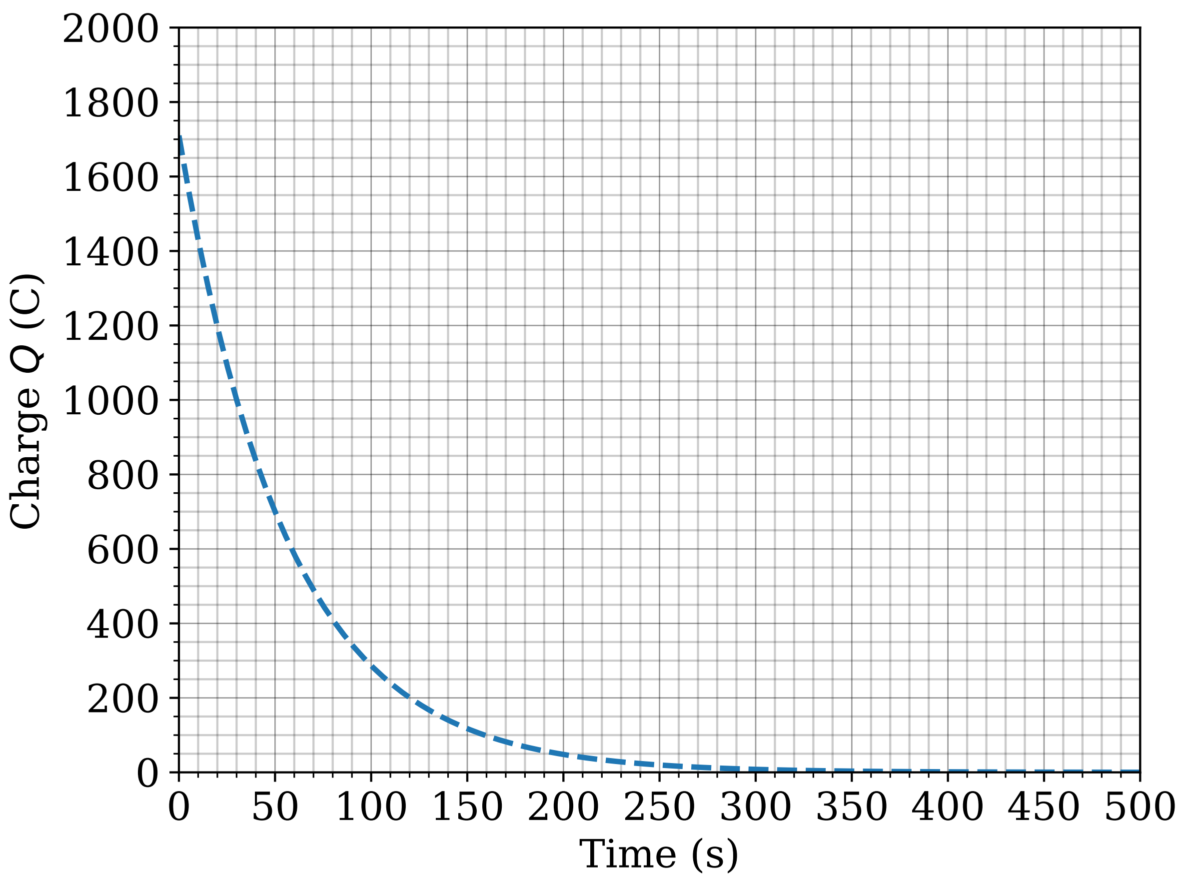
It is possible to find the value of RC from both charging and discharging graphs - the more common type you will see at A-level is to find RC from discharge graphs, though it is not beyond the realm of possibility that you may have to do so from a charging graph, so we will cover this case too.

5 Finding the time constant $\tau = RC$ from discharge graphs

We can use our knowledge of the discharge equation to find the value of RC from discharge graphs. There are several ways to do this, and we will go through each.

5.1 *Finding RC using the 37% rule.*

Worked Example 5-0 - Finding RC from discharge graphs



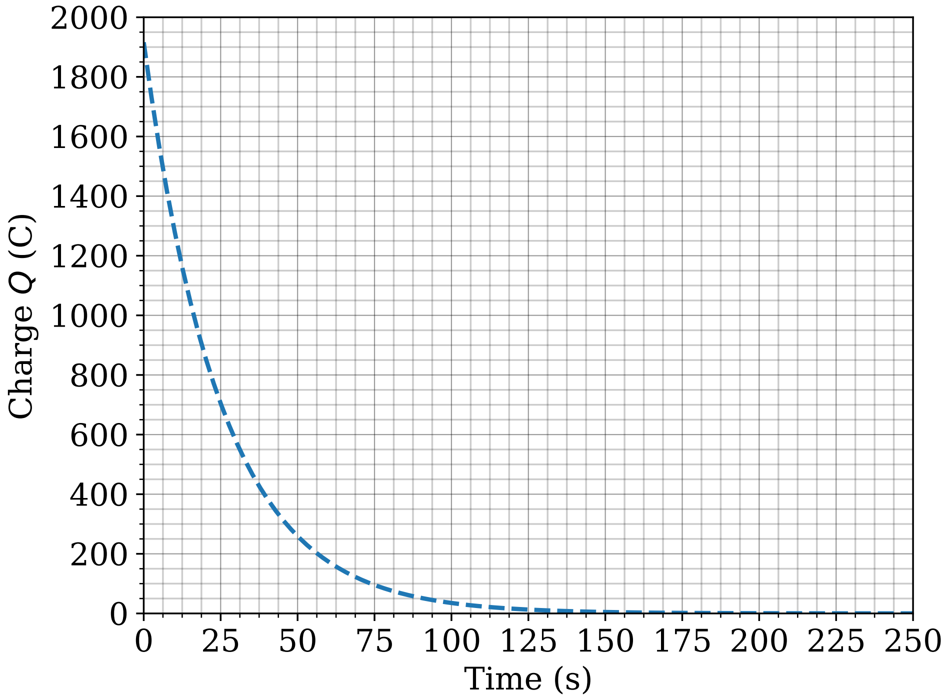
The first way is to find how long it takes for the initial charge to fall to 37% of its original value.

From the graph, the initial charge is $Q_0 = 1700$. 37% of this is $0.37 * Q_0 = 629$. Drawing a line across from the y-axis and down to the x-axis yields a value of 55 on the time axis, and so $RC = 55$ s.

This works because when the elapsed time is $t = RC$ are decay equation turns from $Q = Q_0 e^{-\frac{t}{RC}}$ to $Q = Q_0 e^{-\frac{RC}{RC}} = Q_0 e^{-1} = 0.37 Q_0$.

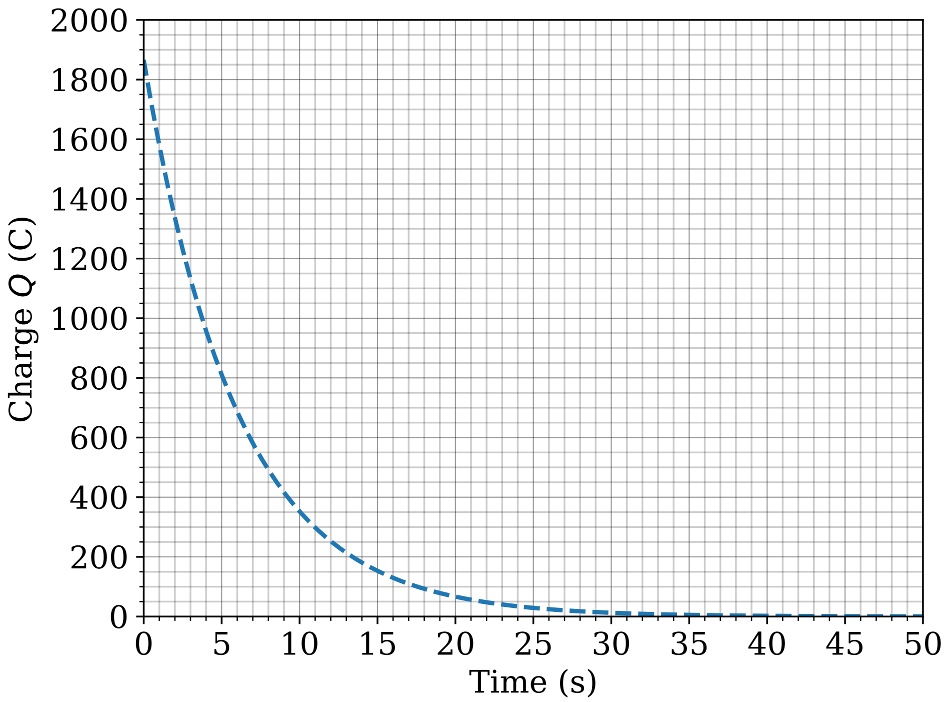
Practice Questions 5-1 - Finding RC from discharge graphs

1.



Initial Charge Q_0 (from graph) =
$0.37Q_0$ (calculated) =
$\tau = RC$ (from graph) =

2.



Initial Charge Q_0 (from graph) =
$0.37Q_0$ (calculated) =
$\tau = RC$ (from graph) =

5.2 *Finding RC using the time to halve*

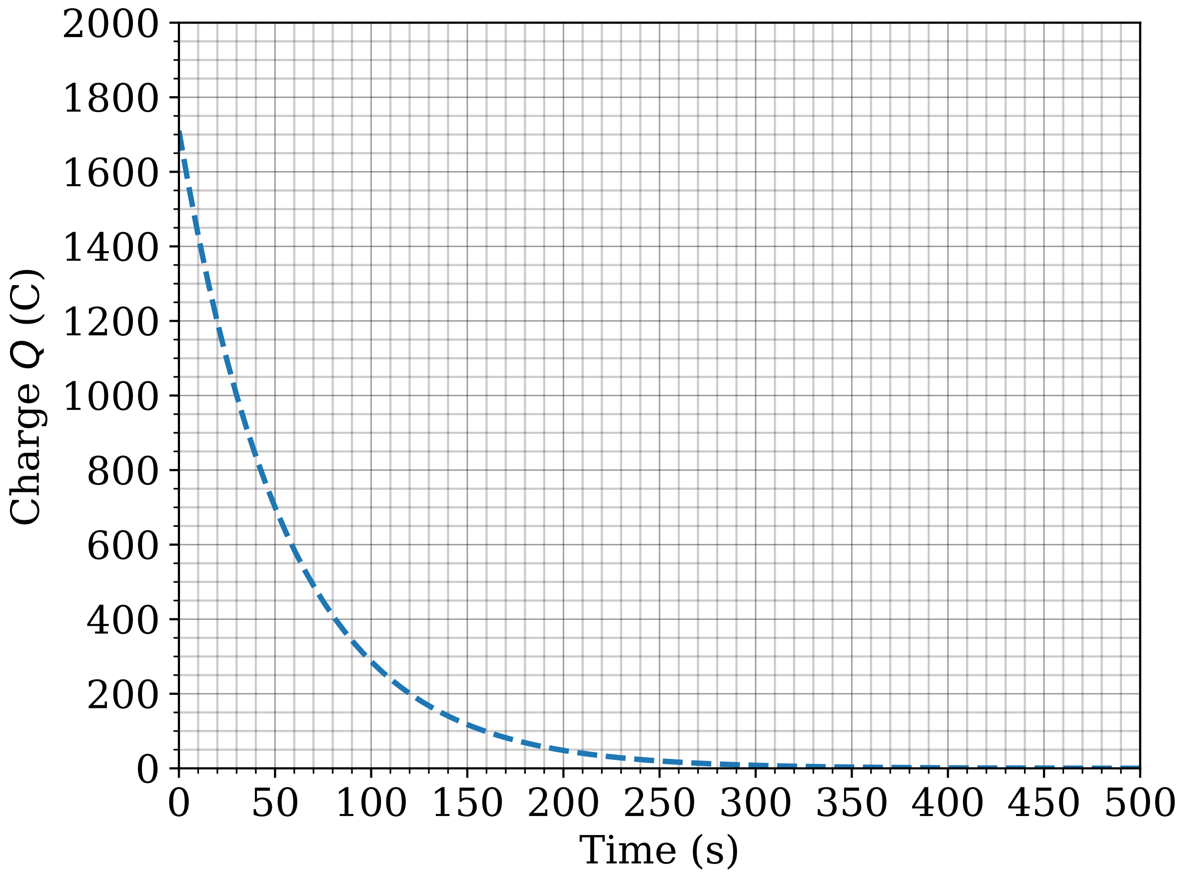
An alternative method is to find out how long it takes for amount of charge to halve - this is very similar to the technique you used to find the half-life of a radioactive element at GCSE and the same as the method you will use for radioactive decay at A-level.

If we re-arrange our equation

$$\begin{aligned}
Q &= Q_0 e^{-\frac{t}{RC}} \\
\implies \frac{Q_0}{2} &= Q_0 e^{-\frac{t_{1/2}}{RC}} \\
\implies \frac{1}{2} &= e^{-\frac{t_{1/2}}{RC}} \\
\implies \ln\left(\frac{1}{2}\right) &= -\frac{t_{1/2}}{RC} \\
\implies \ln 1 - \ln 2 &= -\frac{t_{1/2}}{RC} \\
\implies -\ln 2 &= -\frac{t_{1/2}}{RC} \\
\implies RC \ln 2 &= t_{1/2} \\
\implies RC &= \frac{t_{1/2}}{\ln 2} \\
\implies RC &= \frac{t_{1/2}}{0.69}
\end{aligned}$$

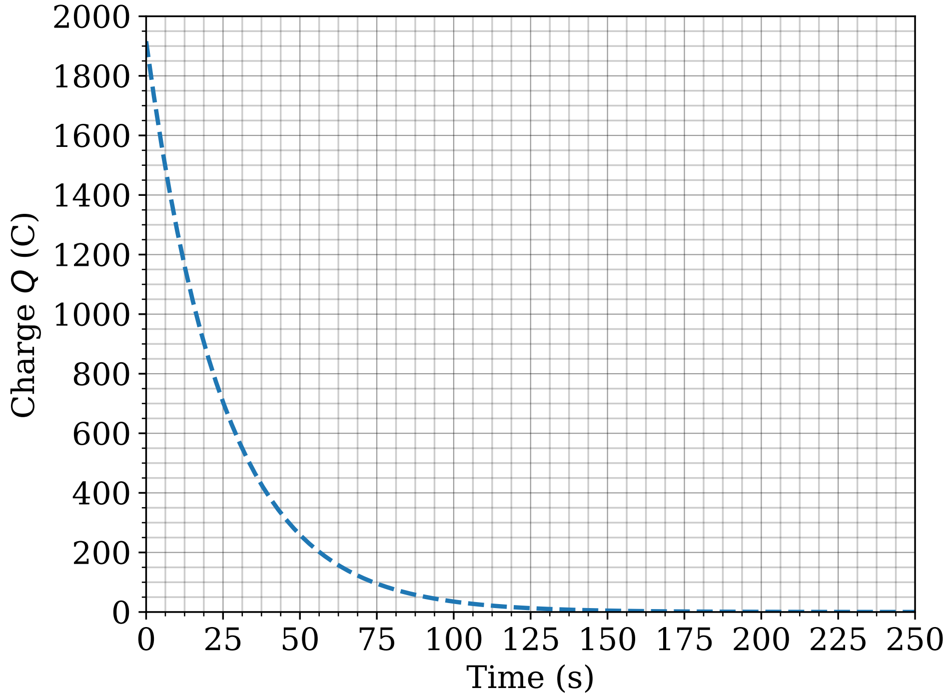
and so we can find the constant RC by finding the time for the charge to halve $t_{1/2}$ from the graph, and then plugging into the equation above.

Worked Example 5-1 - Finding RC from discharge graphs

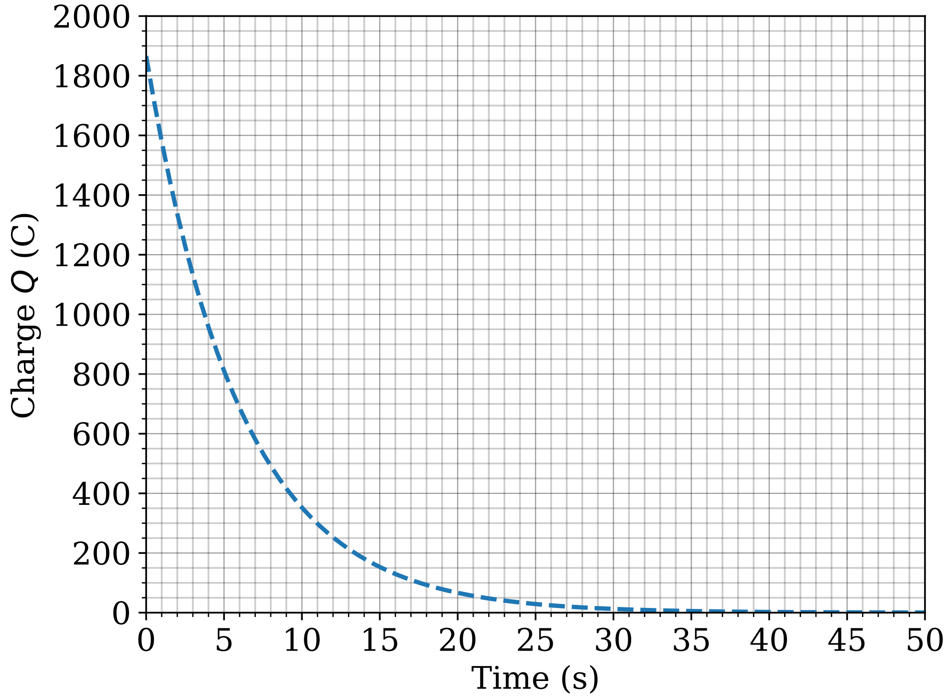


In this particular graph, the initial charge is $Q_0 = 1700$. 50% of this is $0.5 * Q_0 = 850$. Drawing a line across from the y-axis and down to the x-axis yields a half-life of $t_{1/2} = 40$, and so $RC = \frac{t_{1/2}}{0.69} = \frac{40}{0.69} = 58$ s, which is in close agreement with the value obtained using the 37% method - the difference comes from small errors in reading values from the graph.

Practice Questions 5-2 - Finding RC from discharge graphs

1. 

Initial Charge Q_0 (from graph) =
$0.5Q_0$ (calculated) =
$t_{1/2}$ (from graph) =
$RC = \frac{t_{1/2}}{0.69}$ (calculated) =

2. 

Initial Charge Q_0 (from graph) =
$0.5Q_0$ (calculated) =
$t_{1/2}$ (from graph) =
$RC = \frac{t_{1/2}}{0.69}$ (calculated) =

5.3 *Finding RC using log-linear graphs*

The final way is to plot log graphs of the relevant quantity. Starting with our discharge equation:

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

We take logs of both sides:

Here we have used the log rule that $\ln(xy) = \ln x + \ln y$

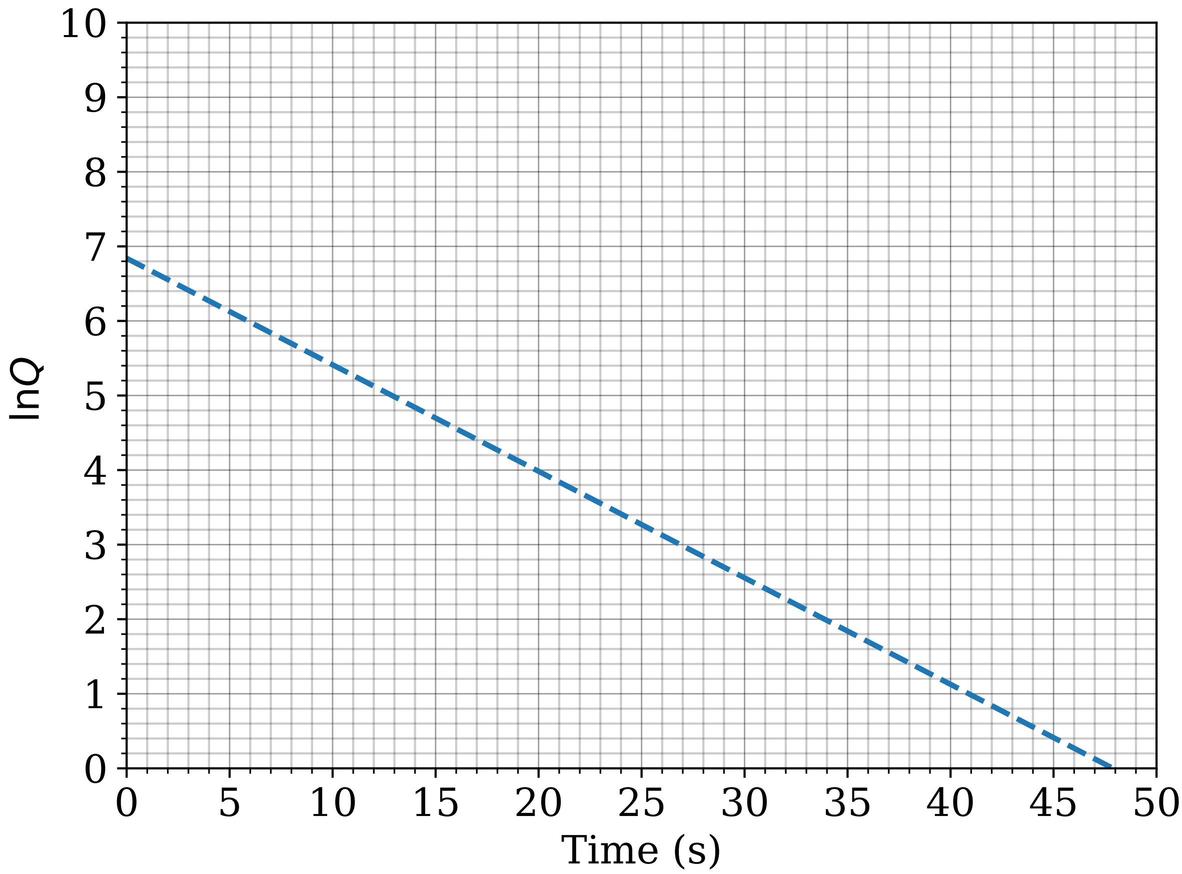
$$\implies \ln Q = \ln\left(Q_0 e^{-\frac{t}{RC}}\right)$$
$$\implies \ln Q = \ln(Q_0) + \ln\left(e^{-\frac{t}{RC}}\right)$$
$$\implies \ln Q = \ln(Q_0) - \frac{t}{RC}$$

If we plot a graph of $\ln Q$ (y-axis) against t (x-axis) and compare with $y = mx + c$ we see that:

$$y = mx + c$$
$$\ln Q = \ln(Q_0) - \frac{t}{RC}$$

and therefore the y-intercept c gives us the log of the initial charge $c = \ln Q_0$ and the gradient of the graph m gives us RC via the relation $m = -\dfrac{1}{RC}$.

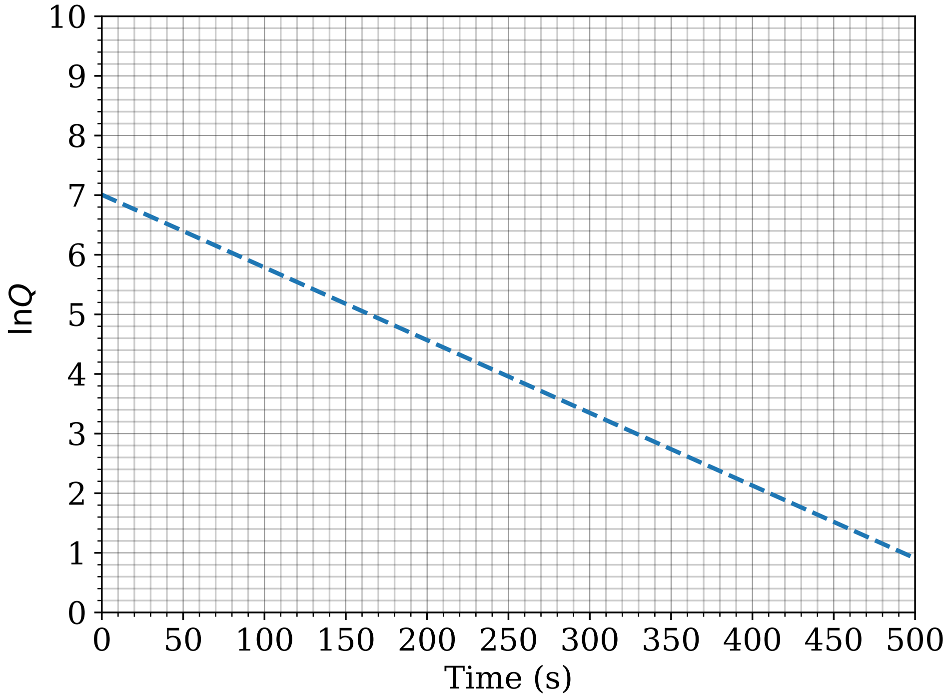
Worked Example 5-2 - Finding RC from log-linear discharge graphs



From the graph:

$$\begin{aligned} \Delta \ln Q &= 0 - 6.85 \\ \Delta t &= 47.5 - 0 \\ \implies m &= \frac{\Delta \ln Q}{\Delta t} = \frac{-6.85}{47.5} = -0.144 \\ \implies RC &= -\frac{1}{m} = -\frac{1}{-0.142} = 7 \end{aligned}$$

Practice Questions 5-3 - Finding RC from log-linear discharge graphs

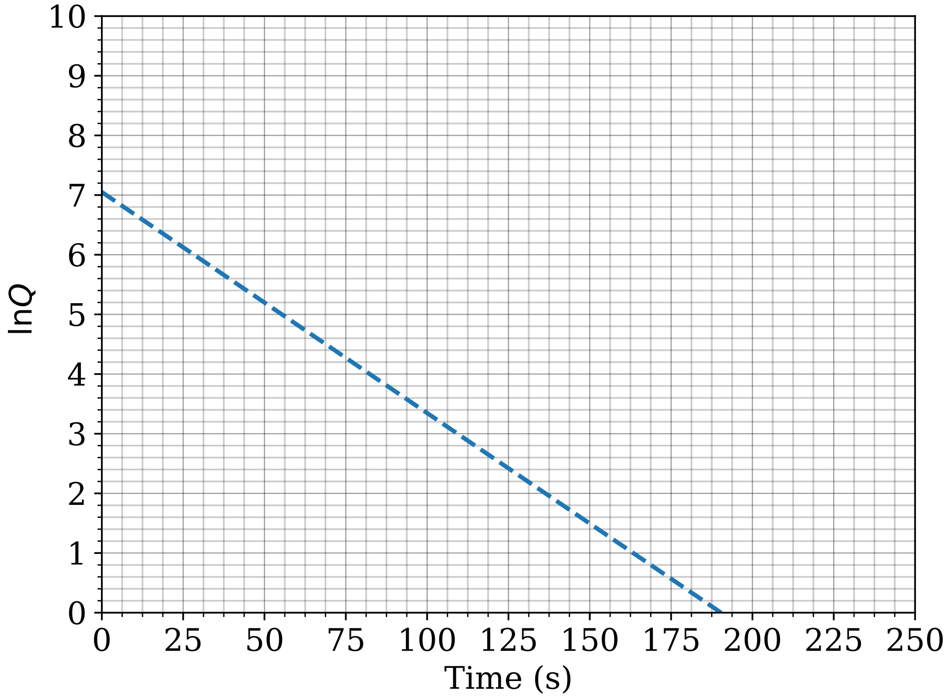
1. 

