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Unit - I
1.8 Capacitor Charging and Revision

Wireless power transmission

↳ Short distance → long ~~st~~ distance

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Syllabus

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. ← 2
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.

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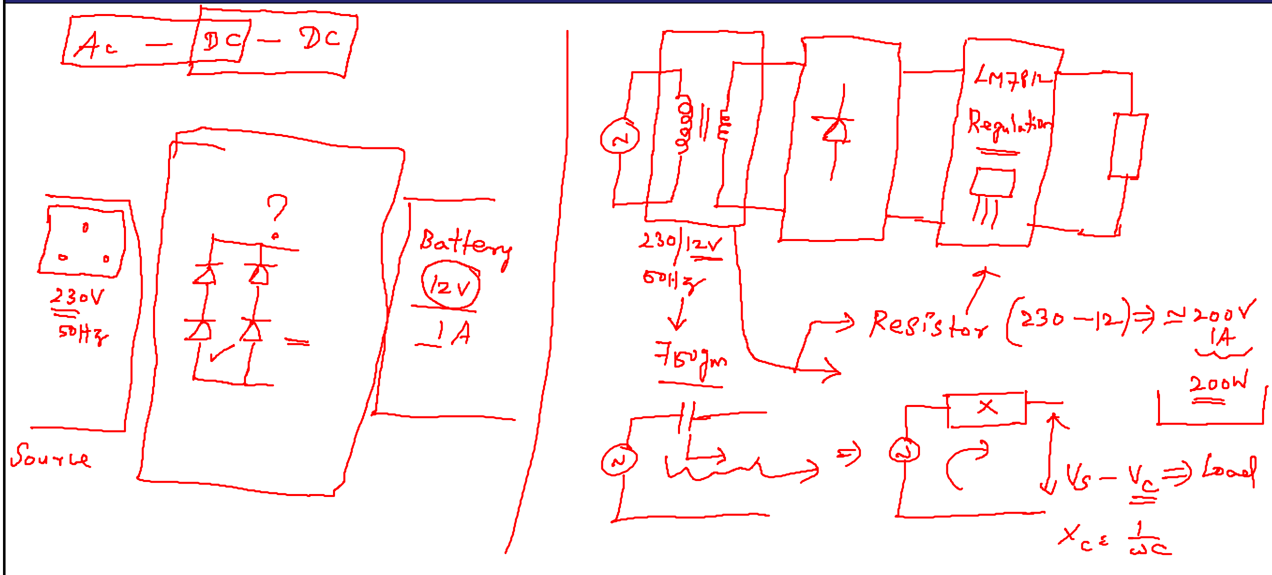
Capacitors in Power Supplies



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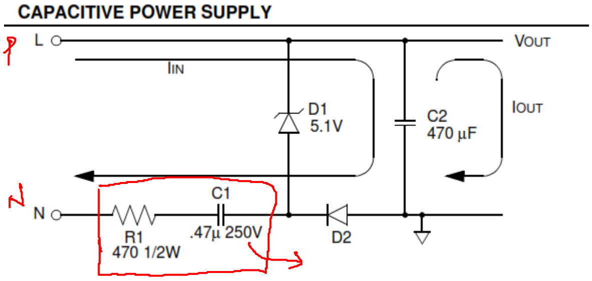
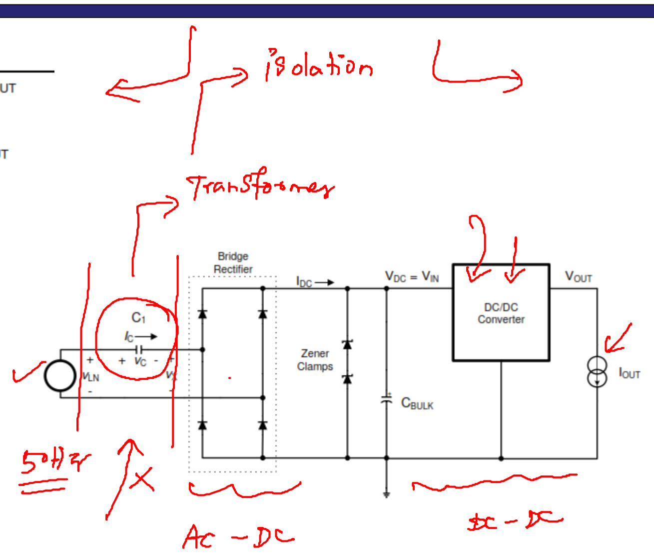
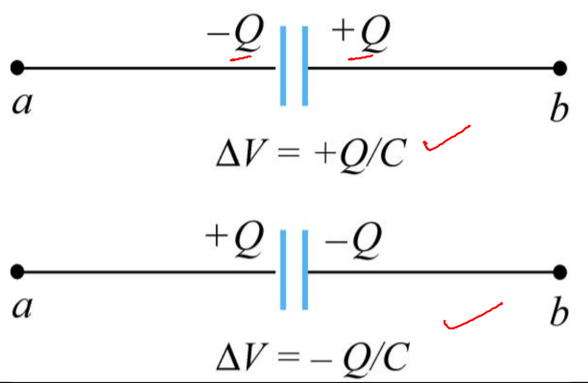
CAPACITIVE POWER SUPPLY





