Electronic Circuits

Week 6: Capacitance

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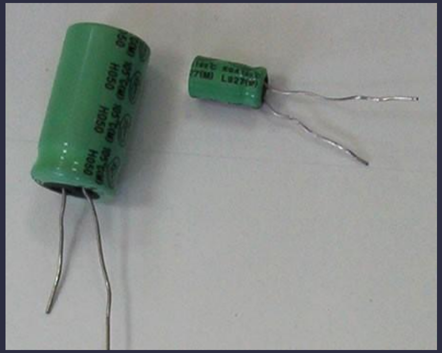
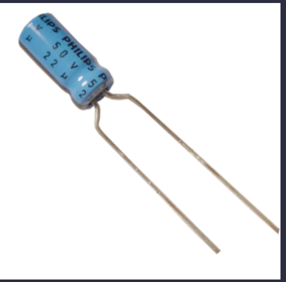
Capacitors

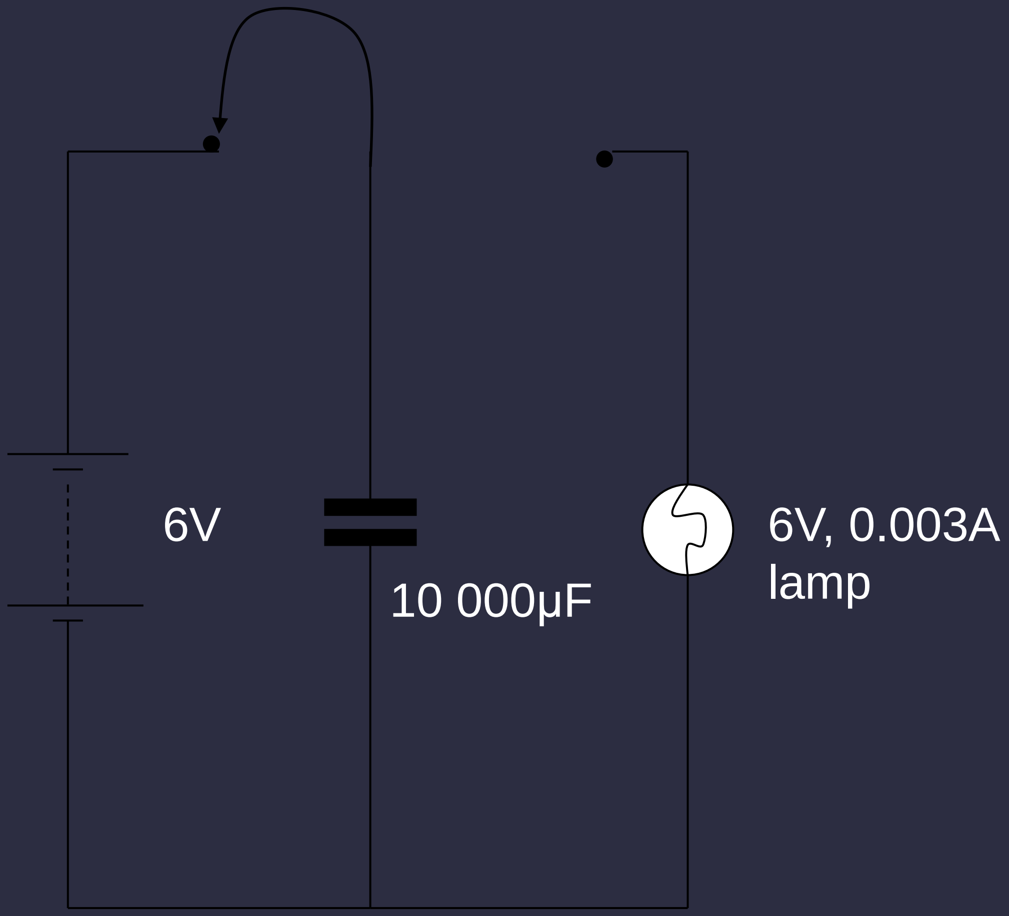
- A capacitor is a circuit element which is used to store electrical charge.

- Any capacitor consists of a pair of conducting plates separated by an insulator. The insulator is called a dielectric and is often air, paper or oil.





Illustrating the action of a capacitor



Set up the circuit.

Connect the flying lead of the capacitor to the battery.

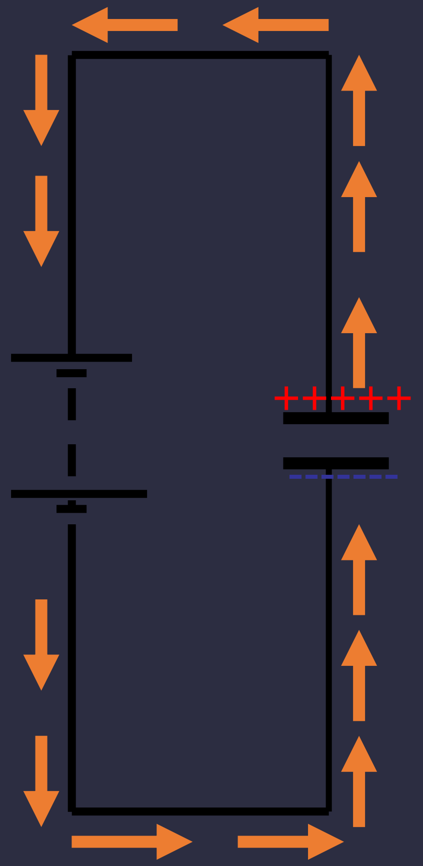
Connect it to the lamp.

Try putting a 100Ω resistor in series with the lamp.

What effect does it have?

