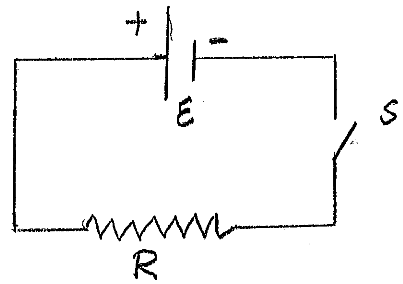
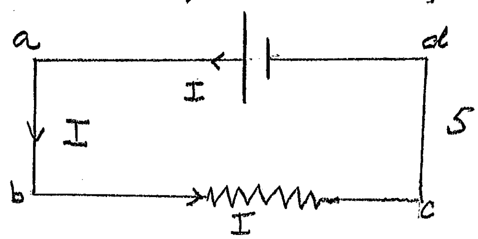
DC-CIRCUITS: BATTERY + RESISTORS + CAPACITORS

1 Ideal Battery + Resistor

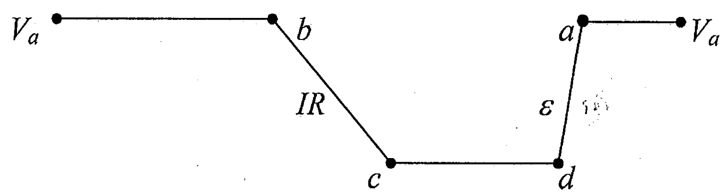
When the switch is closed current will flow counter-clockwise outside battery and from − to + inside battery



[Note: Current consists of electrons outside battery and ions inside it]



The potentials at various points are



clearly,

$$IR = \varepsilon$$

$$I = \frac{\varepsilon}{R}$$

Power absorbed in resistor:

Each electron loses eV Joules going from b to c

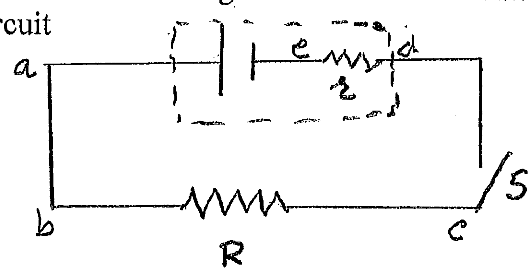
\# electrons per sec $\frac{\Delta n}{\Delta t}$

$$P_w = \frac{\Delta n}{\Delta t} eV = IV \qquad \frac{|e|\Delta n}{\Delta t} = \frac{\Delta q}{\Delta t} = I$$

$$P_w = I^2 R - = \frac{V^2}{R}$$

2 Real Battery + Resistor

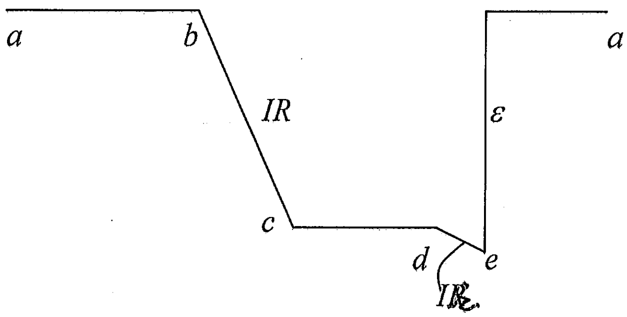
Now there is power absorbed as charge travels inside the battery, we represent it by adding "r" to the circuit



Now when switch closed, current is:

$$I = \frac{\varepsilon}{R + r}$$

and potentials are:



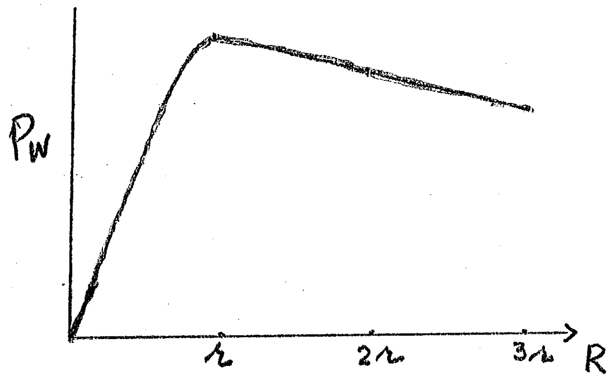
Power Absorbed $P_w = \left(\frac{\varepsilon}{R+r}\right)^2 R$

