Electric Currents + Resistance - Ch 25

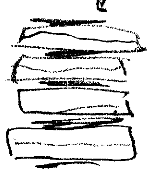
we are moving from static → dynamic   charges in motion!

E field exerts force on electrons to make them move.

E related to V $V = -\int \vec{E} \cdot d\vec{l}$ etc

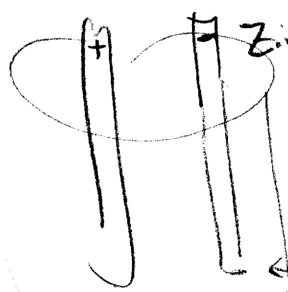
so potential difference needed to make charges move in a wire.

First Battery:



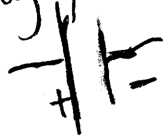
Batteries have + and - terminals

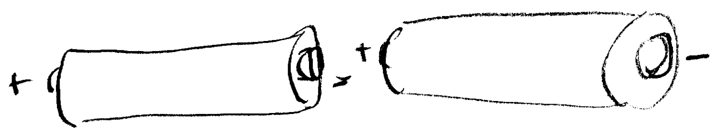
pot'l diff comes from chemical reaction



↑ solution becomes +ively charged, so carbon loses electrons

battery symbol





voltages add up when multiple batteries used "in series"

Current - flow of charge

← wate flows downhill and does work

↑ mill

why does water move? Potential diffrnce.

Similarly, charges move because battery or some source creates a potential difference

average $\bar{I} = \frac{\Delta Q}{\Delta t}$ how much charge passing through a region given amt of time

$I = \frac{dQ}{dt}$ $\frac{\text{coulombs}}{\text{second}}$ = Ampere "Amp" A

$1A = 1 C/s$

note charge only flows if circuit is complete. In open circuits, the charge doesn't move.

go to microscopic view, p

Ohms Law

$I \propto V$

$I \propto \frac{1}{R}$

think mill - the higher the water starts out, the faster it flows. But leaves or friction would also slow down the water

Put together: $I = \frac{V}{R}$

$\boxed{V = IR}$ "Ohms Law"

← actually not, but is what everyone uses

resistance

depends on material

unit of resistance : Ohm Ω (omega)

$$1\Omega = \frac{1V}{A}$$

example flashlight bulb.

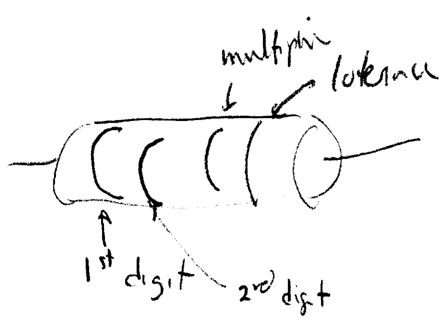
A flashlight draws 300 mA from its 1.5V battery.
what is the resistance of the filament?

$$R = \frac{V}{I} = \frac{1.5V}{0.3A} = 5.0\Omega$$

what if the battery is weak and is 1.2V? $I = ?$

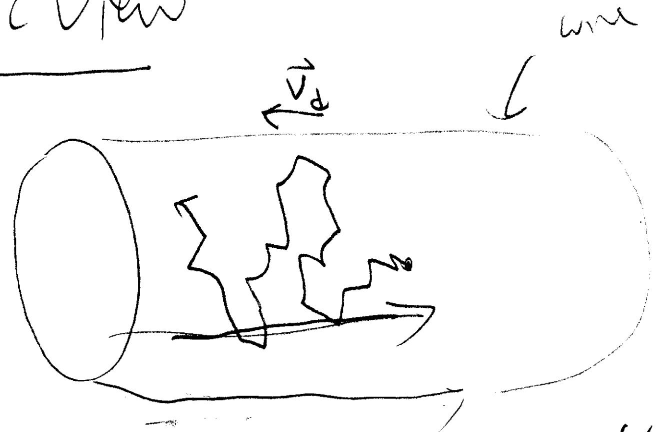
$$I = \frac{V}{R} = 1.2$$

Resistors in the lab: color coded.



color	#	Multiplier	tolerance
black	0	1	
brown	1	10^1	1%
red	2	10^2	2%
orange	3	10^3	
yellow	4	10^4	
green	5	10^5	
⋮			
Gold		10^{-1}	5%
Silver		10^{-2}	10%
no color			20%