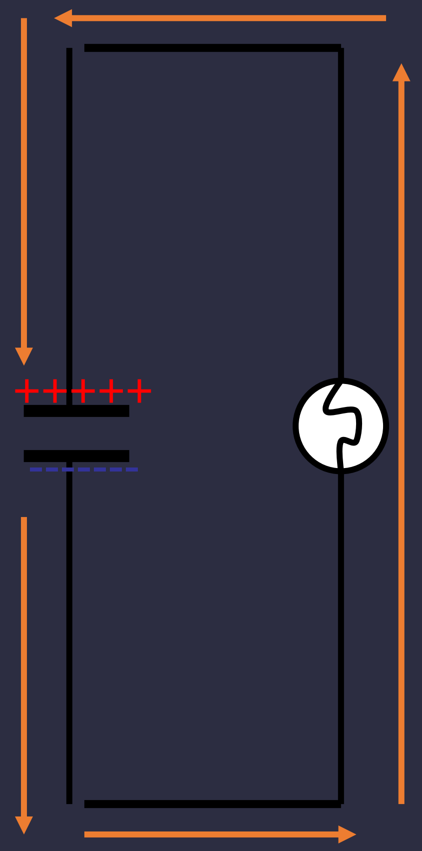
What is happening

- When the capacitor is connected to the battery, a momentary current flows.
- Electrons gather on the plate attached to the negative terminal of the battery. At the same time electrons are drawn from the positive plate of the capacitor



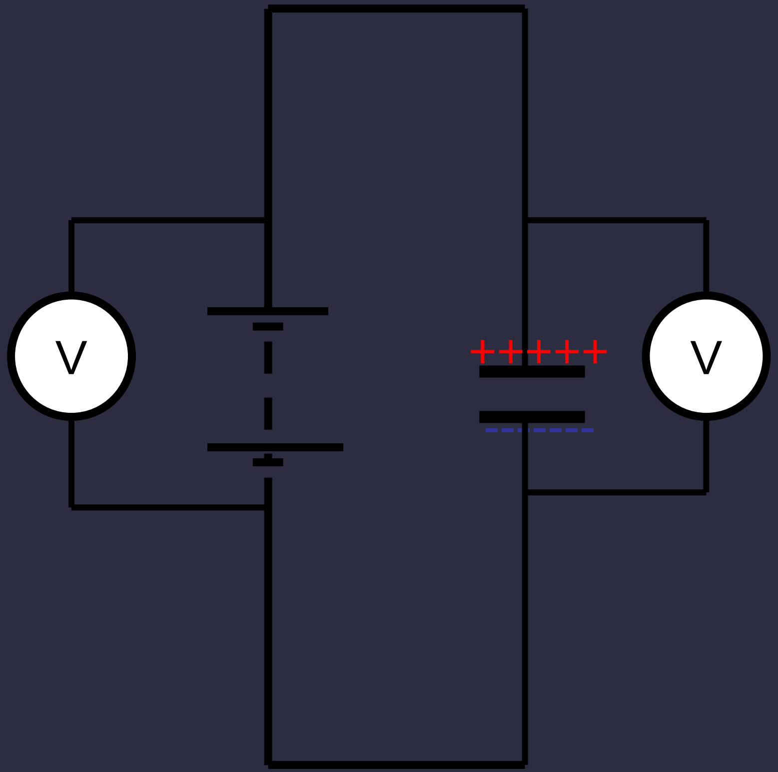
What is happening

- When the capacitor is connected to the lamp, the charge has the opportunity to rebalance and a current flows lighting the lamp.
- This continues until the capacitor is completely discharged.



When the capacitor is fully charged

- When the capacitor is fully charged the pd measured across the capacitor is equal and opposite to the across the battery
- So there can be no further current flow.



Capacitance

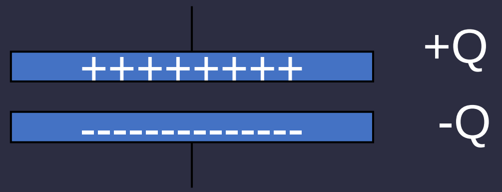
- The measure of the extent to which a capacitor can store charge is called its capacitance.

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

C= capacitance (unit farad (F))

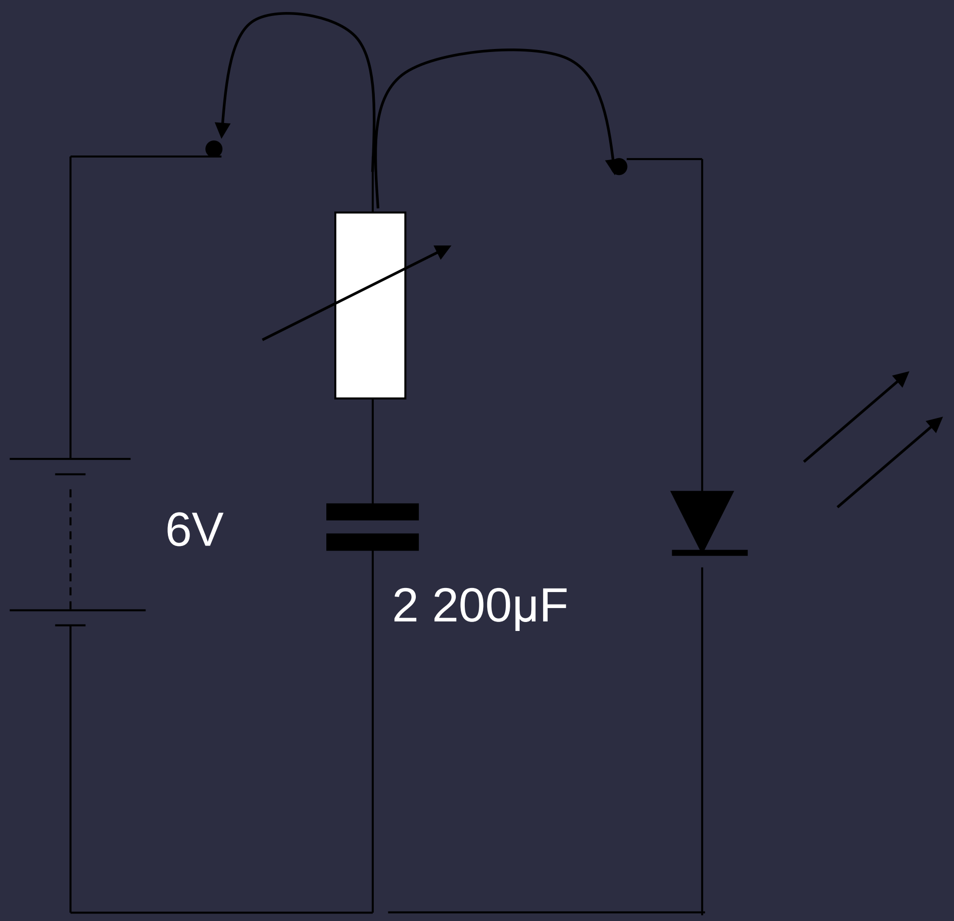
Q = the magnitude of the charge on one plate (unit coulombs (C))

