# Chapter 25 notes

- Charges in motion → current
- electric circuits convey energy from one place to another
- charged particle move, electric potential is transferred from a source to a device where energy is stored, converted to another form ~ sound, heat, light

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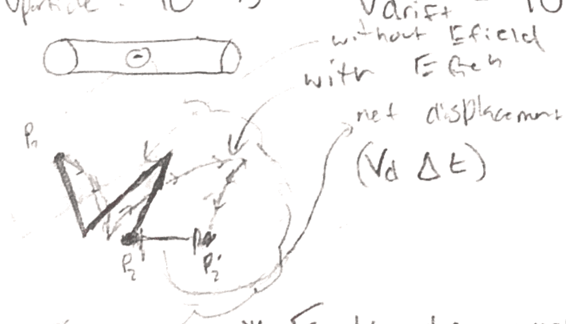
- Before $\vec{E}=0$ in a conductor so no net current, charges do move randomly, just add to 0
- put $\vec{E}$ field inside a conductor

→ particles experience a force $\vec{F}=q\vec{E}$ {in a vacuum it would accelerate}
but its in a conductor, frequently collides with massive stationary ions.
$\vec{F}_{net}$ is an addition to the random motion inside so it doesn't cancel but moves!
The particles slowly move with velocity $V_{drift}$ → NOW A current!
$V_{particle} = 10^6$ m/s $\quad V_{drift} = 10^{-4}$ m/s



The reason your light turns on imediatly?
→ Efield is activated near speed of light
→ which moves all the electrons at once.
So it would take awhile for an electron to move far, they just all move together, called by the Efield

*- Efield does work, causing them to move & bump, heating up wires

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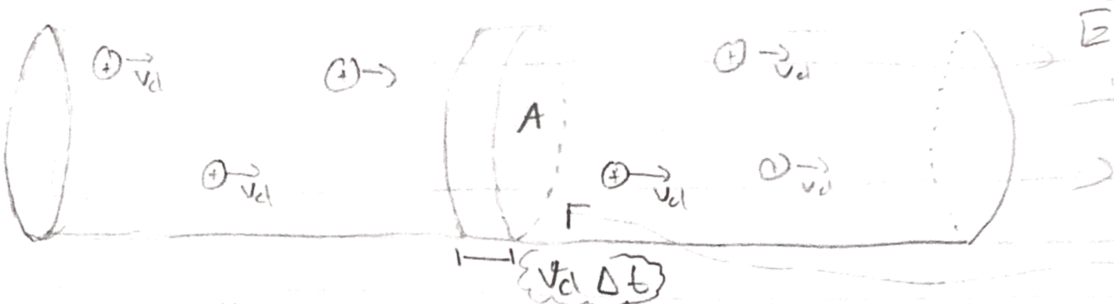
in germanium in silicon, "positive charges can move", really just the absence of $e^-$ that move
called "holes,"

I = flow of charge whether or not the charges are free it can just be those "holes"

$I = \frac{dQ}{dt}$, current is the net charge moving through a cross sectional Area per unit time

ampere $= \frac{1C}{s}$





→ there are "n" moving particles per unit volume = concentration
→ all move same "$V_d$" in a time interval $dt$
→ so they move a distance $V_d\,dt$
volume of this cylinder is $A \cdot V_d\,dt$

→ so $n \left(\frac{\#\text{ of particles}}{\text{volume}}\right)$ so $n \cdot \text{Volume} = \#$ particles
→ $n \cdot A\, V_d\, dt$ ← $q$ times this is the charge through this cylinder
→ $dQ = q[n \cdot A\, V_d\, dt]$

$$I = \frac{dQ}{dt} = n q V_d A$$

and current per cross sectional area is $J = \frac{I}{A} = n q V_d$ *units are $\frac{\text{Amp}}{m^2}$

*if $q = +$ the $V_d$ = to the right, if $q = -$, $V_d$ = to the left so signs cancel
(use $|q|$
or $\vec{J} = nq\vec{V_d}$ ← I is just flow through a wire
$\vec{J}$ is a vector because it tells us how charge flows at a certain point