$\Delta \ln Q$ (from graph) =

Δt (from graph) =

Gradient $m = \dfrac{\Delta \ln Q}{\Delta t}$ (calculated) =

$RC = -\dfrac{1}{m}$ (calculated) =

2. 

$\Delta \ln Q$ (from graph) =

Δt (from graph) =

Gradient $m = \dfrac{\Delta \ln Q}{\Delta t}$ (calculated) =

$RC = -\dfrac{1}{m}$ (calculated) =

6 Capacitors and Circuits

Combinations of capacitors can be added to give "equivalent" capacitances, just as we can do with resistors. Adding combinations of capacitors follows the opposite rule to adding resistors.

6.1 Capacitors in Series

When we have multiple capacitors in a circuit, capacitors in series are added using the following rule:

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

6.2 Capacitors in Parallel

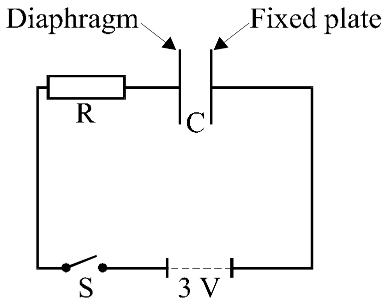
$$C = C_1 + C_2 + ...$$

7 Workbook

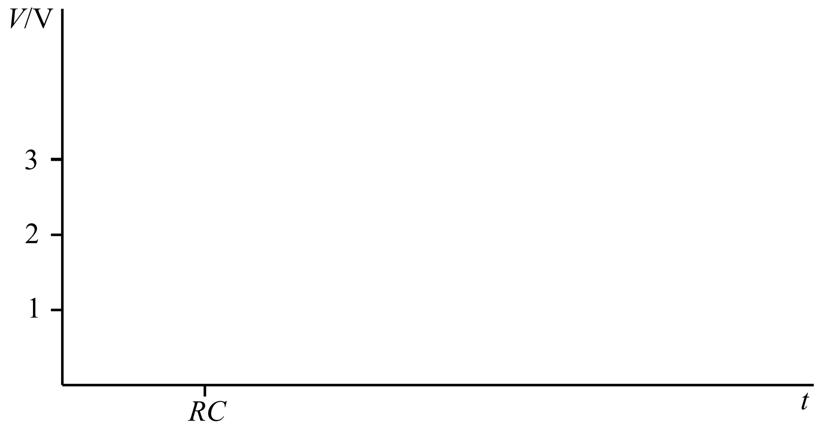
Questions on Capacitors

1. Most types of microphone detect sound because the sound waves cause a diaphragm to vibrate. In one type of microphone this diaphragm forms one plate of a parallel plate capacitor. As the diaphragm plate moves. the capacitance chances. Moving the plates closer together increases the capacitance. Moving the plates further apart reduces the capacitance.

This effect is used to produce the electrical signal. The circuit shown below consists of a 3 V supply, an **uncharged** capacitor microphone C. a resistor R. and a switch S.



The switch S is closed. Sketch a graph of the voltage across the capacitor microphone against time. Assume that the capacitor microphone is not detecting any sound.



(3)

Explain why movement of the diaphragm causes a potential difference (the signal) across R.

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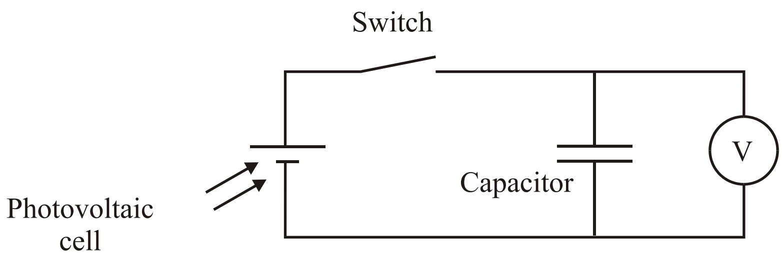
(4)
(Total 7 marks)

2. The circuit below models a single pixel of a CCD device. The photocell generates a voltage which depends on the intensity of light falling on it. When information about light intensity is required, the switch is opened. The voltage across the capacitor at that instant can be read out into an electronic circuit (represented by the voltmeter) at a later time.



The capacitor has a value of 0.22 F. In an experiment the voltmeter reads 95 mV after the switch is opened. Calculate the charge on the capacitor.

....

....

Charge = ...

(2)

This voltmeter reads 95 mV for some considerable time. State what this tells you about this voltmeter.

....

....

(1)

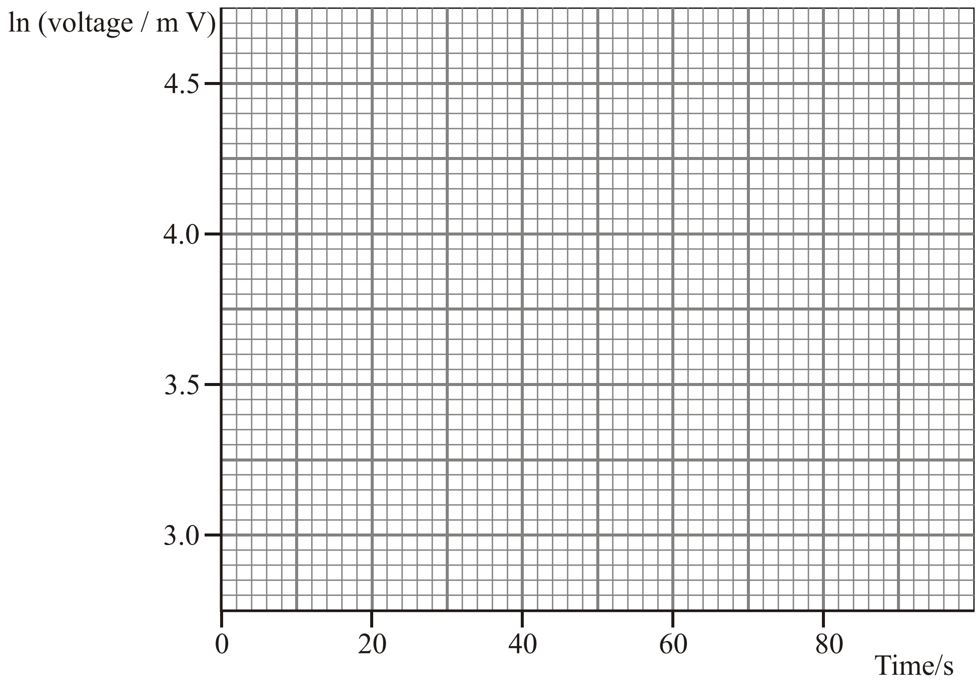
The student doing the experiment changes the voltmeter for another. With the **new** voltmeter the voltage changes with time according to the table below.

Time/s	Voltage/mV	ln(voltage/mV)
0	95	4.55
20	67	4.20
40	46	
60	33	
80	22	

The student thinks the voltage is falling exponentially. To test this he makes a third column in his table to calculate values for ln(voltage/mV). Complete the table.

(1)

Plot the points from the table on the graph below. Join the points with an appropriate line.



(3)

Explain how the graph shows that the voltage decreases exponentially.

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(2)

Find the approximate value for the resistance of the second voltmeter.

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....

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....

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Resistance = ...

(3)
(Total 12 marks)

3. A student is learning about how capacitors work. He uses the circuit shown in Figure 1 to investigate the capacitor C. Letter X labels a connection which he can make to either of the points L or M. Each cell has an e.m.f. of 1.5 V.

Figure 1

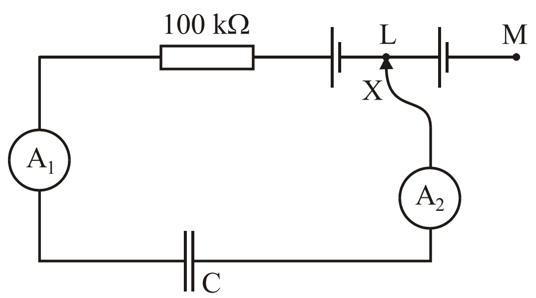
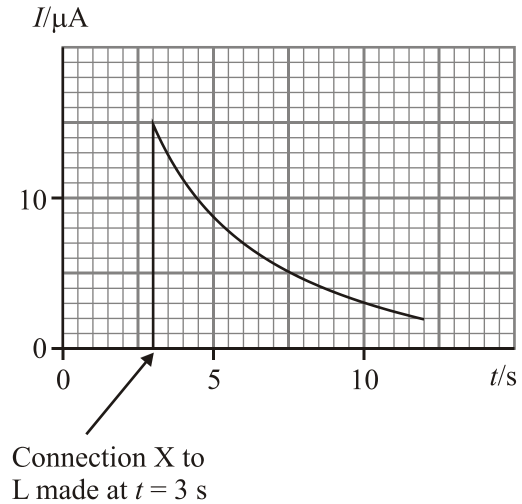


Figure 2



He connects X to L. He sketches how the reading on ammeter 1 varies with time (Figure 2).

Explain in terms of charge what has happened in the circuit.

....

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(3)

Explain what he would have seen if he had watched ammeter 2.

....

....

....

(2)

Use his sketch graph (Figure 2) to estimate the charge which has passed through ammeter 1 between the times t = 3 s and t = 10 s.

....

....

....

Charge = ...

(2)

Use the graph and your answer above to estimate the capacitance of the capacitor.

....

....

....

....

Capacitance = ...

(3)

State and explain what he would observe on each ammeter if he then continued the experiment by moving the connection X from L to M.

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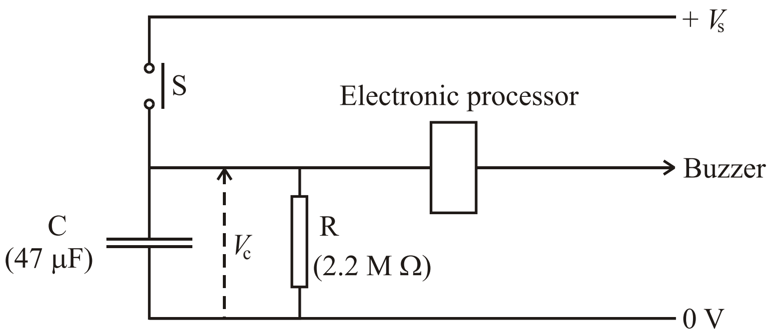
(2)
(Total 12 marks)

4. The diagram shows a simple timing circuit.



The electronic processor operates so that the buzzer sounds when V_c is greater than $\frac{3}{4}$ V_s. The switch S is normally open. Explain in detail what happens in the circuit after the switch S is closed for a moment then opened again. Your answer should include an appropriate calculation and a sketch graph.

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(Total 7 marks)

5. Define capacitance.

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(2)

An uncharged capacitor of 200 μF is connected in series with a 470 kΩ resistor, a 1.50 V cell and a switch. Draw a circuit diagram of this arrangement.

(1)

Calculate the maximum current that flows.

....

....

Current ....

(2)

Sketch a graph of voltage against charge for your capacitor as it charges. Indicate on the graph the energy stored when the capacitor is fully charged.

(4)

Calculate the energy stored in the fully-charged capacitor.

....

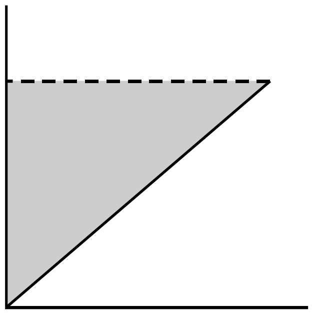
....

Energy = ...

(2)

(Total 11 marks)

6. The diagram shows a graph of charge against voltage for a capacitor.



What quantity is represented by the slope of the graph?

....

What quantity is represented by the shaded area?

....

(2)

An electronic camera flash gun contains a capacitor of 100 μF which is charged to a voltage of 250 V. Show that the energy stored is 3.1 J.

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(2)

The capacitor is charged by an electronic circuit that is powered by a 1.5 V cell. The current drawn from the cell is 0.20 A. Calculate the power from the cell and from this the minimum time for the cell to recharge the capacitor.

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....

....

Minimum time = ...

(3)

(Total 7 marks)

7. A defibrillator is a machine that is used to correct irregular heartbeats by passing a large current through the heart for a short time. The machine uses a 6000 V supply to charge a capacitor of capacitance 20 μF. The capacitor is then discharged through the metal electrodes (defibrillator paddles) which have been placed on the chest of the patient.

Calculate the charge on the capacitor plates when charged to 6000 V.

....

Charge = ...

(2)

Calculate the energy stored in the capacitor.

....

....

Energy = ...

(2)

When the capacitor is discharged, there is an initial current of 40 A through the patient.

Calculate the electrical resistance of the body tissue between the metal electrodes of the paddles.

....

....

Resistance = ...

(1)

Assuming a constant discharge rate of 40 A, calculate how long it would take to discharge the capacitor.

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....

....

Time = ...

(2)

In practice the time for discharge is longer than this calculated time. Suggest a reason for this

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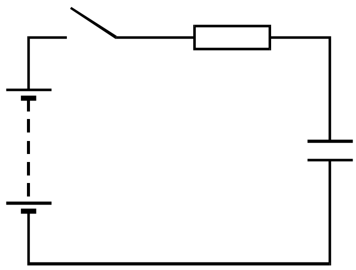
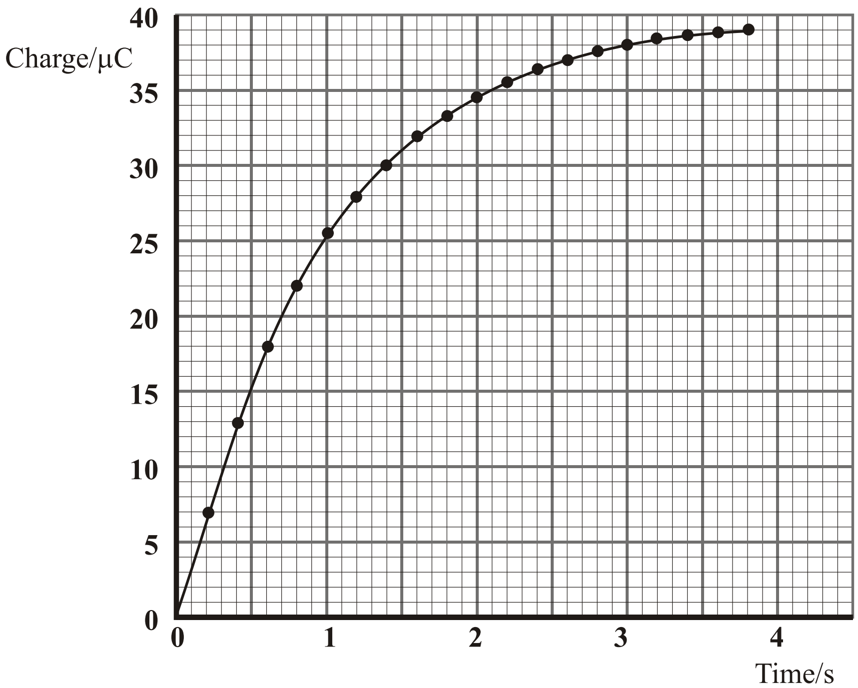
(1)
(Total 8 marks)

8. The circuit shown is used to charge a capacitor.



The graph shows the charge stored on the capacitor whilst it is being charged.



On the same axes, sketch as accurately as you can a graph of current against time.
Label the current axis with an appropriate scale.

(4)

The power supply is 3 V. Calculate the resistance of the charging circuit.

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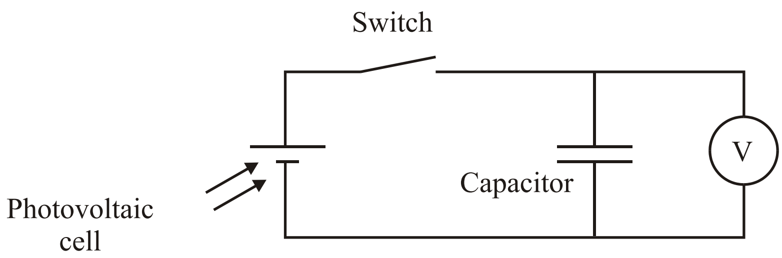
....

Resistance = ...

(2)
(Total 6 marks)

9. The circuit below models a single pixel of a CCD device. The photocell generates a voltage which depends on the intensity of light falling on it. When information about light intensity is required, the switch is opened. The voltage across the capacitor at that instant can be read out into an electronic circuit (represented by the voltmeter) at a later time.



The capacitor has a value of 0.22 F. In an experiment the voltmeter reads 95 mV after the switch is opened. Calculate the charge on the capacitor.

....

....

Charge = ...

(2)

This voltmeter reads 95 mV for some considerable time. State what this tells you about this voltmeter.

....

....

(1)

The student doing the experiment changes the voltmeter for another. With the **new** voltmeter the voltage changes with time according to the table below.

Time/s	Voltage/mV	ln(voltage/mV)
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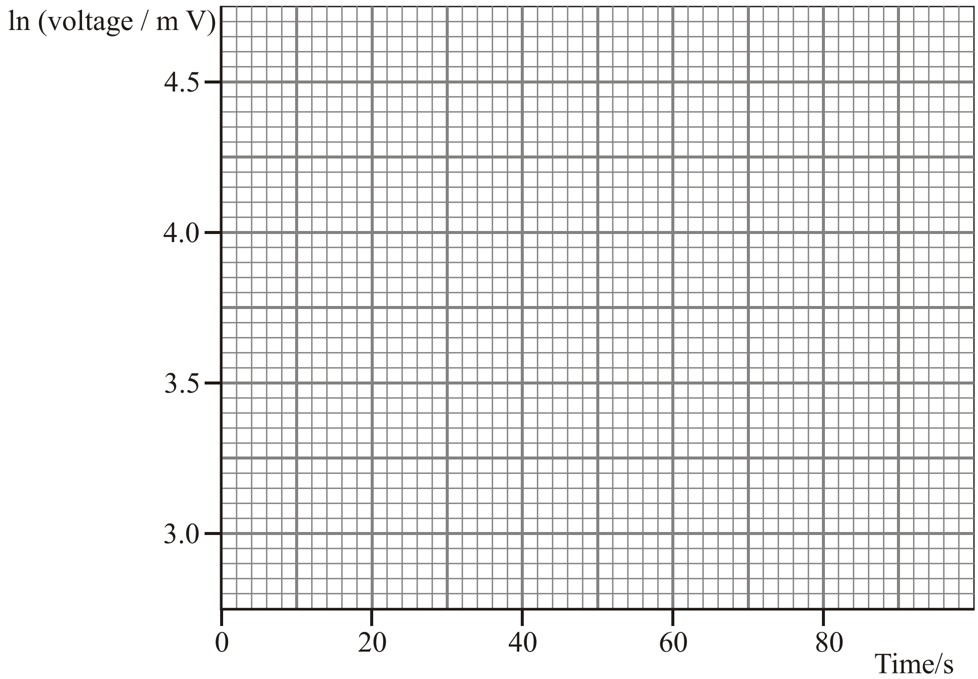
The student thinks the voltage is falling exponentially. To test this he makes a third column in his table to calculate values for ln(voltage/mV). Complete the table.

(1)

Plot the points from the table on the graph below. Join the points with an appropriate line.



(3)

Explain how the graph shows that the voltage decreases exponentially.

....

....

....

(2)

Find the approximate value for the resistance of the second voltmeter.

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....

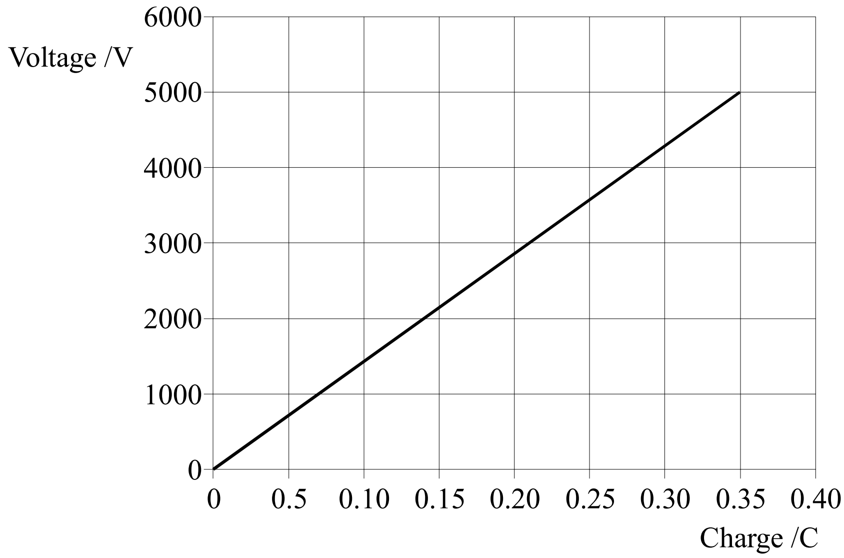
....

Resistance = ...

(3)
(Total 12 marks)

10. To restore a regular heart rhythm to a patient in an emergency, paramedics can use a machine called a defibrillator. The defibrillator uses a capacitor to store energy at a voltage of several thousand volts. Conducting 'paddles' are placed on either side of the patient's chest, and a short pulse of current flows between them when the capacitor is discharged.

The graph below shows voltage against charge for the capacitor used in a defibrillator.



With reference to the graph, show that the energy stored in a capacitor is given by the formula $W = \frac{1}{2}QV$.

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....

(2)

Calculate the energy stored by the capacitor when charged to 5000 V.

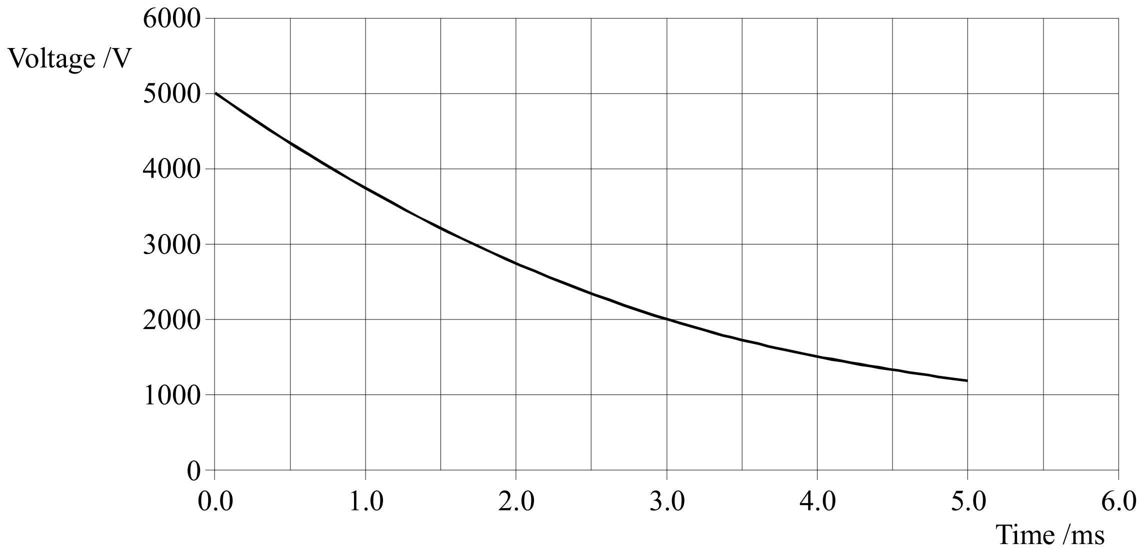
....

