Electrical Resistance

1) IV Devices

An IV device is one where

$$I = I(V)$$

↑ I: current through

↑ V: ~~Vol~~ potential drop across.

Thus I is a function of V and often the function can be inverted to give $V = V(I)$

(i.e., V is a function of I

Recall power ~~transferred~~ in many devices is

$$P = I V$$

- I: current through
- V: ~~volt~~ Potential change across

∴ For an IV device

$$P = I(V)\,V$$

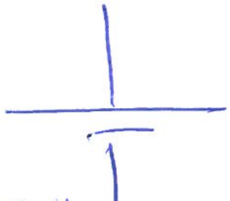
or

$$P = I\,V(I)$$

2) Non-IV device

~~H~~Here we just give 3 important examples.

a) Ideal Battery

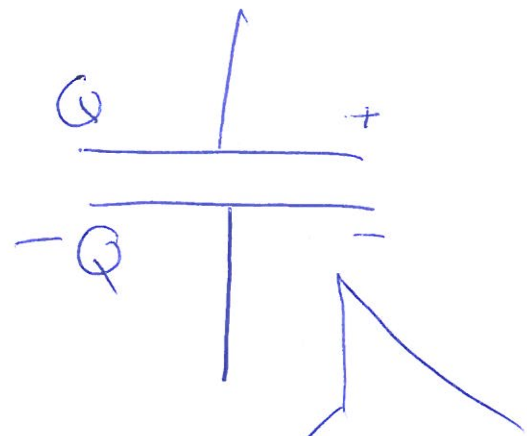


Battery symbol

$V_{Battery}$ = Constant no matter what current flows through.

4) <u>Capacitor</u>

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



Potential drop across

Capacitor symbol

Q is the capacitor charge (i.e., the charge on the positive <u>plate</u>)

There is −Q on the negative plate in ordinary operation.

C is the capacitance which *ideally* depends only on geometry of plates and the dielectric in which the capacitor is embedded.

— capacitor potential depends on *charge on* not *current through*.

c) *Inductor*

symbol

$$V = L \frac{dI}{dt}$$

V — ~~potential~~ drop across ~~per~~ ~~probably~~

L — inductance which ideally only depends on geometry of inductor an magnetic material inside the coil

$\frac{dI}{dt}$ — $\lim_{\Delta t \to 0} \frac{\Delta I}{\Delta t}$

time derivative of current.

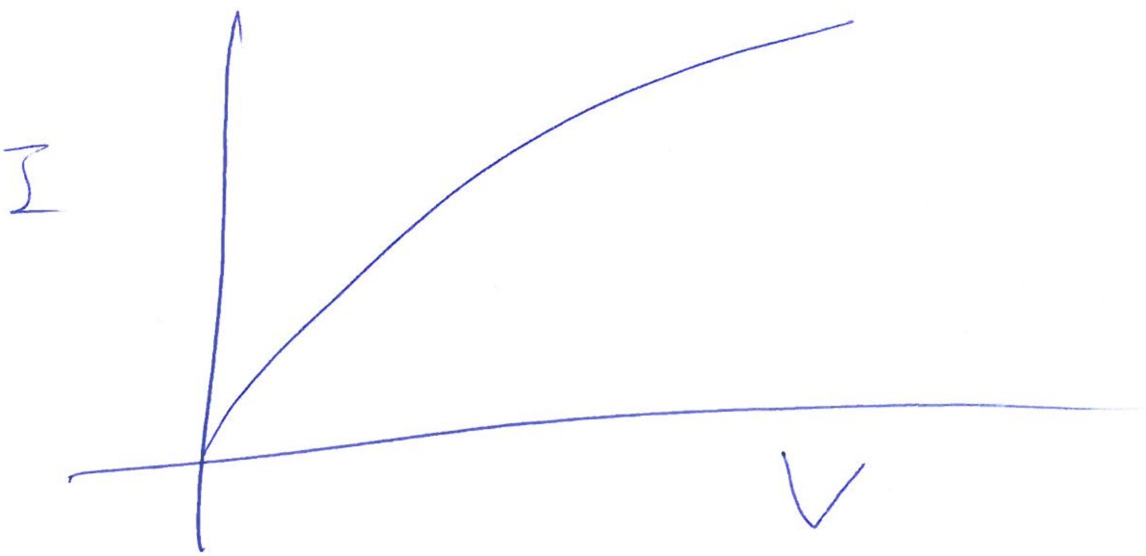
— rate of change of current with time.