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$\vec{J}$ normally depends on $\vec{E}$ and properties of the material which can make it complex
→ but for some metals at given temps $\vec{J} \propto \vec{E}$, and $\frac{|\vec{E}|}{|\vec{J}|}$ = constant
if this ideal picture is kept we have Ohms law

resistivity constant → $\rho = \frac{|\vec{E}|}{|\vec{J}|}$ $\left[\frac{V \cdot m}{A}\right]$ or ($\Omega \cdot$meter) ohm * $\frac{1}{\rho}$ = conductivity

resistivity goes up when temp goes up (cause those ions shake more, hitting more $e^-$)
$\rho(T) = \rho_0[1 + \alpha(T - T_0)]$ $\alpha$ = coefficient of resistivity $\rho_0$ = resistivity at $T_0$

→ from this $\vec{E} = \rho\vec{J}$ to get to ohms law and explain this go to next paper!

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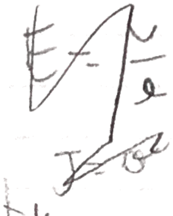
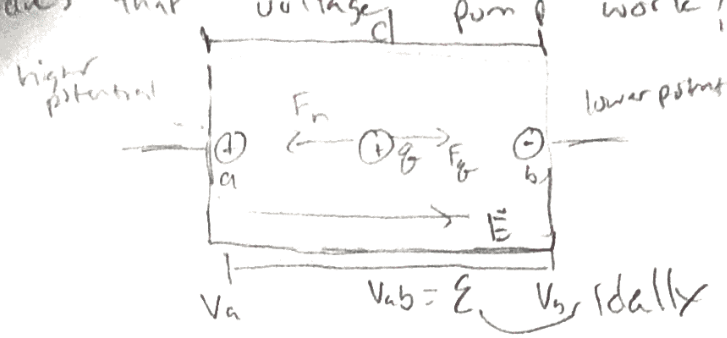
$J = \sigma E$



$\sigma$ is conductivity

does that voltage pump work?




$F_q = qE$

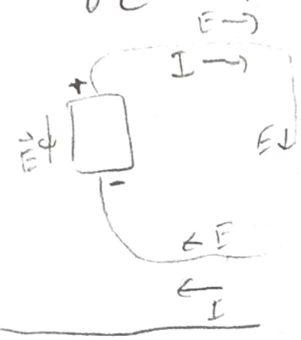
$F_n$ = counteracting force

pushes charges uphill

- if $F_n$ wasn't there charge would flow until potential = 0

Origin of $F_n$ depends on the source, a generator it uses magnetic field forces, in a battery → diffusion process and varying electrolyte concentrations from chemical reactions, Van degraff uses mechanical, moving belt or wheel.

$W_n = q\mathcal{E}$ so potential ergy to move it against $F_q$ is $qV_{ab}$




$\mathcal{E}$ = constant potential difference

ideally $V_{ab} = \mathcal{E}$

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the source has an internal resistance "r"

terminal voltage actually $V_{ab} = \mathcal{E} - Ir$

then $V_{ab} = IR$ so $IR = \mathcal{E} - Ir$ then $\boxed{I = \frac{\mathcal{E}}{R+r}}$

so $I = \frac{\mathcal{E}}{\text{total resistance through the circuit and source}}$

think of it like $V_{expected}$ or $V_{actual}$

magnetic field units 1 T

# Chapter 27, Magnets

- fundamental nature of magnets is in the interaction of moving charges

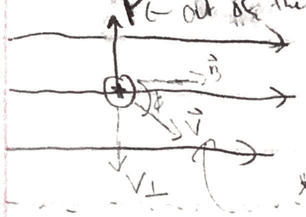
1. moving charges produces a magnetic field 2. a second current responds and experiences mag field

a) a moving charge or current creats a magnetic field

b) the mag field exerts a force on any other moving charge or current

$\vec{B}$ = magnetic field

$\vec{B}$ creates a force but is always $\perp$




$$F = |q| V_\perp B = |q| v B \sin\phi$$

not deduced theoretically, observations

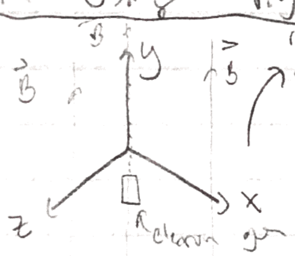
$$\vec{F} = q\vec{v} \times \vec{B}$$

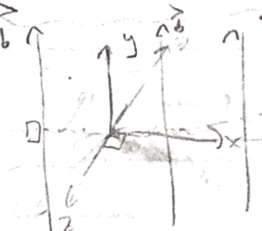
* also equiv: $F = |q| v B_\perp$ ← cause $B\sin\phi = B_\perp$

