Unit - I
1.9 Capacitor Charging and Revision

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Syllabus

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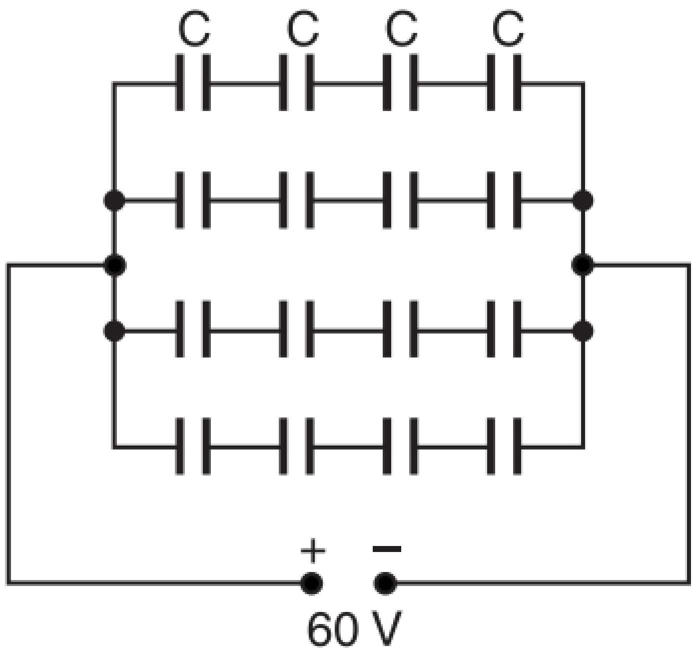
UNIT – I **10 Periods**

Introduction and Basic Concepts: Concept of Potential difference, voltage, current - Fundamental linear passive and active elements to their functional current-voltage relation - Terminology and symbols in order to describe electric networks - Concept of work, power, energy and conversion of energy- Principle of batteries and application.
Principles of Electrostatics: Electrostatic field - electric field intensity - electric field strength - absolute permittivity - relative permittivity - capacitor composite – dielectric capacitors - capacitors in series & parallel - energy stored in capacitors - charging and discharging of capacitors.

Problem

- *Given some capacitors of 0·1 μF capable of withstanding 15V.Calculate the number of capacitors needed if it is desired to obtain a capacitance of 0·1 μF for use in a circuit involving 60 V.*