Sign Conventions - Capacitor

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



$$\boxed{\Delta V = V_b - V_a}$$

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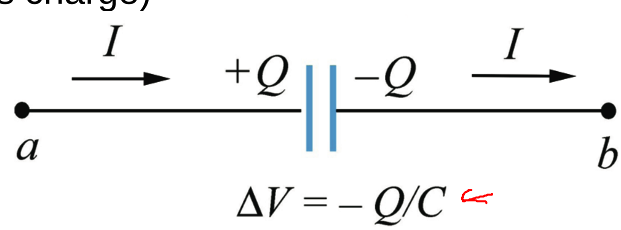
THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

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)



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

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RC Circuits

charging

Inrush currents

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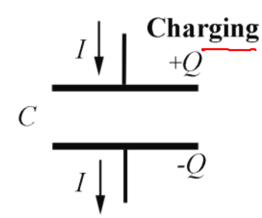
(Dis)Charging a Capacitor

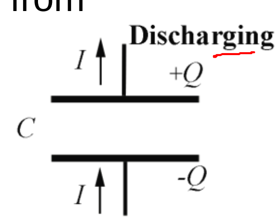
1. When the direction of current flow is toward the positive plate of a capacitor, then

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



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

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



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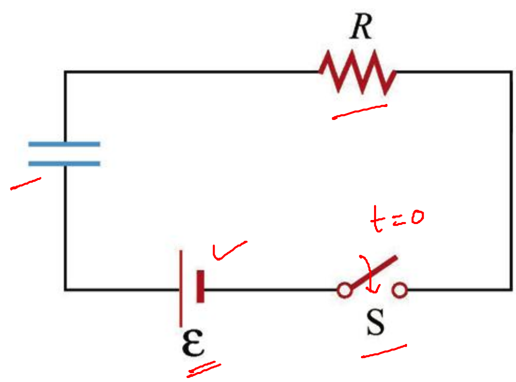
Charging a Capacitor



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

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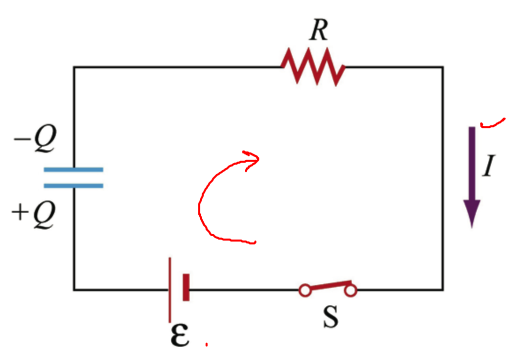
Charging a Capacitor