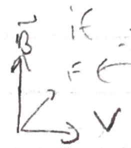
if 90° = $F_{max}$

* if using right hand rule on negative charges, $\vec{F}$ is opposite from RHR

if $\vec{V}$ is $V_{\parallel}$ to $\vec{B}$ so $\phi = 0$ or $\pi$




if tube is turned 90° $\phi = \frac{\pi}{2}$

F is going along z-dir

IF a charged particle is in both a $\vec{E}$ and $\vec{B}$ the Force is $F = q(\vec{E} + \vec{V} \times \vec{B})$

## Magnetic Flux!

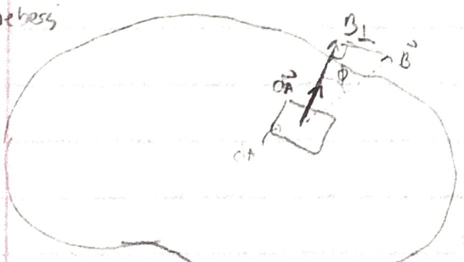
divide any surface into small $dA$'s for each determine $B_\perp$ ← $\vec{B}$ comp normal to surface

Flux units: Webers

1 Wb

$= \frac{N}{A} \cdot m$

$$d\Phi_B = B_\perp dA = B\cos\phi\, dA = \vec{B} \cdot d\vec{A}$$




$$\Phi_B = \int B\cos\phi\, dA = \int B_\perp\, dA = \int \vec{B} \cdot d\vec{A}$$

is $\vec{B}$ is uniform through a surface, $\Phi_B = B_\perp A = BA\cos\phi$

* since there's no such thing as a monopole, so is always a dipole the flux through a closed surface is zero, ← all field lines that exit, re-enter,

$$\oint \vec{B} \cdot d\vec{A} = 0$$

if $dA$ is at right angles to the field lines then $B_\perp = B$, $B = \frac{d\Phi_B}{dA_\perp}$


$$R = \frac{mv}{|q|B}$$

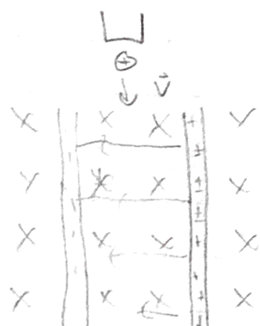
$$F = |q|vB_{\perp} = \frac{mv^2}{R}$$

$\sin(90)$

$V = R\omega \rightarrow \quad \omega = \frac{|q|B}{m} \quad \rightarrow f = \frac{\omega}{2\pi}$

$f$ is ind of $R$, this is called cyclotron $f$, particles moving in circ paths are given a boost twice each revolution increasing energy and $R$ but not $\omega$ or $f$

## Velocity selectors




$qE = qvB$

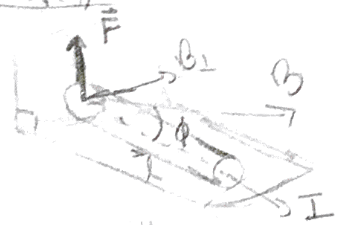
$F_B$ to the left

$F$ is to the right

since forces cancel out

particles with speed $V = \frac{E}{B}$ pass with no deflections

## wires




$\vec{F} = q\vec{V}_d \times \vec{B}$ since $\vec{V}_d$ and $\vec{B}_\perp$ are $\perp \rightarrow F = qV_dB_\perp$

n = number of charges per unit volume

total number of charges = $nAl$

force on all the moving charges $\rightarrow$ $F = (nAl)(qV_dB_\perp) = (nqV_dA)(lB_\perp) = IlB_\perp = IlB\sin\phi$