So ~~Potential~~ change across depends on derivative of current, <u>not</u> current,

3) I V curves

(AKA current-Voltage characteristic)

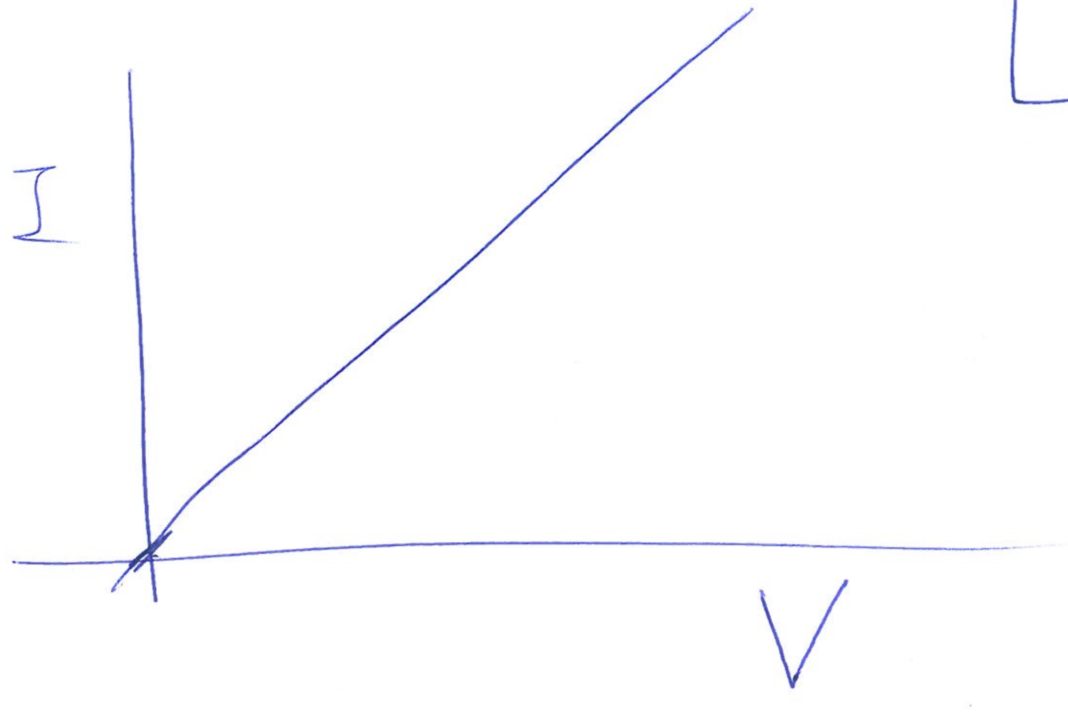
For I V devices, one can plot I V curves



~~a light bul~~

— an incandescent light bulb ~~migh~~ can have curve something like this.

symbol



— a resistor has an IV like this.