V = the potential difference between the plates (unit volts (V))

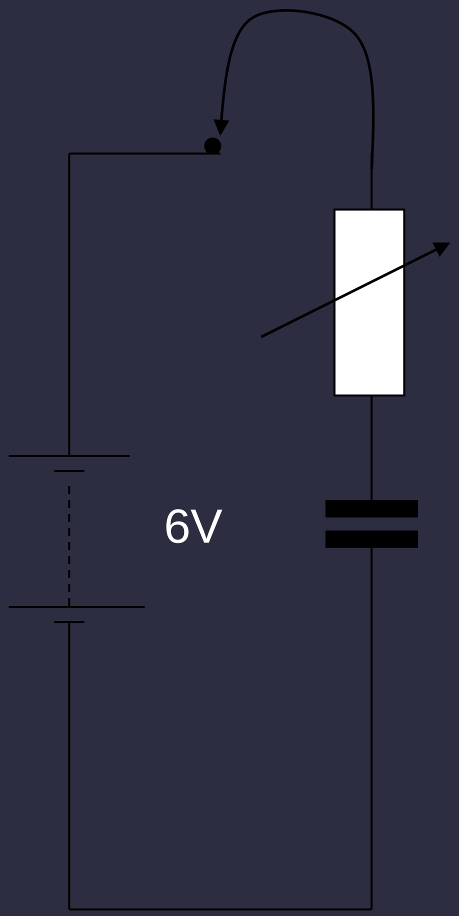


The effect of a resistance on the charging and discharging

- Putting a resistor in series with the capacitor increases the charging time and increases the discharging time



The effect of a resistance on the charging and discharging



$V_{battery} = V_{resistor} + V_{capacitor}$

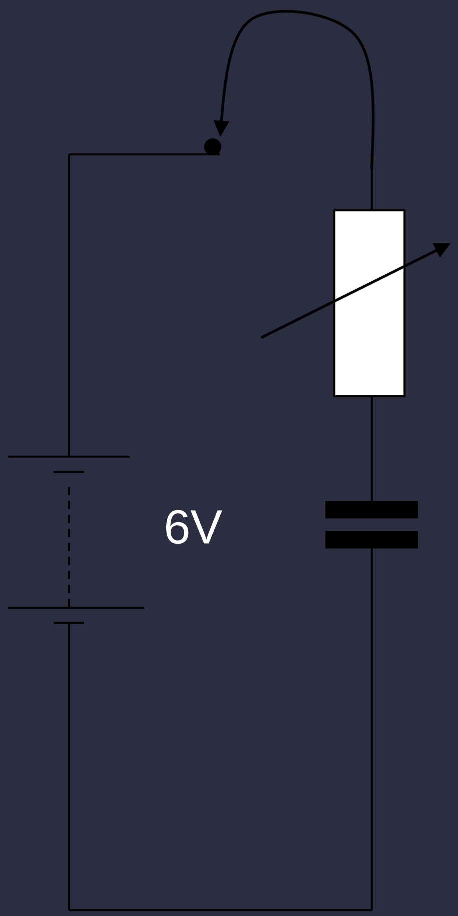
Initially the capacitor is <u>uncharged.</u>