$I$

so $F = IlB\sin\phi = I\vec{l} \times \vec{B}$

and $d\vec{F} = I\,dl \times B$

we can integrate to find total force on a conductor of any shape


this force forces the voice coil causing cone to vibrate making sound

oscillates from signal

the magnet exerts a force on voice coil $\propto$ the current in the coil

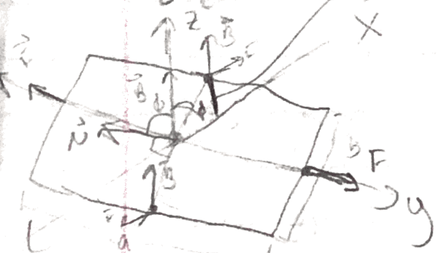
pg 905

moment arm

# Chap 27 notes cont...

## Torque w/ magnetic fields

different angle from $\tau$ cuz $F$ *STUPID!




angle between $B$ and $\vec{\ell}$

from $F = I\vec{\ell}B\sin\phi$   side a $\Rightarrow F = IaB$

and for b $\Rightarrow$ $F = IbB\sin(90° - \phi) = IbB\cos\phi$

idk (since it turns 90°?)

$\phi$ = angle between $\vec{n}$ and $B$

*net force = 0 but net Torque $\neq 0$ usually (only = 0 if $\phi = 0°$)

- the moment arm is the $\perp$ distance from the rotational axis to the force, *Also just draw a line from F to rotational axis, then find $\perp$ pa

Thus:

$$\tau = \underbrace{2}_{\text{two torques}}F\left(\frac{b}{2}\right)\sin\phi = IB\underbrace{ab}_{\text{area of loop}}\sin\phi = IBA\sin\phi$$

$F = IaB$

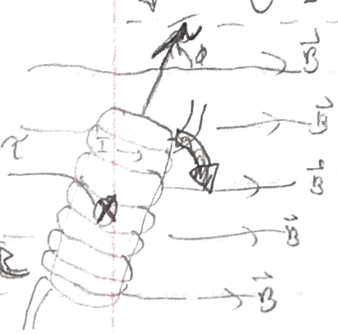
angle between $\vec{n}$ and field direction

- $IA$ is called the magnetic dipole moment $\Rightarrow \mu = IA \leadsto \tau = \mu B\sin\phi$

$\tau = \vec{\mu} \times \vec{B}$

## Potential Energy

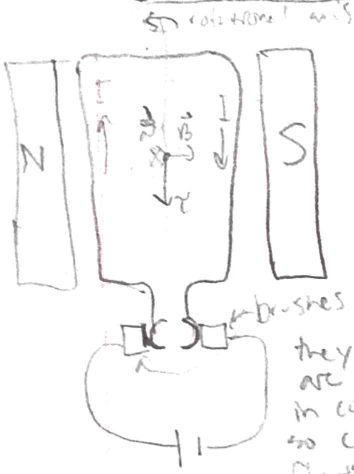
$U = -\vec{\mu}\cdot\vec{B} = -\mu B\cos\phi$ ← angle between $\vec{\mu}$ and $\vec{B}$



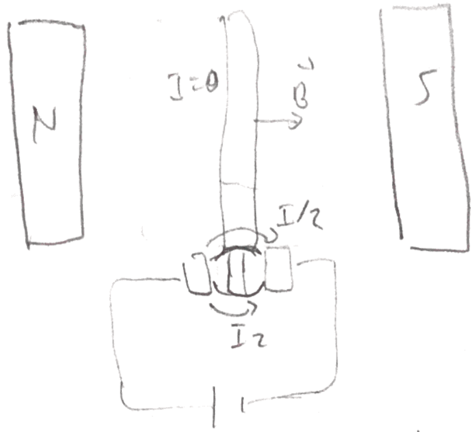

$\tau = N \cdot IA \cdot B\sin\phi$ ← number of turns ← each loop produces a torque

$\boxed{\text{Pg. 902}}$

## Direct current motor




they are in contact so current flows creating a turn




this time brushes are in contact with the open part so current just goes around the small loop

## Power for electric motors:

Potential difference between the terminals = $V_{ab}$

$I \cdot V_{ab}$ = Power

$\mathcal{E}$ comes from magnetic forces exerted on currents in conductors of the rotor. The associated electromotive force is $\mathcal{E}$ and called an induced emf or back emf because its opposite to current

series motor cus rotor is in series with the magnets

$V_{ab} = \mathcal{E} + I r$ R internal resistance

$V_{ab} > \mathcal{E}$

because the magnetic force is $\propto$ to velocity $\mathcal{E}$ is not constant but is $\propto$ to the speed of rotation of the rotor

Hall effect 908.