Microscopic View



electrons move randomly. when E is "turned on" they begin to accelerate, but they collide with other atoms, etc, and reach velocity $\vec{v}_d$

define $\vec{j} = \frac{\vec{I}}{A}$ or $I = jA$

current density   if j not uniform, $I = \int \vec{j} \cdot d\vec{A}$

what is I? $I = \frac{\Delta Q}{\Delta t}$

consider small volume $\Delta l = v_d \Delta t$

Q passing through this small volume in time Δt is (number per unit volume N) $\times$ (volume) $\times$ (charge per particle)

$\Delta Q = n(-e)\,\text{volume}$
$= n(-e)A\,l$
$= n(-e)A\, v_d\, \Delta t$

so $\frac{\Delta Q}{\Delta t} = n(-e) A v_d = I$

$$\boxed{\vec{j} = \frac{I}{A} = -ne\vec{v}_d}$$

~~$I = nA v_d$~~

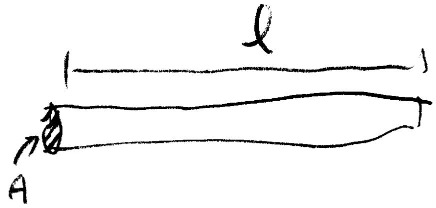
⟵ go back ...

eg: red, green, yellow, silver

Resistance of $25 \times 10^4\ \Omega \pm 10\%$

Resistivity

for a wire



$R = \rho \frac{l}{A}$ ρ is resistivity ($\Omega \cdot m$)

also conductivity $\sigma = \frac{1}{\rho}$ $\left(\frac{1}{\Omega \cdot m}\right)$

example: stretch a wire, keeping volume constant

say stretch so that $l' = 2l$

$V = lA$

$A = \frac{V}{l} \Rightarrow A' = \frac{V}{l'} = \frac{V}{2l} = \frac{1}{2}A$

$R' = \rho \frac{l'}{A'} = \rho \frac{2l}{\frac{1}{2}A} = \boxed{4R}$

In addition, resistance depends on temperature

Atoms move more at higher temps, and interfere more with "flow of e^-"

$\rho_T = \rho_0 [1 - \alpha(T - T_0))$

ρ_0 is resistivity at T_0 (eg $20°C$ or $0°C$)

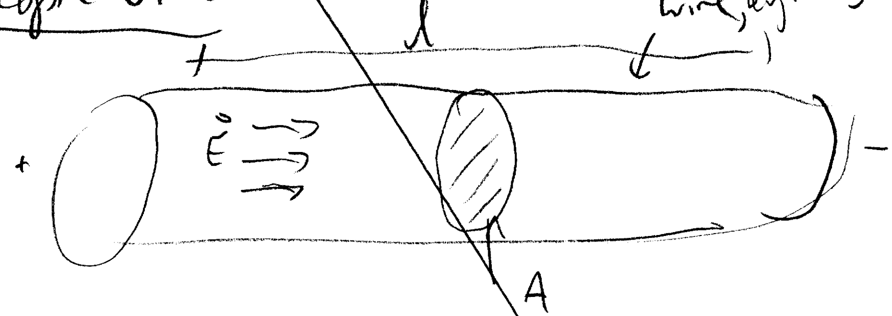
α depends on the material, called the temperature coefficient

$\longrightarrow$ go to the true Ohm's law so $\bar{P} = I_{rms}^2 R$

$\bar{P} = \frac{V_{rms}^2}{R}$ I_{rms}, V_{rms} "effective values

and $\bar{P} = I_{rms} V_{rms}$

Microscopic View



current density $\vec{j} = \sigma \vec{E}$ = electric current per unit cross-sectional area

σ is the conductivity

$j = \frac{I}{A}$ has units of $\frac{Amp}{m^2}$

$I = jA = (\sigma E) A$

$j\cancel{A} = \sigma E \cancel{A}$

$j = \sigma E$ This is Ohm's Law → Go to Ohms law

how is this the same as $V = IR$? (in a wire)