At this time $V_{capacitor} = 0$

And

$$V_{battery} = V_{resistor}$$

The effect of a resistance on the charging and discharging



$V_{battery} = V_{resistor} + V_{capacitor}$

As the capacitor charges

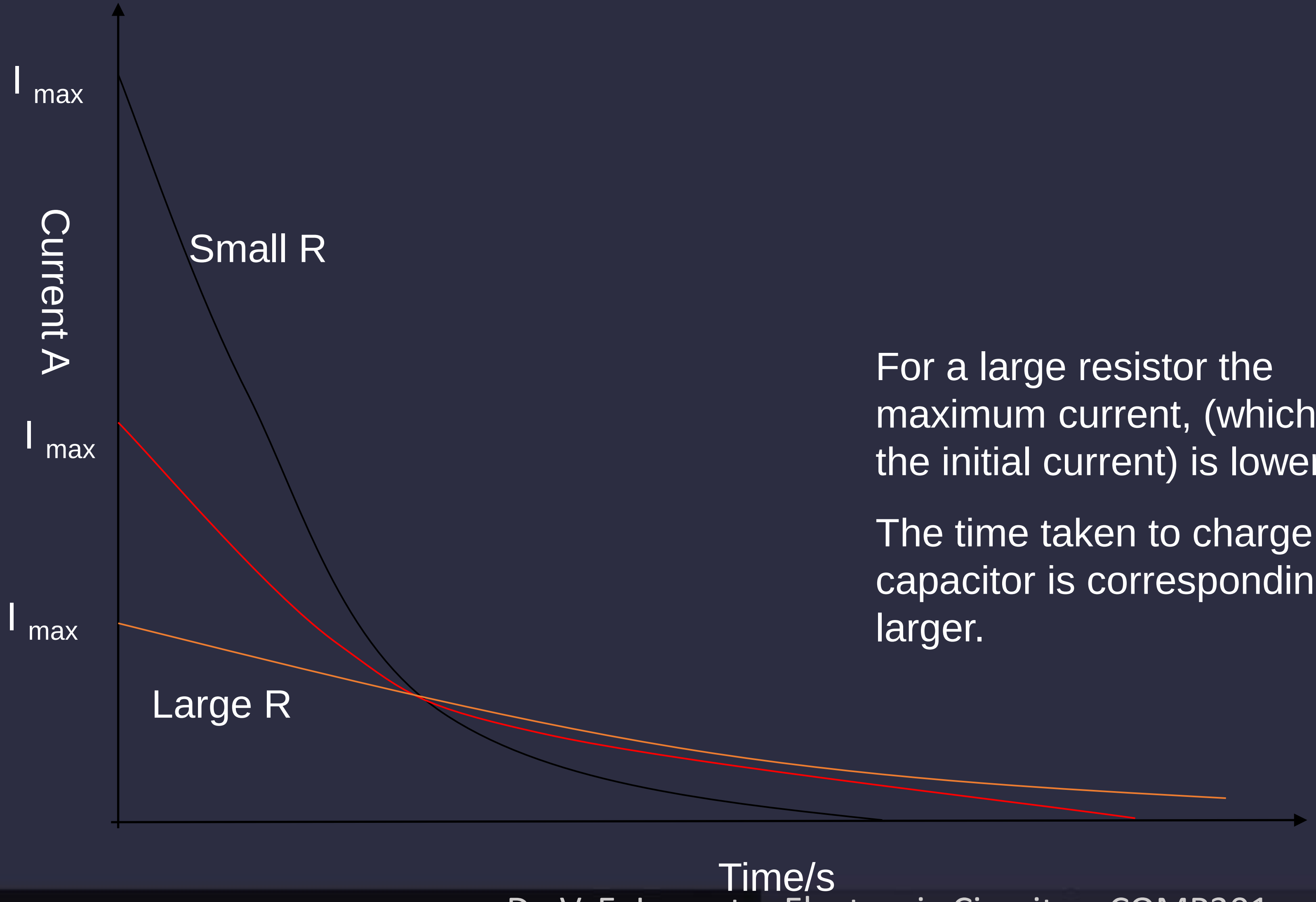
$\mathbf{V_{capacitor}}$ rises and so $\mathbf{V_{resistor}}$ falls.

From

$$I = \frac{V_{resistor}}{R}$$

The current through the resistor (and therefore the whole circuit) falls

The effect of a resistance on the charging and discharging

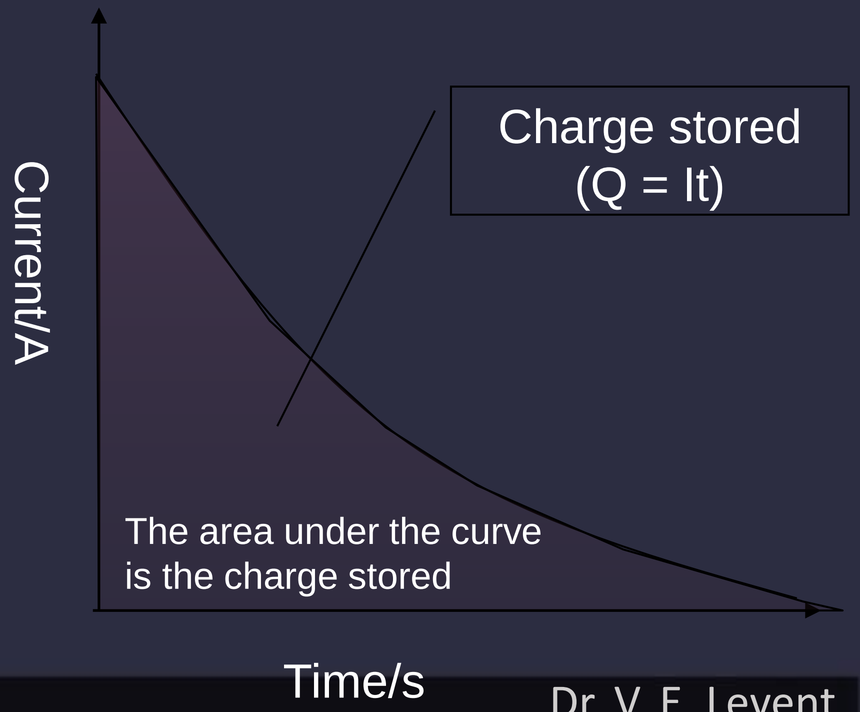


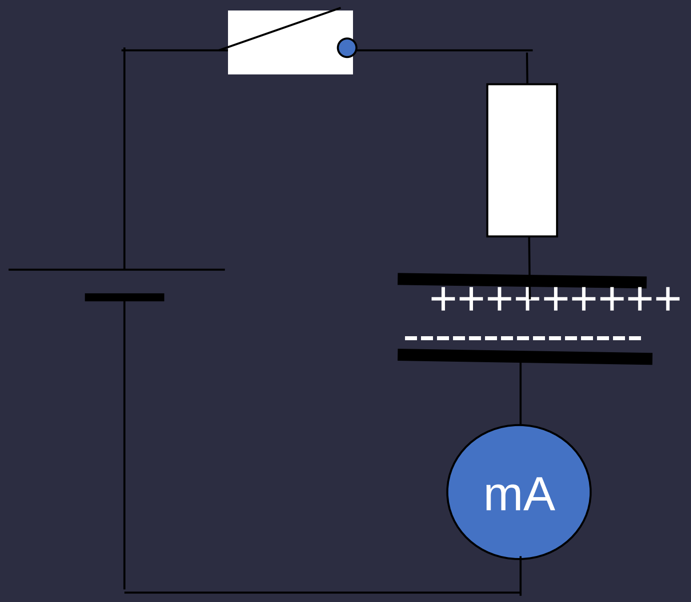
For a large resistor the maximum current, (which is the initial current) is lower.

The time taken to charge the capacitor is correspondingly larger.