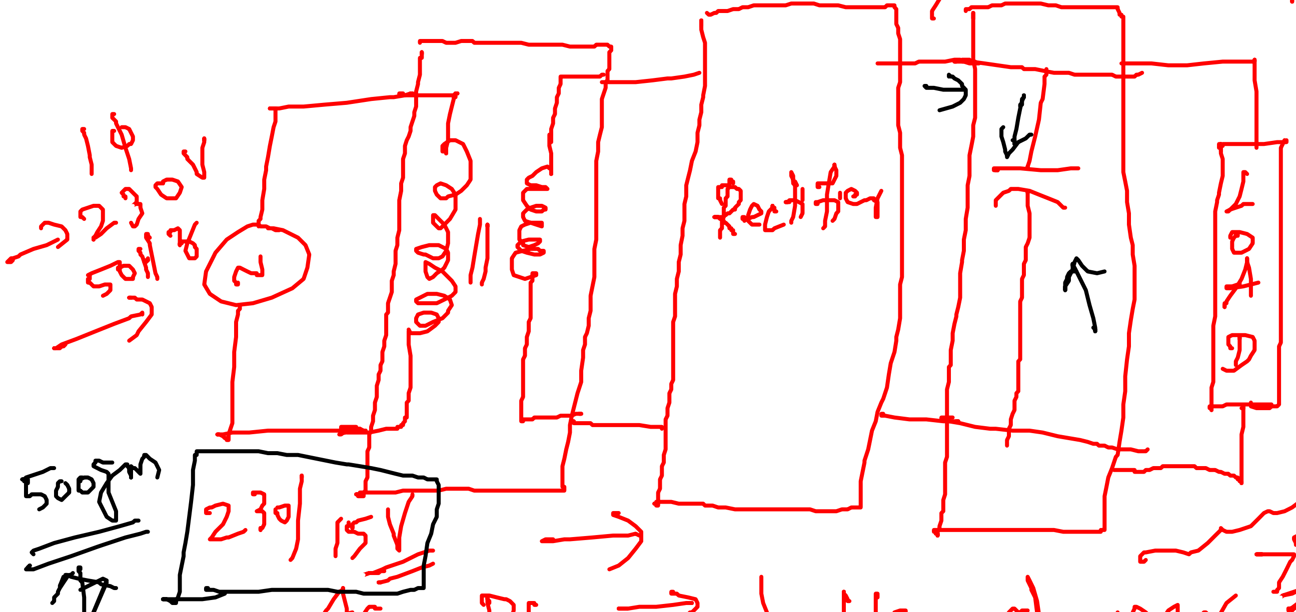


Capacitors in Power Supplies

Capacitors → Filtering

AC or DC

Pulsating DC



AC - DC → battery charger

95% Filter

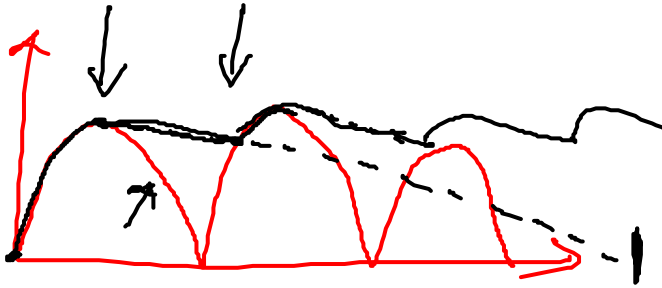
Energy storage

Impedance

$X_C = \frac{1}{\omega C}$

∞

$f = 0$

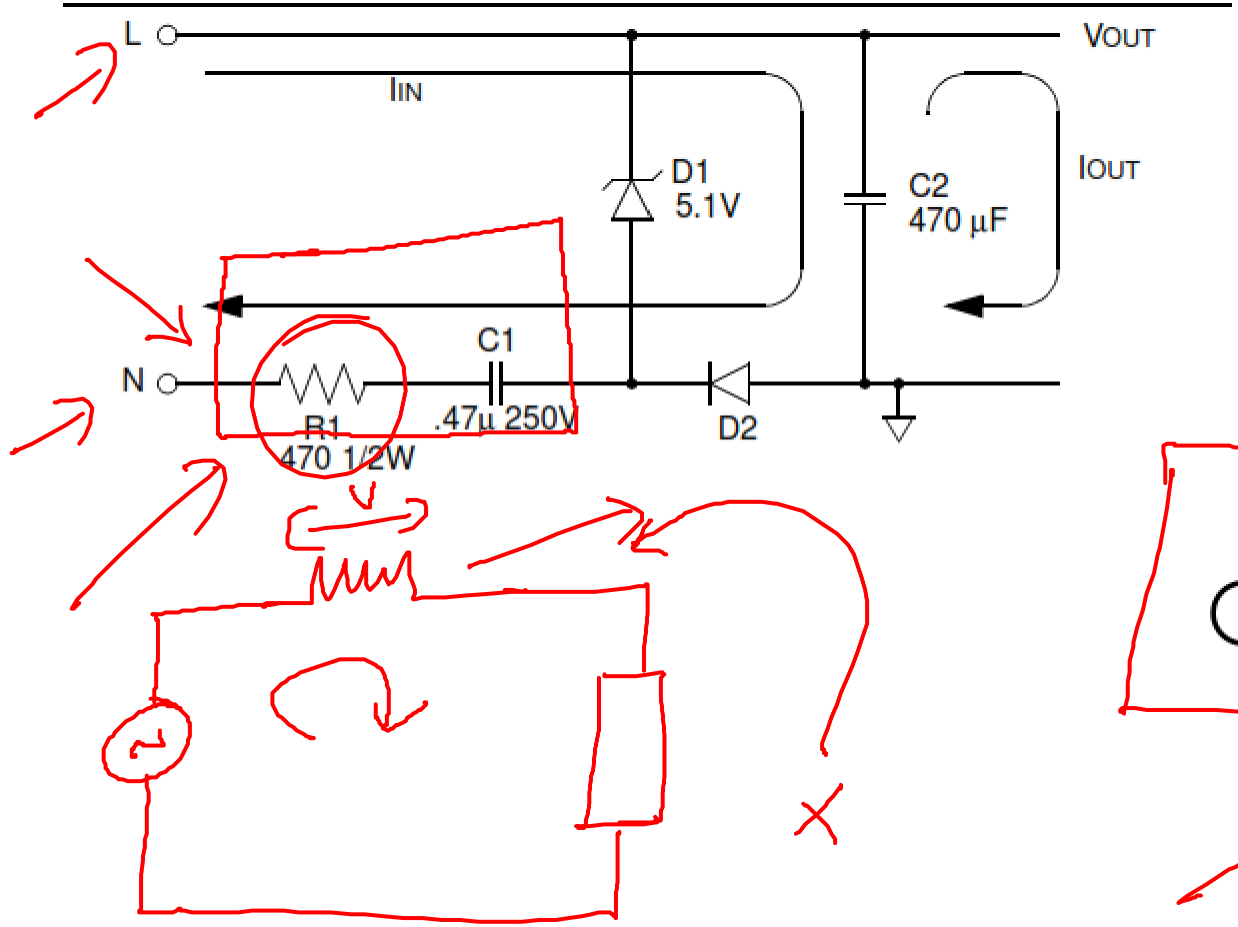


12V

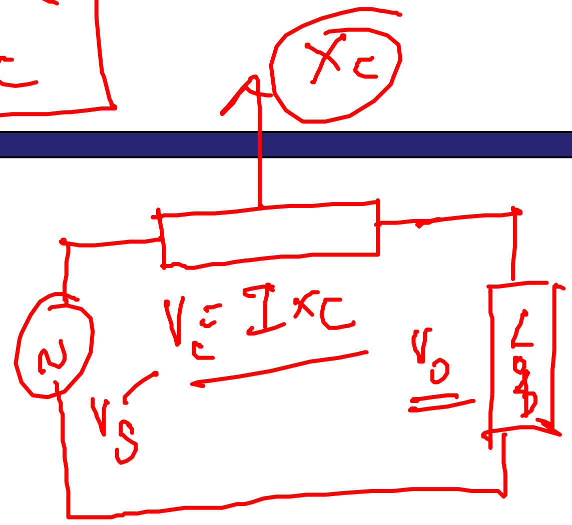
230V → 15V AC → Potential divider

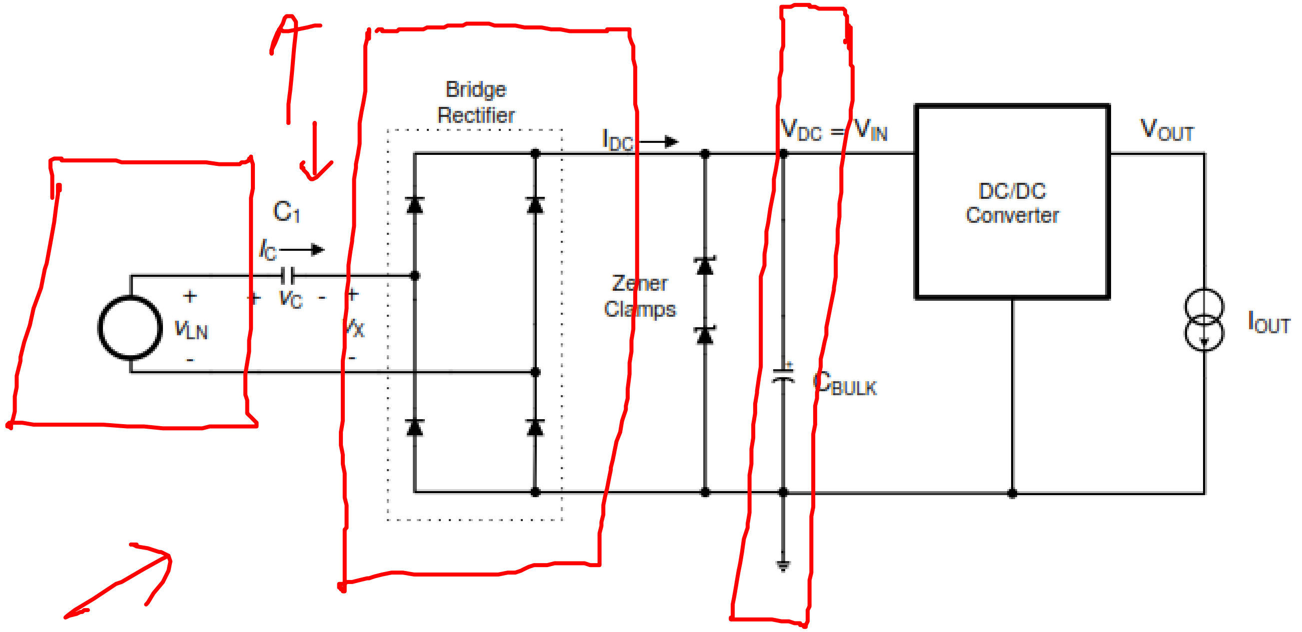
$V_o = V_s - V_c$

CAPACITIVE POWER SUPPLY