....

Energy = ...

(1)

The graph below shows how voltage varies with time as the capacitor's discharged across a test circuit that has a resistance equivalent to that of the patient's chest.



Use the graph to find the time constant for the circuit.

....

....

Time constant = ...

(2)

The total resistance of the circuit, including the paddles and chest, is 47 Ω. Calculate the capacitance of the capacitor.

....

....

Capacitance = ...

(2)

The energy delivered to the patient's chest is selected by the operator from these settings: 50 J, 180 J, 380 J. This is achieved inside the machine electronically, by allowing the discharge to proceed for an appropriate length of time.

On one particular setting, the discharge lasts for 2.0 ms. Calculate the energy left in the capacitor at this time.

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....

(2)

Some energy loss occurs and roughly 60% of the energy leaving the capacitor during the discharge actually goes into the patient. Find which setting the operator has selected.

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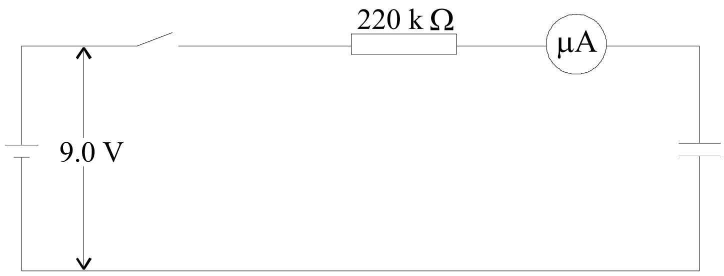
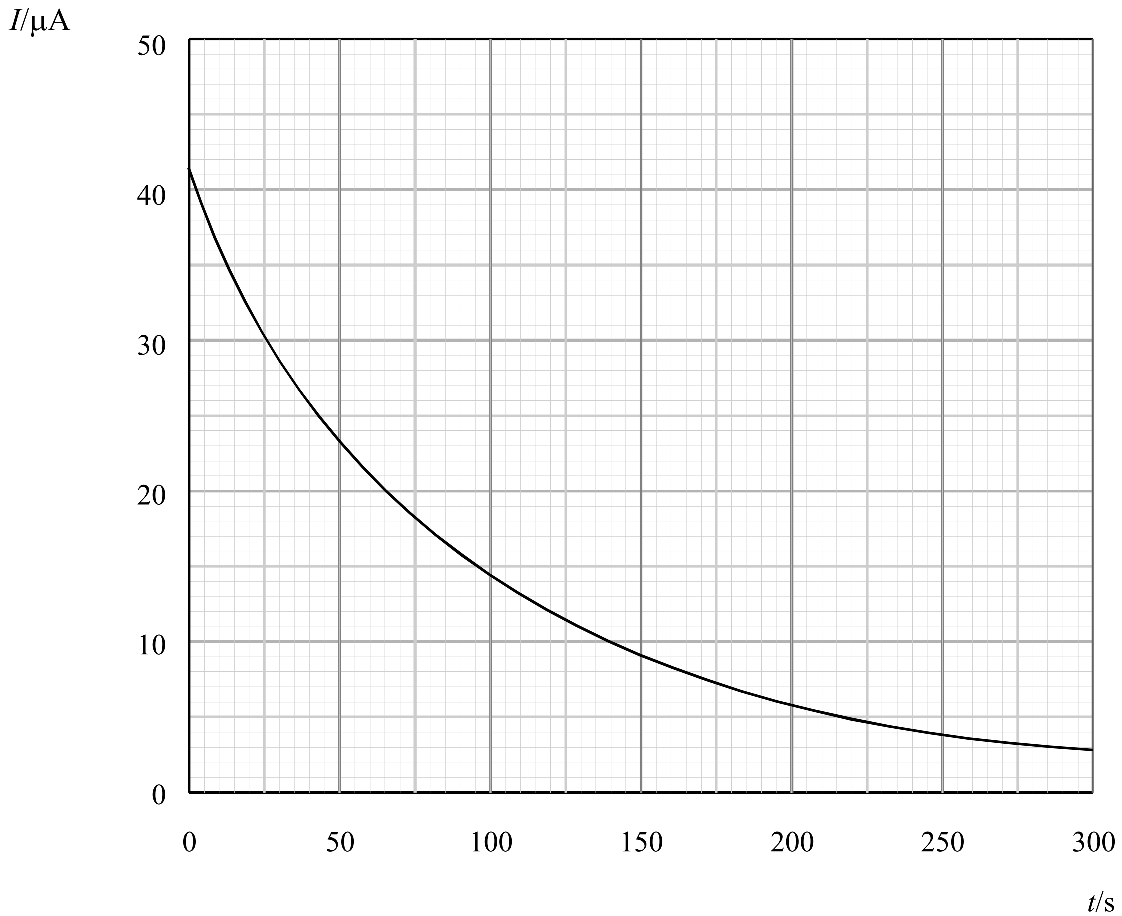
Energy setting = ...

(2)
(Total 11 marks)

11. A student assembles the circuit shown in which the switch is initially open and the capacitor uncharged.



He closes the switch and reads the microammeter at regular intervals of time. The battery maintains a steady p.d. of 9.0 V throughout. The graph shows how the current *I* varies with the time *t* since the switch was closed.



Use the graph to estimate the total charge delivered to the capacitor.

....

....

....

Charge =..

(3)

Estimate its capacitance.

....

....

Capacitance =..

(2)
(Total 5 marks)

12. The potential difference between the plates of a 220 μF capacitor is 5.0 V.

Calculate the **charge** stored on the capacitor.

………..……..………………………………………………………………………………..

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Charge = ...

(2)

Calculate the **energy** stored by the capacitor.

………..……..………………………………………………………………………………..

………..……..………………………………………………………………………………..

Energy = ...

(2)

Describe how you would show experimentally that the charge stored on a 220 μF capacitor is proportional to the potential difference across the capacitor for a range of potential differences between 0 and 15 V. Your answer should include a circuit diagram.

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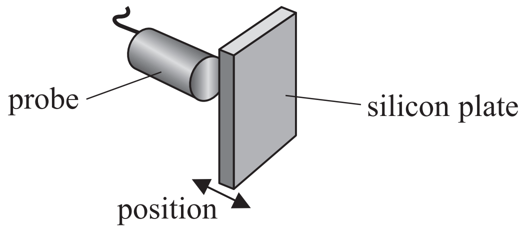
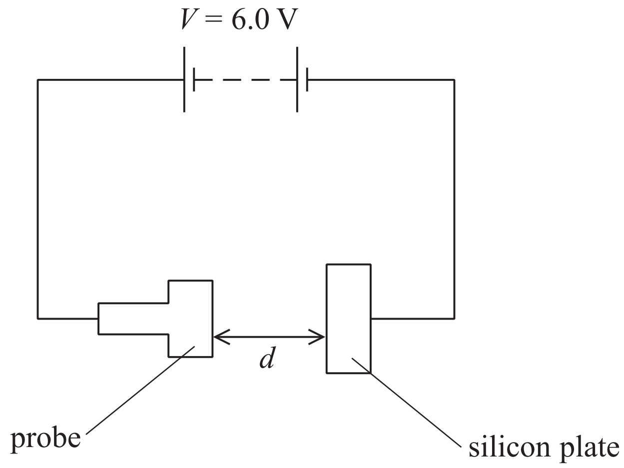
(5)
(Total 9 marks)

1 During the manufacture of some computer components it is necessary to monitor the position of pieces of silicon.

Capacitors can be used to detect a change in the position of a piece of silicon. The piece of silicon forms one plate of a capacitor whilst a probe acts as the other plate as shown in the diagram.



The capacitor is charged by connecting it to a 6.0 V battery as shown in the diagram below.



The relationship between the capacitance C and the distance d between the silicon plate and the probe is

$$C = k/d$$

where k is a constant.

(a) Explain qualitatively how the charge on the capacitor will vary if the silicon plate moves away from the probe.

(2)

(b) When the silicon is in a certain position, the probe is 3.5 mm from it. The silicon must remain within 0.70 mm of this position.

Determine the maximum allowable percentage decrease in the charge on the capacitor.

$k = 2.8 \times 10^{-15}$ F m

(4)

Maximum allowable percentage decrease =

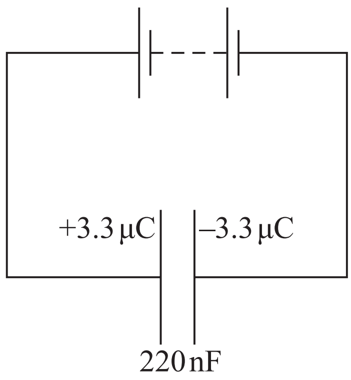
(c) In order to detect rapid changes in the position of the silicon, it is necessary to use a capacitor with a small capacitance.

Explain why.

(2)

(Total for Question = 8 marks)

2 A capacitor is charged by a battery as shown in the circuit diagram2



(a) Calculate the e.m.f. of the battery and the energy stored in the charged capacitor.

(4)

E.m.f. =

Energy =

(b) The capacitor is disconnected from the battery and discharged through a 20 MΩ resistor.

Calculate the time taken for 80% of the charge on the capacitor to discharge through the resistor.

(3)

Time taken =

(c) Use an equation to explain whether the time taken for the capacitor to lose half its energy is greater or less than the time taken to lose half its charge.

(3)

(d) A student carries out an experiment to record data so that she can plot a graph of potential difference against time as the capacitor discharges.

State **two** advantages of using a datalogger rather than a voltmeter and stopwatch to record this data.

(2)

(Total for Question = 12 marks)

3 In recent years there has been a development of ultracapacitors which have much higher capacitance than traditional capacitors. Capacitors store energy due to charge in an electric field whereas batteries store energy due to a chemical reaction. There are several applications where ultracapacitors have an advantage over batteries; for example storing energy from rapidly fluctuating supplies or delivering charge very quickly.

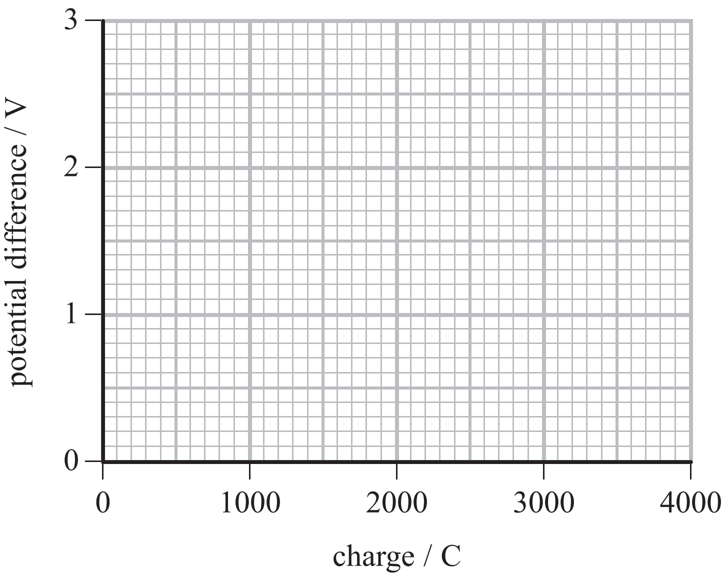
(a) A typical ultracapacitor has a capacitance of 1500 F and a maximum operating potential difference of 2.6 V.

(i) Show that the charge on this capacitor when fully charged is about 4000 C.

(2)

(ii) Complete the graph on the axes below to show how the potential difference varies with charge for this capacitor.

(2)

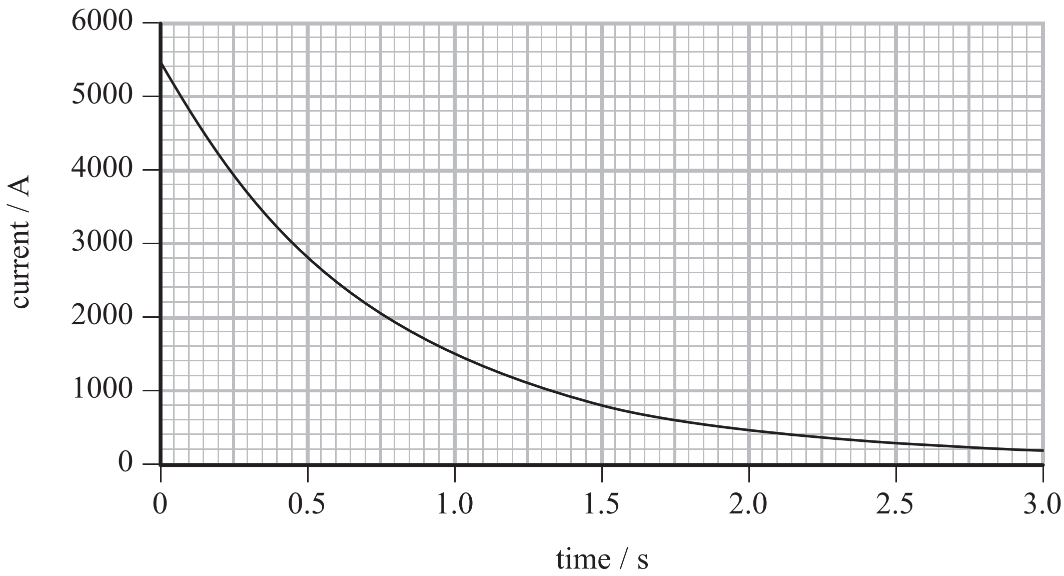


(iii) Calculate the energy stored in this capacitor when fully charged.

(2)

Energy =

(b) The graph below shows how the current varies with time as the capacitor is discharged through a circuit.



(i) Describe and explain the shape of the graph.

(2)

(ii) Calculate the resistance of the circuit.

(4)

Resistance =

(c) There is a limit to the amount of charge an ultracapacitor can hold but it can deliver the charge very quickly. A battery can deliver much more charge but only at a slower rate. For electric powered vehicles it is suggested that using a combination of batteries and ultracapacitors would give the best performance.

Suggest, with reasons, which stages of a journey would be more suited to ultracapacitors and which would be more suited to batteries.

(3)

(Total for Question = 15 marks)

4 A student is investigating how the potential difference across a capacitor varies with time as the capacitor is charging.

He uses a 100 μF capacitor, a 5.0 V d.c. supply, a resistor, a voltmeter and a switch.

(a) (i) Draw a diagram of the circuit he should use.

(2)

(ii) Suggest why a voltage sensor connected to a data logger might be a suitable instrument for measuring the potential difference across the capacitor in this investigation.

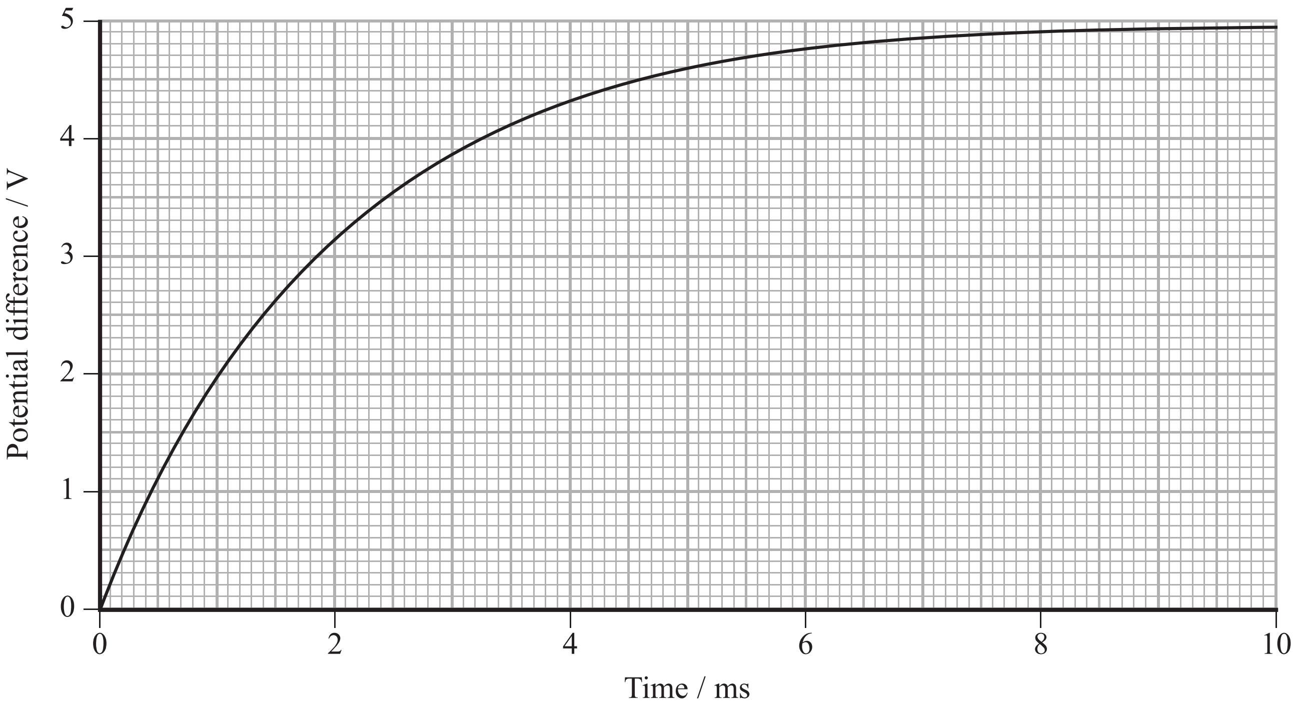
(1)

(b) Calculate the maximum charge stored on the capacitor.

(2)

Charge =

(c) The graph shows how the potential difference across the capacitor varies with time as the capacitor is charging.



(i) Estimate the average charging current over the first 10 ms.

(2)

Average charging current =

(ii) Use the graph to estimate the initial rate of increase of potential difference across the capacitor and hence find the initial charging current.

(3)

Initial charging current =

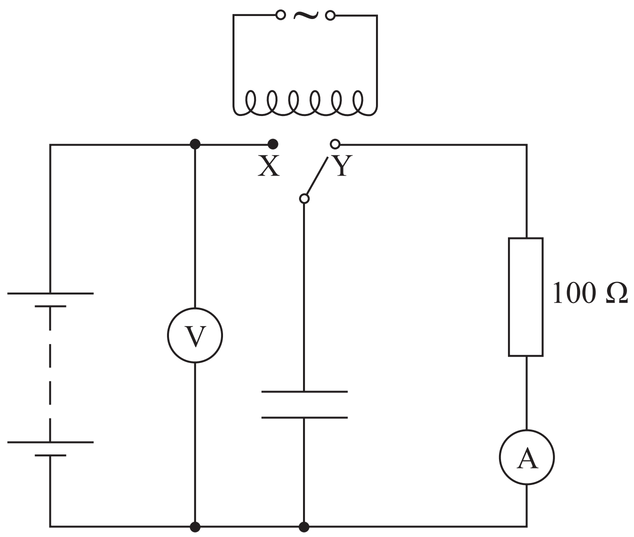
(iii) Use the value of the initial charging current to find the resistance of the resistor.

(2)

Resistance =

(Total for Question = 12 marks)

5 A student is investigating capacitors. She uses the circuit below to check the capacitance of a capacitor labelled 2.2 μF which has a tolerance of ±30%.



The switch flicks between contacts, X and Y, so that the capacitor charges and discharges *f* times per second.

(a) The capacitor must discharge fully through the 100 Ω resistor.

(i) Explain why 400 Hz is a suitable value for *f*.

(3)

....

....

....

....

....

....

(ii) Show that the capacitance C can be given by

$$C = \frac{I}{fV}$$

where I is the reading on the ammeter and V is the reading on the voltmeter.

(3)

....

....

....

....

(iii) The student records I as 5.4 mA and V as 5.0 V.

Calculate the capacitance C.

(2)

....

....

....

....

C ....

(iv) Explain whether you think this value is consistent with the tolerance given for this capacitor.

(2)

....

....

....

....

(b) Calculate the energy stored on the capacitor when it is charged to a potential difference of 5.0 V.

(2)

....

....

....

Energy ....

(Total for Question 12 marks)

6 A student needs to order a capacitor for a project. He sees this picture on a web site accompanied by this information: capacitance tolerance ±20%.

Taking the tolerance into account, calculate

(a) the maximum charge a capacitor of this type can hold.

(3)

Maximum charge =

(b) the maximum energy it can store.

(2)

Maximum energy =

(Total for Question = 5 marks)

1 Figure 1 shows the output from the terminals of a power supply labelled d.c. (direct current).

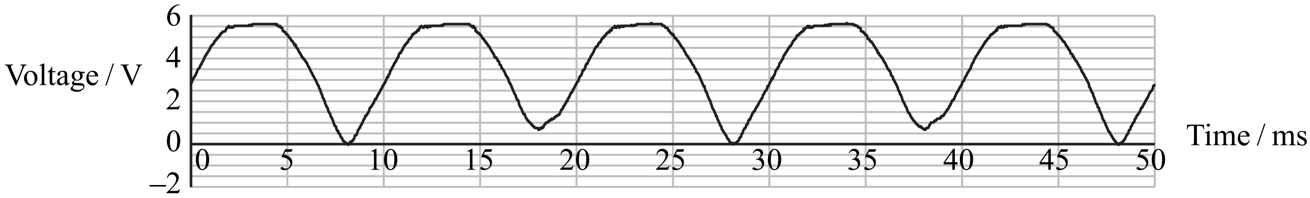


Figure 1

(a) An alternating current power supply provides a current that keeps switching direction.

Explain why the output shown in Figure 1 is consistent with the d.c. label.

(2)

(b) A teacher suggests that certain electronic circuits require a constant voltage supply to operate correctly.

(i) A student places a capacitor across the terminals of this power supply. Suggest how this produces a constant voltage.

(2)

(ii) She uses a 10 μF capacitor. Calculate the maximum energy stored in the capacitor.

(3)

Maximum Energy =

(c) She now adds an electronic circuit to the power supply plus capacitor. Figure 2 shows the supply to the electronic circuit. This is shown in Figure 2.

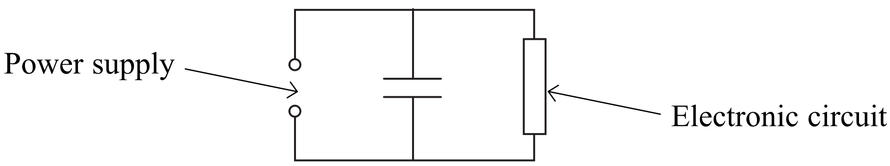


Figure 2

The variation in potential difference is shown by the graph in Figure 3.

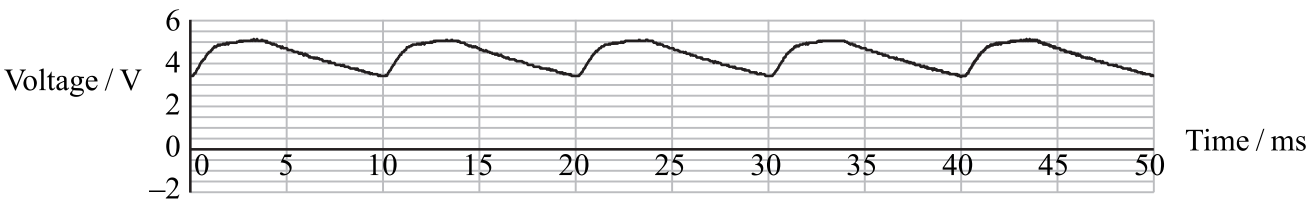


Figure 3

(i) Explain the shape of this gra

(3)

(ii) Take readings from the graph to show that the resistance of the electronic circuit is in the range 1000 Ω to 2000 Ω.

(3)

(iii) Figure 3 shows that the voltage supplied to the electronic circuit still varies. How could the student make it more constant?

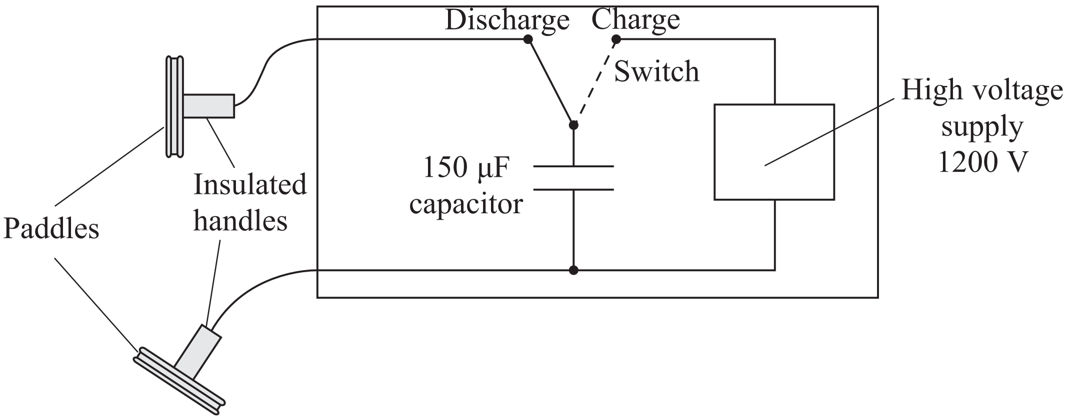
(1)

(Total for Question = 14 marks)

2 A defibrillator is a machine that is used to correct an irregular heartbeat or to start the heart of someone who is in cardiac arrest.