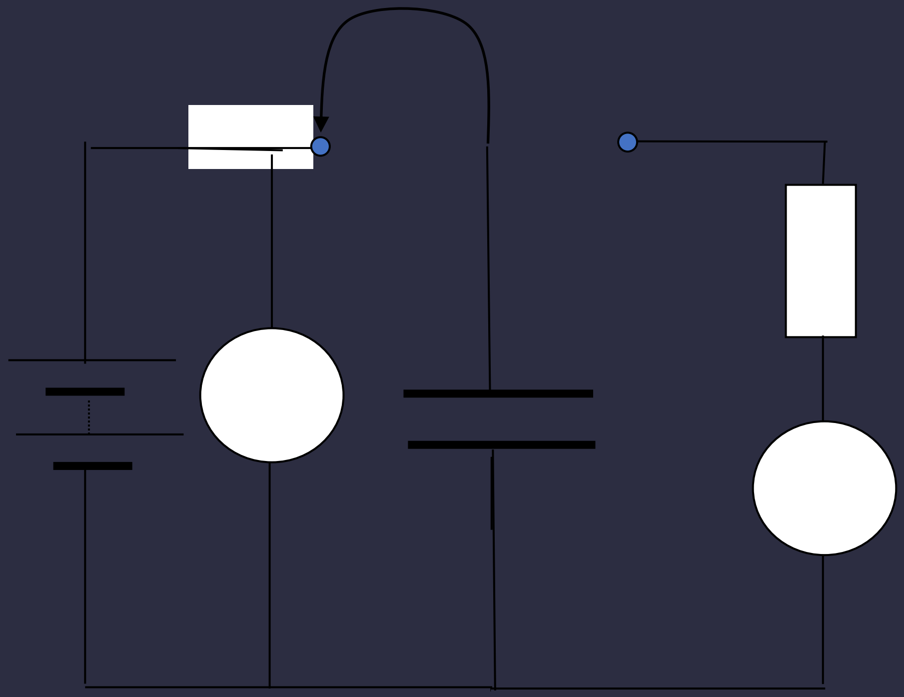
Finding the charge stored

Remember that the charge stored on each plate is the same. Finding the stored charge is another way of saying finding the charge stored on the positive plate.





Discharging a capacitor



Here the 1 000µF capacitor is charged from a battery and discharged through a 100KΩ resistor.

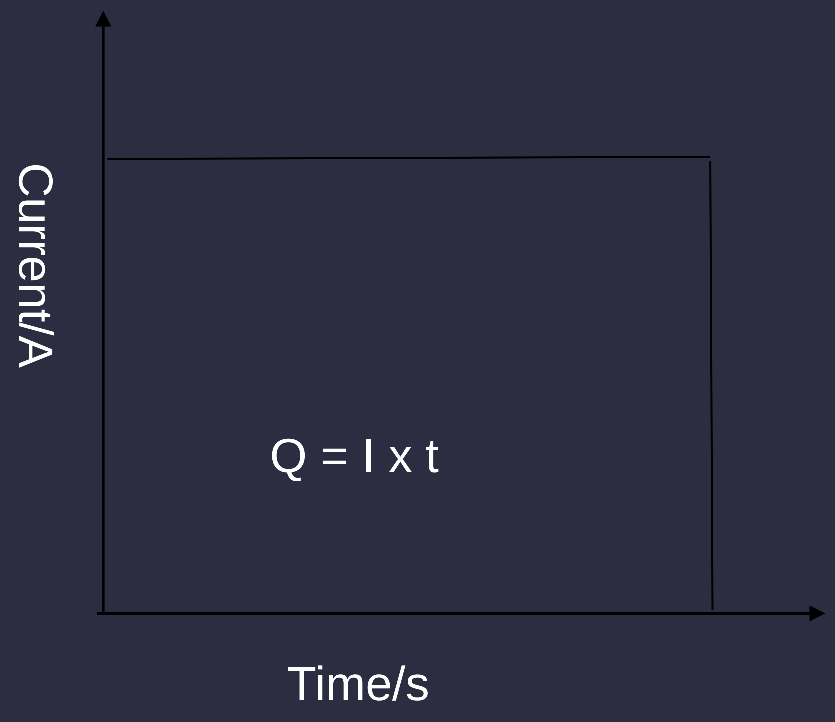
Try timing the discharge with a charging potential of 3V, 4.5V and 6V.

Draw a current against time graph in each case and measure the area under the graph. This area will give you the charge on the capacitor. Calculate the capacitance of the capacitor in each case using