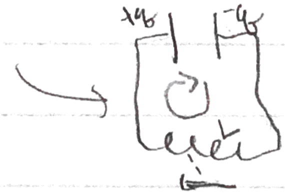
$$\omega = 2\pi f$$

## LC circuit

- shows oscillating current and charge

$Q_m = C V_m$ ← capacitor eq

walkthrough




- capacitor begins to discharge
- causes emf in inductor ($i$ can't change instantly)
- at each instant $V_m \Rightarrow$ emf
- when $V_m = 0$ (emf = 0 too) $I_m$ becomes maximal

now all energy is in inductors $\vec{B}$, The current persists though

- capacitor begins to charge again (flipped polarity though)

then charges, starts cycle over

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* divide by $-L$ and $i = \frac{dq}{dt}$

$$-L\frac{di}{dt} - \frac{q}{C} = 0 \rightarrow \frac{d^2 q}{dt^2} + \frac{1}{LC} q = 0$$ solve diff eq...

$\omega = \sqrt{\frac{1}{LC}}$ and $q = Q_0 \cos(\omega t + \phi)$ and $i = \frac{dq}{dt} = -\omega Q \sin(\omega t + \phi)$

energy: $\frac{1}{2} L i^2 + \frac{q^2}{2C} = \frac{Q_0}{2C}$ solve for $i = \pm\sqrt{\frac{1}{LC}}\sqrt{Q_0^2 - q^2}$

# LRC circuit


LRC series circuit

Loses energy from R.

#1

$$\boxed{-iR - L\frac{di}{dt} - \frac{q}{C} = 0} \rightarrow \frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{1}{LC}q = 0 \qquad q'' + \frac{R}{L}q' + \frac{1}{LC}q = 0$$

$$q = Ae^{-(R/2L)t}\cos\left(\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}\,t + \phi\right)$$

when this = 0 crit damp

corresponds to underdamped behavior.

- less under
- more over

$$\omega_{LRC}^2 = \frac{1}{LC} - \frac{R^2}{4L^2}$$

Chapter 26

# Rough Physics Notes


series


Parallel

$R_{net} = R_{eq}$ * different notation

$V_{ab} = I R_{net}$ or $R_{net} = \frac{V_{ab}}{I}$

Series → $V_{ab} = V_{ax} + V_{xy} + V_{yb} = I(R_1 + R_2 + R_3)$ → $\frac{V_{ab}}{I} = R_1 + R_2 + R_3 + \dots$ ← $R_{net}$

*SERIES Voltage not the same, current constant

Parallel →

* Parallel current different, voltage constant

$I_1 = \frac{V_{ab}}{R_1}$, $I_2 = \frac{V_{ab}}{R_2}$, $I_3 = \frac{V_{ab}}{R_3}$ ← current splits up

$I_{net} = I_1 + I_2 + I_3 = V_{ab}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$ so $\frac{I_{net}}{V_{ab}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ → $\frac{1}{R_{net}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

↑ $V_{net}$

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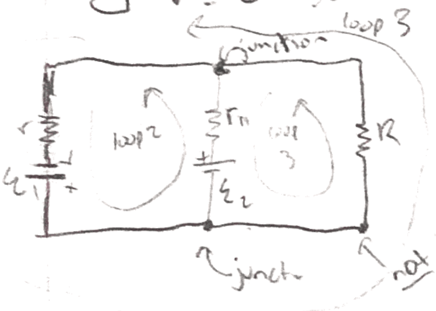
Kirchoff Rules: *many circuits aren't just series-parallel combos

$\sum I = 0$ sum of currents through any junction

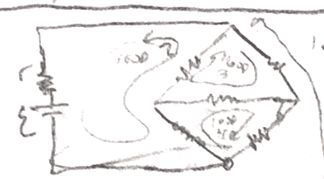
$\sum V = 0$ sum of voltages through any loop