The defibrillator passes a large current through the heart for a short time.

The machine includes a high voltage supply which is used to charge a capacitor. Two defibrillation 'paddles' are placed on the chest of the patient and the capacitor is discharged through the patient.



(a) The 150 μF capacitor is first connected across the 1200 V supply.

Calculate the charge on the capacitor.

(2)

....

....

Charge ....

(b) Calculate the energy stored in the capacitor.

(2)

....

....

....

Energy stored ....

(c) When the capacitor discharges there is an initial current of 14 A in the chest of the patient.

(i) Show that the electrical resistance of the body tissue between the paddles is about 90 Ω.

(1)

....

....

(ii) Calculate the time it will take for three quarters of the charge on the capacitor to discharge through the patient.

(3)

....

....

....

....

....

Time ....

(iii) Body resistance varies from person to person. If the body resistance was lower, the initial current would be greater.

State how this lower body resistance affects the charge passed through the body from the defibrillator.

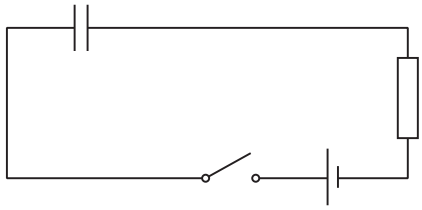
(1)

....

....

(Total for Question 9 marks)

3 The diagram shows a circuit that includes a capacitor.



(a) (i) Explain what happens to the capacitor when the switch is closed.

(2)

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(ii) The potential difference (p.d.) across the resistor rises to a maximum as the switch is closed.

Explain why this p.d. subsequently decreases to zero.

(2)

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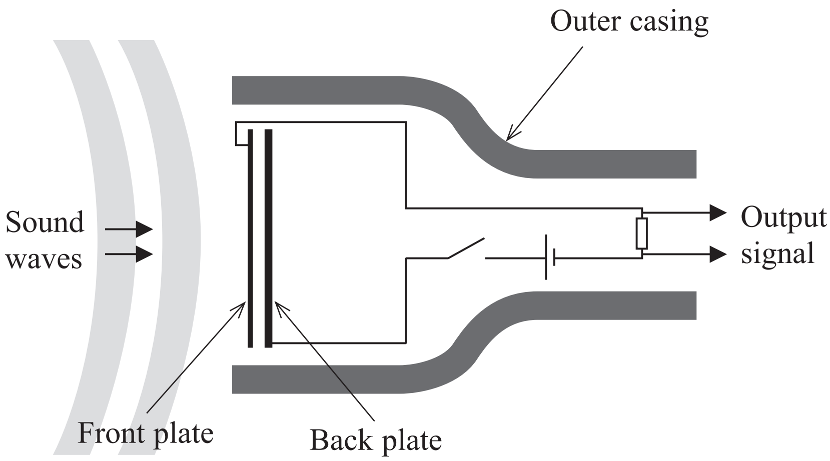
*(b) One type of microphone uses a capacitor. The capacitor consists of a flexible front plate (diaphragm) and a fixed back plate. The output signal is the potential difference across the resistor.



The sound waves cause the flexible front plate to vibrate and change the capacitance. Moving the plates closer together increases the capacitance. Moving the plates further apart decreases the capacitance.

Explain how the sound wave produces an alternating output signal.

(4)

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(c) A microphone has a capacitor of capacitance 500 pF and resistor of resistance 10 MΩ.

Explain why these values are suitable even for sounds of the lowest audible frequency of about 20 Hz.

(4)

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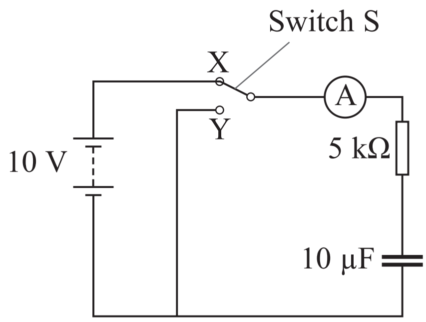
(Total for Question 12 marks)

4 A student sets up the circuit shown in the diagram.



(a) (i) She moves switch S from X to Y. Explain what happens to the capacitor.

(2)

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(ii) On the axis below, sketch a graph to show how the current in the ammeter varies with time from the moment the switch touches Y. Indicate typical values of current and time on the axes of your graph.

(3)

(iii) Describe how the graph would appear when the switch is moved back to X.

(2)

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(b) Calculate the maximum energy stored on the capacitor in this circuit.

(2)

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Maximum energy ....

(c) The student wants to use this circuit to produce a short time delay, equal to the time it takes for the potential difference across the capacitor to fall to 0.07 of its maximum value.

Calculate this time delay.

(2)

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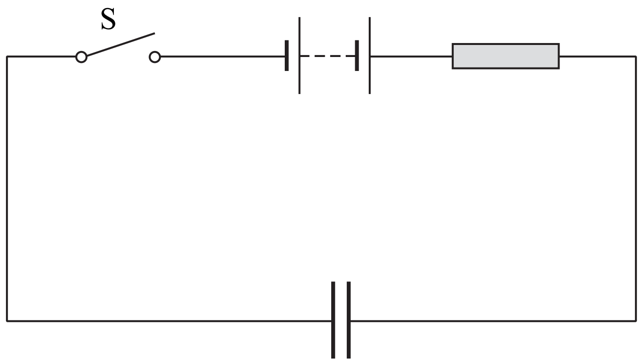
Time delay ....

(Total for Question 11 marks)

1 An uncharged capacitor is connected into a circuit as shown.



(a) Describe what happens to the capacitor when the switch S is closed.

(2)

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(b) A student models the behaviour of the circuit using a spreadsheet. The student uses a 100 μF capacitor, a 3.00 kΩ resistor and 5.00 V power supply. The switch is closed at time $t = 0$ s.

	A	B	C	D	E
1	t / s	I / mA	ΔQ / μC	Q / μC	p.d. across capacitor / V
2	0	1.67	167	167	1.67
3	0.1	1.11	111	278	2.78
4	0.2	0.74	74	352	3.52
5	0.3	0.49	49	401	4.01
6	0.4	0.33	33	434	4.34
7	0.5	0.22	22	456	4.56
8	0.6	0.15	15	471	4.71
9	0.7	0.10	10	480	4.80
10	0.8	0.07	7	487	4.87

(i) Explain how the value in cell C4 is calculated.

(2)

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(ii) Explain how the value in cell E3 is calculated.

(2)

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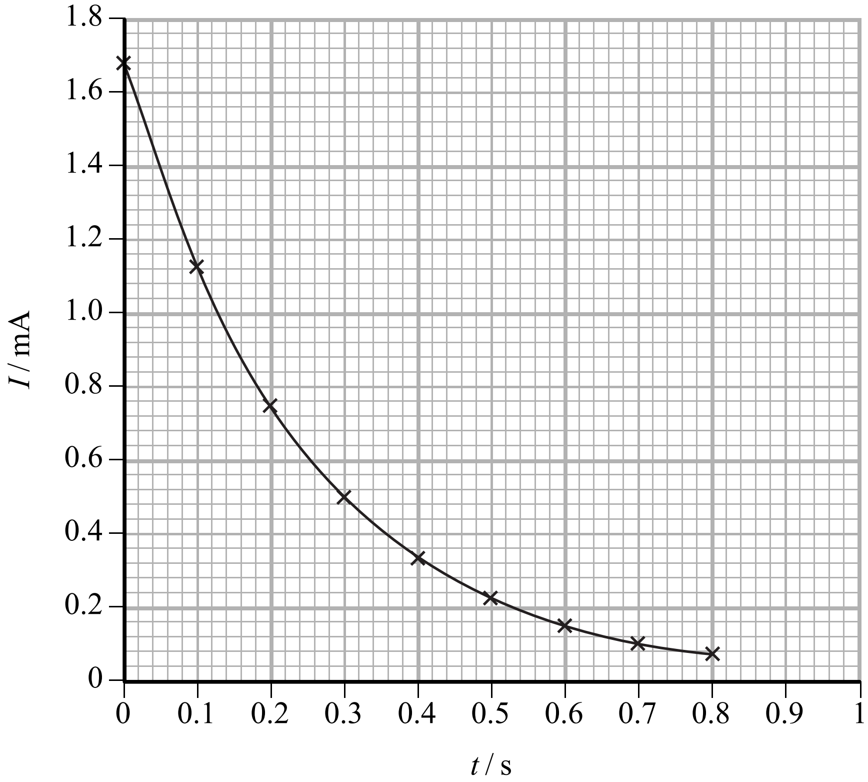
(c) The graph shows how the spreadsheet current varies with time.



(i) Use the graph to show that the time constant is approximately consistent with the component values.

(4)

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(ii) The student thinks that the graph is an exponential curve. How would you use another graph to confirm this?

(3)

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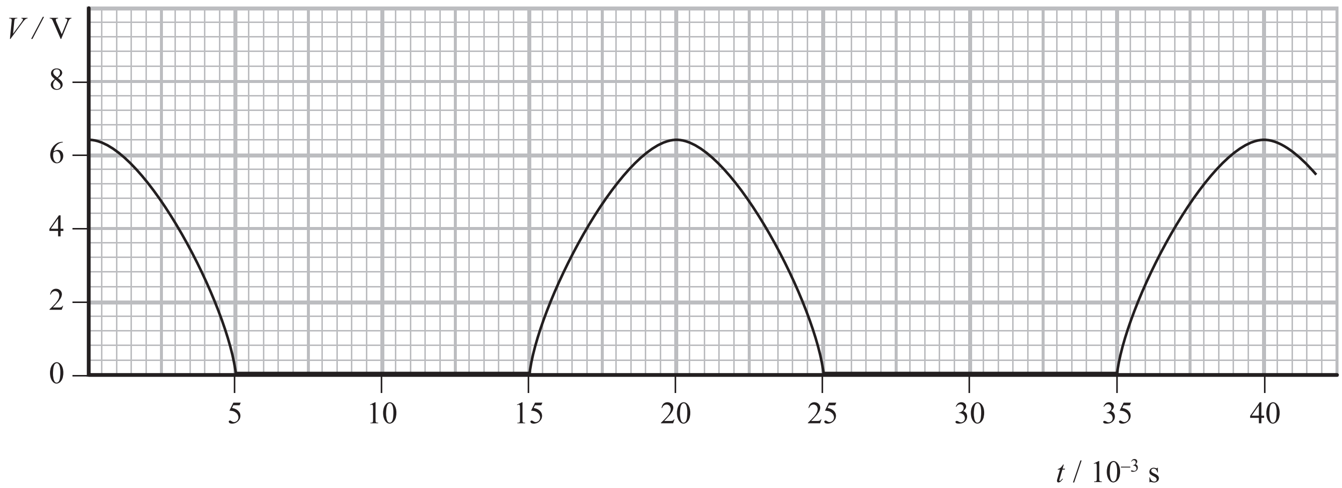
(Total for Question = 13 marks)

2 The graph shows how the output V from the terminals of a power supply labelled d.c. (direct current) varies with time t. This type of supply will not allow current to flow backwards through it.

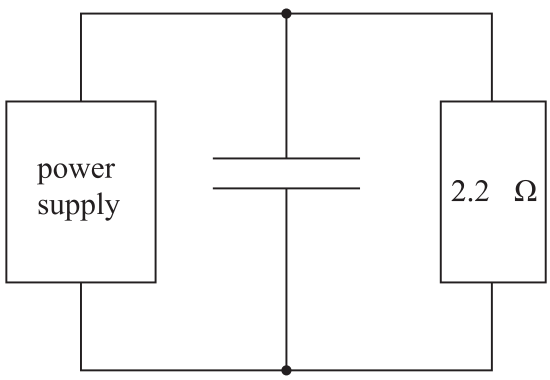


(a) A student connects a capacitor across the terminals of this power supply in order to try to produce a constant voltage.

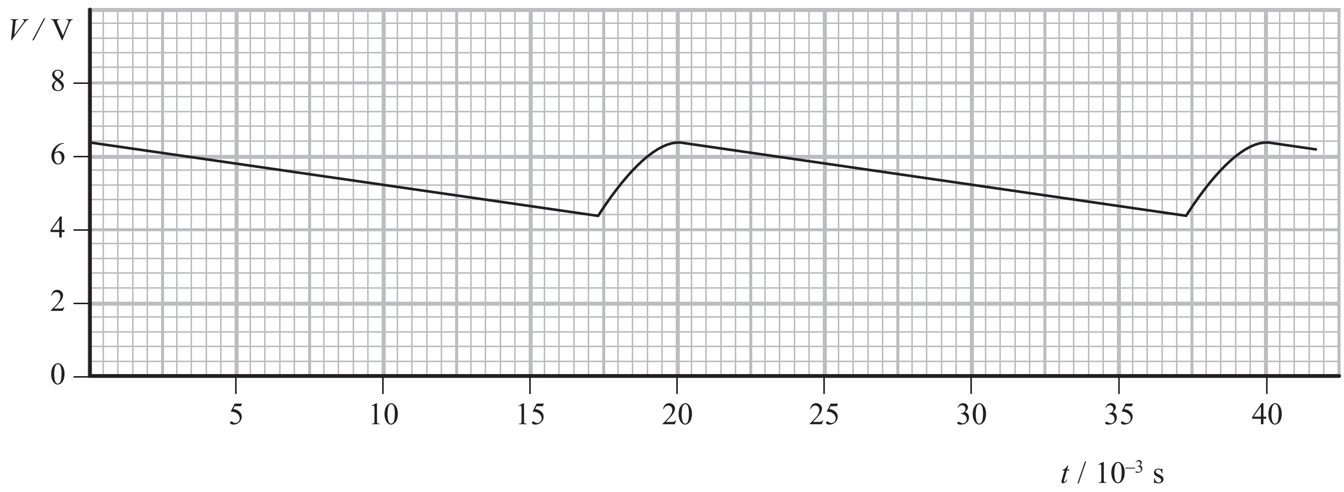
Suggest how this produces a constant voltage.

(2)

(b) The student then connects a resistor across the capacitor as shown.



The graph shows the variation of the potential difference V across the resistor with time t.



(i) Estimate the average potential difference across the resistor.

(1)

Average potential difference =

(ii) Calculate the average current in the resistor.

(2)

Average current =

(iii) Determine the time in each cycle for which the capacitor discharges through the resistor.

(1)

Discharge time =

(iv) Calculate the charge passing through the resistor during one discharge of the capacitor and hence determine the capacitance of the capacitor.

(4)

Charge =

Capacitance =

(c) The student wants to produce a potential difference across the same resistor that has less variation in magnitude.
State, with a reason, what the student could do to achieve this.

(2)

(Total for Question = 12 marks)

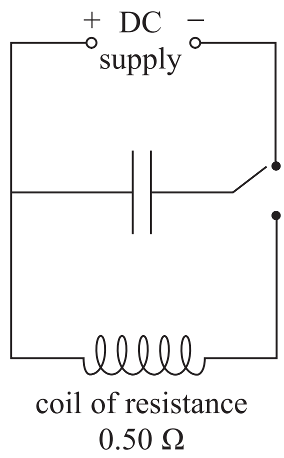
3 A particular experiment requires a very large current to be provided for a short time.

(a) An average current of 2.0×10^3 A is to be supplied to a coil of wire for a time of 1.4×10^{-3} s. The resistance of the coil is 0.50 Ω.

(i) Show that the charge that flows through the coil during this time is about 3 C.

(2)

(ii) The circuit shows how a capacitor could be charged and then discharged through the coil to provide the current.



The circuit contains a capacitor of capacitance 600 μF. This capacitor is suitable to provide the current for 1.4×10^{-3} s.

Explain why the capacitor is suitable.

(3)

(b) It can be assumed that the 600 μF capacitor completely discharges in 1.4×10^{-3} s.

(i) Calculate the potential difference of the power supply.

(2)

Potential difference =

(ii) Calculate the average power delivered to the coil in this time.

(3)

Average power =

(Total for Question = 10 marks)

1 A capacitor is connected to a 6.0 V battery. The charge on the capacitor is 42 pC.
What is the energy stored by the capacitor?

☒ **A** 1.3×10^{-10} J

☒ **B** 2.5×10^{-10} J

☒ **C** 1.3×10^{-7} J

☒ **D** 2.5×10^{-7} J

(Total for Question = 1 mark)

2 A capacitor with an initial charge Q_0 is discharging through a resistor.
The time constant of the circuit is the time for the charge to fall to

☒ **A** $0.25\ Q_0$

☒ **B** $0.37\ Q_0$

☒ **C** $0.50\ Q_0$

☒ **D** $0.63\ Q_0$

(Total for Question = 1 mark)

3 Electrons are released from a heated metal filament.

This process is known as

☒ **A** excitation.

☒ **B** ionisation.

☒ **C** photoelectric emission.

☒ **D** thermionic emission.

(Total for Question = 1 mark)

4 A capacitor is discharging through a resistor and the time constant is 5.0 s. The time taken for the capacitor to lose half its charge is

☒ **A** 0.14 s

☒ **B** 0.81 s

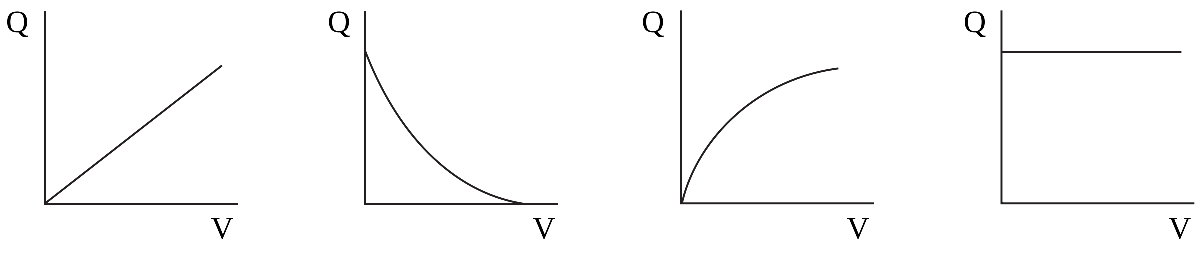
☒ **C** 3.2 s

☒ **D** 3.5 s

(Total for Question 1 mark)

5 An uncharged capacitor is connected to a battery.

Which graph shows the variation of charge with potential difference across the capacitor?

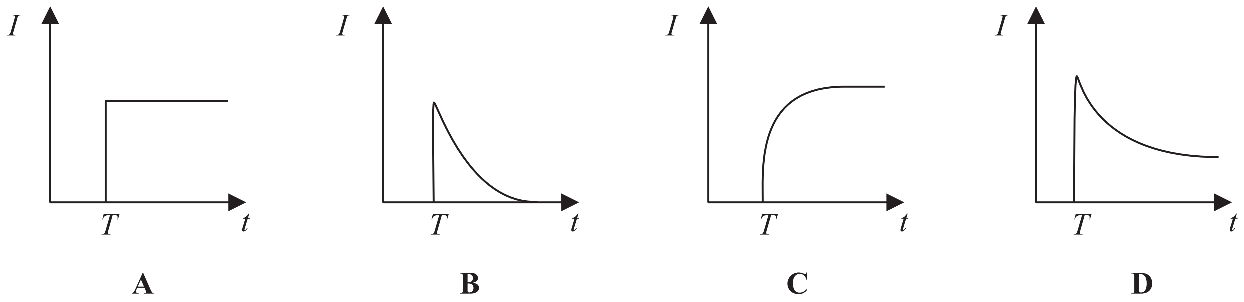


A ☒ **B** ☒ **C** ☒ **D** ☒

(Total for Question = 1 mark)

6 An electric motor is connected via a switch to a battery. A graph is plotted to show the variation of current I with time t. The switch is closed at time T.

Which of the following graphs is correct?



☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 1 mark)

7 The process by which electrons are released from a heated filament is known as

☒ **A** thermionic emission.

☒ **B** photoelectric emission.

☒ **C** ionisation.

☒ **D** excitation.

(Total for Question 1 mark)

8 The potential difference across a capacitor is V. The energy stored on the capacitor is X joules. The potential difference across this capacitor is increased to 3 V. The energy stored, in joules, is increased to

☒ **A** $3X$

☒ **B** $6X$

☒ **C** $9X$

☒ **D** $27X$

(Total for Question = 1 mark)

9 A capacitor of capacitance C has a potential difference V across it. The energy stored on the capacitor is Z joules. A second capacitor of capacitance $C/2$ has a potential difference $2V$ across it.
The energy stored on the second capacitor is

☒ **A** Z

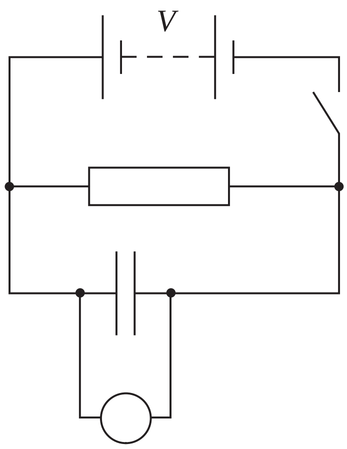
☒ **B** 2Z

☒ **C** 4Z

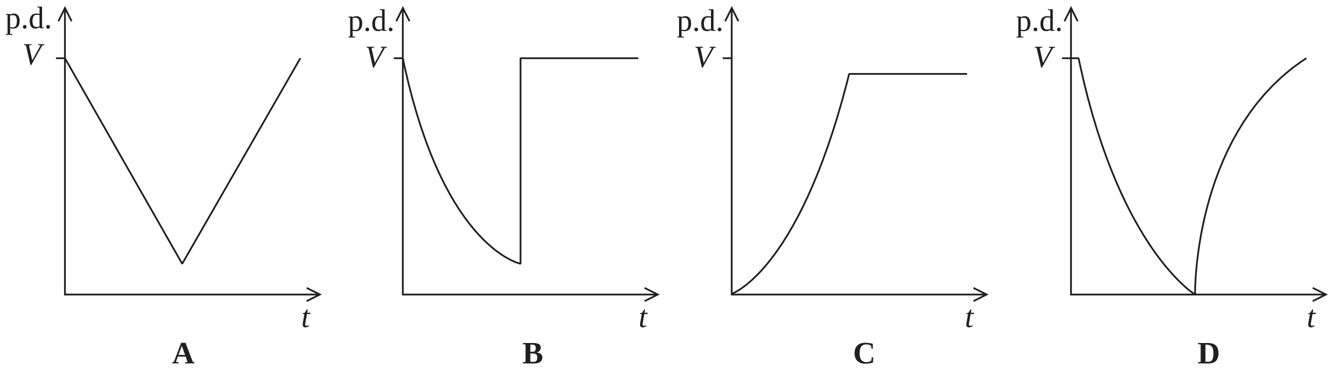
☒ **D** 8Z

(Total for Question = 1 mark)

10 The capacitor shown in the circuit below is initially charged to a potential difference (p.d.) V by closing the switch.
The power supply has negligible internal resistance.



The switch is opened and the p.d. across the capacitor allowed to fall. A short time later the switch is closed again. Select the graph that shows how the p.d. across the capacitor varies with time, after the switch is opened.



- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for Question = 1 mark)

Q1. A 400 μF capacitor is charged so that the voltage across its plates rises at a constant rate from 0 V to 4.0 V in 20 s. What current is being used to charge the capacitor?

A 5 μA

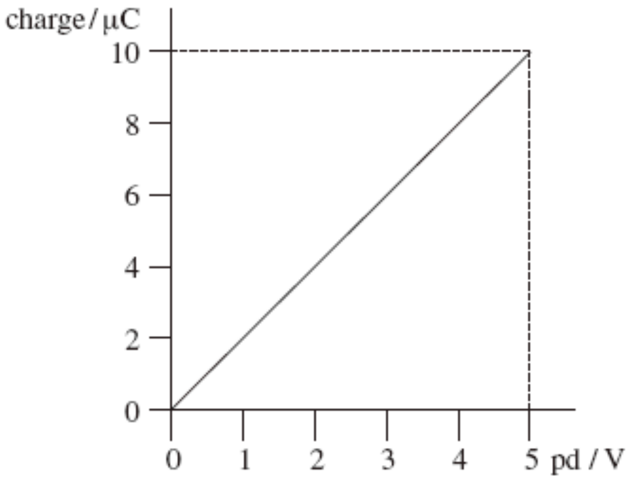
B 20 μA

C 40 μA

D 80 μA

(Total 1 mark)

Q2. The graph shows how the charge stored by a capacitor varies with the pd applied across it.