$V = El$ $j = I/A$, so $I = jA$ $R = \rho \frac{l}{A}$

sub in

$El = (j\cancel{A})(\rho \frac{l}{\cancel{A}})$

$E\cancel{l} = j\rho \cancel{l}$

$\frac{E}{\rho} = j$ but $\frac{1}{\rho} = \sigma$

$E\sigma = j$

Electric Power:

how do we use electricity? one way: convert electric energy to thermal energy

$$dU = V\,dq$$

$$P = \frac{dU}{dt} = V\frac{dq}{dt} + q\cancel{\frac{dV}{dt}}^{\,0}$$

$$= VI$$

applies to all devices →

$$\boxed{P = IV}$$ but $V = IR$, so

$$\boxed{P = I^2R}$$ and $I = \frac{V}{R}$

applies to resistors

$$\boxed{P = \frac{V^2}{R}}$$

* hint – be careful which equation you use. eg if V is changing, you can't use $P = I^2R$

Unit of power? J/s = watt

$$\boxed{1\,W = 1\,J/s}$$

Example: Extension cord: Your 1800-W electric heater is too far away, so you use an extension cord rated at 11A. Is this dangerous?

Outlet: 120 V Power 1800 W

$$P = IV$$

$$I = \frac{P}{V} = \frac{1800}{120V} = 15A$$

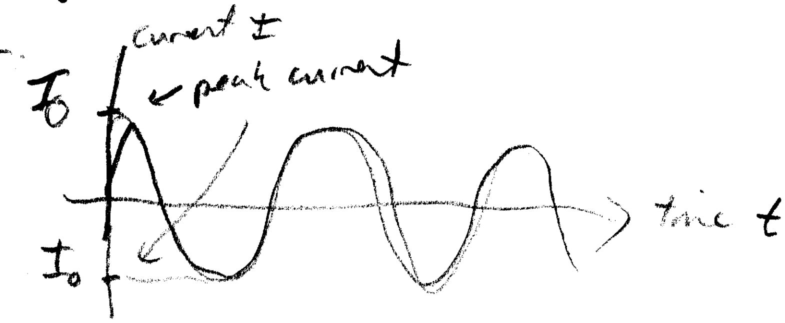
4 "extra" A, could melt insulation of wire!

AC – Alternating Current:

up till now:

eg battery "direct current"

now consider:



$I = I_0 \sin \omega t$ $\quad (\omega = 2\pi f)$

$V = IR = I_0 R \sin \omega t$

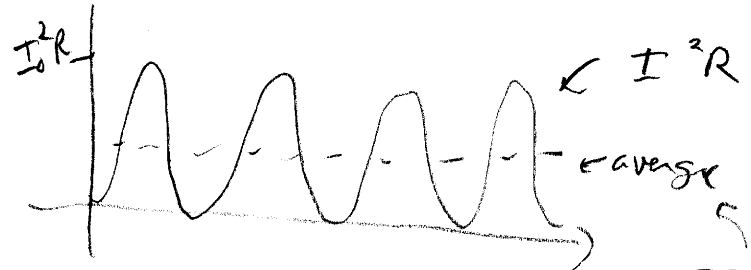
$= V_0 \sin \omega t$

what is the average current? zero

does this mean no power?

$P = I^2 R = I_0^{\,2} R \sin^2 \omega t$

I is squared, so always positive



so average power $\bar{P} = \overline{I^2}R = \frac{1}{2} I_0^{\,2} R$

useful quantities

$I_{rms} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}}$ root of the mean of the square

$V_{rms} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}}$

So that $\bar{P} = I_{rms} V_{rms}$

$= \frac{1}{2} I_0^2 R = I_{rms}^2 R$

$= \frac{1}{2} \frac{V_0^2}{R} = \frac{V_{rms}^2}{R}$

switch order for clarity

Problem: Calculate the peak current in a 2.7 kΩ resistor connected to a 220-V rms ac source

Find I_0 given R, V_{rms}

$\frac{1}{2} I_0^2 R = \frac{V_{rms}^2}{R}$

$I_0^2 = \frac{2 V_{rms}^2}{R^2}$

$I_0 = \frac{\sqrt{2}(220 \text{ V})}{(2.7 \times 10^3 \, \Omega)}$

~~$V = IR$~~

~~$V^2 = I^2 R^2$~~

$V_{rms} = I_{rms} R_{rms}$