And if you vary R, P_w will go to zero both when $R << r$ or $R >> r$

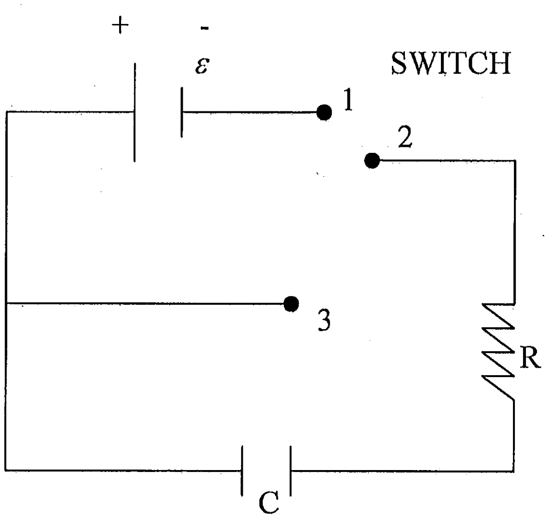
P_w is maximum when $R = r$.

General Rule:

Maximum power $[\varepsilon^2/4r]$ is delivered to load when load resistance is equal to the internal resistance of the generator.

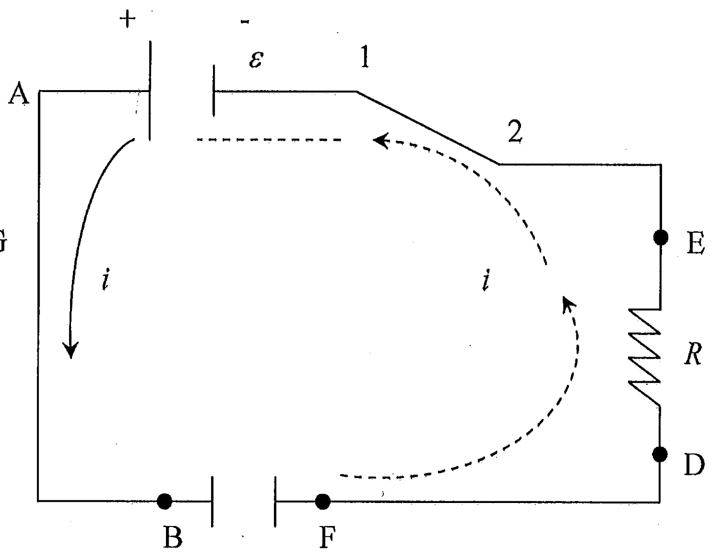


Next, put all 3-devices together in a Circuit:



At t=0, connect 1 to 2: charge will flow from battery to capacitor plates.

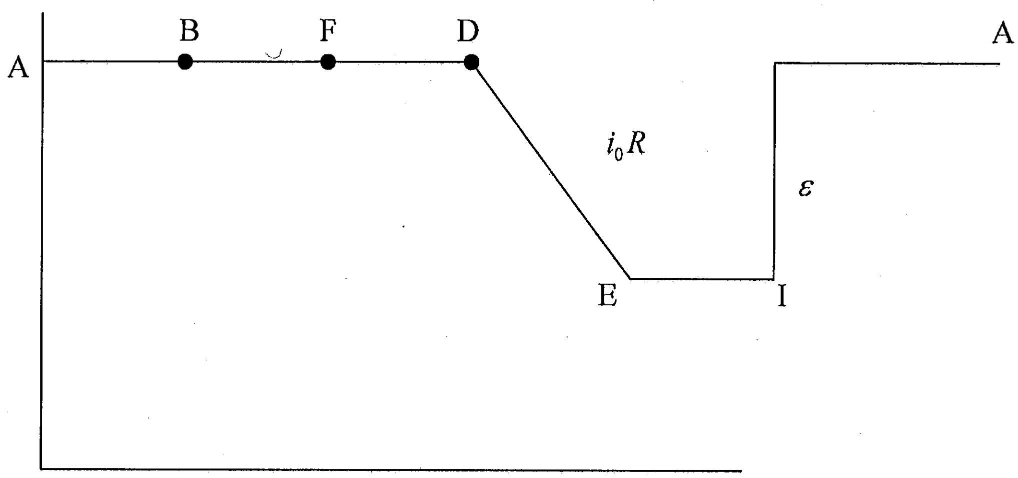
CHARGING



NOTICE NO CURRENT IN CAPACITOR.