Which line, **A** to **D**, in the table gives the capacitance and the energy stored when the potential difference is 5.0 V?

	capacitance/μF	**energy stored/μJ**
A	2.0	25
B	2.0	50
C	10.0	25
D	10.0	50

(Total 1 mark)

Q3. In experiments to pass a very high current through a gas, a bank of capacitors of total capacitance 50 μF is charged to 30 kV. If the bank of capacitors could be discharged completely in 5.0 ms, what would be the mean power delivered?

A 22 kW

B 110 kW

C 4.5 MW

D 9.0 MW

(Total 1 mark)

Q4. A 10 mF capacitor is charged to 10 V and then discharged completely through a small motor. During the process, the motor lifts a weight of mass 0.10 kg. If 10% of the energy stored in the capacitor is used to lift the weight, through what approximate height will the weight be lifted?

A 0 05 m

B 0.10 m

C 0.50 m

D 1.00 m

(Total 1 mark)

Q5. A capacitor of capacitance *C* stores an amount of energy *E* when the pd across it is *V*. Which line, **A** to **D**, in the table gives the correct stored energy and pd when the charge is increased by 50%?

	energy	**pd**
A	1.5 *E*	1.5 *V*
B	1.5 *E*	2.25 *V*
C	2.25 *E*	1.5 *V*
D	2.25 *E*	2.25 *V*

(Total 1 mark)

Q6. A capacitor of capacitance C discharges through a resistor of resistance R. Which one of the following statements is **not** true?

A The time constant will decrease if C is increased.

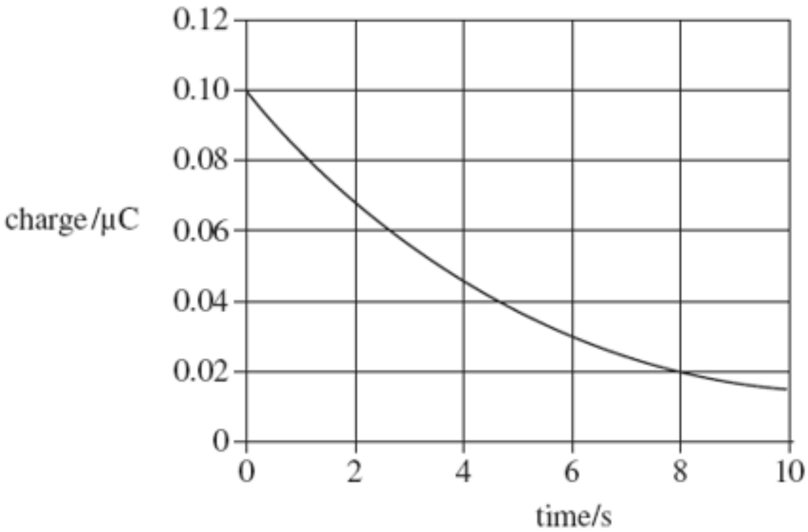
B The time constant will increase if R is increased.

C After charging to the same voltage, the initial discharge current will increase if R is decreased.

D After charging to the same voltage, the initial discharge current will be unaffected if C is increased.

(Total 1 mark)

Q7. The graph shows how the charge on a capacitor varies with time as it is discharged through a resistor.



What is the time constant for the circuit?

A 3.0 s

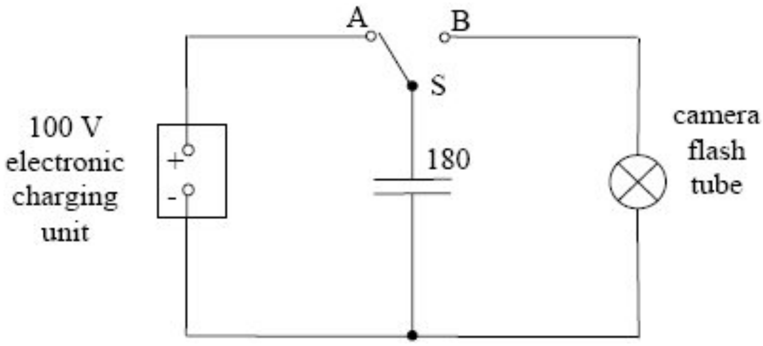
B 4.0 s

C 5.0 s

D 8.0 s

(Total 1 mark)

Q8. The flash tube in a camera produces a flash of light when a 180 μF capacitor is discharged across the tube.



(a) The capacitor is charged to a pd of 100 V from an electronic charging unit in the camera, as shown in the diagram above.
Calculate,

(i) the energy stored in the capacitor,

....

....

....

(ii) the work done by the battery.

....

....

(2)

(b) When a photograph is taken, switch S in the diagram above is automatically moved from A to B and the capacitor is discharged across the flash tube. The discharge circuit has a resistance of 1.5 Ω. Emission of light from the flash tube ceases when the pd falls below 30 V.

(i) Calculate the duration of the light flash.

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(ii) The capacitor in the circuit in the diagram above is replaced by a capacitor of greater capacitance. Discuss the effect of this change on the photograph image of a moving object.

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(4)
(Total 6 marks)

Q9. A capacitor of capacitance 330 μF is charged to a potential difference of 9.0 V. It is then discharged through a resistor of resistance 470 kΩ.

Calculate

(a) the energy stored by the capacitor when it is fully charged,

....

....

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....

(2)

(b) the time constant of the discharging circuit,

....

....

(1)

(c) the p.d. across the capacitor 60 s after the discharge has begun.

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(3)
(Total 6 marks)

Q10. A 680 μF capacitor is charged fully from a 12 V battery. At time $t = 0$ the capacitor begins to discharge through a resistor. When $t = 25$ s the energy remaining in the capacitor is one quarter of the energy it stored at 12 V.

(a) Determine the pd across the capacitor when $t = 25$s.

....

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....

(2)

(b) (i) Show that the time constant of the discharge circuit is 36 s.

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(ii) Calculate the resistance of the resistor.

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(4)
(Total 6 marks)

Q11. Capacitors and rechargeable batteries are examples of electrical devices that can be used repeatedly to store energy.

(a) (i) A capacitor of capacitance 70 F is used to provide the emergency back-up in a low voltage power supply.

Calculate the energy stored by this capacitor when fully charged to its maximum operating voltage of 1.2 V. Express your answer to an appropriate number of significant figures.

answer = ...J

(3)

(ii) A rechargeable 1.2 V cell used in a cordless telephone can supply a steady current of 55 mA for 10 hours. Show that this cell, when fully charged, stores almost 50 times more energy than the capacitor in part (a)(i).

(2)

(b) Give **two** reasons why a capacitor is **not** a suitable source for powering a cordless telephone.

Reason 1..

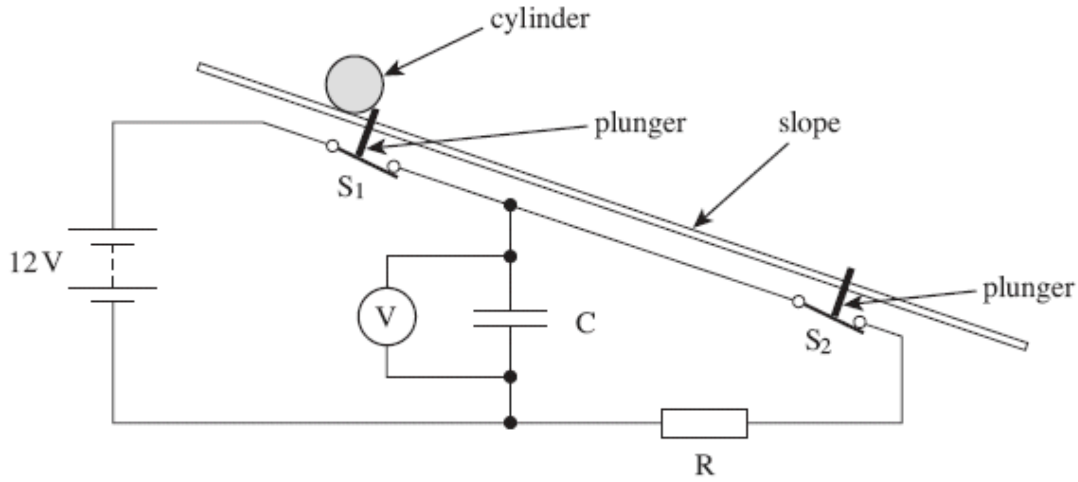
....

Reason 2..

....

(2)
(Total 7 marks)

Q12. 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 the figure below.



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 capacitor 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)

(b) When the student set up his experiment using the arrangement shown in the figure above, 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.

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

answer = ... s

(3)

(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)

(Total 11 marks)

1. Fig.1 shows two capacitors, **A** of capacitance 2μF, and **B** of capacitance 4μF, connected in parallel. Fig. 2 shows them connected in series. A two-way switch **S** can connect the capacitors either to a d.c. supply, of e.m.f. 6 V, or to a voltmeter.

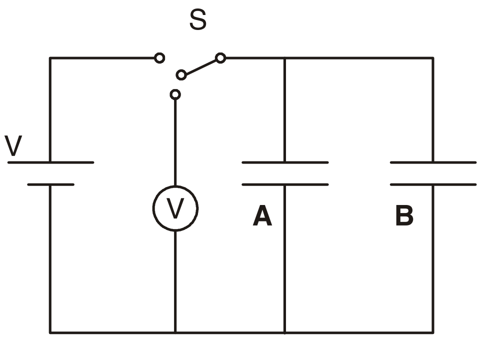

Fig. 1

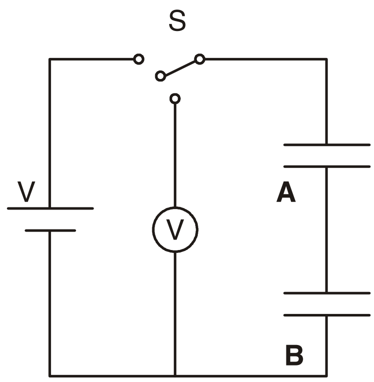

Fig. 2

(a) Calculate the total capacitance of the capacitors

(i) when connected as in Fig. 1

capacitance = ... μF

[1]

(ii) when connected as in Fig. 2

capacitance = ... μF

[2]

(b) The switch in the circuit shown in Fig. 1 is then connected to the battery. Calculate

(i) the potential difference across capacitor **A**

potential difference = ... V

[1]

(ii) the total charge stored on the capacitors.

charge = ...μC

[2]

(c) The switch in the circuit shown in Fig.2 is then connected to the battery. Calculate the total energy stored in the two capacitors.

energy = ... J

[2]

(d) The switch S in the circuit of Fig. 1 is moved to connect the charged capacitors to the voltmeter. The voltmeter has an internal resistance of 12 MΩ.

(i) Explain why the capacitors will discharge, although very slowly.

....

....

....

[1]

(ii) Calculate the time t taken for the voltmeter reading to fall to a quarter of its initial reading.

t = ... s

[3]

[Total 12 marks]

2. Fig. 1 shows a football balanced above a metal bench on a length of plastic drain pipe. The surface of the ball is coated with a smooth layer of an electrically conducting paint. The pipe insulates the ball from the bench.

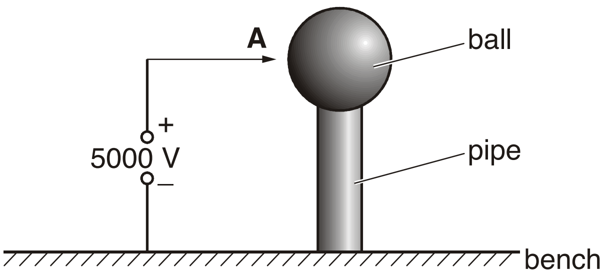

Fig. 1

(a) The ball is charged by touching it momentarily with a wire **A** connected to the positive terminal of a 5000 V power supply. The capacitance C of the ball is 1.2×10^{-11} F. Calculate the charge Q_o on the ball. Give a suitable unit for your answer.

Q_o = ... unit ....

[3]

(b) The charge on the ball leaks slowly to the bench through the plastic pipe, which has a resistance R of $1.2 \times 10^{15}\ \Omega$.

(i) Show that the time constant for the ball to discharge through the pipe is about 1.5×10^{4} s.

[1]

(ii) Show that the initial value of the leakage current is about 4×10^{-12} A.

[1]

(iii) Suppose that the ball continues to discharge at the constant rate calculated in (ii). Show that the charge Q_0 would leak away in a time equal to the time constant.

[2]

(iv) Using the equation for the charge Q at time t

$$Q = Q_o e^{-t/RC}$$

show that, in practice, the ball only loses about 2/3 of its charge in a time equal to one time constant.

[2]

(c) The ball is recharged to 5000 V by touching it momentarily with wire **A**. The ball is now connected in parallel via wire **B** to an uncharged capacitor of capacitance 1.2×10^{-8} F and a voltmeter as shown in Fig. 2.

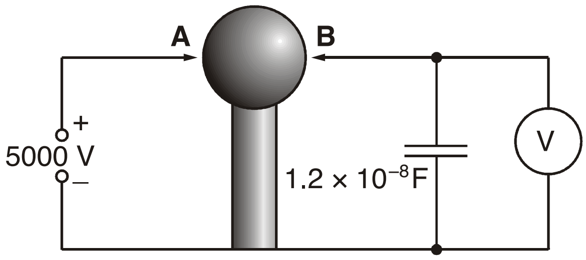

Fig. 2

(i) The ball and the uncharged capacitor act as two capacitors in parallel. The total charge Q_o is shared instantly between the two capacitors. Explain why the charge left on the ball is $Q_o/1000$.

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....

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....

....

....

[3]

(ii) Hence or otherwise calculate the initial reading V on the voltmeter.

V = ... V

[2]

[Total 14 marks]

3. This question is about the energy stored in a capacitor.

(a) (i) One expression for the energy W stored on a capacitor is

$$W = \frac{1}{2} QV$$

where Q is the charge stored and V is the potential difference across the capacitor.
Show that another suitable expression for the energy stored is

$$W = \frac{1}{2} CV^2$$

where C is the capacitance of the capacitor.

[2]

(ii) Draw a graph on the axes of Fig. 1 to show how the energy W stored on a 2.2 F capacitor varies with the potential difference V across the capacitor.

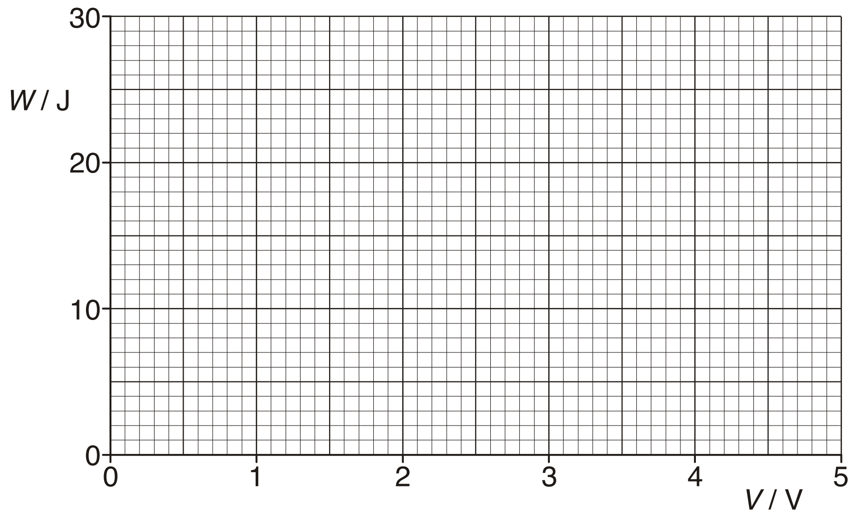


Fig. 1

[2]

(b) The 2.2 F capacitor is connected in parallel with the power supply to a digital display for a video/DVD recorder. The purpose of the capacitor is to keep the display working during any disruptions to the electrical power supply. Fig. 2 shows the 5.0 V power supply, the capacitor and the display. The input to the display behaves as a 6.8 kΩ resistor. The display will light up as long as the voltage across it is at or above 4.0 V.

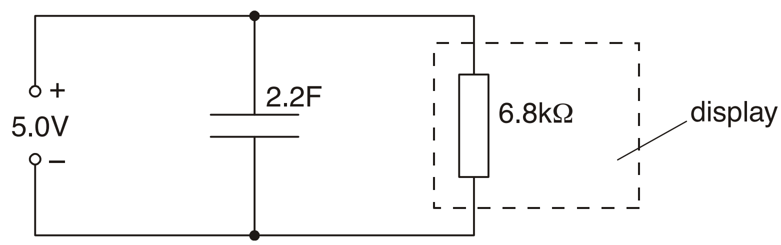


Fig. 2

Suppose the power supply is disrupted.

(i) Show that the time constant of the circuit of Fig. 2 is more than 4 hours.

[2]

(ii) Find the energy lost by the capacitor as it discharges from 5.0 V to 4.0 V.

energy lost = ...J

[2]

(iii) The voltage V across the capacitor varies with time t according to the equation

$$V = V_o e^{-t/RC}.$$

Calculate the time that it takes for the voltage to fall to 4.0 V.

time = ... s

[2]

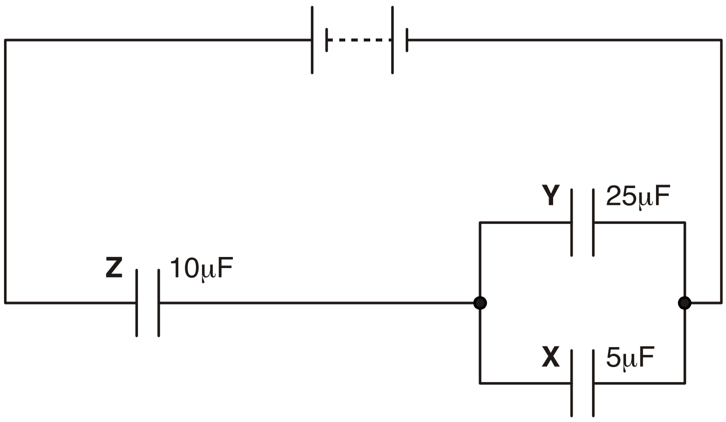
(iv) Calculate the mean power consumption of the display during this time.

mean power = ... W

[1]

[Total 11 marks]

4. The charge stored in the capacitor **X** of capacitance 5 μF in the circuit given in the figure below is 30 μC.



(a) (i) Complete the table for this circuit.

capacitor	capacitance / μF	charge / μC	p.d. / V	energy / μJ
X	5	30		
Y	25			
Z	10			

[9]

(ii) Using data from the table find

1 the e.m.f. of the battery

e.m.f. = ... V

[1]

2 the total charge supplied from the battery

charge = ... μC

[1]

3 the total circuit capacitance

capacitance = ... μF

[1]

4 the total energy stored in all the capacitors.

energy = ... μJ

[1]

(b) (i) What law or principle of physics was used to determine **(a)(ii)1**?

....

[1]

(ii) What law or principle of physics was used to determine **(a)(ii)2**?

....

[1]

(c) The battery is removed and replaced by a resistor of resistance 200 kΩ. The capacitors now discharge through this resistor. Calculate

(i) the time constant of the circuit

time constant = ... s

[2]

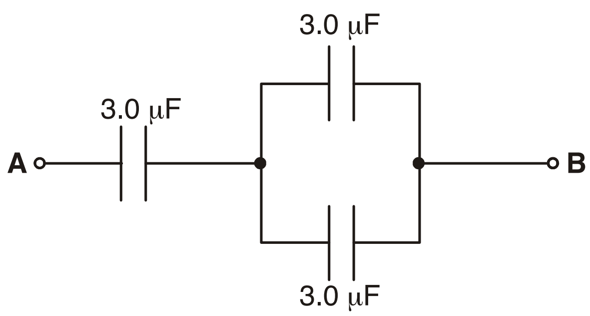
(ii) the fraction of the total charge remaining on the capacitors after a time equal to **four** time constants.

fraction remaining = ...

[2]

[Total 19 marks]

5. You are provided with a number of identical capacitors, each of capacitance 3.0 μF. Three are connected in a series and parallel combination as shown in the diagram below.



(i) Show that the total capacitance between the terminals **A** and **B** is 2.0 μF.

[3]

(ii) Draw a diagram in the space below to show how you can produce a total capacitance of 2.0 μF using **six** 3.0 μF capacitors.

[2]

[Total 5 marks]

Q1.

8 (a) Define *capacitance*.

....

....[1]

(b) (i) One use of a capacitor is for the storage of electrical energy.
Briefly explain how a capacitor stores energy.

....

....

....[2]

(ii) Calculate the change in the energy stored in a capacitor of capacitance 1200 μF when the potential difference across the capacitor changes from 50 V to 15 V.

energy change = ... J [3]

Use

Q2.

5 A capacitor C is charged using a supply of e.m.f. 8.0 V. It is then discharged through a resistor R.
The circuit is shown in Fig. 5.1.

For Examin Use

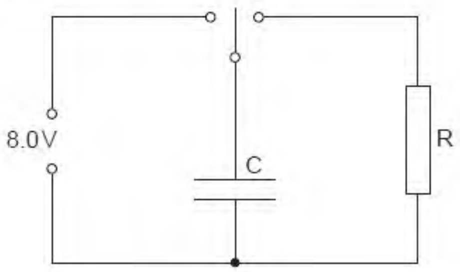


Fig. 5.1

The variation with time *t* of the potential difference *V* across the resistor R during the discharge of the capacitor is shown in Fig. 5.2.

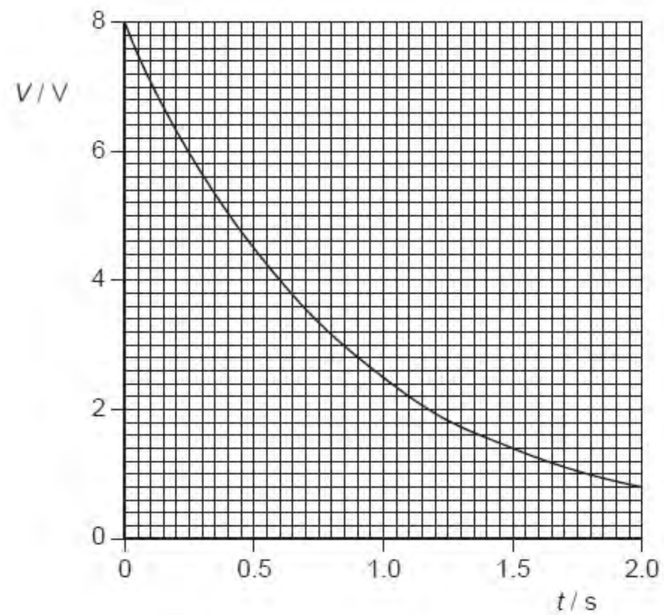


Fig. 5.2

(a) During the first 1.0 s of the discharge of the capacitor, 0.13 J of energy is transferred to the resistor R.
Show that the capacitance of the capacitor C is 4500 μF.

[3]

(b) Some capacitors, each of capacitance 4500 μF with a maximum working voltage of 6V, are available.

Draw an arrangement of these capacitors that could provide a total capacitance of 4500 μF for use in the circuit of Fig. 5.1.

[2]

Q3.

5 A solid metal sphere, of radius *r*, is insulated from its surroundings. The sphere has charge +*Q*.
This charge is on the surface of the sphere but it may be considered to be a point charge at its centre, as illustrated in Fig. 5.1.

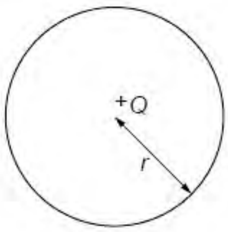


Fig. 5.1

(a) **(i)** Define *capacitance*.

....

.... [1]

(ii) Show that the capacitance C of the sphere is given by the expression

$$C = 4\pi\varepsilon_0 r.$$

[1]

(b) The sphere has radius 36 cm.
Determine, for this sphere,

(i) the capacitance,

capacitance = ... F [1]

(ii) the charge required to raise the potential of the sphere from zero to 7.0×10^5 V.

Ex

charge = ... C [1]

(c) Suggest why your calculations in **(b)** for the metal sphere would not apply to a plastic sphere.

....

....

....

.... [3]

(d) A spark suddenly connects the metal sphere in **(b)** to the Earth, causing the potential of the sphere to be reduced from 7.0×10^5V to 2.5×10^5V.

Calculate the energy dissipated in the spark.

energy = ... J [3]

Q4.

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

1. ....

2. .... [2]

(b) Three capacitors, each marked '30 μF, 6V max', are arranged as shown in Fig. 5.1.

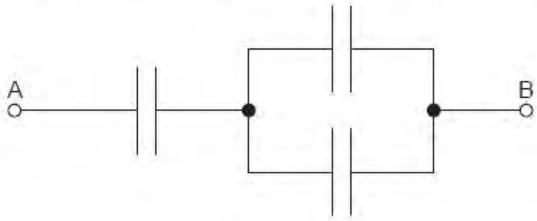


Fig. 5.1

Determine, for the arrangement shown in Fig. 5.1,

(i) the total capacitance,

capacitance = ... μF [2]

(ii) the maximum potential difference that can safely be applied between points A and B.

potential difference = ... V [2]

(c) A capacitor of capacitance 4700 μF is charged to a potential difference of 18 V. It is then partially discharged through a resistor. The potential difference is reduced to 12 V. Calculate the energy dissipated in the resistor during the discharge.

energy = ... J [3]

Q5.

