Circuits

Investigating (idealized) motion of electrons in metals (conductors) in ways that do useful work.

Reminder for a charged particle

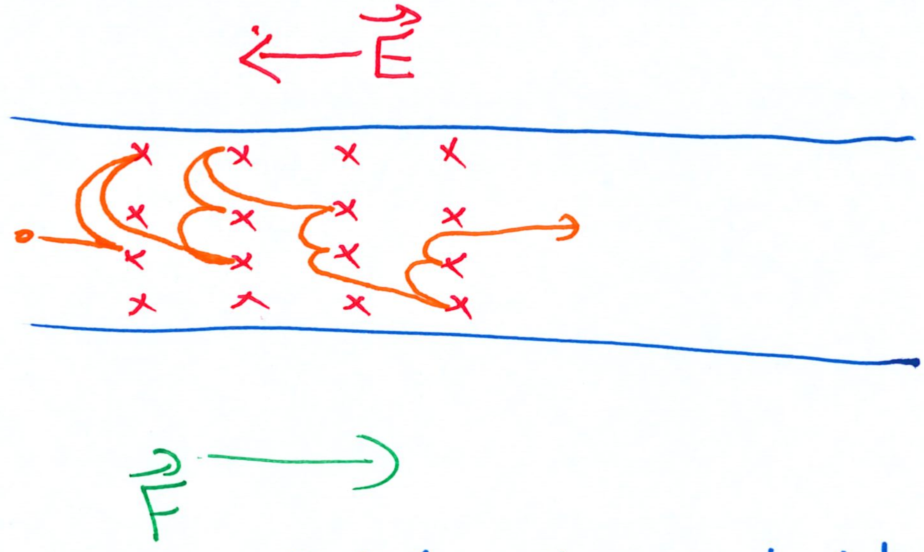
$$PE(\vec{r}) = q\underbrace{V(\vec{r})}_{\text{electric potential at that location}}$$

If $V(\vec{r})$ changes as $\vec{r}$ changes then q will feel a force in direction of lower PE

$$\vec{F} = -\vec{\nabla}\, PE$$

As q moves towards lower PE, $\vec{F}$ does work on it

Expect KE to increase

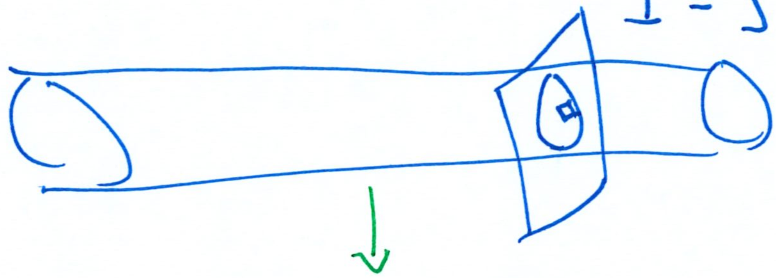


Electron collided with individual atoms ; interact via coulomb force $\Rightarrow$ elastic collision
$\Rightarrow$ Some KE gets transferred to atoms in material
(Effect: Heats up b/c ρ ||| average KE related to temp)

Turns out that speed of conduction electrons is relatively constant so work done on electrons by force ends up either heats things or does mechanical work.

When I talk about current

$I = \int \vec{J} \cdot d\vec{A}$



$A \sim C/s$

I →

model as line

Current = total charge per time moving along line

direction: Way positive charges would move

Any place where q's do work "resistor"

PE decreases
Does work

All wires assume charges move along wires unimpeded.

12-2-Example-DCcircuits1

DC circuits - I

An electron moves from a location where it is at potential $1V$ to a place where it is at potential $3V$.

- What is the change in the electron's potential energy?
- Assuming the electron's kinetic energy has not changed, how much work did the electron do?