At t=0, no charge on C, $V_C = 0$, Potential at various points looks like

t=0

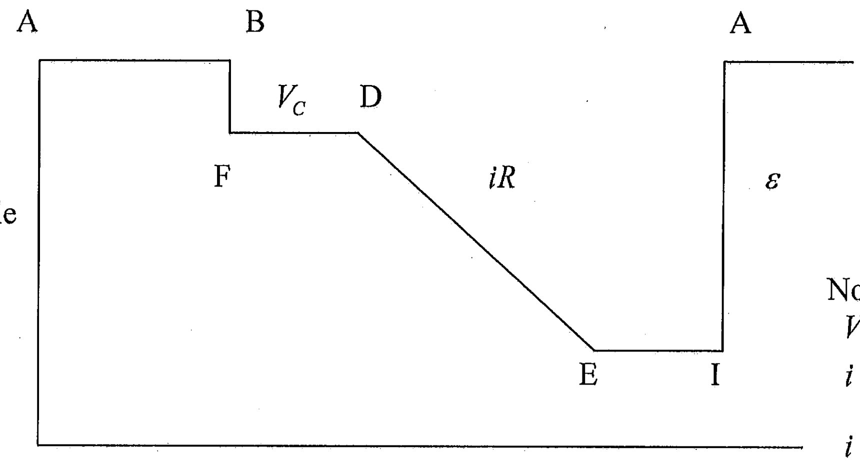


So $i_0 = \dfrac{\varepsilon}{R}$

That is, R limits the maximum current that can flow so it will take time to build up charge on C.

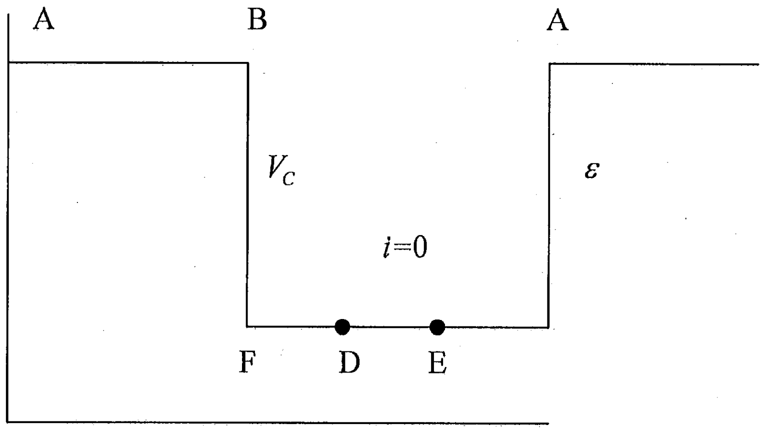
a little later C has $\overset{+}{q}\,|\;|\,\overset{-}{q}$, $V_C = \dfrac{q}{C}$, and the Potential becomes

A little later



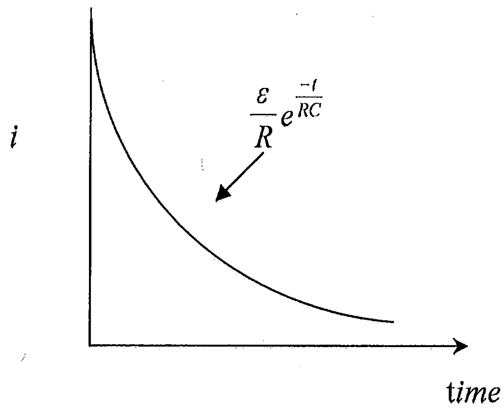
Now
$V_C + iR = \varepsilon$
$i < i_o$
$i = \dfrac{\varepsilon - V_C}{R}$

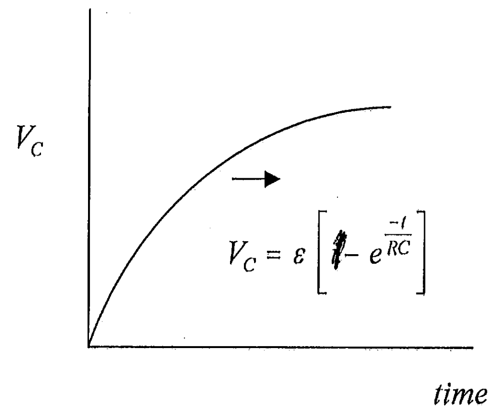
Eventually $q \to C\varepsilon$



$V_C = \varepsilon$.
$i \to 0$.