3 A capacitor consists of two metal plates separated by an insulator, as shown in Fig. 3.1.

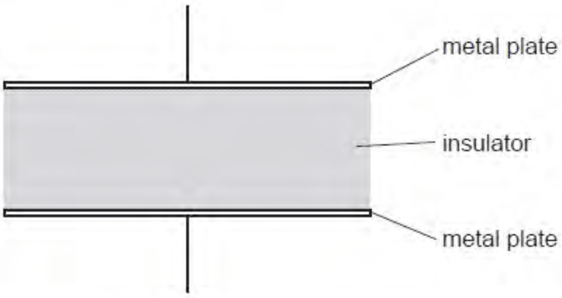


Fig. 3.1

The potential difference between the plates is *V*. The variation with *V* of the magnitude of the charge *Q* on one plate is shown in Fig. 3.2.

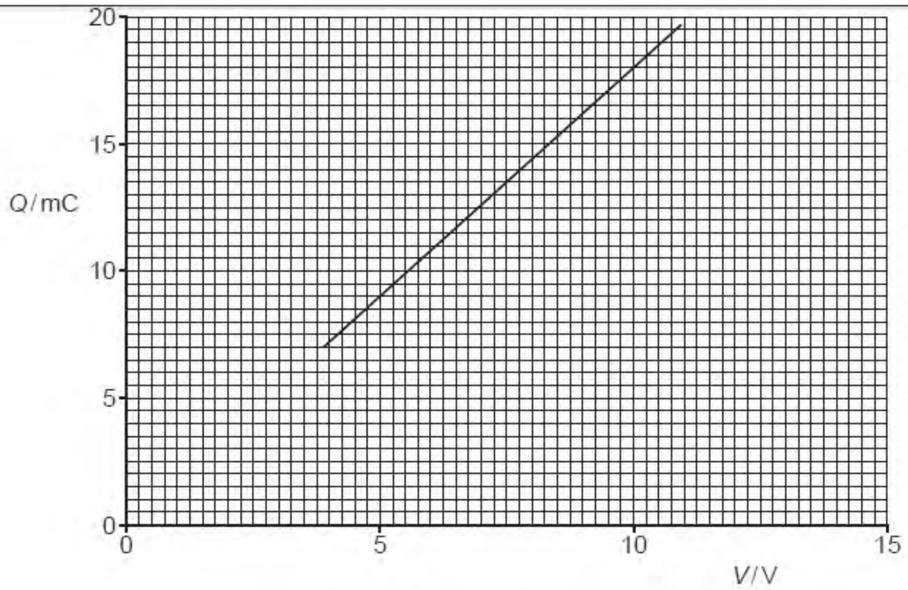


Fig. 3.2

(a) Explain why the capacitor stores energy but not charge.

....

....

....

.... [3]

(b) Use Fig. 3.2 to determine

(i) the capacitance of the capacitor,

capacitance = ... μF [2]

(ii) the loss in energy stored in the capacitor when the potential difference *V* is reduced from 10.0 V to 7.5 V.

energy = ... mJ [2]

(c) Three capacitors X, Y and Z, each of capacitance 10 μF, are connected as shown in Fig. 3.3.

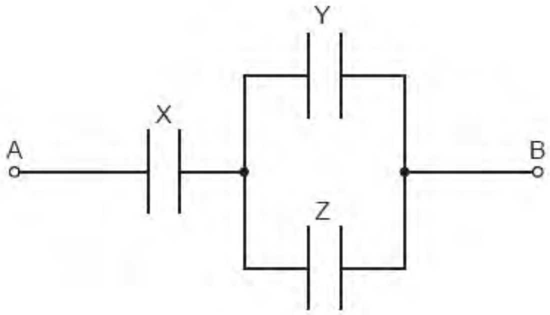


Fig. 3.3

Initially, the capacitors are uncharged.
A potential difference of 12 V is applied between points A and B.
Determine the magnitude of the charge on one plate of capacitor X.

charge = ... μC [3]

Q6.

5 Some capacitors are marked '48 μF, safe working voltage 25 V'.

Show how a number of these capacitors may be connected to provide a capacitor of capacitance

(a) 48 μF, safe working voltage 50 V,

[2]

(b) 72 μF, safe working voltage 25 V.

[2]

Q7.

5 **(a)** State one function of capacitors in simple circuits.

....

....[1]

(b) A capacitor is charged to a potential difference of 15 V and then connected in series with a switch, a resistor of resistance 12 kΩ and a sensitive ammeter, as shown in Fig. 5.1.

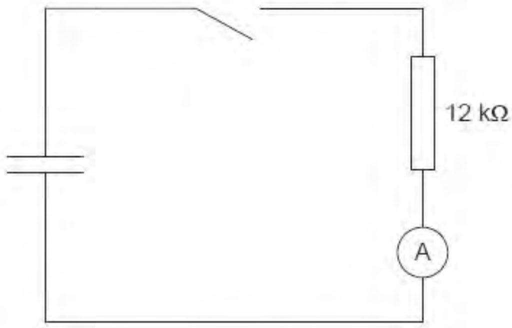


Fig. 5.1

The switch is closed and the variation with time t of the current I in the circuit is shown in Fig. 5.2.

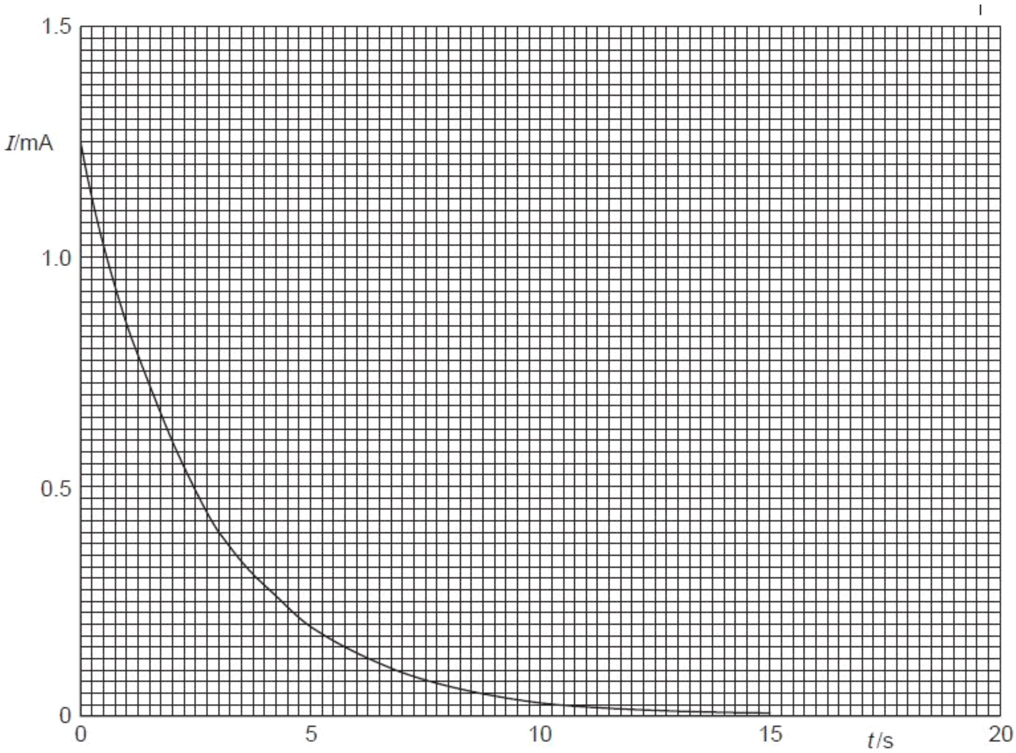


Fig. 5.2

(i) State the relation between the current in a circuit and the charge that passes a point in the circuit.

....

....[1]

(ii) The area below the graph line of Fig. 5.2 represents charge.
Use Fig. 5.2 to determine the initial charge stored in the capacitor.

charge = ... μC [4]

(iii) Initially, the potential difference across the capacitor was 15 V.
Calculate the capacitance of the capacitor.

capacitance = ... μF [2]

(c) The capacitor in **(b)** discharges one half of its initial energy. Calculate the new potential difference across the capacitor.

potential difference = ...V [3]

Q8.

4 **(a)** Define *capacitance*.

For Examiner's Use

....

.... [1]

(b) An isolated metal sphere of radius R has a charge $+Q$ on it.

The charge may be considered to act as a point charge at the centre of the sphere.

Show that the capacitance C of the sphere is given by the expression

$$C = 4\pi\varepsilon_0 R$$

where ε_0 is the permittivity of free space.

[1]

(c) In order to investigate electrical discharges (lightning) in a laboratory, an isolated metal sphere of radius 63 cm is charged to a potential of 1.2×10^6 V.

At this potential, there is an electrical discharge in which the sphere loses 75% of its energy.

Calculate

(i) the capacitance of the sphere, stating the unit in which it is measured,

capacitance = ... [3]

(ii) the potential of the sphere after the discharge has taken place.

For Examiner's Use

potential = ... V [3]

Q9.

4 (a) Define *capacitance*.

....

....[1]

(b) An isolated metal sphere has a radius *r*. When charged to a potential *V*, the charge on the sphere is *q*.
The charge may be considered to act as a point charge at the centre of the sphere.

(i) State an expression, in terms of *r* and *q*, for the potential *V* of the sphere.

....[1]

(ii) This isolated sphere has capacitance. Use your answers in **(a)** and **(b)(i)** to show that the capacitance of the sphere is proportional to its radius.

[1]

(c) The sphere in **(b)** has a capacitance of 6.8 pF and is charged to a potential of 220 V.

Calculate

(i) the radius of the sphere,

radius = ... m [3]

(ii) the charge, in coulomb, on the sphere.

For Examin Use

charge = ... C [1]

(d) A second uncharged metal sphere is brought up to the sphere in **(c)** so that they touch. The combined capacitance of the two spheres is 18 pF.

Calculate

(i) the potential of the two spheres,

potential = ... V [1]

(ii) the change in the total energy stored on the spheres when they touch.

change = ... J [3]

Q10.

4 (a) (i) State what is meant by *electric potential* at a point.

For Examiner's Use

....

....

.... [2]

(ii) Define *capacitance*.

....

.... [1]

(b) The variation of the potential V of an isolated metal sphere with charge Q on its surface is shown in Fig. 4.1.

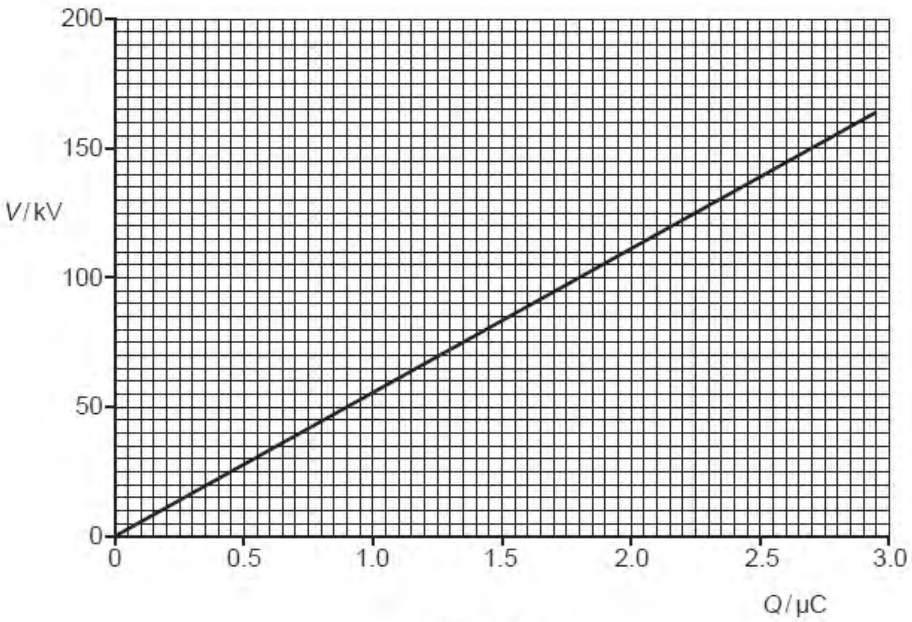


Fig. 4.1

An isolated metal sphere has capacitance.

For Examiner's Use

Use Fig. 4.1 to determine

(i) the capacitance of the sphere,

capacitance = ... F [2]

(ii) the electric potential energy stored on the sphere when charged to a potential of 150 kV.

energy = ... J [2]

(c) A spark reduces the potential of the sphere from 150 kV to 75 kV.
Calculate the energy lost from the sphere.

energy = ... J [2]

Q11.

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

For Examiner's Use

1. ....

....

2. ....

.... [2]

(b) Three uncharged capacitors of capacitance C_1, C_2 and C_3 are connected in series, as shown in Fig. 4.1.

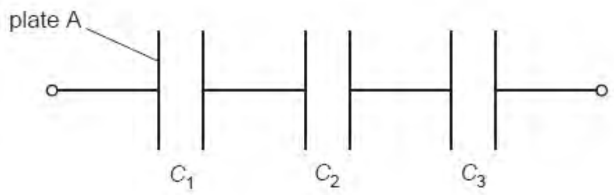


Fig. 4.1

A charge of $+Q$ is put on plate A of the capacitor of capacitance C_1.

(i) State and explain the charges that will be observed on the other plates of the capacitors.
You may draw on Fig. 4.1 if you wish.

....

....

.... [2]

(ii) Use your answer in **(i)** to derive an expression for the combined capacitance of the capacitors.

[2]

(c) A capacitor of capacitance 12 μF is charged using a battery of e.m.f. 9.0 V, as shown in Fig. 4.2.

For Examiner's Use

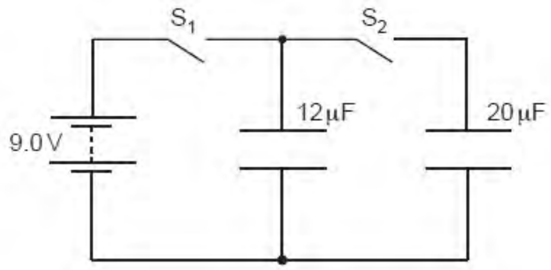


Fig. 4.2

Switch S_1 is closed and switch S_2 is open.

(i) The capacitor is now disconnected from the battery by opening S_1.
Calculate the energy stored in the capacitor.

energy = ... J [2]

(ii) The 12 μF capacitor is now connected to an uncharged capacitor of capacitance 20 μF by closing S_2. Switch S_1 remains open.
The total energy now stored in the two capacitors is 1.82×10^{-4} J.

Suggest why this value is different from your answer in **(i)**.

....

.... [1]

Q12.

5 (a) (i) Define *capacitance*.

....

....[1]

(ii) A capacitor is made of two metal plates, insulated from one another, as shown in Fig. 5.1.

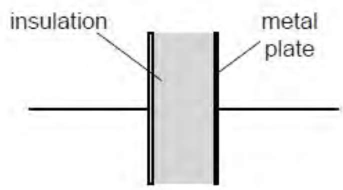


Fig. 5.1

Explain why the capacitor is said to store energy but not charge.

....

....

....

....

....[4]

(b) Three uncharged capacitors X, Y and Z, each of capacitance 12 μF, are connected as shown in Fig. 5.2.

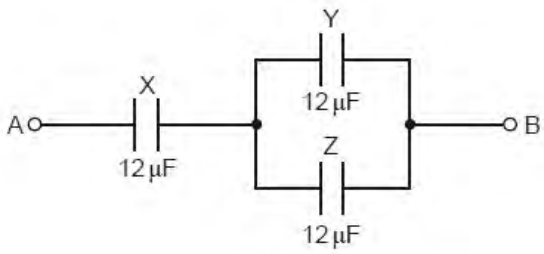


Fig. 5.2

A potential difference of 9.0 V is applied between points A and B.

(i) Calculate the combined capacitance of the capacitors X, Y and Z.

For Examiner's Use

capacitance = ... μF [2]

(ii) Explain why, when the potential difference of 9.0 V is applied, the charge on one plate of capacitor X is 72 μC.

....

....

....[2]

(iii) Determine

1. the potential difference across capacitor X,

potential difference = ... V [1]

2. the charge on one plate of capacitor Y.

charge = ... μC [2]

Q13.

4 **(a)** State two functions of capacitors connected in electrical circuits.

For Examiner's Use

1. ....

....

2. ....

.... [2]

(b) Three capacitors are connected in parallel to a power supply as shown in Fig. 4.1.

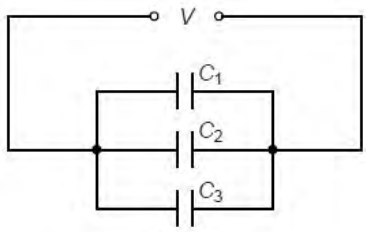


Fig. 4.1

The capacitors have capacitances C_1, C_2 and C_3. The power supply provides a potential difference V.

(i) Explain why the charge on the positive plate of each capacitor is different.

....

....

.... [1]

(ii) Use your answer in **(i)** to show that the combined capacitance C of the three capacitors is given by the expression

$$C = C_1 + C_2 + C_3.$$

[2]

(c) A student has available three capacitors, each of capacitance 12 μF.
Draw circuit diagrams, one in each case, to show how the student connects the three capacitors to provide a combined capacitance of

For Examiner's Use

(i) 8 μF,

[1]

(ii) 18 μF.

[1]

Q14.

6 An uncharged capacitor is connected in series with a battery, a switch and a resistor, as shown in Fig. 6.1.

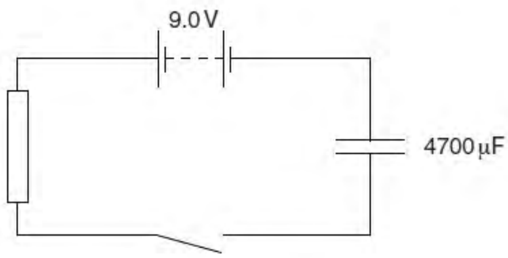


Fig. 6.1

The battery has e.m.f. 9.0 V and negligible internal resistance. The capacitance of the capacitor is 4700 μF.
The switch is closed at time $t = 0$.
During the time interval $t = 0$ to $t = 4.0$ s, the charge passing through the resistor is 22 mC.

(a) **(i)** Calculate the energy transfer in the battery during the time interval $t = 0$ to $t = 4.0\,\text{s}$.

energy transfer = ... J [2]

(ii) Determine, for the capacitor at time $t = 4.0\,\text{s}$,

1. the potential difference V across the capacitor,

V = ... V [2]

2. the energy stored in the capacitor.

energy = ... J [2]

(b) Suggest why your answers in **(a)(i)** and **(a)(ii) part 2** are different.

....

.... [1]

Q15.

6 Three capacitors, each of capacitance 48 μF, are connected as shown in Fig. 6.1.

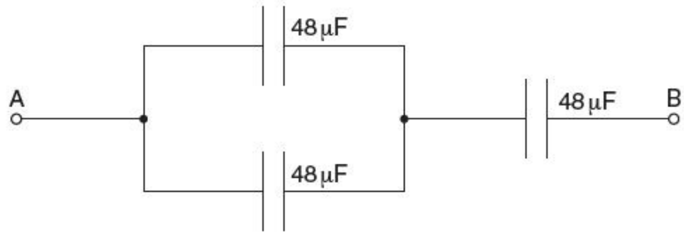


Fig. 6.1

(a) Calculate the total capacitance between points A and B.

capacitance = ... μF [2]

(b) The maximum safe potential difference that can be applied across any one capacitor is 6 V.

Determine the maximum safe potential difference that can be applied between points A and B.

potential difference = ... V [2]

8 Solutions

Questions on Capacitors MS

1. Exponential shape **(1)**

Value at RC > 1.5 V [only if shape correct] **(1)**

Levels off at 3 V **(1)** — 3

Why movement of diaphragm causes p.d:

No movement, no change in C, no signal **(1)**

OR moving diaphragm changes C

As C changes so V changes **(1)**

$Vc + IR$ is constant **(1)**

Hence IR changes – signal **(1)** — 4

OR for last 3 marks

As C changes Q changes

Q flows through R

hence V = IR for resistor as signal — 7

2. Calculation of charge

$Q=CV$) Equation or substitution **(1)**

$= 0.22 \times 95 \times 10^{-3}$C)

= 0.021 C **(1)** — 2

What voltmeter reading tells about voltmeter

Very high resistance **(1)** — 1

Table

3.83, 3.50, 3.09 **(1)** — 1

Graph

Points 1, 2 correctly plotted **(1)**

Points 3, 4, 5 correctly plotted **(1)**

Joined with straight line **(1)** — 3

Explanation

Straight line (→ exponential) **(1)**

Negative gradient (→ decreases) **(1)** — 2

Value for resistance of second voltmeter

95 mV ÷ e = 35 mV)

OR 95mV ÷ 3=32mV) **(1)**

Time to fall to 32/35 mV
≈ 55 – 60 s **(1)**
This time = RC **(1)**
[OR Gradient of graph method → RC 2 marks]
∴ R = 240 – 280 Ω **(1)** — Max 3

[OR $V = V_0e^{-t/RC}$ method:

Correct substitution (any consistent values) 1 mark
Taking ln (maths) 1 mark
Answer 1 mark]

[12]

3. Explanation of what has happened in circuit

Charging process **(1)**

Plates oppositely charged OR charge moves from one plate to another **(1)**

Charge flows anticlockwise OR electrons flow clockwise OR left plate becomes positive OR right plate becomes negative **(1)**

Build up of Q/V reduces flow rate **(1)** — Max 3

Explanation of what would have been seen

Same as ammeter 1 **(1)**

Reason: Same I everywhere OR series circuit OR same I/Q in each component **(1)** — 2

Estimate of charge

Attempt to find area under correct region of graph **(1)**

= 52 μC **(1)** — 2

[Allow 45 – 65 μC]

Estimate of capacitance

p.d. across resistor at t = 10 s = $100 \times 10^3\ \Omega \times 3 \times 10^{-6}$ A = 0.3 V **(1)**

(hence p.d. across capacitor = 1.5 V – 0.3 V = 1.2 V)

$C = \frac{Q}{V} = \frac{5 \times 10^{-5}\text{C}}{1.2\text{V}}$ (equation or sub) [ecf] **(1)**

C = 42 μF [If 1.5 V is used to obtain C = 33 μF, then 2/3] **(1)** — 3

Alternative method using $e^{-t/RC}$

Correct answer appropriate to set of values **(1)**

Correct ln line **(1)**

Correct answer (40–44uF) **(1)**

Alternative method using $T = RC$

Using $T = RC$ **(1)**

Appropriate T value **(1)**

⇒ correct answer **(1)**

Observations

Same picture as before **(1)**

since same ΔV **(1)** — 2

[OR C now carries twice the previous charge]

[12]

4. What happens in circuit after switch closed then opened again

Any seven from:

S closed → C charges **(1)**

up to V_S **(1)**

Instantly/very quickly **(1)**

S open: discharge starts **(1)**

Exponential discharge **(1)**

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

¾ $V_s = V_s\, e^{-t/RC}$ **(1)**

⇒ ln ¾ = $-t/RC$ **(1)**

⇒ t = 29.7 s OR RC = 103 s [if no other calculation] **(1)**

Buzzer sounds for 29.7 s [ecf] **(1)** Max 7

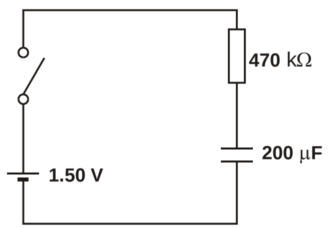
[Marks 1-5 and mark 9 are available via appropriate graph. For mark 5 graph must have axes labelled with a *V/Q/I* and same *t*, and a recognisable exponential curve.]

5. Define capacitance

Capacitance = Charge / Potential difference.

(2 marks)

An uncharged capacitor of 200 μF is connected in series with a 470 kΩ resistor, a 1.50 V cell and a switch. Draw a circuit diagram of this arrangement.



(1 mark)

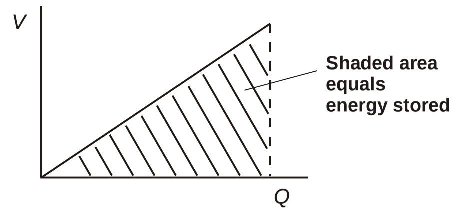
Calculate the maximum current that flows.

Current = 1.5 V/470 kΩ

Current = 3.2 μA

(2 marks)

Sketch a graph of voltage against charge for your capacitor as it charges. Indicate on the graph the energy stored when the capacitor is fully charged.



(4 marks)

Calculate the energy stored in the fully-charged capacitor.

½*CV*² = ½ (200 μF) (1.5 V)²

Energy = 2.25 μJ

(2 marks)
[Total 11 marks]

6. Slope of graph:

Capacitance

Shaded area of graph:

Energy/work done 2

Energy stored 3.1 J:

$CV^2/2$

$= 100 \times 10^{-6} \times 250^2/2$ [formula + correct substitution]

(= 3.125) = 3.1 J [Must have previous mark] 2

Power from cell, and minimum time for cell to recharge capacitor:

Cell power = 1.5 V × 0.20 A

= 0.30 W [allow 3/10 W here]

Time = 3.1 J/0.30 W(e.c.f.)