- junctions are where 3 or more conductors meet
- loop is any closed conducting path

ex 1

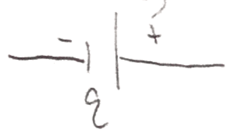



ex 2




a) sign conventions for emf

travel $= +\mathcal{E}$




← travel $= -\mathcal{E}$

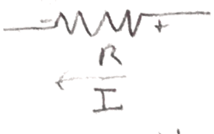

*not necessary in the direction of the current!

b) sign conventions for resistors

travel opposite to current $= +IR$

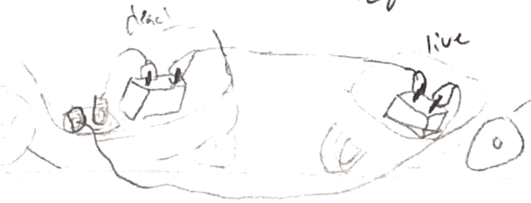

goes in the direction of increasing potential

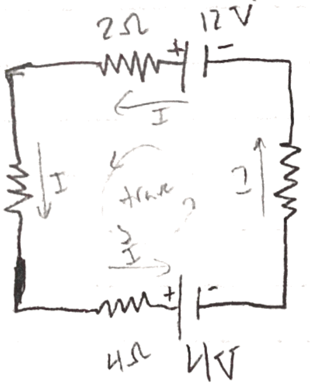
← travel $= -IR$ travels with current




goes in the direction of decreasing potential car battery loop example

$\Sigma V = 0$ in a loop




← resistance or jumper cable and conduction path through the car

↳ higher current going from high potential to lower potential

* if you have multiple batteries guess which one will "overpower" then use Kirchoff's rules

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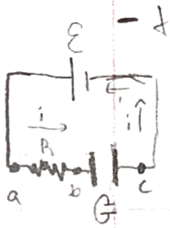
## R-C circuits

- this is when all voltages, current, power change with time




- this circuit charges a capacitor
  - starts off uncharge until we turn it on.
  - $V_{bc}$ (at $t=0$) $= 0$
  - with Kirchoffs loop rule $V_{ab}$ (at $t=0$) $= \mathcal{E}$ (across resistor) $\rightarrow I_0 = \frac{V_{ab}}{R} = \frac{\mathcal{E}}{R}$
    - ↳ since $V_{bc}$ is 0 then the voltage across a loop has to exist somewhere
- as capacitor charges, so, $V_{bc}$ increases, $V_{ab}$ decreases $(V_{ab} + V_{bc} = \mathcal{E}) \rightarrow$ corresponding to ↓ current
- after a long time capacitor charges then $I \rightarrow 0$, then $V_{ab} \rightarrow 0$
- that means from $V_{ab} + V_{bc} = \mathcal{E} \rightarrow 0 + V_{bc} = \mathcal{E}$ $V_{bc} = \mathcal{E}$

Let $q$ = charge on capacitor, $i$ be the current in the circuit,
and the instantaneous potential differences $V_{ab}$ and $V_{bc}$ are! $V_{ab} = iR$, $V_{bc} = \frac{q}{C}$
Kirchoff loop rule: $\mathcal{E} - iR - \frac{q}{C} = 0 \rightarrow i = \frac{\mathcal{E}}{R} - \frac{q}{RC}$
at $t=0 \rightarrow C = 0 \Rightarrow q = 0$ substituting in $q=0$ for $I_0 = \frac{\mathcal{E}}{R}$ (as we have already noted, good check)
as $q$ increases $\frac{q}{RC}$ increases, and $C$ approaches full charge, lets call it $Q_f$, then $i = 0$
so you get $\frac{\mathcal{E}}{R} = \frac{Q_f}{RC}$ when $C$ is fully charged, simplify $Q_f = C\mathcal{E}$

~~I, V, $\mathcal{E}$~~ NOT CONSTANT


# R-C circuits continued

General function of charge $q$ and current $i$ as functions of time

Using equation $i = \frac{\mathcal{E}}{R} - \frac{q}{RC}$ (from Kirchoff rule $\sum V = 0$ through loop $\mathcal{E} - iR - \frac{q}{C} = 0$)

$V_{ab}$ $V_{bc}$

so $i = \frac{\mathcal{E}}{R} - \frac{q}{RC}$, as $t$ → fin capacitance charge, $i = 0$