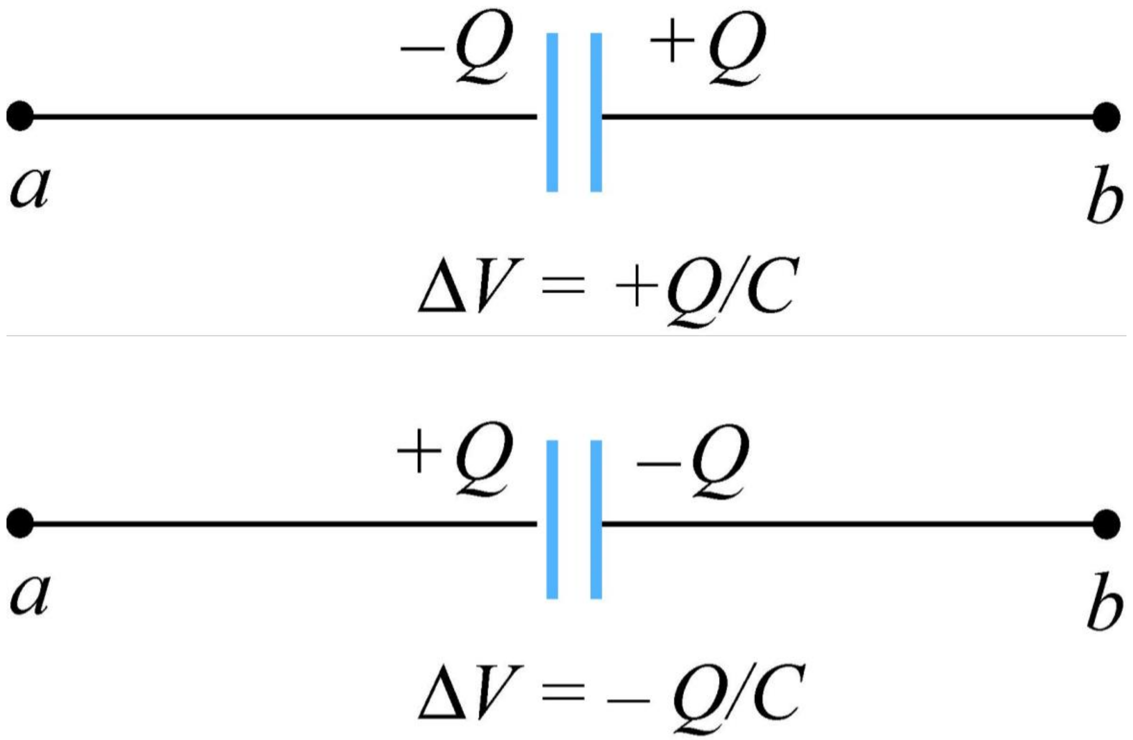
Transformer





Sign Conventions - Capacitor

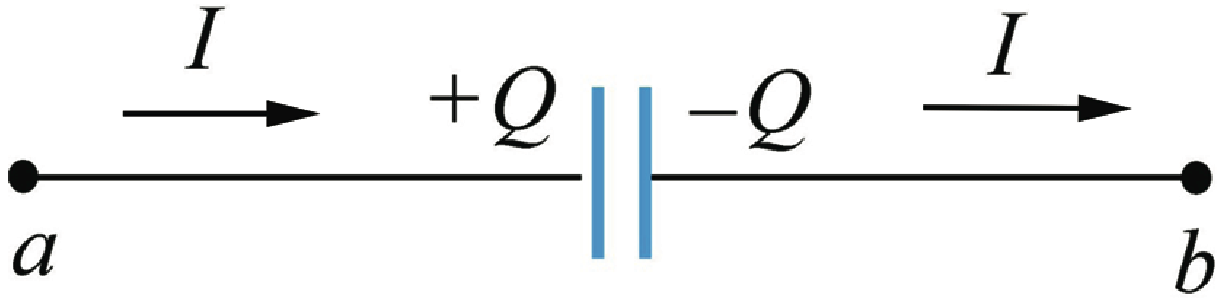
Moving across a capacitor from the negatively to positively charged plate **increases** the electric potential



$$\boxed{DV = V_b - V_a}$$

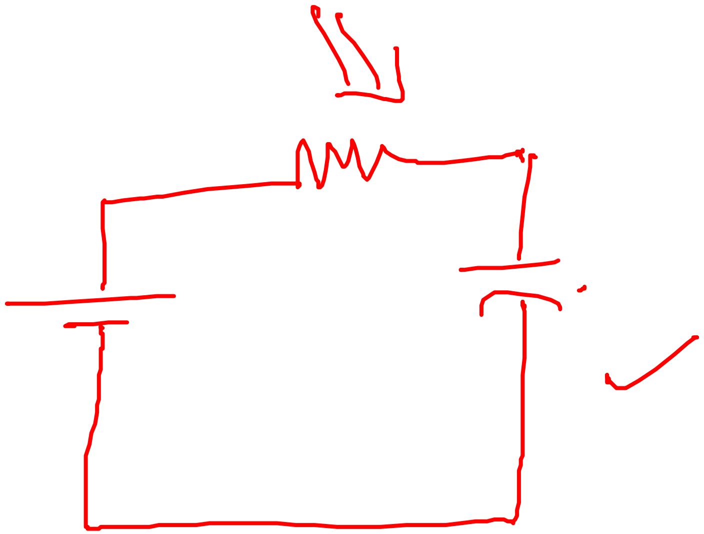
Power - Capacitor

Moving across a capacitor from the positive to negative plate **decreases** your potential. If current flows in that direction the capacitor **absorbs** power (stores charge)