= 10 s 3

[7]

7. Calculation of charge

$6000 \text{ V} \times 20 \times 10^{-6} \text{ F}$ **(1)**

= 0.12 C **(1)** 2

Energy stored in capacitor

$\left(\frac{CV^2}{2}\right) \quad \frac{20 \times 10^{-6} \text{ C} \times (6000 \text{ V})^2}{2}$ **(1)**

= 360 J **(1)** 2

Resistance

$\frac{6000 \text{ V}}{40 \text{ A}} = 150\ \Omega$ **(1)** 1

Time to discharge capacitor

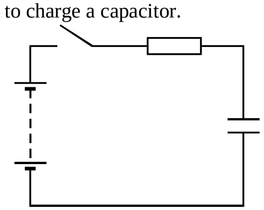
Time = $\frac{0.12 \text{ C}}{40 \text{ A}}$ /their Q **(1)**

= 0.0030 s / 3.0 × 10^{-3} s [e.c.f.] **(1)** 2

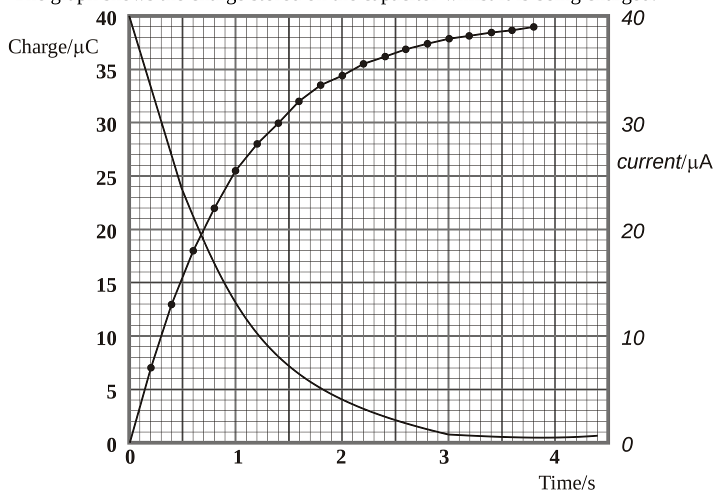
Reason
Time is longer because the rate of discharge decreases/ current decreases with time **(1)** 1

[8]

8. The circuit shown is used to charge a capacitor.



The graph shows the charge stored on the capacitor whilst it is being charged.



On the same axes, sketch as accurately as you can a graph of current against time. Label the current axis with an appropriate scale.

Label current axis (1)

Current at *t* = 0 within range 30 – 45 µA (1)

Current graph right shape (1)

Exponential decay (1)

(4 marks)

The power supply is 3 V. Calculate the resistance of the charging circuit.

Resistance = 3 V / 40 µA (1)
= 75 kΩ (1)

Resistance = Allow 66 kΩ →100 kΩ

(2 marks)
[Total 6 marks]

9. Calculation of charge

$Q=CV$) Equation or substitution **(1)**

= 0.22 × 95 × 10^{-3}C)

= 0.021 C **(1)** 2

What voltmeter reading tells about voltmeter

Very high resistance **(1)** 1

Table

3.83, 3.50, 3.09 **(1)** 1

Graph

Points 1, 2 correctly plotted **(1)**

Points 3, 4, 5 correctly plotted **(1)**

Joined with straight line **(1)** 3

Explanation

Straight line (→ exponential) **(1)**

Negative gradient (→ decreases) **(1)** 2

Value for resistance of second voltmeter

95 mV ÷ e = 35 mV)

OR 95mV ÷ 3=32mV) **(1)**

Time to fall to 32/35 mV
≈ 55 – 60 s **(1)**
This time = RC **(1)**
[OR Gradient of graph method → RC 2 marks]
∴ R = 240 – 280 Ω **(1)** Max 3

[OR $V = V_0 e^{-t/RC}$ method:

Correct substitution (any consistent values) 1 mark
Taking ln (maths) 1 mark
Answer 1 mark]

[12]

10. Energy stored in a capacitor

Justify area: $W = QV$
OR
work/area of thin strip = $V \times \Delta Q$ **(1)**

Area under graph **(1)** 2

Energy stored when capacitor charged to 5000 V

$W = \frac{1}{2} QV = \frac{1}{2} \times 0.35 \times 5000$ J

= 875 J **(1)** 1

Time constant for circuit

5000/e or 3 = 1840/1667 V **(1)**

⇒ T.C = 3.3 m s [3.1 – 3.6 m s] **(1)**

OR

Initial tangent → t-axis **(1)**

Accept between 3.5 and 4.0 m s **(1)** 2

[Also allow use of exponential formula with appropriate substitution of correct V and t, e.g. 2000 and 3 ms]

<u>Capacitance</u>

$C = \frac{T}{R}$ or as numbers **(1)**

3.3 m s → 7.0 × 10^{-5} F [Allow e.c.fs.]

4.0 m s → 8.5 × 10^{-5} F **(1)** 2

[OR using graph: $C = Q/V$ **(1)**
= 0.35/5000 = 7.0 × 10^{-5} F **(1)**]

<u>Energy left in capacitor</u>

At 2 ms, V = 2700 V [2600 – 2800] **(1)**

$\Rightarrow E = \frac{1}{2}CV^2$ *OR* $\frac{1}{2}QV$

= 255 J [e.c.f, depends on method] **(1)** 2

<u>Energy setting</u>

Energy leaving capacitor = (875 – 255) J

= 620 J [e.c.f] **(1)**

Energy delivered = 620 × 60/100 J

= 372 J

⇒ 380 J setting [Allow e.c.f] **(1)** 2

[11]

11. Estimation of charge delivered:

Charge = area under graph **(1)**

= a number of squares × correct calculation for charge of one square i.e. correct attempt at area e.g. single triangle **(1)**

= (3.5 to 4.8) × 10^{-3} C (A s, μA s) **(1)**

[Limit = triangle from 41 μA → 300 s]

OR

Charge = average current × time **(1)**

= (something between 10 and 20 μA) × 300 s **(1)**

= (3.5 to 4.8) × 10^{-3} C **(1)** 3

[But $Q = It$ → 0/3, e.g. 41 μA × 300 s]

Estimation of capacitance

C = calculated charge/9.0V   time constant ≈100 s **(1)**

= 390 to 533 μF C = 100 s/220 k.Ω = 450 μF **(1)** 2

[5]

12. <u>Charge on capacitor</u>

220 μF × 5 V [use of CV ignore powers of 10] **(1)**
= 1100 μC **(1)** 2

<u>Energy on capacitor</u>

$\frac{220}{2}$ μF × (5 V)^2 / $\frac{1100}{2}$ μC ×5 V / $\frac{1100^2\ \mu C^2}{2 \times 220 \mu F}$ [ignore powers of 10] **(1)**

= 2750 μJ (2.8 × 10^{-3} J) **(1)** 2

<u>Experiment</u>

Method 1 (constant current method):

- Circuit **(1)**
- For a given V record time to charge capacitor at a constant rate **(1)**
- for a range of values of V **(1)**
- Use $Q = It$ to calculate Q **(1)**
- Plot $Q \to V$– straight line graph through origin / sketch graph / dive Q/V and obtain constant value **(1)**

Method 2:

- Circuit **(1)**
- For a given value V measure I and t **(1)**
- Plot $I \to t$ find area under graph Q **(1)**
- Repeat for a range of values of V **(1)**
- Plot $Q \to V$ for straight line graph through origin/ sketch graph / dive Q/V and obtain constant value **(1)**

Method 3 (joulemeter method):

- Circuit **(1)**
- Record V and energy stored **(1)**
- For range of V **(1)**
- Determine Q from ½ QV or $\frac{Q^2}{2C}$ **(1)**
- Plot $Q \to V$– straight line graph through origin / sketch graph / divide Q/V and obtain constant value **(1)** 5

[Coulombmeter (will not work with this value of capacitor)
circuit **(1)** ; record charge Q on colombmeter **(1)**; for a range of values of V **(1)**; Plot $Q \to V$ for straight line through origin **(1)** – Max 3]

[9]

Question Number	Answer	Mark
1(a)	Increasing d will lead to a decrease in C **Or** see $Q/V = k/d$ **(1)** Since $C = Q/V$ (a decrease in C) means a decrease in the charge on the capacitor **Or** if V is constant (a decrease in C) means a decrease in charge on capacitor **(1)**	2
1(b)	Use of $C = k/d$ with $d = 4.2$ (mm) **(1)** use of $Q = CV$ *with* $V = 6$ V or cancelled later **(1)** use of $\Delta Q/Q$ or $\Delta C/C$ **(1)** % change = 17% **(1)** Example of calculation $Q = \frac{6\text{ V} \times 2.8\times10^{-15}\text{ F m}}{3.5\times10^{-3}\text{ m}} = 4.8\times10^{-12}$ C $Q = \frac{6\text{ V} \times 2.8\times10^{-15}\text{ F m}}{4.2\times10^{-3}\text{ m}} = 4.0\times10^{-12}$ C $\frac{4.8\times10^{-12}\text{ C} - 4.0\times10^{-12}\text{ C}}{4.8\times10^{-12}\text{ C}} = 16.7\%$	4
1(c)	(rapid changes in position) mean that rapid changes in Q **Or** a shorter time to charge/discharge **(1)** (small C gives) shorter time constant/RC **(1)**	2
	Total for question 13	**8**

Question Number	Answer	Mark
2(a)	Use of $C=Q/V$ **(1)** V= 15 V **(1)** Use of $W = QV/2$ **Or** $W = CV^2/2$ **Or** $W = Q^2/2C$ **(1)** $W = 2.5 \times 10^{-5}$ J **(1)** (candidates who use 6.6×10^{-6} C can only score MP1 and MP3) Example of calculation $V = Q/C = 3.3 \times 10^{-6}$ C / 220×10^{-9} F V= 15 V $W = QV/2 = (3.3 \times 10^{-6}$ C × 15 V)/2 $W = 2.5 \times 10^{-5}$ J	4
2(b)	$Q = 0.2\,Q_0$ **Or** $Q = 6.6\times 10^{-7}$ C **(1)** Use of $Q = Q_o\,e^{-t/RC}$ **(1)** t = 7.1 s **(1)** (candidates who use $Q = 0.8\,Q_0$ can only score MP2) Example of calculation $Q = 0.2\,Q_0$ $Q = Q_0\,e^{-t/RC}$ $0.2\,Q_0 = Q_0\,e^{-t/RC}$ ln (0.2) = - t/ ($20\times 10^6\,\Omega \times 220 \times 10^{-9}$ F) t = 7.1 s	3
2(c)	**Either** refers to $W = Q^2/2C$ **Or** $W \alpha Q^2$ **(1)** If Q halves, $W \rightarrow Q^2/8C$ Or halving Q quarters W **(1)** (Since W becomes a quarter in the time for Q to half) it takes less time for the energy to halve than the charge to halve. (dependent mark on either MP1 or MP2) **(1)** **Or** Refers to $W = QV/2$ **(1)** Q and V both decrease over time **(1)** W will decrease faster so takes less time to half in value. (dependent mark on either MP1 or MP2) **(1)**	3
2(d)	Synchronous readings **Or** data logger records readings at exact time **Or** voltmeter and stop watch need 2 people and data logger only one **(1)** More readings can be taken in a shorter time **Or** higher sampling rate **(1)** (treat as neutral any reference to graph plotting automatically, human reaction time or accuracy)	2
	Total for question 15	**12**

Question Number	Answer		Mark
3(a)(i)	Use of $Q = CV$ Q = 3900 (C) <u>Example of answer</u> Q = 1500 F × 2.6 V Q = 3900 C	(1) (1)	2
3(a)(ii)	Straight line through the origin Passing through 2.6 V and answer to (a)(i) or 4000 C	(1) (1)	2
3(a)(iii)	Use of $W = QV/2$ **Or** $W = CV^2/2$ **Or** use of area under graph W = 5.1 kJ (use of 4000 C gives W = 5.2 kJ (allow ecf from (a)(i)) <u>Example of answer</u> W = 3900 C × 2.6 V / 2 W = 5070 J	(1) (1)	2
3(b)(i)	Exponential decay Current decreases by equal fractions in equal time intervals	(1) (1)	2
3(b)(ii)	See attempt of I_0/e Finds time (accept 0.75-0.80s) Use of $\tau = RC$ R = 0.0005 Ω **Or** Finds the time for I_o to half Uses $t_{1/2} = \tau \ln 2$ Use of $\tau = RC$ R = 0.00050 – 0.00053 Ω **Or** See attempt of 37% of 5400 A Finds time (accept 0.75 to 0.80 s) Use of $\tau = RC$ R = 0.0005 – 0.00053Ω **Or** Draws tangent at t = 0 to meet time axis. Records intercept of tangent with axis (accept 0.6 s - 0.9 s) Use of $\tau = RC$ R = 0.0004 Ω – 0.0006 Ω **Or** reads a value off the y-axis and corresponding time Subs into formula using 5400 (A) to find RC Substitutes for C to find R R = 0.00050 Ω – 0.00058 Ω <u>Example of calculation</u> 37% of 5400 A is 1998 A Time to fall to this value is 0.75 s RC = 0.75 s R =0.75 s / 1500 F = 0.0005 Ω	(1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	4

3(c)	**Max 3** Ultracapacitor used for: overtaking **Or** going up a hill **Or** starting (from rest) **Or** accelerating. Because this requires a large <u>current/power</u>. Batteries used for travelling at constant speed Because this requires a small <u>current/power</u> for a longer time	 (1) (1) (1) (1)	3
	Total for question 17		**15**

Question Number	Answer		Mark
4(a)(i)	Capacitor, resistor, supply and switch all in series (ignore voltmeter) Voltmeter directly across capacitor	**(1)** **(1)**	**2**
4(a)(ii)	Datalogger allows large number of readings to be taken **Or** graph can be plotted directly/automatically **Or** simultaneous reading of t and V can be taken **Or** idea that people can't record quickly enough, (treat as neutral accuracy, precision misreading or human reaction time)	**(1)**	**1**
4(b)	Use of $C = Q/V$ $Q = 5.0 \times 10^{-4}$ C Example of calculation $Q = 100 \times 10^{-6}$ F × 5.0 V $Q = 5.0 \times 10^{-4}$ C	**(1)** **(1)**	**2**
4(c)(i)	Use of $I = \Delta Q/\Delta t$ e.c.f their value of C from (b) $I = 0.05$ A (accept recalculation of Q using $V = 4.90$ or 4.95 V) Example of calculation $I = 5.0 \times 10^{-4}$ C / 10×10^{-3} s $I = 0.05$ A	**(1)** **(1)**	**2**
4(c)(ii)	tangent drawn at t = 0 $\Delta V/\Delta t = 2000 - 3300$ V s^{-1} Initial current = 0.22 - 0.28 A (MP2 & 3 can be scored even if no tangent drawn) (No credit for exponential calculation) Example of calculation $\Delta V/\Delta t = 1.1$ V/ 0.5 ms = 2200 V s^{-1} $I = (\Delta V/\Delta t) \times C$ $I = 2200$ V s^{-1} × 100 × 10^{-6} F $I = 0.22$ A	**(1)** **(1)** **(1)**	**3**
4(c)(iii)	Use of $V = IR$ using answer from (ii) correct evaluation of R (5V used with current range in (ii) gives 18 - 23 Ω) Example of calculation 5 V = 0.22 A × R R = 23 Ω	**(1)** **(1)**	**2**
	Total for question 14		**12**

Question Number	**Answer**		**Mark**
5(a)(i)	Use of $t=RC$ Use of $T=1/f$ **Or** $f = 1/t$ Comparison of 2.2 x10^{-4} (s) << 2.5 x10^{-3} (s) **Or** comparison of 400 (Hz)<< 4500 (Hz) **Or** reference to nRC (needed for complete discharge) where n = 3 – 11 **Or** $e^{-T/t}$ is a very small value	**(1)** **(1)** **(1)**	**3**
5(a)(ii)	See $C = Q/V$ **Or** $Q = CV$ See $Q = It$ See $t = 1/f$ **Or** $f = 1/t$ (Answers based on t = RC and V = IR scores 0)	**(1)** **(1)** **(1)**	**3**
5(a)(iii)	sub in $C = I/fV$ C = 2.7 μF Example of calculation C = 5.4 × 10^{-3} A/ (400 s^{-1} × 5.0 V) C = 2.7 μF	**(1)** **(1)**	**2**
5(a)(iv)	2.2 + 30% = 2.9 (μF) **Or** shows that 2.7 (uF) is +22% of 2.2 (uF) Within tolerance / consistent (2nd mark can only be awarded following an attempt at either of the above calculations) If candidates make an error in (iii) allow full ecf with a valid comment based on their values.	 **(1)** **(1)**	**2**
5(b)	Use of ½ CV^2 W = 3.4 × 10^{-5} J (allow ecf from (iii) or use of 2.2 μF→2.75 × 10^{-5} J) Example of calculation W = ½ 2.7 μF × (5.0 V)^2 W = 3.4 × 10^{-5} J	**(1)** **(1)**	**2**
	Total for question 16		**12**

Question Number	Answer	Mark
6(a)	Method marks only Use of $Q=CV$ with $V=16$ V **(1)** Max value of $C = 12000$ (μF) **(1)** μF means 10^{-6} conversion of μF to F **(1)** <u>Example of calculation</u> $C_{max} = 1.20 \times 10000 = 12000$ F $C_{max} = 12000$ F × 16 V $Q_{max} = 0.192$ C	**3**
6(b)	Either use of ½ QV or ½ CV^2 **(1)** Energy = 1.5 J **(1)** <u>Example of calculation</u> $W = ½\ 0.192$ C × 16 V Energy = 1.54 J	**2**
	Total for question 13	**5**

Question Number	Answer	Mark
1(a)	(Trace) always positive/not negative/not below 0/ if it was AC the graph would be positive and negative Indicating one/same direction	(1) (1)
1(b)(i)	Capacitor stores charge/charges up (If voltage is constant) capacitor doesn't discharge	(1) (1)
1(b)(ii)	Recall of E = ½ CV^2 or use of Q=CV and QV/2 Substitution of C and any reasonable V [ignore power of 10 for C] eg = ½ 10 x 10^{-6} x $5.5^2/5.6^2$ = 1.5 x 10^{-4} - 1.6 x 10^{-4} J	(1) (1) (1)
1(c)(i)	Capacitor charges up From the supply (then) Capacitor discharges Through circuit / exponentially	(1) (1) (1) (1) (max 3)
1(c)(ii)	Corresponding time interval for a change in V eg 6-7 ms for ΔV = 2V $V = V_0 e^{-t/RC}$ or rearrangement seen [eg Ln 0.7 = 6 x10^{-3} /RC] R approx 1700 Ω (allow 1600 – 1800) or Time constant = 14 – 20 ms T = RC seen R approx 1700 Ω (allow 1600 – 1800) or Corresponding time interval for a change in V eg 6-7 ms for ΔV = 2V Q = C V and I = Q/t seen R approx 1700 Ω (allow 1600 – 1800)	(1) (1) (1) (1) (1) (1) (1) (1) (1)
1(c)(iii)	Use larger capacitor	(1)
	Total for question 16	**14**

Question Number	Answer		Mark
2(a)	Use of $Q = CV$ Q = 0.18 C Example of calculation $Q = 150 \times 10^{-6}$ F × 1200 V Q = 0.18 C	(1) (1)	2
2(b)	Use of $W = ½ CV^2$ **Or** of $W = ½ QV$ **Or** of $W = ½ Q^2/C$ W = 110 J Allow ecf from (a) if ½ QV or ½ Q^2/C used Example of calculation $W = ½ \times 150 \times 10^{-6}$ F × $(1200 \text{ V})^2$ W = 108 J	(1) (1)	2
2(c)(i)	R = 86 (Ω) Example of calculation $R = V/I$ = 1200 V / 14 A R = 85.7 Ω	(1)	
2(c)(ii)	$Q = 0.25\ Q_0$ **Or** Q = 0.045 C Use of RC (0.013 s) Use of $Q = Q_0 e^{-t/RC}$ to give t = 0.018 s (show that value will give t = 0.019 s) [Use of ln 4 gives the correct answer if the − sign is ignored , scores 1 for use of RC use of ¾Q →3.7 × 10^{-3} s scores 1 mark] **Or** Use of RC Use of 2 × 0.69 × RC t = 0.018 s Example of calculation $Q = 0.25\ Q_0$ $Q = Q_0 e^{-t/RC}$ $0.25\ Q_0 = Q_0 e^{-t/RC}$ ln (0.25) = - t/ (86 Ω × 150 × 10^{-6} F) t = 0.0178 s	(1) (1) (1)	3
2(c)(iii)	Same charge (flows for shorter time) **OR** (Same charge flows for) shorter time	(1)	1
	Total for question 15		9

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Question Number	Answer	Mark
3(a)(i)	Capacitor charges up **Or** p.d. across capacitor becomes (equal to) p.d. of cell **(1)** Negative charge on one plate and positive charge on the other **Or** opposite charges on each plate **Or** movement of electrons from one plate and to the other (around the circuit) **(1)** (Reference to positive charges moving or to charge moving directly between the plates negates the second mark)	2
3(a)(ii)	As capacitor charges current decreases **Or** As capacitor charges current drops to zero **Or** p.d. across capacitor becomes (equal to) p.d. of cell **(1)** No current through R (means no p.d.) **Or** $V_{cell} = V_{capacitor} + V_{resistor}$ **(1)**	2
*3(b)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) See Q=CV **(1)** As C increased then charge flows (**Or** more charge stored) on capacitor **(1)** So p.d. across R **(1)** Charge flow / current /output signal reversed when plates move apart **(1)** **Or** See Q=CV **(1)** As C increased p.d. across capacitor decreased **(1)** So p.d. across R must increase **(1)** p.d. reverses when plates move apart **(1)**	4
3(c)	Use of time constant =RC **Or** attempt to find half life **(1)** Time constant = 0.005 (s) **Or** $t_{½}$ = 0.0035 (s) **(1)** Use of $T = 1/f$ (to give T = 0.05 s for the lowest audible frequency) **(1)** Capacitor completes discharging/charging during cycle of signal **(1)** (last mark can only be gained if supported by calculations) ($f = 1/CR$ may be used to find the 'frequency of the microphone', rather than time. In this case candidates may just calculate f =200 Hz rather than a time. Only first 3 marks are available) Example of calculation $RC = 10 \times 10^6\ \Omega \times 500 \times 10^{-12}$ F RC = 0.005 s $F = 1/T = 1/20 = 0.05$ s	4
	Total for question 16	**12**

Question Number	Answer	Mark
4(a)(i)	Discharges / loses charge (1) Idea that discharge is not instantaneous (1) [e.g. over period of time, gradually, exponential]	2
4(a)(ii)	Decay curve starting on y-axis and not reaching x-axis (1) [no rise at the end] Initial current marked 2 mA (1) X-axis labelled such that $T_{½}$ = 0.02 to 0.06 s (1)	3
4(a)(iii)	Same graph (1) On negative side of current axis/current in the opposite direction (1)	2
4(b)	Use of $W = ½\ CV^2$ / Use of $Q = CV$ and $W = ½\ QV$ (1) $W = 5 \times 10^{-4}$ J (1) Example of calculation $W = ½\ (10 \times 10^{-6}\ \text{F})\ (10\ \text{V})^2$ $W = 5 \times 10^{-4}$ J	2
4(c)	Use of ln $V/V_0 = (-)\ t/RC$ or $V = V_0\ e^{-t/RC}$ with V and V_0 correct (1) t = 0.13 s (1) Example of calculation ln(10 V/0.7 V) = t / 0.05 s t = 0.13 s	2
	Total for question 15	**11**

Question Number	Answer	Mark
1(a)	Charges **(1)** Movement of electrons from one plate to the other OR one plate becomes + the other – OR until pd across C equals V_{supply} **(1)**	**2**
1(b)(i)	Use of $Q = It$ (both 0.74 and 0.1/0.2) **(1)** Recognition of milli and Δt =0.1 **(1)** Eg $Q = 0.74 \times 10^{-3} \times 0.1 = 74 \times 10^{-6}$ C	**2**
1(b) (ii)	Use of $V = Q/C$ **(1)** Explains unit conversion **(1)** Eg $V = 278 \times 10^{-6} / 100 \times 10^{-6} = 2.78$ [accept μ/μ]	**2**
1(c)(i)	Recall of RC **(1)** Answer = 0.3 (s) **(1)** Eg $T = 3000 \times 0.0001$ **plus either** 1/e or 37% of initial **(1)** =0.23 - 0.27 (s) **(1)** **or** sub in formula $I = Ioe^{-t/RC}$ **(1)** = 0.23 - 0.27 (s) **(1)** **or** Initial Tangent drawn **(1)**	
	Time constant = 0.2-0.3 (s) **(1)**	**4**
1(c)(ii)	Plot Ln I / Log I **(1)** Against t **(1)** (dependent on first mark) or Gradients of graph (1) Against **I** (1) (dependent on first mark) should be straight line **(1)** (dependent on previous 2)	**3**
	Total for question	**13**