Know $PE = qV$

$$\Delta PE = qV_f - qV_i$$

$$= q(V_f - V_i)$$

$$= (-1.6\times10^{-19}C)(3V - 1V) \qquad 1V = 1J/C$$

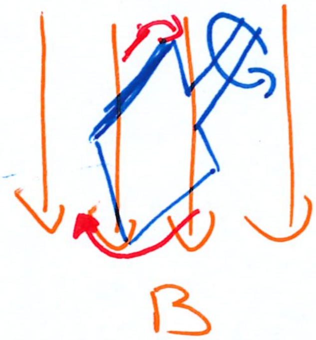
$$= -3.2\times10^{-19}J$$

$$\Delta KE + \Delta PE = W_{NC\text{ on Electron}}$$

$$0 + (-3.2\times10^{-19}J) = W_{NC\text{ on Electron}}$$

Electron has done $-W_{NC\text{ on electron}}$ or $3.2\times10^{-19}J$ of work

How electric power is actually generated

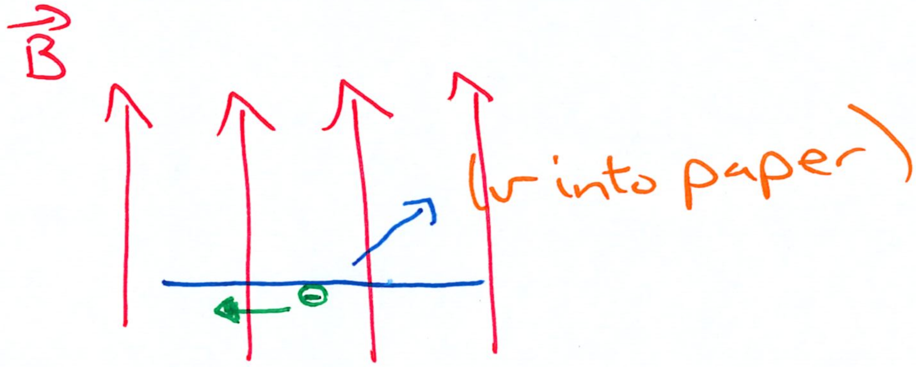


A current carrier is moved in the presence of a magnetic field ; charged particles feel a force , which does work on them , increasing their P.E.

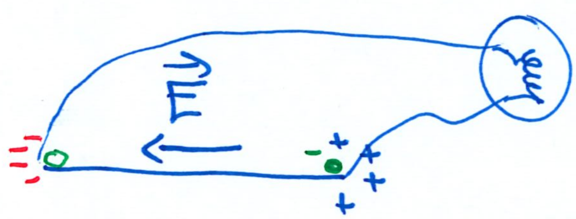
DC circuits - II

A $1.5m$ long piece of metal is oriented in the x-direction. It is moved with a velocity $20\frac{m}{s}\hat{\jmath}$ in a region where the magnetic field is $0.4T\hat{k}$.

How much work would be done on an electron by the Lorentz force as it moves from one end of the metal to the other?



$$\vec{F} = q\vec{v}\times\vec{B}$$
$$= (-1.6\times10^{-19}C)(20\,m/s\,\hat{\jmath})\times(0.4T\hat{k})$$
$$= -1.28\times10^{-18}N\,\hat{\imath}$$



B/c of charge separation there is an $\vec{E}$, so potential difference

$$W = \vec{F} \cdot \Delta\vec{r}$$

$$= (-1.28\times10^{-18}\,N\,\hat{i}) \cdot (-1.5\,m\,\hat{i})$$

$$= 1.92\times10^{-18}\,J$$

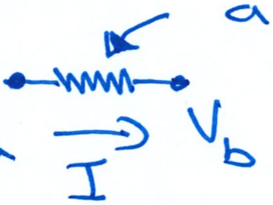
Similar way of saying

$\Delta PE \rightarrow q\Delta V$

$(-1.6\times10^{-19}\,C)(-12V)$

Charge separation $\rightarrow$ V not constant

Resistors:



a region where electric charges do work.

$$\Delta V = V_b - V_a = -IR$$

resistance Ω

$1\Omega = 1\,V/A$
$= 1\,Vs/C$
$= 1\,Js/C^2$

A positive charge moving in direction I will have its potential decreased by IR

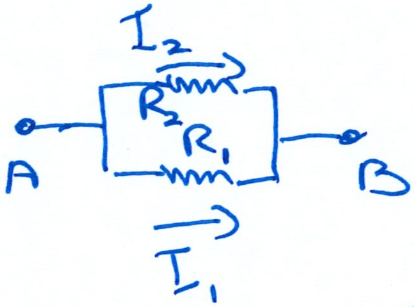
Multiple resistors / resistive elements

$$V_B - V_A = -R_1 I$$

$$V_C - V_B = -R_2 I$$

$$V_C - V_A = V_C - V_B + V_B - V_A$$
$$= -R_2 I + (-R_1 I)$$
$$= -(R_1 + R_2) I$$

$R_{eq} = R_1 + R_2$ (in series)



$V_B - V_A = -I_1 R_1$

$V_B - V_A = -I_2 R_2$

as well)

Total through both $= I_1 + I_2$

$V_B - V_A = -(I_1 + I_2) R_{eq}$

How do we work out R_{eq}

Want it as a function of R_1 & R_2

Know $I_1 R_1 = I_2 R_2 = -(V_B - V_A)$

$\left(I_1 = \frac{-(V_B - V_A)}{R_1} \quad I_2 = -\frac{(V_B - V_A)}{R_2} \right)$

$V_B - V_A = -\left[\frac{-(V_B - V_A)}{R_1} + \frac{-(V_B - V_A)}{R_2}\right] R_{eq}$

$1 = \left[\frac{1}{R_1} + \frac{1}{R_2}\right] R_{eq}$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{(in parallel)}$$

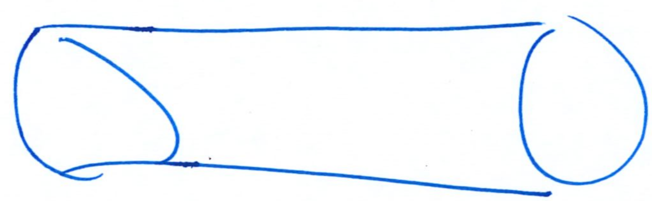
Ohm's law says that current density $\vec{J}$ is proportional to $\vec{E}$

$$\vec{J} = \sigma \vec{E}$$

"conductivity" depends on material

$\vec{E} \longrightarrow$

Small wire ~ smaller current



thick wire ~ bigger current

Electric field $\sim \frac{d}{dx} V \sim \frac{\Delta V}{l}$