$c = \frac{q}{v}$

$\Rightarrow v = \frac{q}{c}$



Circulate clockwise

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

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

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

First order linear inhomogeneous differential equation

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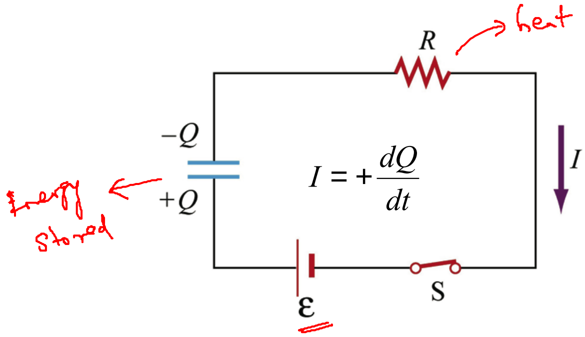
Energy Balance: Circuit Equation



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

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

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

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

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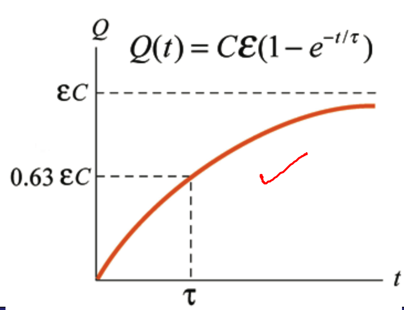
RC Circuit Charging: Solution

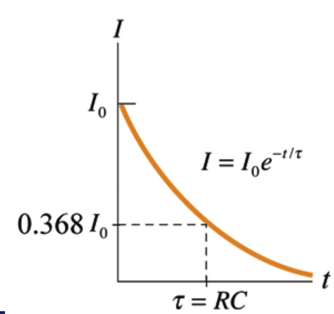
$$\frac{dQ}{dt} = -\frac{1}{RC}\left(Q - C\varepsilon\right)$$

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)





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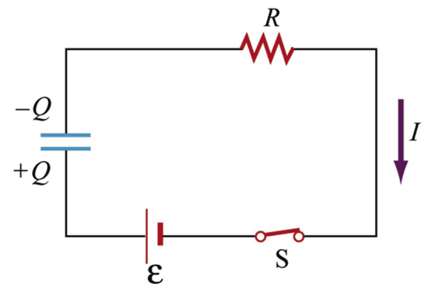
Concept Question: RC Circuit

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

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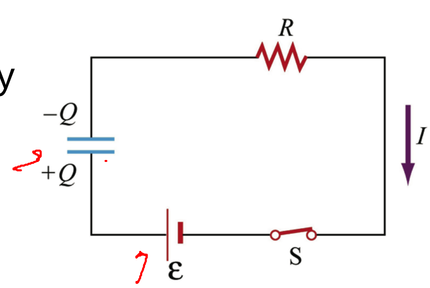
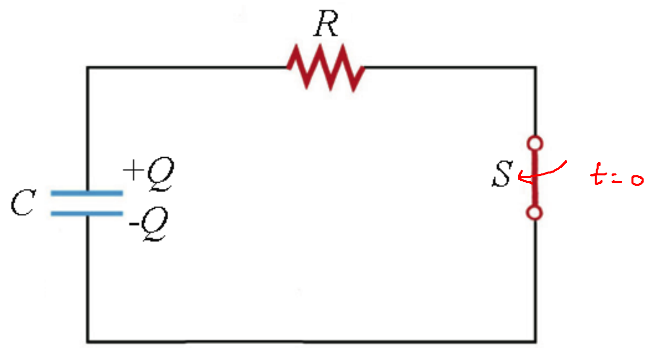
Concept Q. Answer: RC Circuit

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.