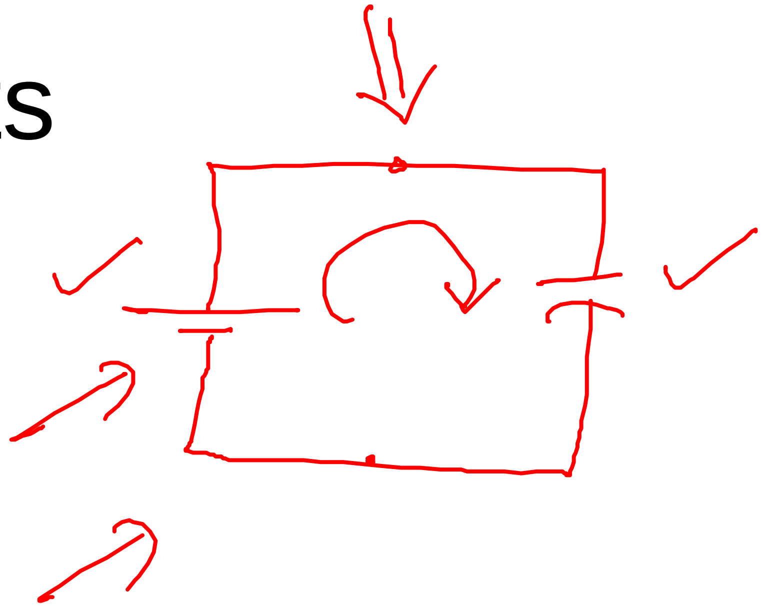


$$\Delta V = -Q/C$$

$$\boxed{P_{\text{absorbed}} = I\,\Delta V = \frac{dQ}{dt}\frac{Q}{C} = \frac{d}{dt}\frac{Q^2}{2C} = \frac{dU}{dt}}$$



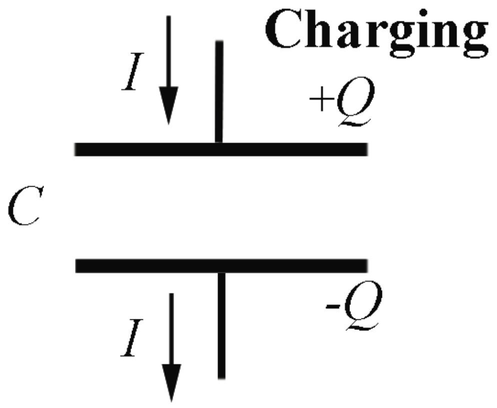
RC Circuits



(Dis)Charging a Capacitor

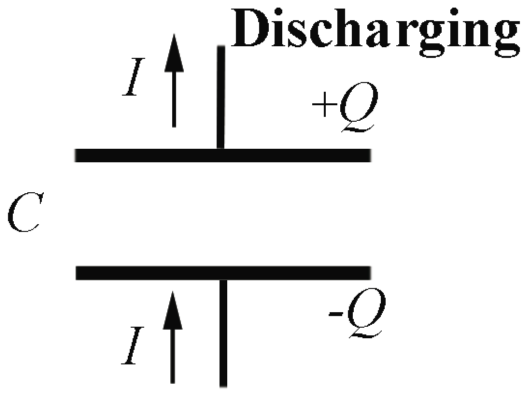
1. When the direction of current flow is toward the positive plate of a capacitor, then

$$I = +\frac{dQ}{dt}$$



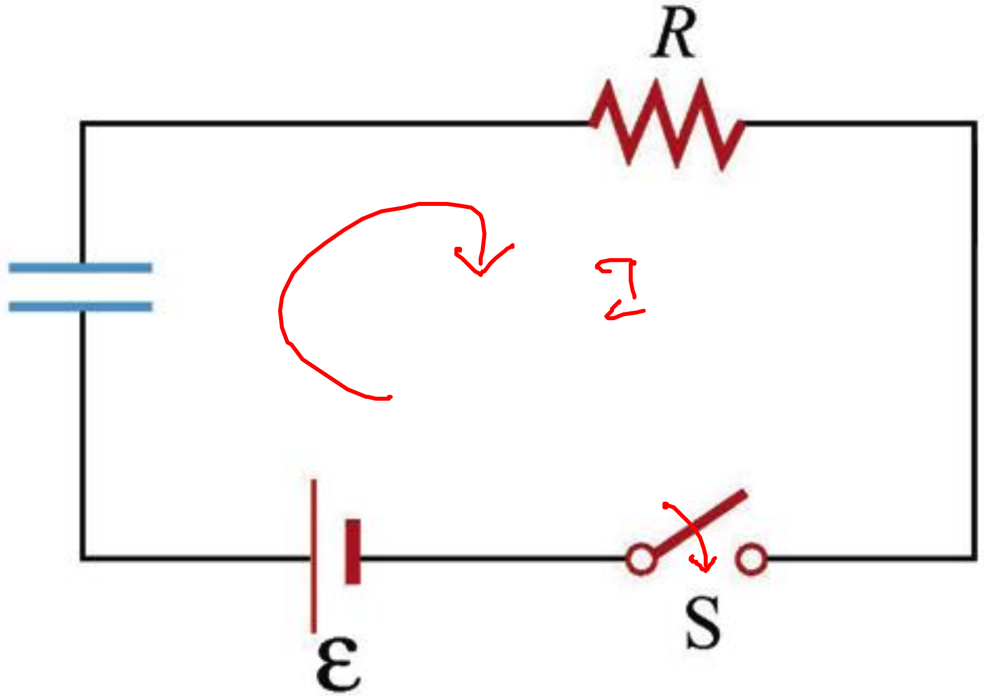
2. When the direction of current flow is away from the positive plate of a capacitor, then