symbol

4) Resistance

— Resistance can be defined for IV devices

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$$R = \frac{V}{I} = \frac{V}{I(V)}$$

unit of R $= \frac{\text{Volt}}{\text{Ampere}}$

$= \frac{V}{C/s}$

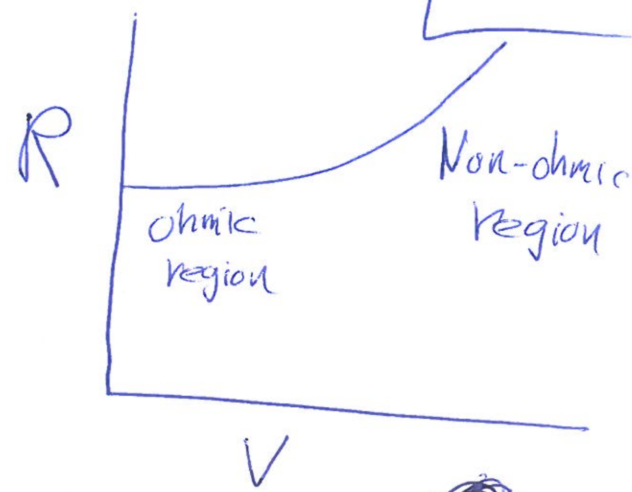
$= \frac{J \cdot s}{C^2}$

$= \Omega$, the ohm

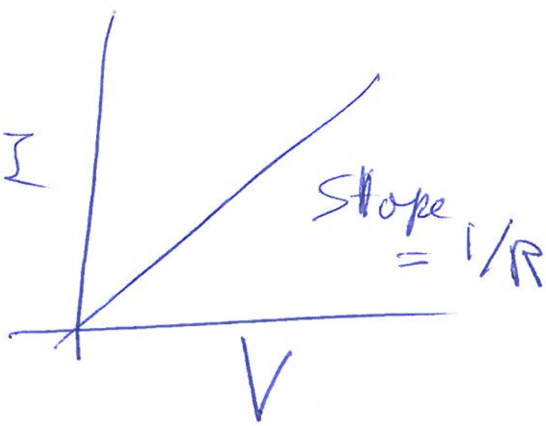
It has its own name and symbol

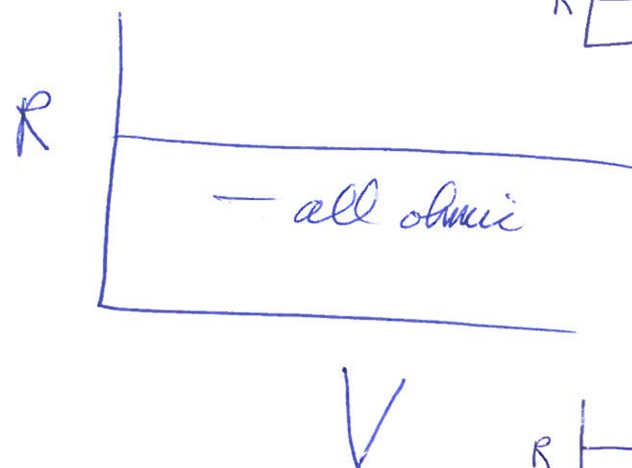
If

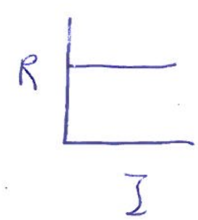
then



If







Ohmic devices have constant R.

– a resistor is an ohmic device

– a light bulb is NOT.

But the distinction is NOT hard in reality

- non-ohmic device are often ohmic over some range ~~usully~~ usually at very low ~~vol~~ potential
- ohmic devices will behave non-ohmically at high enough potential.

5) Resistances in Series & Parallel

- Note resistances, and

So these results are NOT just for resistors or other ohmic devices.

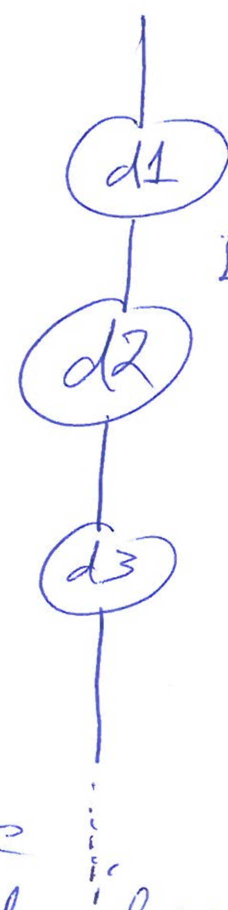
They apply to all IV devices.