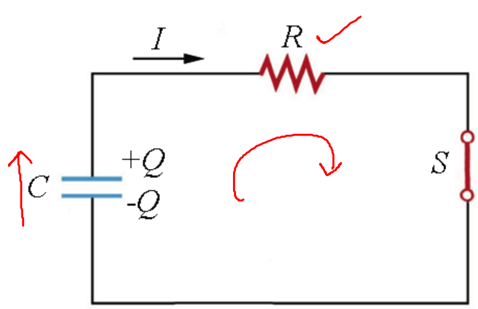


Discharging A Capacitor



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

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

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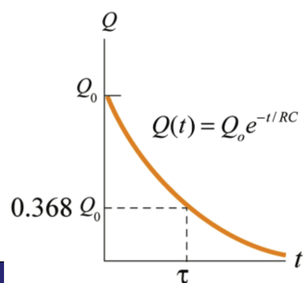
RC Circuit: Discharging

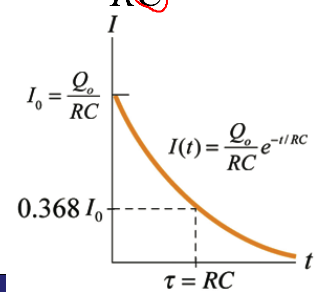
$$\frac{dQ}{dt} = -\frac{1}{RC}Q \Rightarrow Q(t) = Q_o e^{-t/RC}$$

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

I_0

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





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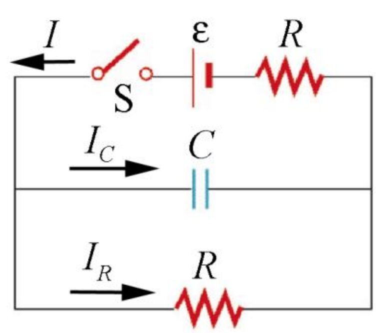
Concept Question: RC Circuit

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. $I_R = e/2R\,,\ I_C = e/R$

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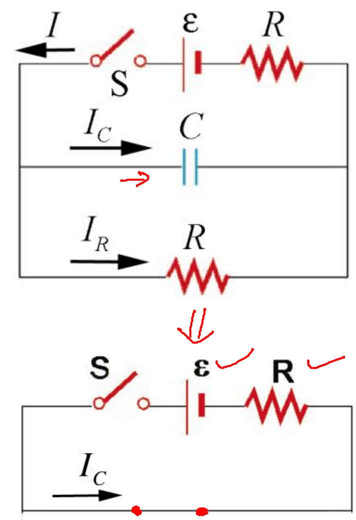
Concept Question Answer: RC Circuit

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:



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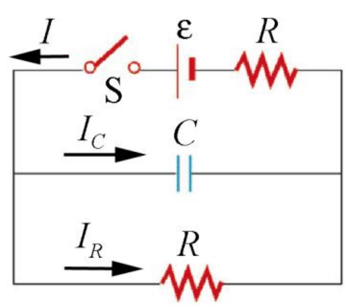
Concept Q.: Current Thru Capacitor

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

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



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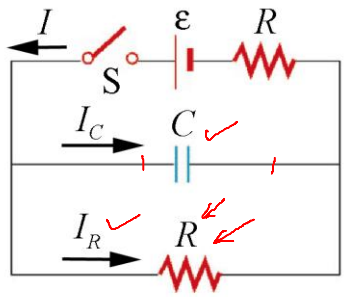
Con. Q. Ans.: Current Thru Capacitor

Answer 1. $I_C = 0$

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



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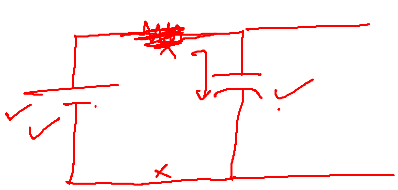
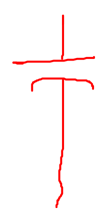
Charging & Discharging



Polarity
→ Current
→ Power
→ charging
→ Discharging



→ Internal discharge
↓
Batteries
→ Lead-acid
→ Li-ion
} 1 month.

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Summary

Unit - I Capacitors AC, DC

→ Basics → Review, I, R, L, C →

→ problems

→ Batteries

→ Composite capacitor →

→ Electrostatics → Synthesis → Definitions →

→ Capacitors → Supercapacitors

→ Charging / Discharging

Unit - II circuit Analysis