$\frac{\mathcal{E}}{R} = \frac{Q_f}{RC} \rightarrow Q_f = C\mathcal{E}$

$\frac{dq}{dt} = \frac{\mathcal{E}}{R} - \frac{q}{RC} = -\frac{1}{RC}(q - C\mathcal{E})$

rearrange to: $\frac{1}{q - C\mathcal{E}} dq = -\frac{1}{RC} dt$

integrate: $\int_0^q \frac{dq}{q - C\mathcal{E}} = -\int_0^t \frac{dt}{RC} \rightarrow \ln\left(\frac{q - C\mathcal{E}}{-C\mathcal{E}}\right) = -\frac{t}{RC}$

then $\boxed{e^{-t/RC} = \frac{q - C\mathcal{E}}{0 - C\mathcal{E}} \rightarrow q = C\mathcal{E}(1 - e^{-t/RC}) = Q_f(1 - e^{-t/RC})}$

$Q_f = C\mathcal{E}$

capacitance, battery emf, time since it was turned on

and $\boxed{i = \frac{dq}{dt} = \frac{\mathcal{E}}{R} e^{-t/RC} = I_0 e^{-t/RC}}$

from $\mathcal{E} - iR - \frac{q}{C}$ at $I_0$ $t = 0$, $q = 0$ so $I_0 = \frac{\mathcal{E}}{R}$

when $t = RC$ in $i$ has decreased to $1/e$, and $q = (1 - \frac{1}{e})$ of its final value $Q_f = C\mathcal{E}$

RC is then a measure of how quickly the capacitor charges

RC = time constant or relaxation time

$\boxed{\tau = RC}$, when $\tau$ is small capacitor charges quick, $\tau$ is larger, charging is slow

gives ball park for whats happening

## discharging a capacitor

now lets say a C has an intial charge $Q_0$ then we remove the emf, so


now use $i = \frac{dq}{dt} = \frac{\mathcal{E}}{R} - \frac{q}{RC}$ but $\mathcal{E} = 0$ so $i = \frac{dq}{dt} = -\frac{q}{RC}$

$\left(I_0 = -\frac{Q_0}{RC}\right)$

$\int_{Q_0}^{q} \frac{dq}{q} = -\frac{1}{RC}\int_0^t dt \rightarrow \ln\left(\frac{q}{Q_0}\right) = -\frac{t}{RC} \rightarrow \boxed{q = Q_0 e^{-t/RC}}$

$\boxed{i = \frac{dq}{dt} = -\frac{Q_0}{RC} e^{-t/RC} = I_0 e^{-t/RC}}$

$P = \mathcal{E}i = i^2R$, remember $V_{bc}$ = (voltage across C $= \frac{q}{C}$ → multiply by $i$ → $\frac{iq}{C} = V_{bc} i$

power stored by C

Using $\mathcal{E} = iR + \frac{q}{C}$, multiply by $i$, → $i\mathcal{E} = i^2R + \frac{iq}{C}$

