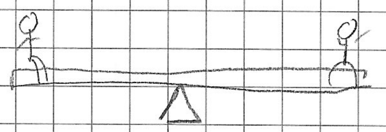
The Future isn't in solving problems to which we already know the answers
it is in learning how to work through the problems you'll experience in any subject

better implies different

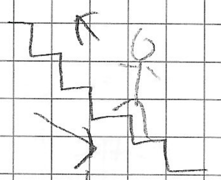
Electric Currents and resistance

Static electricity → no $\vec{E}$ in conductor

Dynamic equilibrium → $\vec{E}$ field in conductor



static



dynamic

Until 1800s → Electric charge from friction

After 1800s → Volta's battery

Galvani → life force

Volta → metals are different!

↓ better instrument than frog (10V per degree)

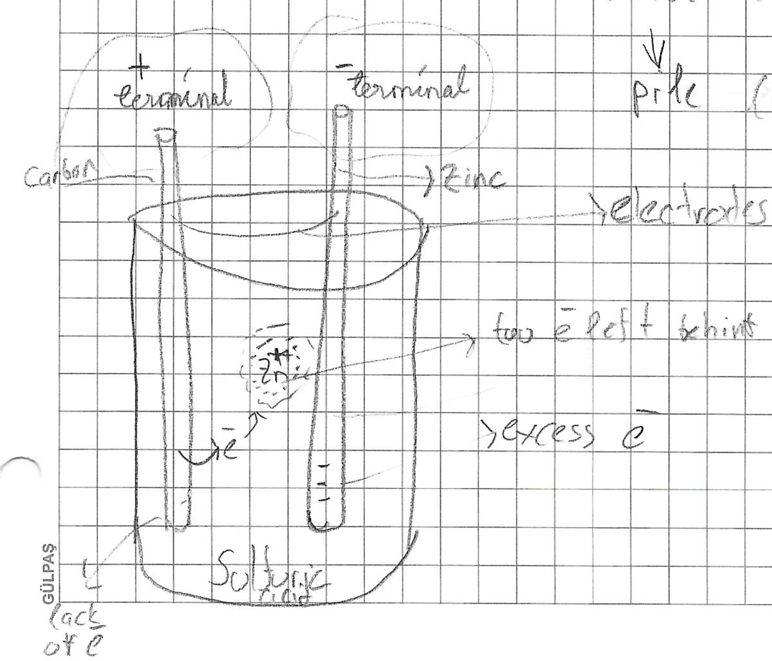
Silver zinc → volta 0.7
modern 0.78

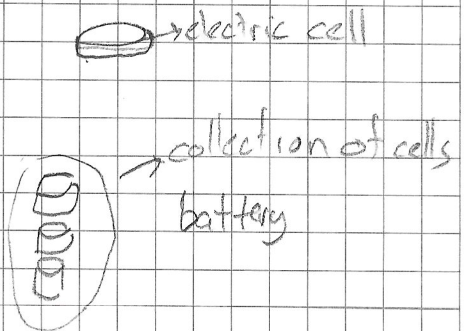
↓ electrochemical series

(V vs metal combinations (still in use))

↓ acid (or salt solution)

↓ pile (battery)





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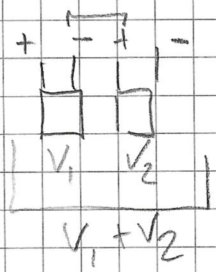
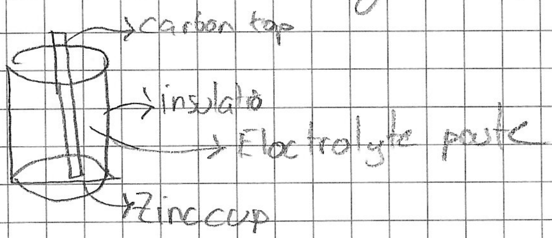
potential difference depends on what the electrodes are made of and their relative ability to exchange $\bar{e}$

When there is no load → battery is in static eq

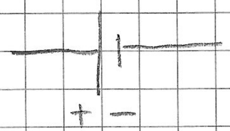
when we connect a load → dynamic eq





Electric current

Battery supplies voltage which makes $\bar{e}$ flow



A flow of charge is called electric current

average current: $\bar{I} = \dfrac{\Delta Q}{\Delta t}$ → amount of charge that passes in the region → per unit time

instanteneous current $I = \dfrac{dQ}{dt}$

André Ampere → $1A = 1\,C/s$

V source loops → complete circuit → current flows

V source loop broken → open circuit → current doesn't flow

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ex. A steady current of 2.5A exists in a wire for 4min

a) How much total charge passed by a given point in the circuit during that 4min?

b) How many electrons does that correspond to?