$$I = -\frac{dQ}{dt}$$



Charging a Capacitor

V_c



I

$\mathcal{E} - V_c - IR = 0$

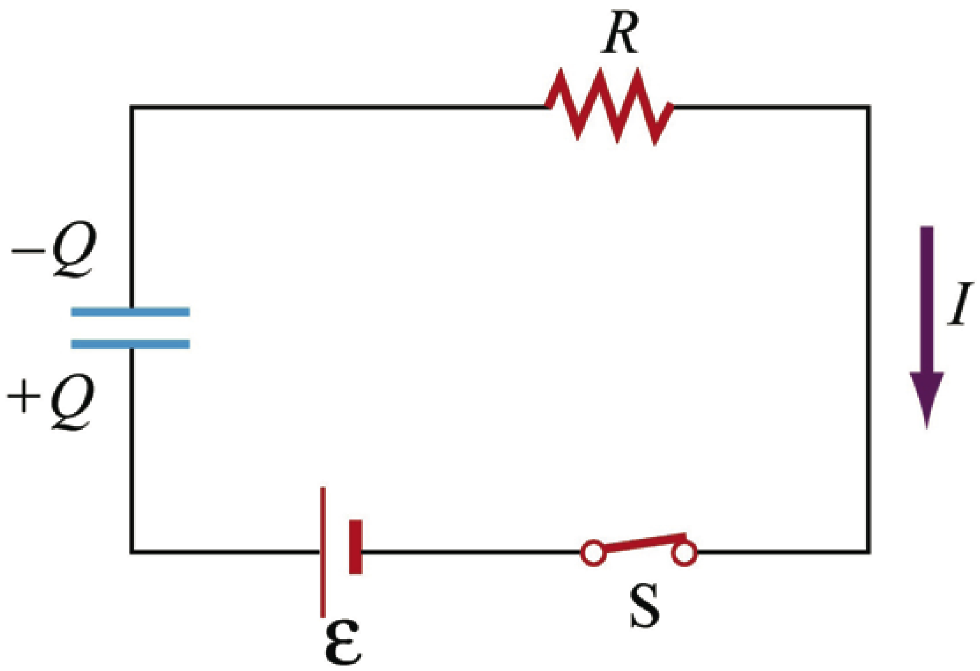
$\downarrow$

$\frac{Q}{C}$

↳ Source

What happens when we close switch S at $t = 0$?

Charging a Capacitor



Circulate clockwise

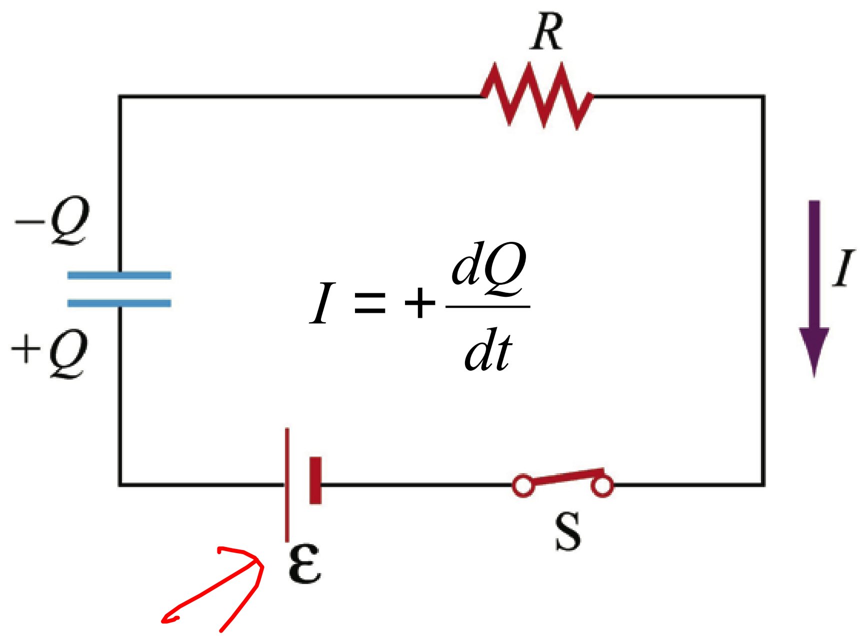
$$\sum_i \Delta V_i = \varepsilon - \frac{Q}{C} - IR = 0$$

$$I = +\frac{dQ}{dt}$$

First order linear inhomogeneous differential equation

$$\frac{dQ}{dt} = -\frac{1}{RC}(Q - C\varepsilon)$$

Energy Balance: Circuit Equation



$$I = +\frac{dQ}{dt}$$

$$\varepsilon - \frac{Q}{C} - IR = 0$$

Multiplying by $I = +\dfrac{dQ}{dt}$

$$\varepsilon I = I^2 R + \frac{Q}{C}\frac{dQ}{dt} = I^2 R + \frac{d}{dt}\left(\frac{1}{2}\frac{Q^2}{C}\right)$$

(power delivered by battery) = (power dissipated through resistor)
+ (power absorbed by the capacitor)

RC Circuit Charging: Solution

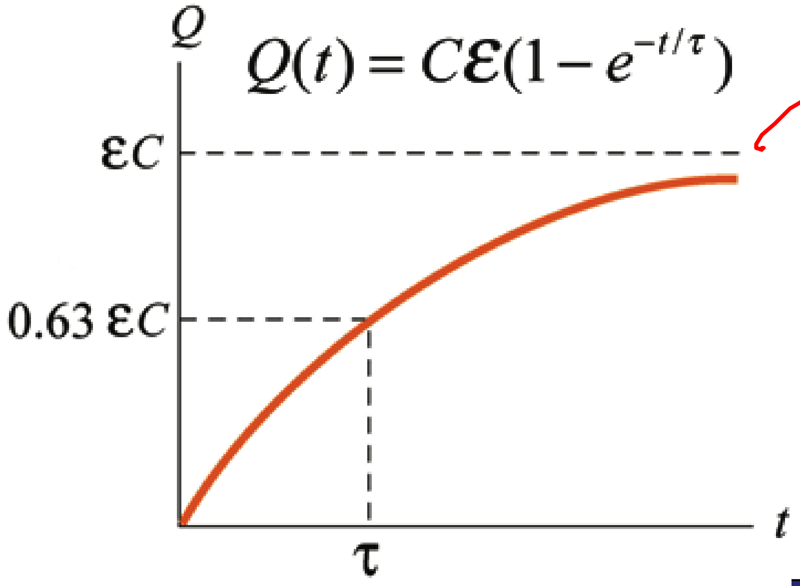
$$\frac{dQ}{dt} = -\frac{1}{RC}\left(Q - C\varepsilon\right)$$

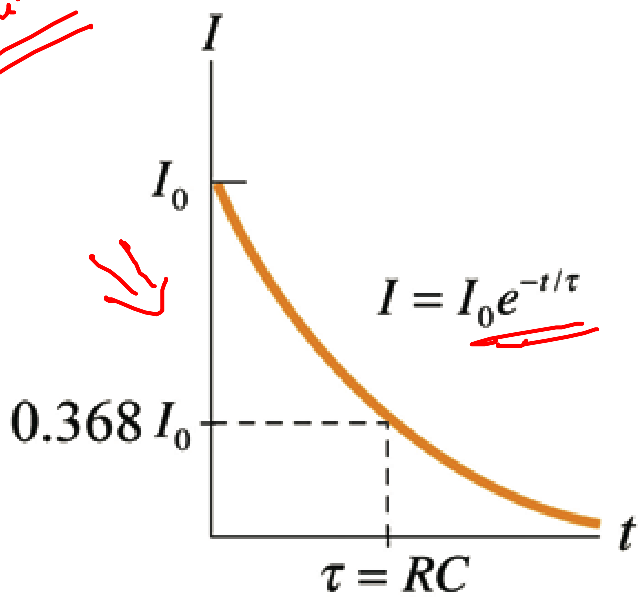
Solution to this equation when switch is closed at $t = 0$:

$$Q(t) = C\varepsilon\left(1 - e^{-t/\tau}\right) \qquad I(t) = +\frac{dQ}{dt} \Rightarrow I(t) = I_0 e^{-t/\tau}$$