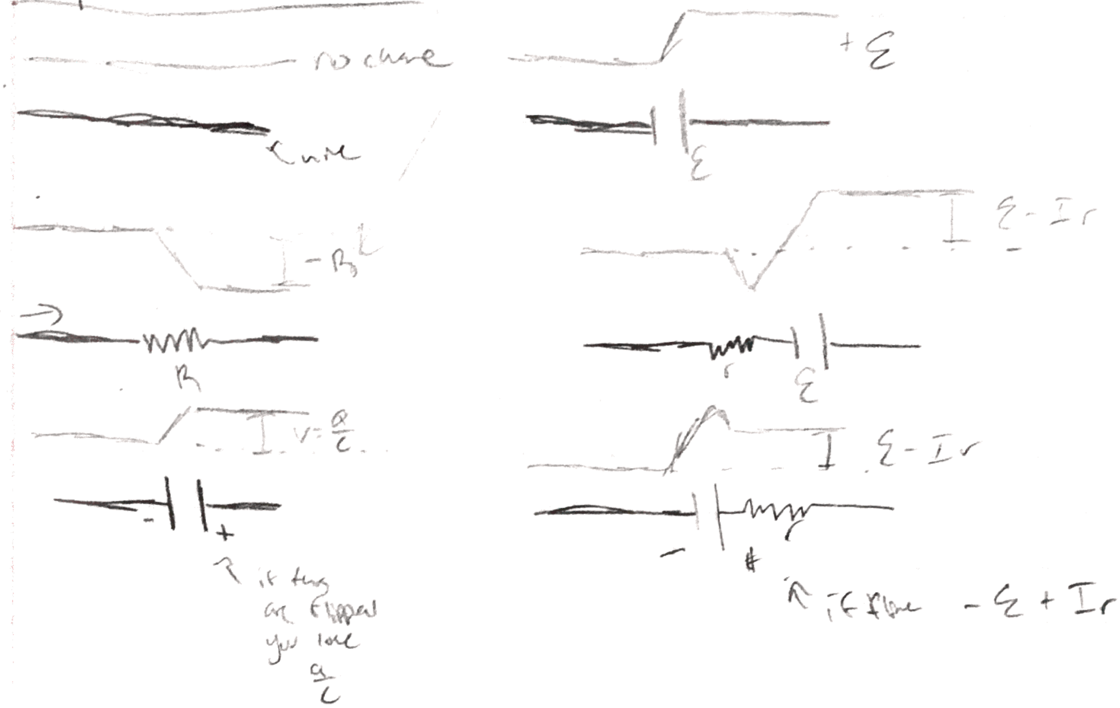
$P_{bat} = P_{diss\ by\ R} + P_{capacitor}$

from $\frac{1}{2}QV$

* total energy stored by C $= \frac{Q_f \mathcal{E}}{2}$ so 1/2 of $\mathcal{E}$ stored in capacitor, the other half dissipated by R

* if you travel in direction of current through resistor you lose V
vice versa

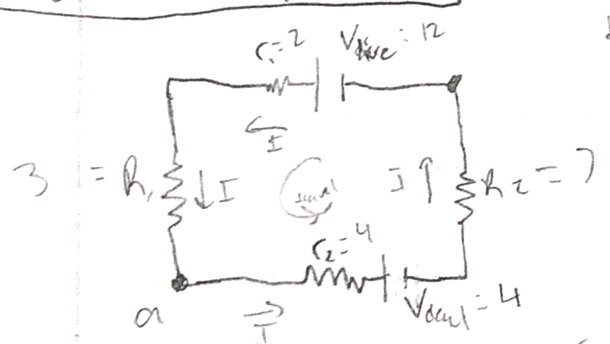
## loop rule in circuits




↑ if they are flipped you lose $\frac{q}{c}$

↑ if flow $-\mathcal{E}+Ir$

## Charging Battery Pt. 2




red w/ dead to live pos to pos
then from live neg to dead neg (usually bad)
so don't connect directly
but through a metal piece

$\sum V = 0 = -4 - 4I - 7I + 12 - 2I - 3I = 0$

$I = .5\ A$


$I=.5$

$P_{live} = V_l I = (V_{live} - Ir_1)I = (12-2I)I = 5.5W$

$P_{dead} = V_{\ } \cdot I = (V_{dead} - Ir_2) = (-4-4I)I = -3W$

$P_{3\Omega} = V \cdot I = -3I \cdot I = -3I^2 = -.75W$

$P_{7\Omega} = V \cdot I = -7I\ I = -1.75W$

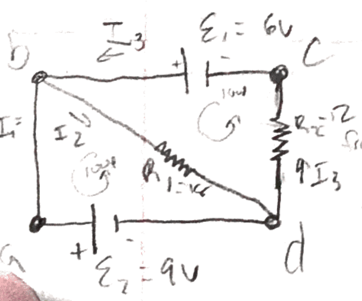
$\sum P = 0$

$V_a - 4 - 4I - 7I = V_b$

traveling from a to b

$V_a - 4 - 11I = V_b$

$V_a - V_b = 4 + 11 \frac{1}{2} = 9.5V$




$\sum I_{in} = \sum I_{out} \rightarrow \quad I_3 = I_1 + I_2$

from a to b to d $\rightarrow \quad 0 = -18 I_2 + 9 \quad I_2 = .5A$

from b c d $\rightarrow \quad 0 = -I_2 \cdot 1k - 12 \cdot I_3 + 6$

with these 3 you can solve everything

$I_3 = -.75$

$I_1 = +.25$


← can change sign as long as you change all