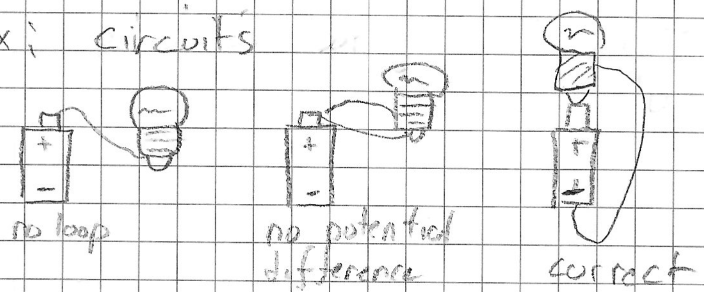
a) $2.5A = 2.5\ C/s$

$4\text{min} = 240\ s$

$\Delta Q = I\Delta t = (2.5\ C/s)(240s) = 600C$

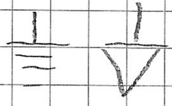
b) $\dfrac{600C}{1.6\times10^{-19}\ C/e^-} = 3.8\times10^{21}$ electrons

ex; circuits



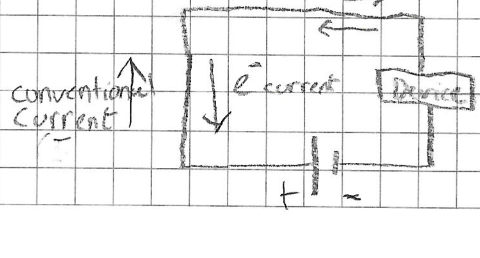
In many real circuits wires are connected to a common conductor that provides continuity

This common conductor is called the ground



In a car, "the ground" is the chassis!
(not the real ground)

Benjamin Franklin's convention



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Georg Simon Ohm (1787–1854)

↓ University of Erlangen phd → no prospects

↓ Bamberg school unhappy → prussia king → cologne fired ← Ohm's law

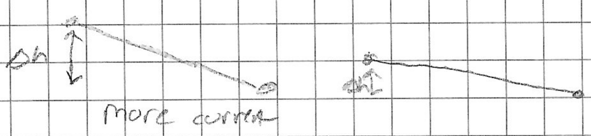
↓ Nuremberg polytechnic

↓ Munich professor

established experimentally that the current in a wire is proportional to the potential difference applied to its two ends

$$I \propto V$$

A useful analogy compares the flow of e^- with that of a river



a resistance resists to the current like a rock ridge in a river

$$I = V/R \qquad \boxed{V = IR}$$

$\underbrace{\text{R is a constant and independent of V}}_{\text{Ohm's law}}$

There are many many nonohmic elements

R in a metal depends on temperature

other materials have R depending on V

diodes, transistors etc

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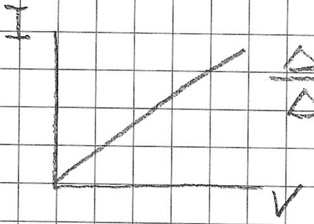
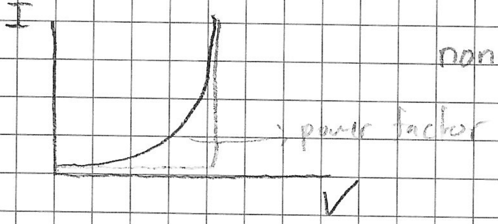
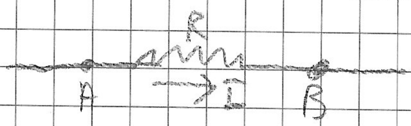
The unit of resistance is called Ohm



$\frac{\Delta I}{\Delta V} = \frac{1}{R}$ ohmic device



non-ohmic device (semiconductor diode)



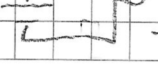
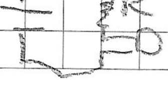
is the potential higher at point A or B
is the current higher at point A or B

in the standard convention, the current flows from + to − , from high potential to low potential so A has higher potential than B

charge is conserved. Since resistor does not get charged the net amount of charge change is zero, so the current in points A and B is the same

The potential decrease such as above is called a potential drop or voltage drop

In electronic circuits resistors are often used as current limiters

 = dead led  = long lasting led

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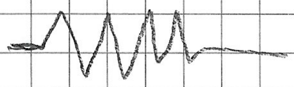
Resistance symbol 