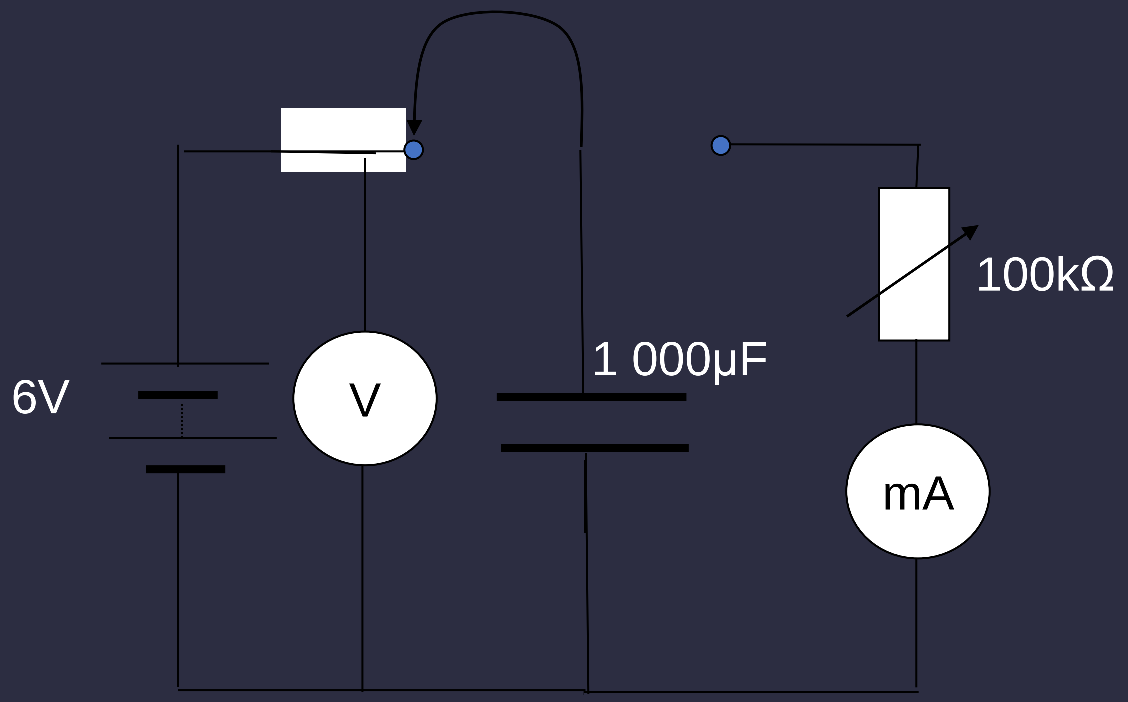
$$C = \frac{Q}{V}$$

Discharging with a constant current

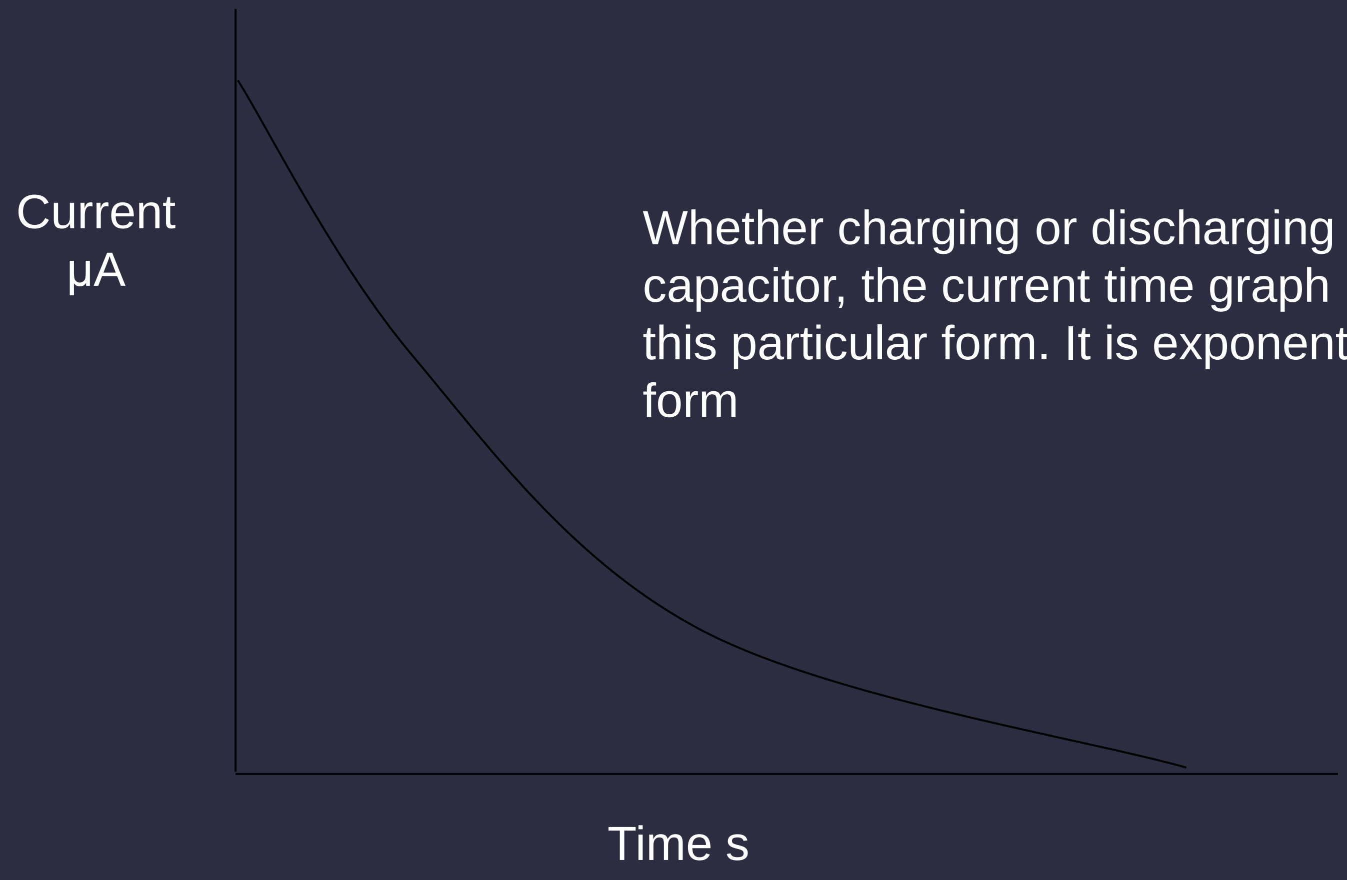
If the series resistance is decreased continuously as the capacitor is discharged it is possible to keep the current constant while discharging the capacitor. The advantage of this is that the charge on the capacitor is easier to calculate.