Series

$$V = \sum_i V_i$$

↑ drop across all

↑ drop across device I



IV devices in series

The current I is the same through all by Kirchhoff's current law.

$$\therefore \; IR = \sum_i I R_i$$

and so

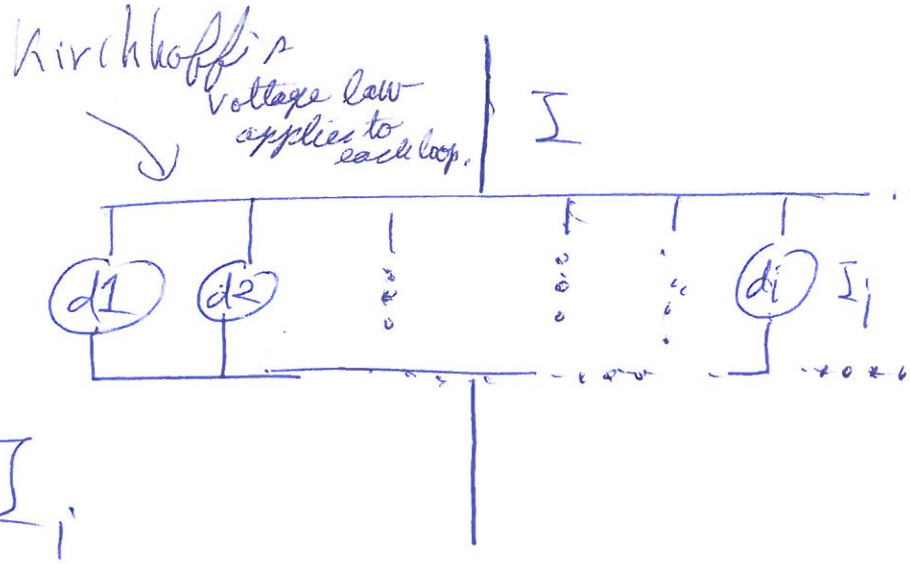
$$R = \sum R_i$$

resistance across net device

resistance of individual devices

If N identical ~~resists~~ resistors $R = NR_i$

Parallel



$$I = \sum_i I_i$$

current through net device

current through device i

Potential drop V is the same across all devices by Kirchhoff's ~~v~~ Voltage law applied to each loop of the ~~device~~ array.

$$\therefore \frac{I}{V} = \sum_i \frac{I_i}{V}$$

$$\frac{1}{R} = \sum_i \frac{1}{R_i}$$

Note $\frac{1}{R} \geq \max\left(\frac{1}{R_i}\right)$

$$\therefore R \leq \text{Min}(R_i)$$

Case of only 2 resistors

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R = \frac{1}{1/R_1 + 1/R_2} = \frac{R_1 R_2}{R_1 + R_2}$$