Battery: constant V

Current passes through a load

Resistance is an intrinsic property

I is the response

Resistivity

the resistance of an ohmic load is simply

$$R = \rho \frac{l}{A}$$

length

cross section area

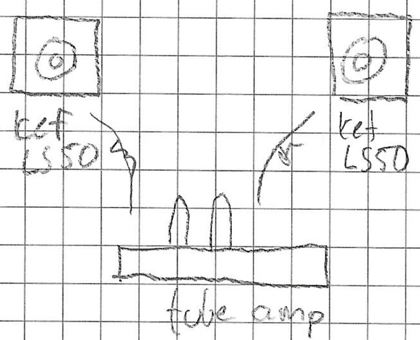
resistivity

conductor		
Silver	1.59×10^{-8}	$\Omega . m$
Copper	1.68×10^{-8}	$\Omega . m$
Gold	2.44×10^{-8}	$\Omega . m$
Semiconductor		
Silicon	$0.1 - 60$	
Insulator		
Glass	$10^{9} - 10^{12}$	
Hard rubber	$10^{13} - 10^{15}$	

Conductivity is the inverse of resistivity

$$\sigma = \frac{1}{\rho} \quad (\Omega . m)^{-1}$$

Speaker wires



if the cable will be 20m what diameter of copper wire is required to keep the resistance less than 0,10 Ω per wire

if the current to each speaker is 1.0 A what is the potential difference (voltage drop) accross each wire?

$$A = \rho \frac{L}{R} = \frac{(1.68 \times 10^{-8}\,\Omega.m)(20m)}{0.10\,\Omega} = 3.4 \times 10^{-6}\,m^2$$

$A = \pi r^2$ $\qquad r = \sqrt{\frac{A}{\pi}} = 1.04 \times 10^{-3}\,m = 1.04mm$

diameter $= 2r = 2.1\,mm$

b) $V = IR = (1.0A)(0.10\,\Omega) = 0.1\,V$

Stretching a wire

$l \to$ doubles $\quad A$ is halved $\quad$ ($V = Al$ remains const.)

$$R = \rho \frac{l \to \times 2}{A \to \frac{1}{2}}$$ $\times 4$ increase

Temperature dependence

$$\rho_T = \rho_0 \left[1 + \alpha (T - T_0)\right]$$

ρ_0 probe temperature

temperature coefficient

......./......./........

Resistance thermometer

platinium at 20.0 C 164.2 Ω

$\alpha = 3.927 \times 10^{-3} (C^{\circ})^{-1}$ in a solution 187.4 Ω

what is the temperature of the solution

$$R = R_0 \left[1 + \alpha (T - \underset{20.0\,C}{T_0}) \right]$$

$$T = T_0 + \frac{R - R_0}{\alpha R_0} = 20.0\,C + \frac{187.4\,\Omega - 164\,\Omega}{(3.927 \times 10^{-3} (C^{\circ})^{-1})(164.2\,\Omega)}$$

$$= 56.C$$

Resistive thermometers are very useful in high or low extreme temperatures

thermistors (metal → oxide or semiconductor resistance) are better (small and fast)

Be careful α also depends on temperature so. when $T - T_0$ is too large, the above formula is not valid

Electric Power

IT is relatively easy to convert electric energy into mechanical energy, thermal energy or light

the

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To find the power transformed:

$$dU = V\,dq$$

dU: energy transformed; V: potential; dq: charge

$$P = \frac{dU}{dt} = \frac{dq}{dt}V = IV$$

$$\boxed{P = IV}$$

$$P = IV = I(IR) = I^2R$$
$$P = IV = \left(\frac{V}{R}\right)V = \frac{V^2}{R}$$

only to resistors

ex. Calculate the resistance of a 40W auto headlight (12V supply)

$$R = \frac{V^2}{P} = \frac{(12V)^2}{40W} = 3.6\,\Omega$$

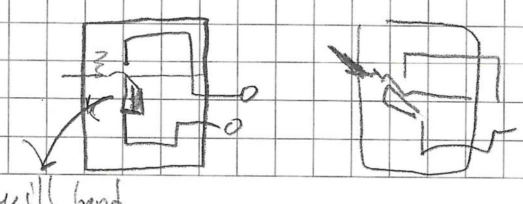
bulb is cold → resistance is lower → more current