Discharging with a constant current

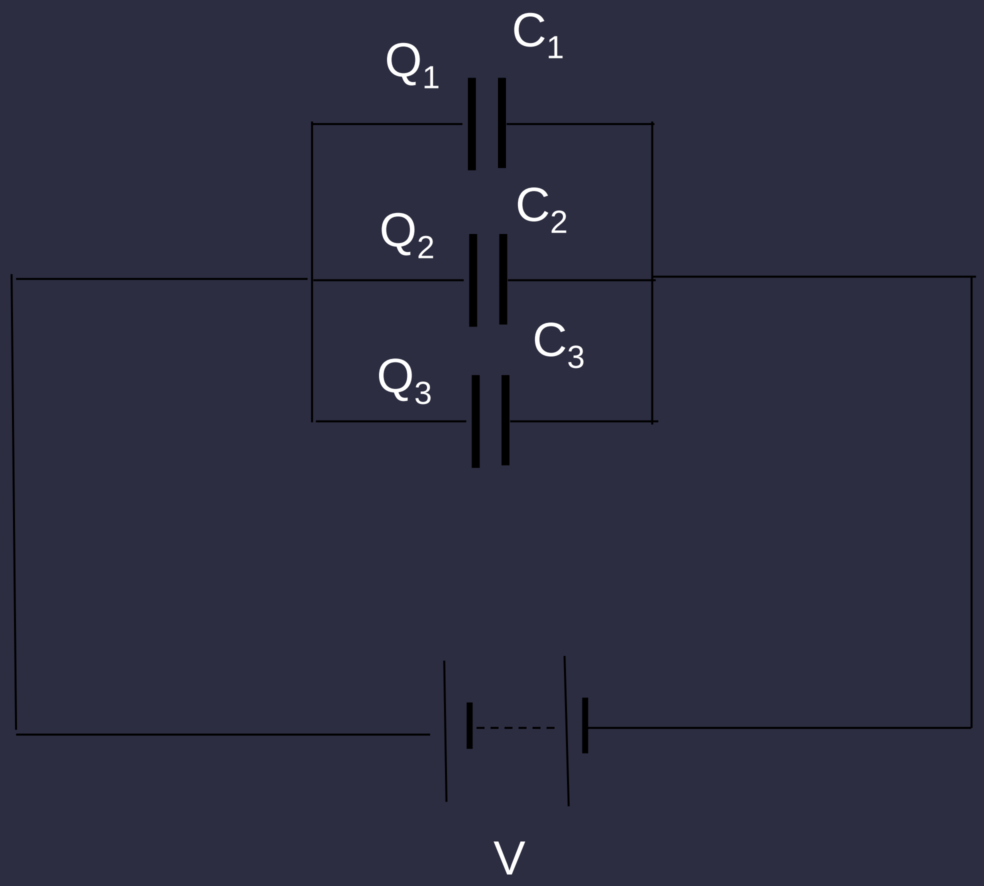


Exponential decay



Whether charging or discharging the capacitor, the current time graph has this particular form. It is exponential in form

Capacitors in parallel



The capacitors are in parallel and therefore there is the same p.d. across each

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

$Q_1 = C_1 V \qquad Q_2 = C_2 V \qquad Q_3 = C_3 V$

$$Q_1 + Q_2 + Q_3 = C_1 V + C_2 V + C_3 V$$

$$Q_1 + Q_2 + Q_3 = (C_1 + C_2 + C_3) V$$

A single capacitor which stores as much charge ($Q = Q_1 + Q_2 + Q_3$) is represented by:

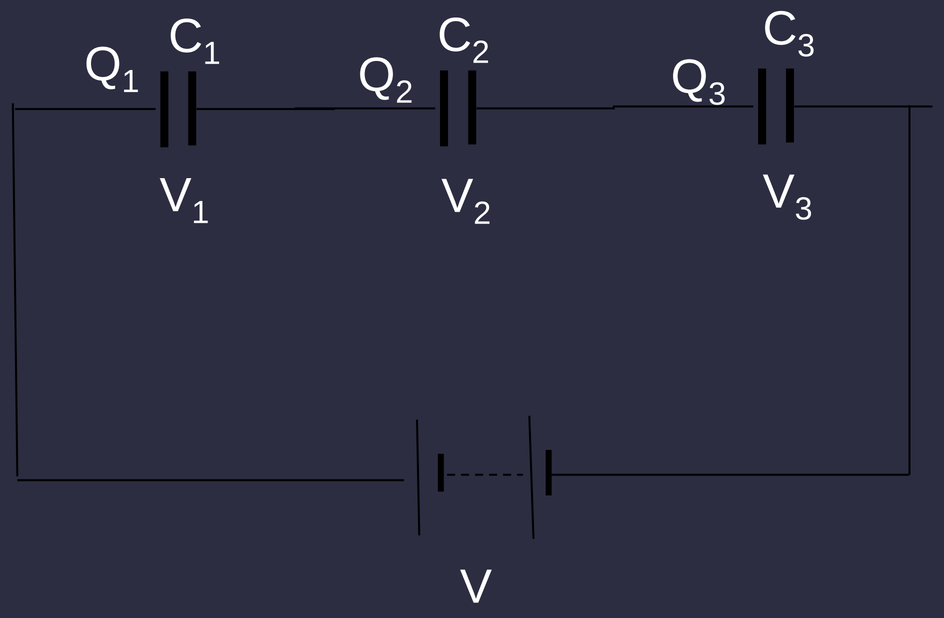
$$Q = CV$$

So $C = C_1 + C_2 + C_3$

It follows that capacitors in parallel have a total capacitance which is equal to the sum of their individual capacitances.

Capacitors in series

$V_1 = \frac{Q}{C_1}$ $\qquad V_2 = \frac{Q}{C_2}$ $\qquad V_3 = \frac{Q}{C_3}$



adding

$$V_1 + V_2 + V_3 = Q \rightleftarrows \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

i.e. $$V = Q \rightleftarrows \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