$\tau = RC$: time constant (units: seconds)

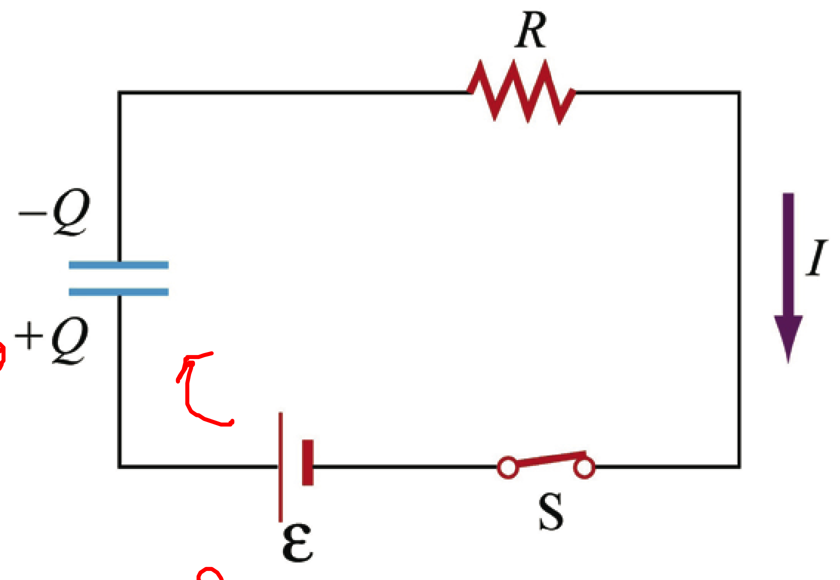
Saturation





Concept Question: RC Circuit

An uncharged capacitor is connected to a battery, resistor and switch. The switch is initially open but at *t* = 0 it is closed. A very long time after the switch is closed, the current in the circuit is

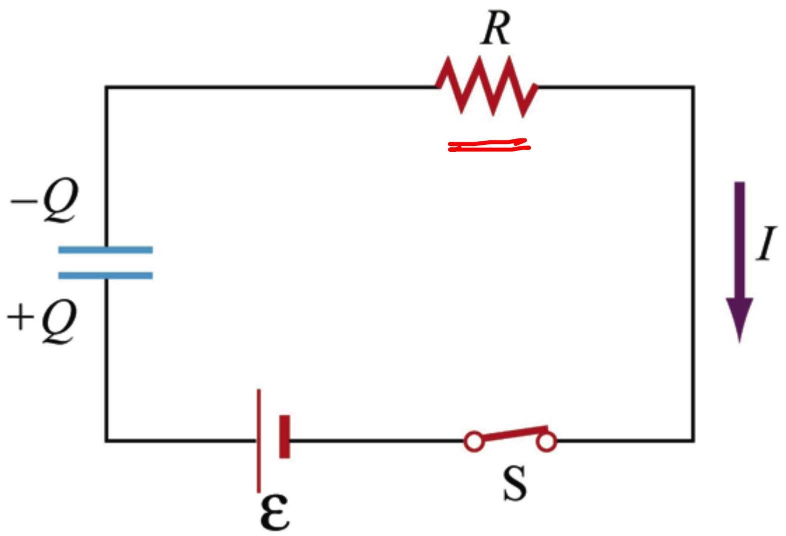


1. Nearly zero
2. At a maximum and decreasing
3. Nearly constant but non-zero

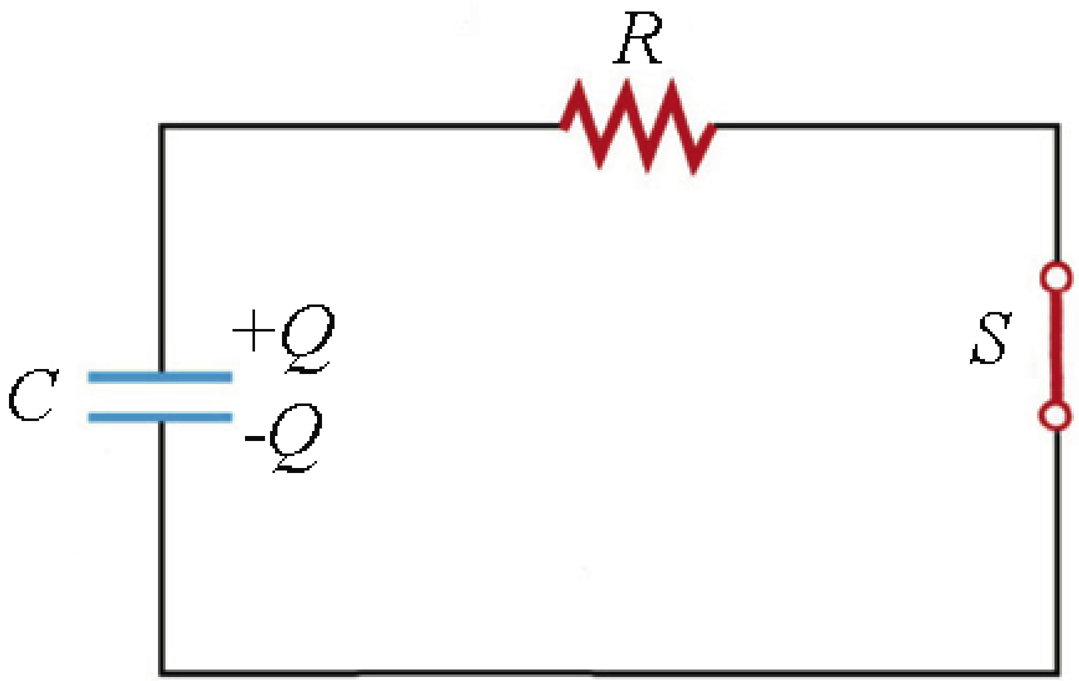
Concept Q. Answer: RC Circuit

Answer: 1. After a long time the current is 0

Eventually the capacitor gets "completely charged" – the voltage increase provided by the battery is equal to the voltage drop across the capacitor. The voltage drop across the resistor at this point is 0 – no current is flowing.