burn out

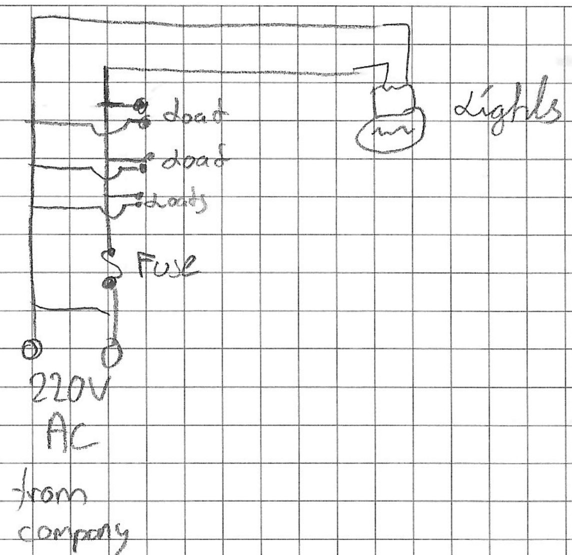
Fuses:

A wire with finite resistance will heat up at a rate equal to I^2R

A fuse is a switch that prevents too much current from the circuit, so that you don't have fire



will bend due to thermal



In household, the circuits are connected in parallel

you should choose a fuse that is compatible with the maximum your wiring can carry! otherwise, the heat buildup may cause fire!

Example: your house is wired by 3x3.5mm single core wires, so your main fuse is 32A. you use a cheap extension cord and plug in a kettle of 1000 W and a space heater of 2800 W. Since most cheap extension cords are 2x0.7 mm wires, they are rated for 11 A. what will happen?

$\frac{(2800+1000)\,W}{220\,V} \cong 17A$. The fuse will not blow

but the extension cord will start burning

This is the reason why the fuses in the house should never be exchanged with higher rated ones without changing the wiring first

Chapter 25 P6 V1

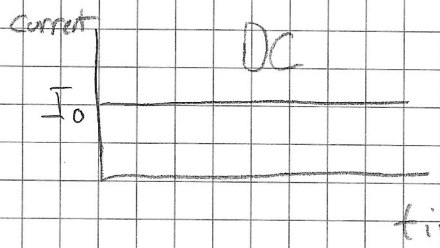
24/03/2019

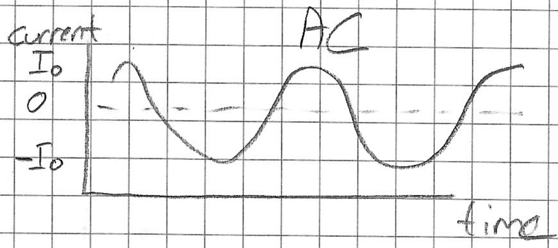
Alternating current

The war of the currents

Tesla vs Edison

AC vs DC





$V =$ constant

$V = V_0 \sin 2\pi f t = V_0 \sin \omega t$

(f:) cycles per second, TR ~50 Hz

Resistive loads

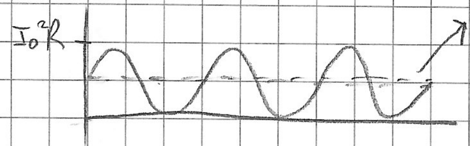
$I = \frac{V}{R} = \frac{V_0}{R} \sin \omega t = I_0 \sin \omega t$

the peak is called $I_0 = V_0/R$

since this is positive and negative, average current is 0

this does not mean the power is zero

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



$\overline{I^2} R = \frac{1}{2} I_0^2 R$

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

$\bar{P} = I_{rms} V_{rms}$ → $I_{rms} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707\, I_0$

$V_{rms} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0$

$\bar{P} = I_{rms}^2 R$

$V_{rms}^2 R$

240V AC is the rms value, the peak is

$$V_0 = \sqrt{2}\, V_{rms} = 340\,V$$

Example:

if you plug a 4000W hair dryer in US where ac is 120V, what would be it's power

$$I_{rms} = \frac{\bar{P}}{V_{rms}} = \frac{4000W}{240V} = 16.67\,A$$

the resistance is

$$R = \frac{V_{rms}}{I_{rms}} = \frac{240V}{16.67A} = 14.4\,\Omega$$

when plugged to 120V

$$\bar{P} = \frac{V^2_{rms}}{R} = \frac{(120V)^2}{(14.4\,\Omega)} = 1000W$$

Why do we use AC current

- at the time of the tesla, transformer technology was the most efficient way to up the Voltage. (High power is required to minimize losses in transmission)
- Westinghouse was producing really good AC generators and DAMS were all the rage
- Most applications were AC (lamps etc)

Now: It is also effortless to upconvert DC
Most applications are DC (phone batteries, LED lights, ..)
renewables store electricity in batteries (DC)
- we loose a lot of energy converting AC to DC

Microscopic views of Electric current

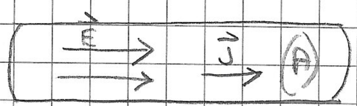
since the electrons are moving (not static), there must be an $\vec{E}$ inside the conductor!