Mathematically it can be proved that:



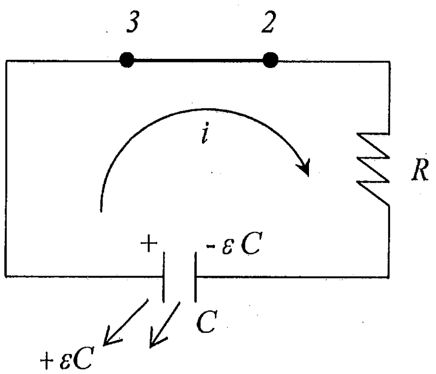


So now $V_C = \varepsilon$, i=0

Switch from 2 → 1 to 2 → 3. circuit is below

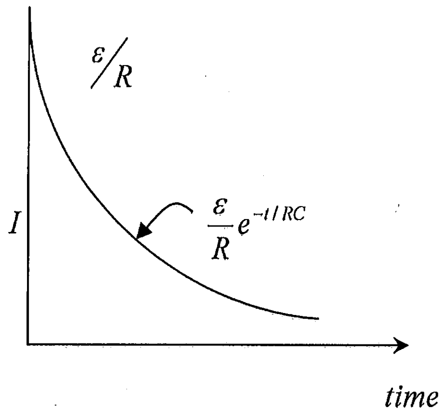
Start clock again

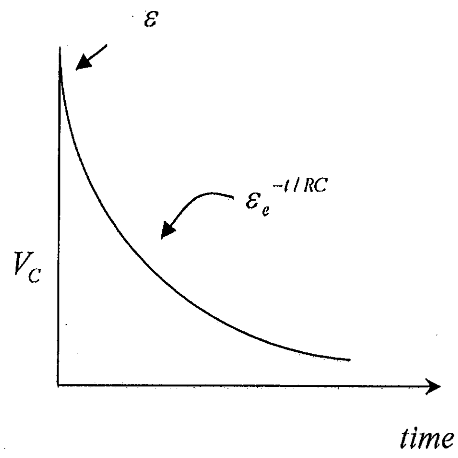
<u>DISCHARGING</u>: No battery in circuit current is due to capacitor's stored charge ($\vec{E}$-field)



current flows in opposite direction

NO CURRENT IN CAPACITOR





CHARACTERISTIC TIME $\tau = RC$!!!

$$R = \frac{V}{I} \Rightarrow \frac{VT}{Q}$$

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

$$So,\ RC \Rightarrow \frac{Q}{V} \bullet \frac{VT}{Q} \Rightarrow T$$

RC has dimensions of time!

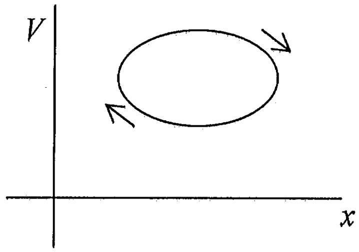
Process involves transference of charge [from battery to *C* during charging from one terminal of *C* to the other during discharging]. *R* controls rate of flow. *C* controls amount of *Q* to be transferred for a given ε.

<u>KIRCHHOFF'S RULES:</u> PHYSICAL BASIS

<u>Loop Rule:</u> Change of potential between two points is independent of the path because potential is derived from potential energy and the latter is defined for a <u>CONSERVATIVE</u> force so net change of potential on a closed loop must be zero.

$$\sum_{LOOP} \Delta V_i \equiv 0$$

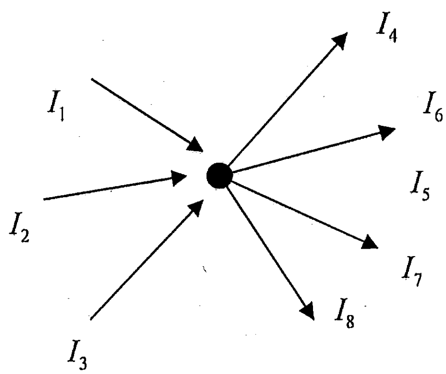
Potential at any point is unique!



[Recall that in a Thermodynamic cyclic process $dU = 0$, Thermodynamic potential (Internal energy)]

<u>Junction Rule:</u> Flow of charge is continuous, i.e., apart from what is involved in setting up the original field to drive a current, there can be no continuous accumulation (depletion) of charge at junction consequently,

Current is flux of charge, charge is conserved hence charge flow per sec. out of junction must equal charge flow into junction per sec.



$$\Sigma I_{out} = \Sigma I_{in}$$