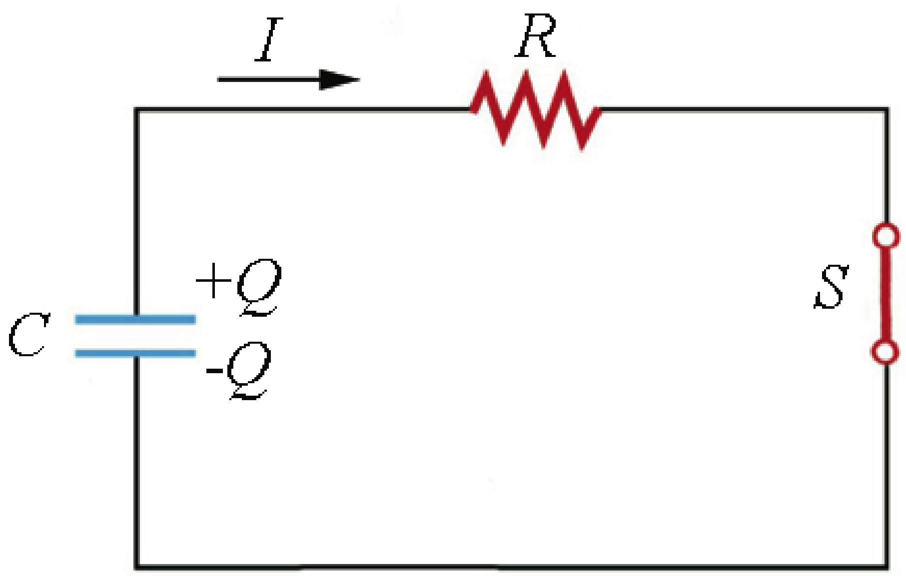


Discharging A Capacitor



At t = 0 charge on capacitor is Q_0. What happens when we close switch S at t = 0?

Discharging a Capacitor



Circulate clockwise

$$\sum_i \Delta V_i = \frac{Q}{C} - IR = 0$$

$$I = -\frac{dQ}{dt} \Rightarrow$$

First order linear differential equation

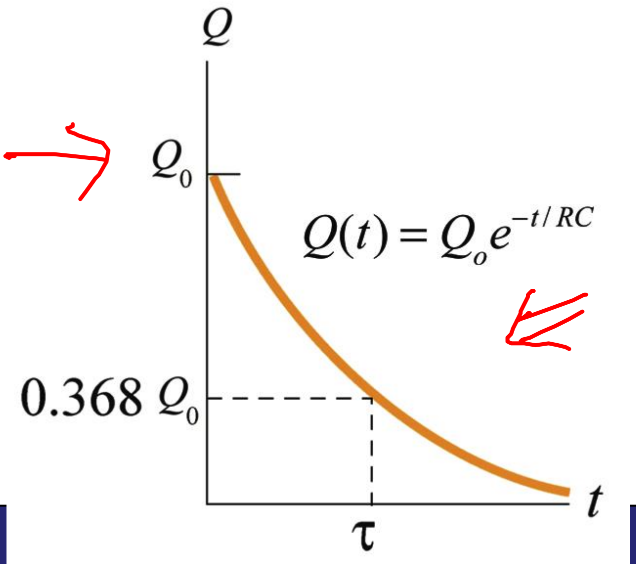
$$\frac{dQ}{dt} = -\frac{Q}{RC}$$

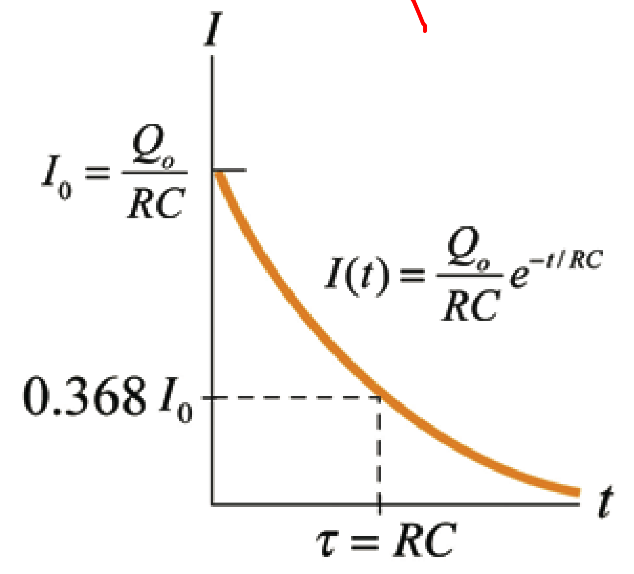
RC Circuit: Discharging

$$\frac{dQ}{dt} = -\frac{1}{RC}Q \quad Þ \quad Q(t) = Q_o e^{-t/RC}$$

Solution to this equation when switch is closed at $t = 0$ with time constant $t = RC$

$$I = -\frac{dQ}{dt} \quad Þ \quad I(t) = \frac{Q_o}{t}e^{-t/t} = \frac{Q_o}{RC}e^{-t/t}$$

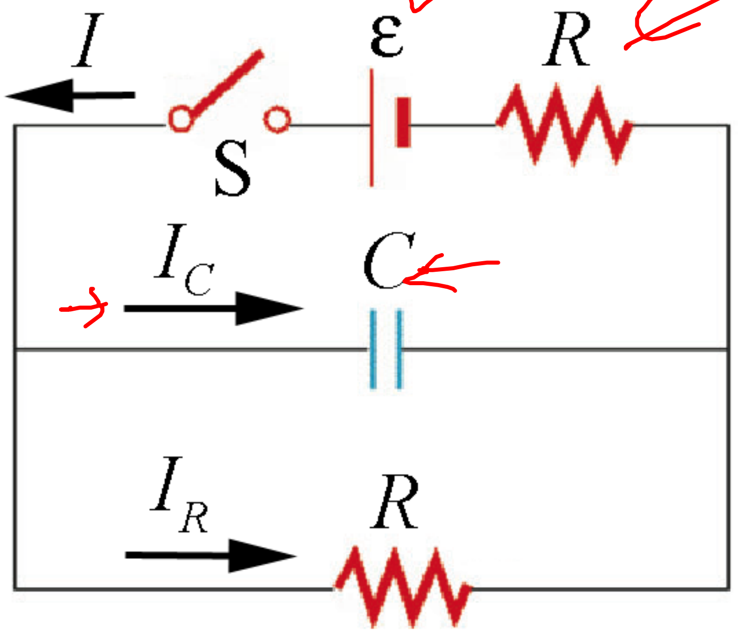




Concept Question: RC Circuit

Consider the circuit at right, with an initially uncharged capacitor and two identical resistors. At the instant the switch is closed:

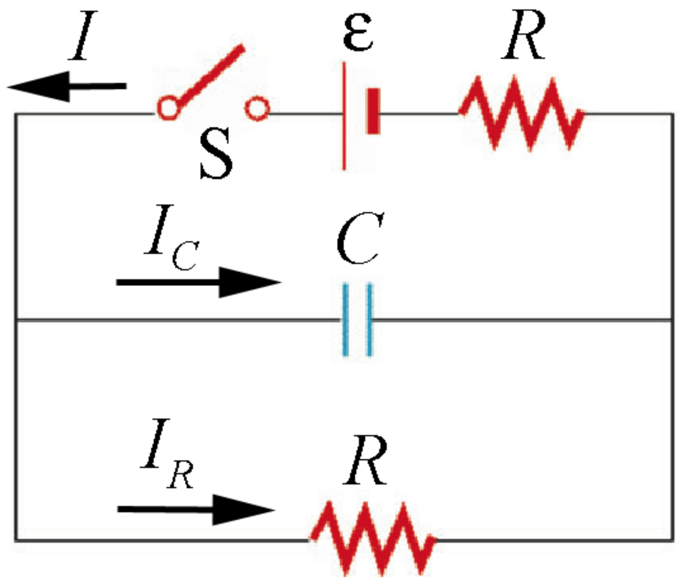
1. $I_R = I_C = 0$
2. $I_R = e/2R,\ I_C = 0$
3. $I_R = 0,\ I_C = e/R$
4. $I_R = e/2R,\ I_C = e/R$

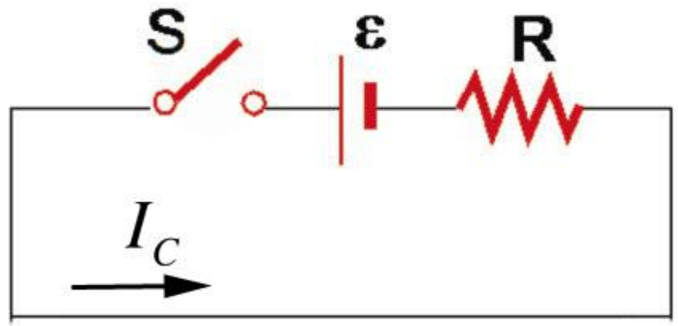


Concept Question Answer: RC Circuit

Answer: 3. $I_R = 0 \quad I_C = \varepsilon / R$

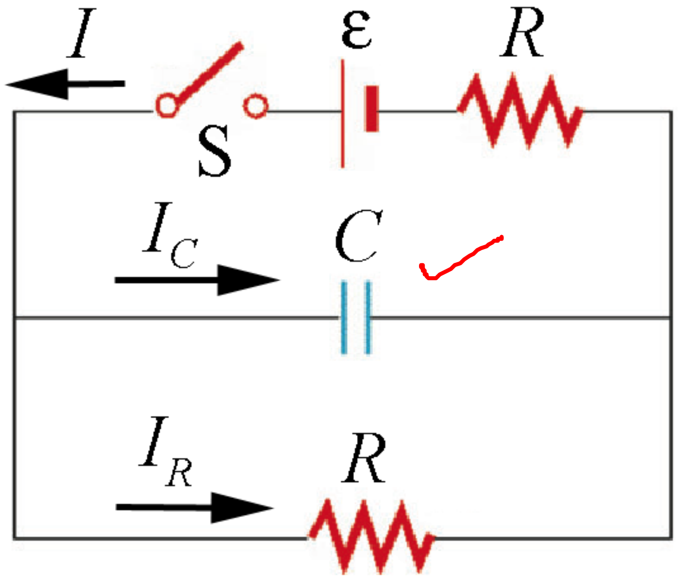
Initially there is no charge on the capacitor and hence no voltage drop across it – it looks like a short. Thus all current will flow through it rather than through the bottom resistor. So the circuit looks like:





Concept Q.: Current Thru Capacitor

In the circuit at right the switch is closed at $t = 0$. At t = ∞ (long after) the current through the capacitor will be:

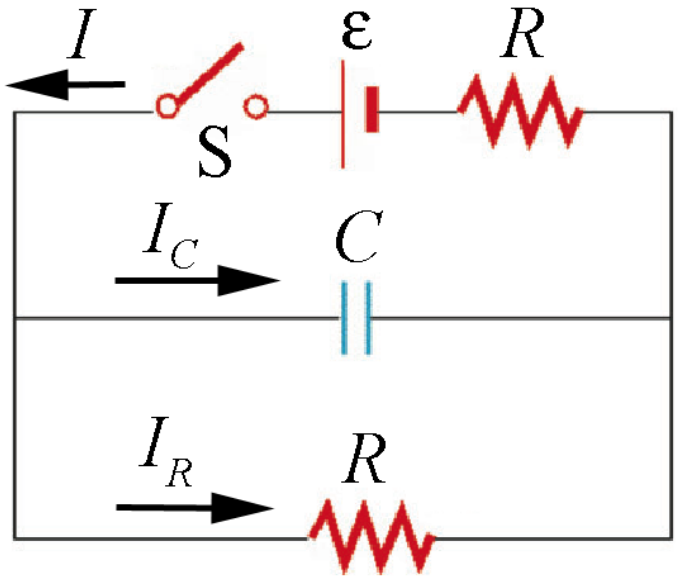


1. $I_C = 0$
2. $I_C = \varepsilon / R$
3. $I_C = \varepsilon / 2R$

Con. Q. Ans.: Current Thru Capacitor

Answer 1. $I_C = 0$

After a long time the capacitor becomes "fully charged." No more current flows into it.



SASTRA
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DEEMED TO BE UNIVERSITY
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Revision

charge → Voltage & Current

R, L, C → i, v ,

Energy Conversion

Batteries

Electrostatics → Capacitors

Summary

Capacitors →

charging & discharging

Unit - II