Let's define a microscopic quantity current density

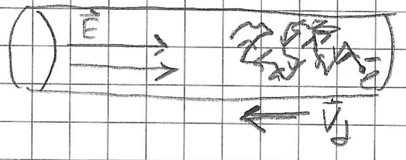
$$J = \frac{I}{A}\qquad I = J \cdot A \longrightarrow I = \int \vec{J} \cdot d\vec{A}$$

current

cross section area

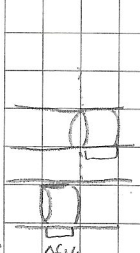


$\vec{J}$ is in the direction of the conventional current, so $\bar{e}$ flow is in the opposite direction of $\vec{J}$ (like $\bar{e}$ moves in opposite direction of $\vec{E}$)



electrons in the conductor experience a very bumpy voyage: they constantly get scattered by collisions. The average speed they can travel is much less than their instanteneay velocity. This average velocity is called the "drift velocity" $\vec{V_d}$

connection between current and drift velocity



$l = V_d \Delta t$ (the average distance travelled by $\bar{e}$)

$V = Al = A V_d \Delta t$ (the Volume of $\bar{e}$ that will pass through cross section A)

$\Delta Q = n V(-e) = -(n A V_d \Delta t)(e)$

number of $\bar{e}$

....../....../.......

$$I = \frac{\Delta Q}{\Delta t} = -ne\,A v_d$$

$$J = I/A = -ne\,v_d \rightarrow \vec{J} = -ne\,\vec{v_d}$$

generalising:

$$\vec{J} = \sum_i n_i q_i \vec{v}_{di}$$

i can be ions or $\bar{e}$

ex $\bar{e}$ speed in a wire!

copper wire of 3.2 mm diameter / 5.0 A current

a) current density?

b) the drift velocity?

c) rms speed of $\bar{e}$ assuming a gas at 20.0 C°

assume 1 $\bar{e}$ per Cu
atomic weight 63.5u (63
$\rho_d = 8.9 \times 10^3$ kg/m3

a) $r = \frac{1}{2}(3.2\text{ mm}) = 1.6 \times 10^{-3}$ m $\quad J = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{5.0\text{A}}{\pi(1.6 \times 10^{-3}\text{m})}$

$= 6.2 \times 10^5$ A/m2

b) number of electrons per unit volume $= \frac{6.02 \times 10^{23}\text{ electrons}}{63.5 \times 10^{-3}\text{kg}}\ 8.9 \times 10^3$ kg/m3

$= 8.4 \times 10^{28}$ electrons/m3

$$V_d = \frac{J}{ne} = \frac{6.2 \times 10^5\text{ A/m}^2}{(8.4 \times 10^{28}\text{ m}^{-3})(1.6 \times 10^{-19}\text{ C})} = 4.6 \times 10^{-5}\text{ m/s} \simeq 0.05\text{ mm/s}$$

c)

$$\frac{1}{2} m_e v_{rms}^2 = \frac{3}{2} kT \rightarrow v_{rms} = \sqrt{\frac{3kT}{m_e}} = 1.2 \times 10^5\text{ m/s}$$

(quantum estimate 1.6×10^6 m/s)

1 meter travel will take 5 ½ h to travel

internet → speed of light → correlation of electrons

Electric field inside a wire

$$R = \rho \frac{l}{A}$$

uniform E-field

$$I = JA \qquad V = El$$

cross section

potential diff.

$$El = (JA)\left(\rho \frac{l}{A}\right) = J\rho l$$

generalising:

$$\vec{J} = \frac{1}{\rho}\vec{E} = \sigma \vec{E}$$

resistivity

conductivity

in the previous example

$$J = 6.2 \times 10^5 \ A/m^2$$

$$E = \rho J = 1.0 \times 10^{-2} \ V/m$$

so, a modest $\vec{E}$-field gives a large current!

....../....../.......