Question Number	Answer		Mark
2(a)	The capacitor stores charge **Or** capacitor charges from the supply The idea that the capacitor doesn't fully discharge before being recharged.	**(1)** **(1)**	**2**
2(b)(i)	(6.4 + 4.4)/2 = 5.4 V	**(1)**	**1**
2(b)(ii)	Use of $V = IR$ Average $I = 5.4\ \text{V}/(2.2 \times 10^{3}\,\Omega) = 2.5 \times 10^{-3}$ A ecf value form (b)(i)	**(1)** **(1)**	**2**
2(b)(iii)	Time = 17 ms or 17.5 ms	**(1)**	**1**
2(b)(iv)	Use of $Q = It$ Use of $C = Q/V$ Use of $\Delta V = 2.0$ V $C = 21$ μF (ecf values of I and t from above) Example of calculation $Q = 2.5 \times 10^{-3}\ \text{A} \times 17 \times 10^{-3}\ \text{s} = 4.25 \times 10^{-5}$ C $C = 4.25 \times 10^{-5}\ \text{C} / 2.0\ \text{V}$ $C = 21$ μF	**(1)** **(1)** **(1)** **(1)**	**4**
2(c)	Uses a larger capacitance Because a larger time constant is needed **Or** stores more charge **Or** less $\Delta V \rightarrow \Delta Q/C$	**(1)** **(1)**	**2**
	Total for question 17		**12**

Question Number	Answer		Mark
3(a)	Use of $Q = It$ $Q = 2.8$ C <u>Example of calculation</u> $Q = 2.0 \times 10^{3}$ A $\times 1.4 \times 10^{-3}$ s $Q = 2.8$ C	**(1)** **(1)**	**2**
3(a)(ii)	See $\tau = RC$ $\tau = 3.0 \times 10^{-4}$ (s) Relates time constant to the time for which current is required <u>Example of calculation</u> $\tau = 0.50\Omega \times (600 \times 10^{-6}$ F) $\tau = 3.0 \times 10^{-4}$ s 1.4×10^{-3}s / 3.0×10^{-4} s = 4.7RC	**(1)** **(1)** **(1)**	**3**
3(b)(i)	Use of $Q = CV$ $V = 4700$ V (e.c.f from (a)(i)) <u>Example of calculation</u> $V = 2.8$V / (600×10^{-6} F) $V = 4670$ V	**(1)** **(1)**	**2**
3(b)(ii)	Use of $W = ½ QV$ **Or** $W = ½ Q^2/C$ **Or** $W = ½ CV^2$ Use of $P = W/t$ $P = 4.7$ MW (e.c.f. from (a)(i) and/or (b)(i)) <u>Example of calculation</u> $P = (2.8$ C $\times 2.8$ C) / ($2 \times 600 \times 10^{-6}$ F $\times 1.4 \times 10^{-3}$ s) $P = 4.7$ MW	**(1)** **(1)** **(1)**	**3**
	Total for question 15		**10**

1. A
2. B
3. D
4. D
5. A
6. D
7. A
8. C
9. B
10. B

M1. D **[1]**

M2. A **[1]**

M3. C **[1]**

M4. A **[1]**

M5. C **[1]**

M6. A **[1]**

M7. C **[1]**

M8. (a) (i) E (= ½ CV^2 = 0.5 × 180 × 10^{-6} × 100^2) = 0.90J **(1)**

(ii) W (= QV = CV^2 = 180 × 10^{-6} × 100^2) = 1.8 J **(1)**

2

(b) (i) ($V = V_0 e^{-t/RC}$) gives $30 = 100\ e^{-t/RC}$ **(1)**

∴ t = ($-RC$ ln (30/100) = −1.5 × 180 × 10^{-6} × −1.204 s)
= 3.3 × 10^{-4} s **(1)**

(ii) image would be less sharp (or blurred) because the discharge would last longer and the image would be photographed as it is moving **(1)**

image would be brighter becau e the capacitor tore more energy and therefore produces more light **(1)**

4

[6]

M9. (a) Q (= CV = 330 × 9.0) = 2970 (μC) **(1)**
E (= ½QV) = ½ x 2.97 × 10^{-3} × 9.0 = 1.34 × 10^{-2}J **(1)**
[or E (½CV^2) ½ × 300 × 10^{-6} × 9 0^2 **(1)** 1 34 × 10^{-2}J **(1)**]

2

(b) time constant (= RC) = 470 × 10^3 × 330 × 10^{-6} = 155 s **(1)**

1

(c) $Q\left(= Q_0 e^{-t/RC}\right)$ = 2970 × $e^{-60/155}$

= 2020 (μC)

(allow C.E. for time constant from (b))

$V = \left(\frac{Q}{C}\right) = \frac{2020}{330} = 6.11\ V$ **(1)**

(allow C.E. for Q)

[or $V = V_0 e^{-t/RC}$ **(1)** = 9.0 $e^{-60/155}$ **(1)** = 6.11 V **(1)**]

3

[6]

M10. (a) $E \propto V^2$ (or $E = {}^1/_2 CV^2$) **(1)**

pd after 25 s = 6 V **(1)**

2

(b) (i) use of $Q = Q_0 e^{-t/RC}$ or $V = V_0 e^{-t/RC}$ **(1)**

(e.g. $6 = 12e^{-25/RC}$) gives $e^{\frac{25}{RC}} = \frac{12}{6}$ and $\frac{25}{RC}$ = 1n 2 **(1)**

(RC = 36(.1) s)

[alternatives for (i):

$V = 12\ e^{-25/36}$ gives V = 6.0 V **(1)** (5.99 V)

or time for pd to halve is 0.69RC

$\therefore RC = \frac{25}{0.69}$ **(1)** = 36(.2) s]

(ii) $R = \frac{36.1}{680 \times 10^{-6}}$ **(1)** = 5.3(0) × 10^4 Ω **(1)**

4

[6]

M11. (a) (i) energy stored by capacitor (= ½ CV^2)

= ½ × 70 × 1.2^2 ✓ (= 50.4) = 50 (J) ✓

to **2 sf** only ✓

3

(ii) energy stored by cell (= $I\ V\ t$) = 55 × 10^{-3} × 1.2 × 10 × 3600 ✓

(= 2380 J)

$\frac{\text{energy stored by cell}}{\text{energy stored by capacitor}} = \frac{2380}{50} = 48$ (ie about 50) ✓

2

(b) capacitor would be impossibly large (to fit in phone) ✓

capacitor would need recharging very frequently
[**or** capacitor could only power the phone for a short time] ✓

capacitor voltage [**or** current supplied or charge] would fall continuously while in use ✓

max 2

[7]

M12. (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of the three levels according to the following criteria.

High Level (good to excellent) 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate provides a comprehensive and logical description of the sequence of releasing the ball and taking measurements of initial and final voltages. They should identify the correct distance measurement and show a good appreciation of how to use these measurements to calculate the time and acceleration from them. Time should be found from capacitor discharge, using known C and R values. Repeated readings would be expected in any answer worthy of full marks, but five marks may be awarded where repetition is omitted.

Intermediate Level (modest to adequate) 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate provides a comprehensive and logical description of the sequence of releasing the ball and taking measurements of the initial and final voltages. They are likely to show some appreciation of the use of suvat equations to calculate the acceleration, although they may not recognise the need to measure a distance.

Low Level (poor to limited) 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may only be partly appropriate.

The candidate is likely to have recognised that initial and final voltages should be measured, but may not appreciate the need for any other measurement. They may present few details of how to calculate the acceleration from the voltage measurements.

The explanation expected in a competent answer should include a coherent selection of the following points.

Measurements

- initial pd across C (V_0) from voltmeter (before releasing roller)
- distance s along slope between plungers
- final pd across C (V_1) from voltmeter
- measurements repeated to provide a more reliable result

Analysis

- time t is found from $V_1 = V_0 e^{-t/RC}$, giving $t = RC \ln (V_0/V_1)$
- from $s = ut + ½ at^2$ with $u = 0$, acceleration $a = 2s/t^2$
- repeat and find average a from several results

(b) (i) $RC = 22 \times 10^{-6} \times 200 \times 10^3$ [or = 4.4 (s)] **(1)** (4.40)

$5.8 = 12.0\ e^{-t/4.40}$ **(1)**

gives $t = 4.40 \ln (12.0/5.8) = 3.2$ (3.20) (s) **(1)**

3

(ii) $a\left(= \frac{2s}{t^2}\right) = \frac{2 \times 2.5}{3.20^2}$ **(1)**

= 0.49 (0.488) (m s^{-2}) **(1)**

2

[11]

1. (a) (i) $C_p = 2 + 4 = 6\ \mu F$ — A1

(ii) $1/C = 1/2 + ¼$ — C1
$Cs = 4/3 = 1.33\ \mu F$ — A1

(b) (i) 6.0 V — A1

(ii) $Q = C_pV$ — C1
$= 6 \times 6 = 36\ \mu C$ — A1

(c) $E = ½\ C_sV^2$ — C1
$= 24 \times 10^{-6}$ — A1

(d) (i) The capacitors discharge <u>through</u> the voltmeter. — B1

(ii) $V = V_0e^{-t/CR}$
$1/4 = e^{-t/(6\times12)}$ — C1
$\ln 4 = t / 72$ — C1
$t = 72 \ln 4 \approx 100$ s — A1

[12]

2. (a) $Q_o = CV = 1.2 \times 10^{-11} \times 5.0 \times 10^3; = 6.0 \times 10^{-8}$; C (3) — 3

(b) (i) $RC = 1.2 \times 10^{15} \times 1.2 \times 10^{-11}$ *or* $= 1.44 \times 10^4$ (s) (1) — 1

(ii) $I = V/R = 5000/1.2 \times 10^{15}$ *or* $= 4.16 \times 10^{-12}$ (A) (1) — 1

(iii) $t = Q_o/I; = 6 \times 10^{-8} / 4.16 \times 10^{-12} = 1.44 \times 10^4$ (s) — 2

(iv) $Q = Q_oe^{-1}; Q = 0.37Q_o$ so Q lost $= 0.63Q_o$ — 2

(c) (i) capacitors in parallel come to same voltage (1)
so Q stored α C of capacitor (1)
capacitors in ratio 10^3 so only $10^{-3}\ Q_o$ left on football (1) — 3

(ii) $V = Q/C = 6.0 \times 10^{-8} /1.2 \times 10^{-8}$ *or* $6.0 \times 10^{-11} /1.2 \times 10^{-11}$ *or* only 10^{-3} Q left so 10^{-3} V left; = 5.0 (V) — 2

[14]

3. (a) (i) $Q = VC; W = ½\ VC.V\ (= ½\ CV^2)$ (2)

(ii) parabolic shape passing through origin (1)
plotted accurately as $W = 1.1\ V^2$ (1) — 4

(b) (i) $T = RC; = 6.8 \times 10^3 \times 2.2 = 1.5 \times 10^4$ s = 4.16 h — 2

(ii) $\Delta W = ½\ C(V_1^{\ 2} - V_2^{\ 2}) = 1.1(25 - 16)$; = 9.9 (J) — 2

(iii) $4 = 5 \exp(-t/1.5 \times 10^4)$; giving $t = 1.5 \times 10^4 \times \ln 1.25 = 3.3 \times 10^3$ (s) — 2

(iv) $P = \Delta W/\Delta t = 9.9/3.3 \times 10^3 = 3.0$ mW *ecf b(ii) and (iii)* — 1
allow $P = V_{av}^{\ 2} /R = 4.5^2/6.8 \times 10^3 = 2.98$ mW

[11]

4. (a) (i)

capacitor	capacitance / μF	charge / μC	p.d. / V	energy / μJ
X	5	30	= *Q/C* = 6 (V) (1)	= ½ CV^2(1) = ½ × 5 × 6^2 = 90 (1)
Y	25	= *CV* = 25 × 6 =150 (μC) (1)	= 6 (V) (1)	= 450 (1)
Z	10	30 + 150 = 180 (μC) (1)	= *Q/C* = 180/10 = 18 (V) (1)	= 1620 (1)

Each box correctly calculated scores (1) + (1) for ½ CV^2 — 9

(ii) **1** 18 V + 6 V = 24 (V) (1)
2 180 (μC) (1)
3 180 / 24 = 7.5 (1)
4 90 + 450 + 1620 = 2160 (μJ) (1) — 4

(b) (i) Kirchhoff's second law OR conservation of energy (1) — 1

(ii) Kirchhoff's first law OR conservation of charge (1) — 1

(c) (i) time constant = *CR* (1)
$= 7.5 \times 10^{-6} \times 200\ 000 = 1.5$ (s) (1) — 2

(ii) $Q = Q_o e^{-\frac{4CR}{CR}}$ (1)

$Q/Q_o = e^{-4} = 0.0183$ (1) 2

[19]

5. (i) $C_p = C + C = 6\ \mu F$; $1/C_s = 1/2C + 1/C; = 3/2C$ giving $Cs = 2C/3 = (2\ \mu F)$ 3

(ii) 2 sets of (3 in series) in parallel/ 3 sets of (2 in parallel) in series 2

[5]

Q1.

8 (a) Q/V, with symbols explained [do not allow in terms of units] **B1** **[1]**

(b) (i) on a capacitor, there is charge separation/there are + and - charges **M1**
<u>either</u> to separate charges, work must be done
<u>or</u> energy released when charges 'come together' **A1** **[2]**

(ii) <u>either</u> energy = $\frac{1}{2}CV^2$ <u>or</u> energy = $\frac{1}{2}QV$ and $C = Q/V$ **C1**
change = $\frac{1}{2} \times 1200 \times 10^{-6} (50^2 - 15^2)$ **C1**
change = 1.4 J (1.37) **A1** **[3]**
[allow 2 marks for $\frac{1}{2}C(\Delta V)^2$, giving energy = 0.74 J)

Q2.

5 (a) at t = 1.0 s, V = 2.5 V C1
energy = $\frac{1}{2}CV^2$ C1
$0.13 = \frac{1}{2} \times C \times (8.0^2 - 2.5^2)$ M1
C = 4500 μF A0 [3]

(b) use of two capacitors in series in all branches of combination M1
connected into correct parallel arrangement A1 [2]

Q3.

5 (a) (i) ratio of charge (on body) and its potential B1 [1]
(do not allow reference to plates of a capacitor)

(ii) (potential at surface of sphere =) $V = Q / 4\pi\varepsilon_0 r$ M1
$C = Q / V = 4\pi\varepsilon_0 r$ A0 [1]

(b) (i) $C = 4 \times \pi \times 8.85 \times 10^{-12} \times 0.36$
$= 4.0 \times 10^{-11}$ F *(allow 1 s.f.)* A1 [1]

(ii) $Q = CV$
$= 4.0 \times 10^{-11} \times 7.0 \times 10^5$
$= 2.8 \times 10^{-5}$ C A1 [1]

(c) plastic is an insulator / not a conductor / has no free electrons B1
charges do not move (on an insulator) B1
either so no single value for the potential
or charge cannot be considered to be at centre B1 [3]

(d) *either* energy = $\frac{1}{2}CV^2$ *or* energy = $\frac{1}{2}QV$ <u>and</u> $C = Q/V$ C1
energy = $\frac{1}{2} \times 4 \times 10^{-11} \times \{(7.0 \times 10^5)^2 - (2.5 \times 10^5)^2\}$ C1
= 8.6 J A1 [3]

Q4.

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5 (a) e.g. 'storage of charge' / storage of energy
blocking of direct current
producing of electrical oscillations
smoothing
(any two, 1 mark each) B2 [2]

(b) (i) capacitance of parallel combination = 60 μF C1
total capacitance = 20 μF A1 [2]

(ii) p.d. across parallel combination = $\frac{1}{2} \times$ p.d. across single capacitor C1
maximum is 9V A1 [2]

(c) *either* energy = $\frac{1}{2}CV^2$ *or* energy = $\frac{1}{2}QV$ <u>and</u> $Q = CV$ C1
energy = $\frac{1}{2} \times 4700 \times 10^{-6} \times (18^2 - 12^2)$ C1
= 0.42 J A1 [3]

Q5.

3 (a) charges on plates are equal and opposite M1
so no resultant charge A1
energy stored because there is charge separation B1 [3]

(b) (i) capacitance = Q / V C1
$= (18 \times 10^{-3}) / 10$
= 1800 μF A1 [2]

(ii) use of area under graph *or* energy = $\frac{1}{2}CV^2$ C1
energy = $2.5 \times 15.7 \times 10^{-3}$ *or* energy = $\frac{1}{2} \times 1800 \times 10^{-6} \times (10^2 - 7.5^2)$
= 39 mJ A1 [2]

(c) combined capacitance of Y & Z = 20 μF *or* total capacitance = 6.67 μF C1
p.d. across capacitor X = 8V *or* p.d. across combination = 12V C1
charge = $10 \times 10^{-6} \times 8$ *or* $6.67 \times 10^{-6} \times 12$
= 80 μC A1 [3]

Q6.

5 (a) two capacitors in series
or any circuit such that $V \leq 25$ V across any C B1
in parallel with second series pair or any correct combination .... B1 [2]

(b) two capacitors in series in parallel with a single capacitor
or other correct combination .... B2 [2]
(leads not shown, then –1 overall)

Q7.

5 (a) e.g. separate charges, store energy, smoothing circuit. etc. .... B1 [1]
(allow 'stores charge')

(b) (i) charge = current × time .... B1 [1]

(ii) area is 21.2 cm^2 (*allow ±0.5 cm^2*) C2
(*allow 1 mark if outside ±0.5 cm^2 but within ±1.0 cm^2*)
1.0 cm^2 represents (0.125 × 10^{-3} × 1.25 =) 156 μC C1
charge = 3300 μC .... A1 [4]

(iii) capacitance = Q/V C1
= (3300 × 10^{-6}) / 15
= 220 μF .... A1 [2]

(c) *either* energy = ½CV^2 or energy = ½QV and $C = Q/V$ C1
½ × C × 15^2 = 2 × ½ × C × V^2 .... C1
V = 10.6 V .... A1 [3]

Q8.

4 (a) charge / potential ……...(*ratio must be clear*) .... B1 [1]

(b) potential (at surface of sphere) = $Q / 4\pi\varepsilon_0 R$ M1
$C = Q / V = 4\pi\varepsilon_0 R$ .... A0 [1]

(c) (i) C = 4π × 8.85 × 10^{-12} × 0.63 .... C1
= 7.0 × 10^{-11} A1
farad / F .... B1 [3]

(ii) energy = ½CV^2 .... C1
0.25 × ½C × (1.2 × 10^6)^2 = ½CV^2 .... C1
V = 6.0 × 10^5 V .... A1 [3]
(*use of 0.75 rather than 0.25, allow max 2 marks*)

[Total: 8]

Q9.

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4 (a) charge / potential (difference) (*ratio must be clear*)	B1	[1]
(b) (i) $V = Q / 4\pi\varepsilon_0 r$	B1	[1]
(ii) $C = Q / V = 4\pi\varepsilon_0 r$ and <u>$4\pi\varepsilon_0$ is constant</u>	M1	
so $C \propto r$	A0	[1]
(c) (i) $r = C / 4\pi\varepsilon_0 r$	C1	
r = (6.8 × 10^{-12}) / (4π × 8.85 × 10^{-12})	C1	
= 6.1 × 10^{-2} m	A1	[3]
(ii) $Q = CV$ = 6.8 × 10^{-12} × 220		
= 1.5 × 10^{-9} C	A1	[1]
(d) (i) $V = Q/C$ = (1.5 × 10^{-9}) / (18 × 10^{-12})		
= 83 V	A1	[1]
(ii) *either* energy = ½CV^2	C1	
ΔE = ½ × 6.8 × 10^{-12} × 220^2 – ½ × 18 × 10^{-12} × 83^2	C1	
= 1.65 × 10^{-7} – 6.2 × 10^{-8}		
= 1.03 × 10^{-7} J	A1	[3]
or energy = ½QV	(C1)	
ΔE = ½ × 1.5 × 10^{-9} × 220 – ½ × 1.5 × 10^{-9} × 83	(C1)	
= 1.03 × 10^{-7} J	(A1)	

Q10.

4 (a) (i) work done moving unit positive charge	M1	
from infinity <u>to the point</u>	A1	[2]
(ii) charge / potential (difference) (*ratio must be clear*)	B1	[1]
(b) (i) capacitance = (2.7 × 10^{-6}) / (150 × 10^3)	C1	
(*allow any appropriate values*)		
capacitance = 1.8 × 10^{-11} (*allow 1.8 ±0.05*)	A1	[2]
(ii) *either* energy = ½CV^2 *or* energy = ½QV <u>*and*</u> $Q = CV$	C1	
energy = ½ × 1.8 × 10^{-11} × (150 × 10^3)^2 *or* ½ × 2.7 × 10^{-6} × 150 × 10^3		
= 0.20 J	A1	[2]
(c) *either* since energy ∝ V^2, capacitor has (½)^2 of its energy left		
or full formula treatment	C1	
energy lost = 0.15 J	A1	[2]

Q11.

4 (a) e.g. storing energy
separating charge
blocking d.c.
producing electrical oscillations
tuning circuits
smoothing
preventing sparks
timing circuits
(any two sensible suggestions, 1 each, max 2) B2 [2]

(b) (i) $-Q$ (induced) on opposite plate of C_1 B1
by charge conservation, charges are $-Q$, $+Q$, $-Q$, $+Q$, $-Q$ B1 [2]

(ii) total p.d. $V = V_1 + V_2 + V_3$ B1
$Q/C = Q/C_1 + Q/C_2 + Q/C_3$ B1
$1/C = 1/C_1 + 1/C_2 + 1/C_3$ A0 [2]

(c) (i) energy $= ½CV^2$ or energy $= ½\,QV$ and $C = Q/V$ C1
$= ½ \times 12 \times 10^{-6} \times 9.0^2$
$= 4.9 \times 10^{-4}$ J A1 [2]

(ii) energy dissipated in (resistance of) wire/as a spark B1 [1]

Q12.

5 (a) (i) ratio of charge and potential (difference) / voltage
(ratio must be clear) B1 [1]

(ii) capacitor has equal magnitudes of (+)ve and (-)ve charge B1
total charge on capacitor is zero (so does not store charge) B1
(+)ve and (-)ve charges to be separated M1
work done to achieve this so stores energy A1 [4]

(b) (i) capacitance of Y and Z together is 24 μF C1
$1/C = 1/24 + 1/12$
$C = 8.0$ μF (*allow* 1 s.f.) A1 [2]

(ii) some discussion as to why all charge of one sign on one plate of X B1
$Q = (CV =)\ 8.0 \times 10^{-6} \times 9.0$ M1
$= 72$ μC A0 [2]

(iii) 1. $V = (72 \times 10^{-6}) / (12 \times 10^{-6})$
$= 6.0$ V (*allow* 1 s.f.) (allow 72/12) A1 [1]

2. *either* $Q = 12 \times 10^{-6} \times 3.0$ *or* charge is shared between Y and Z C1
charge = 36 μC A1 [2]
*Must have correct voltage in **(iii)**1 if just quote of 36μC in **(iii)**2.*

Q13.

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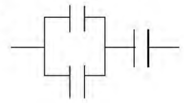
4 (a) e.g. store energy (do not allow 'store charge')
in smoothing circuits
blocking d.c.
in oscillators
any sensible suggestions, one each, max. 2 B2 [2]

(b) (i) potential across each capacitor is the same and $Q = CV$ B1 [1]

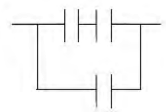
(ii) total charge $Q = Q_1 + Q_2 + Q_3$ M1
$CV = C_1V + C_2V + C_3V$ M1
(*allow* $Q = CV$ *here* or in (i))
so $C = C_1 + C_2 + C_3$ A0 [2]

(c) (i)



A1 [1]

(ii)



A1 [1]

Q14.

6 (a) (i) energy $= EQ$ C1
$= 9.0 \times 22 \times 10^{-3}$
$= 0.20$ J A1 [2]

(ii) 1. $C = Q/V$
$V = (22 \times 10^{-3})/(4700 \times 10^{-6})$ C1
$= 4.7$ V A1 [2]

2. *either* $E = ½CV^2$ C1
$= ½ \times 4700 \times 10^{-6} \times 4.7^2$
$= 5.1 \times 10^{-2}$ J A1 [2]

or $E = ½QV$ (C1)
$= ½ \times 22 \times 10^{-3} \times 4.7$
$= 5.1 \times 10^{-2}$ J (A1)

or $E = ½Q^2/C$ (C1)
$= ½ \times (22 \times 10^{-3})^2/4700 \times 10^{-6}$
$= 5.1 \times 10^{-2}$ J (A1)

(b) energy lost (as thermal energy) in resistance/wires/battery/resistor B1 [1]
*(award only if answer in **(a)(i)** > answer in **(a)(ii)2**)*

Q15.

6	(a)	for the two capacitors in parallel, capacitance = 96 μF	C1	
		for complete arrangement, $1 / C_T = 1/96 + 1/48$		
		$C_T = 32\,\mu F$	A1	[2]
	(b)	p.d. across parallel combination is one half p.d. across single capacitor	C1	
		total p.d. = 9 V	A1	[2]