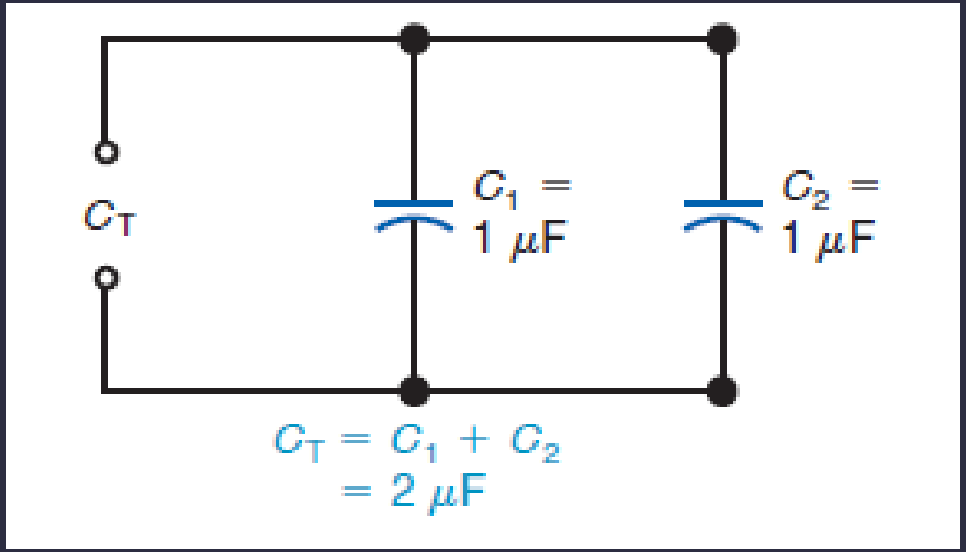
A single capacitor which has the same effect is: $V = \frac{Q}{C}$

So: $$\frac{1}{C} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

Capacitors and resistors compared

	capacitors	resistors
Series connection	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	$R = R_1 + R_2 + R_3$
Parallel connection	$C = C_1 + C_2 + C_3$	$R = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

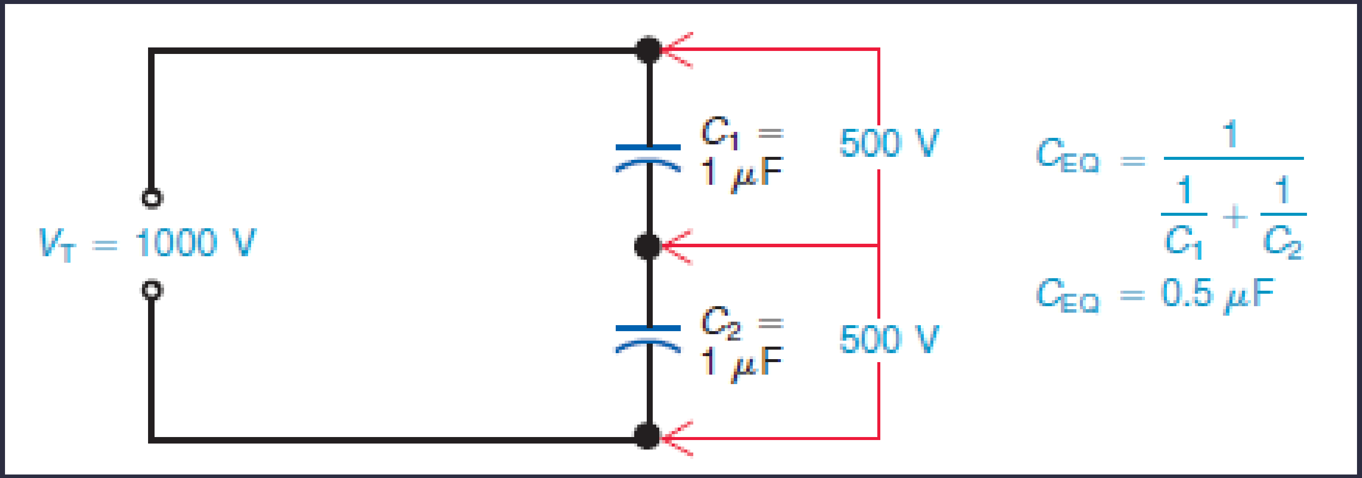
Capacitors



Parallel Capacitors

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

Capacitors

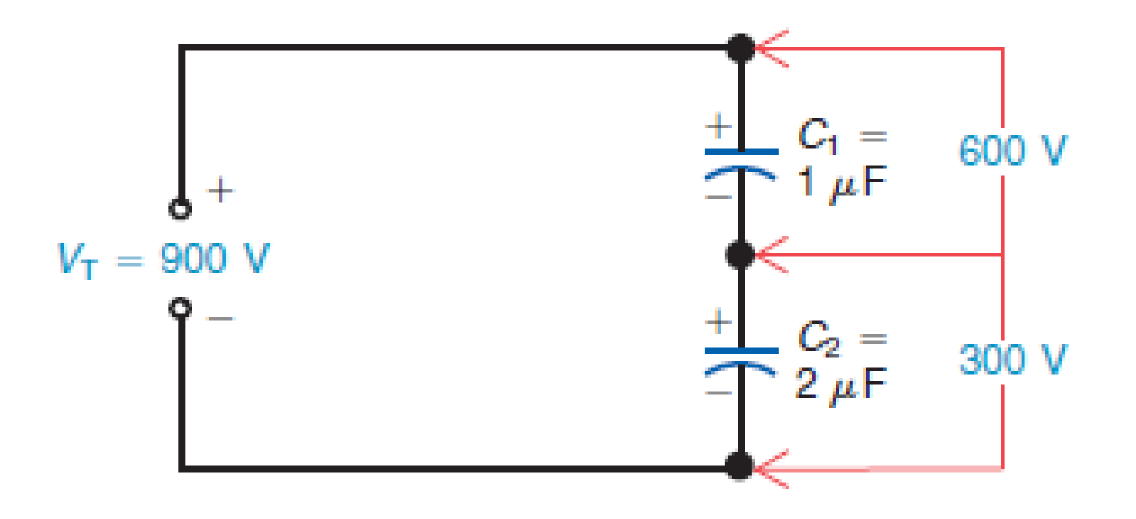


$$C = \frac{Q}{V}$$

Series Capacitors

Capacitors

Series Capacitors



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

$$V_1 = \frac{Q}{C_1} = \frac{600\ \mu C}{1\ \mu F} = 600\ V$$

$$V_2 = \frac{Q}{C_2} = \frac{600\ \mu C}{2\ \mu F} = 300\ V$$