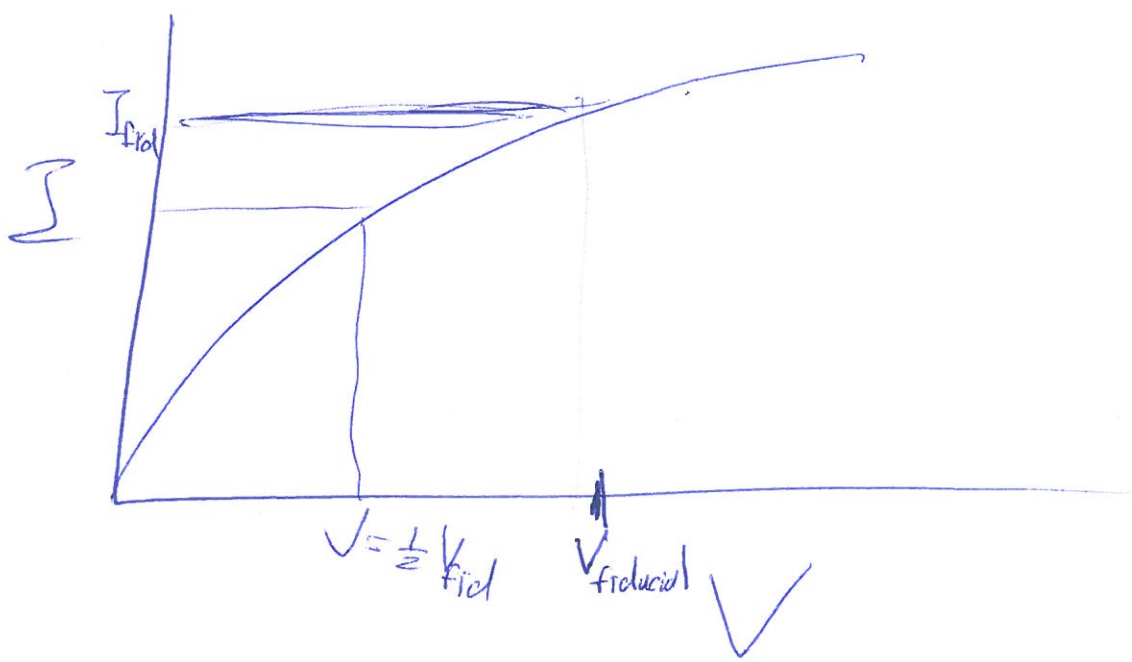
Case of N identical resistors

$$\frac{1}{R} = \sum \frac{1}{R_i} = \frac{N}{R_i}$$

or $R = \frac{R_i}{N}$

6) Current through a light bulb like I V device

Say



$$I_{fiducial} = I(V_{fiducial})$$

Examples

$$V = \frac{1}{2} V_{fid}, \quad I > \frac{1}{2} I_{fid}$$

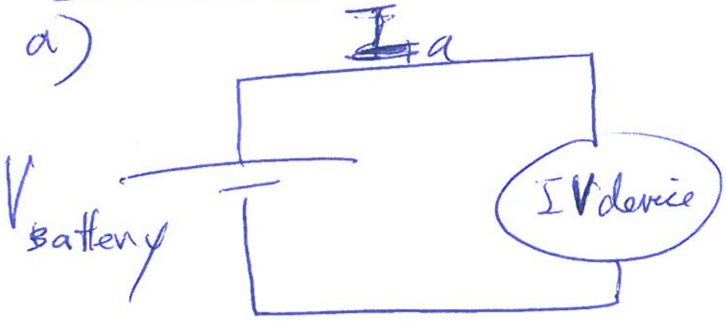
$$V = \frac{2}{3} V_{fid}, \quad I > \frac{2}{3} I_{fid}$$

$$V = \frac{1}{n} V_{fid}, \quad I > \frac{1}{n} I_{fid}$$

$V = n V_{fid}$, $I < n I_{fid}$

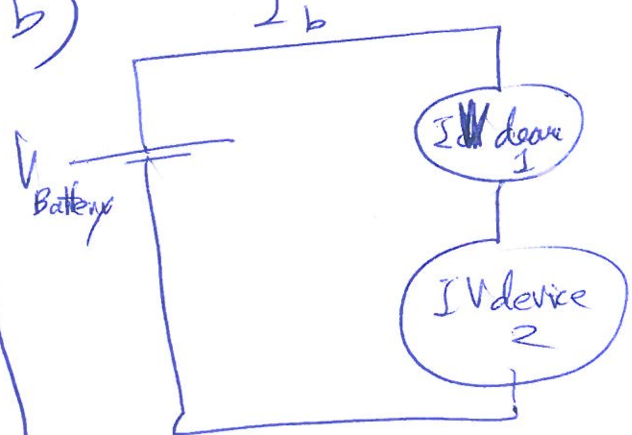
Question

a)



$V_{device} = ?$

b)



The devices are identical

$V_{device 1} = ?$

~~$I_{device 1}$~~

$I_b = x I_a$

What is x?

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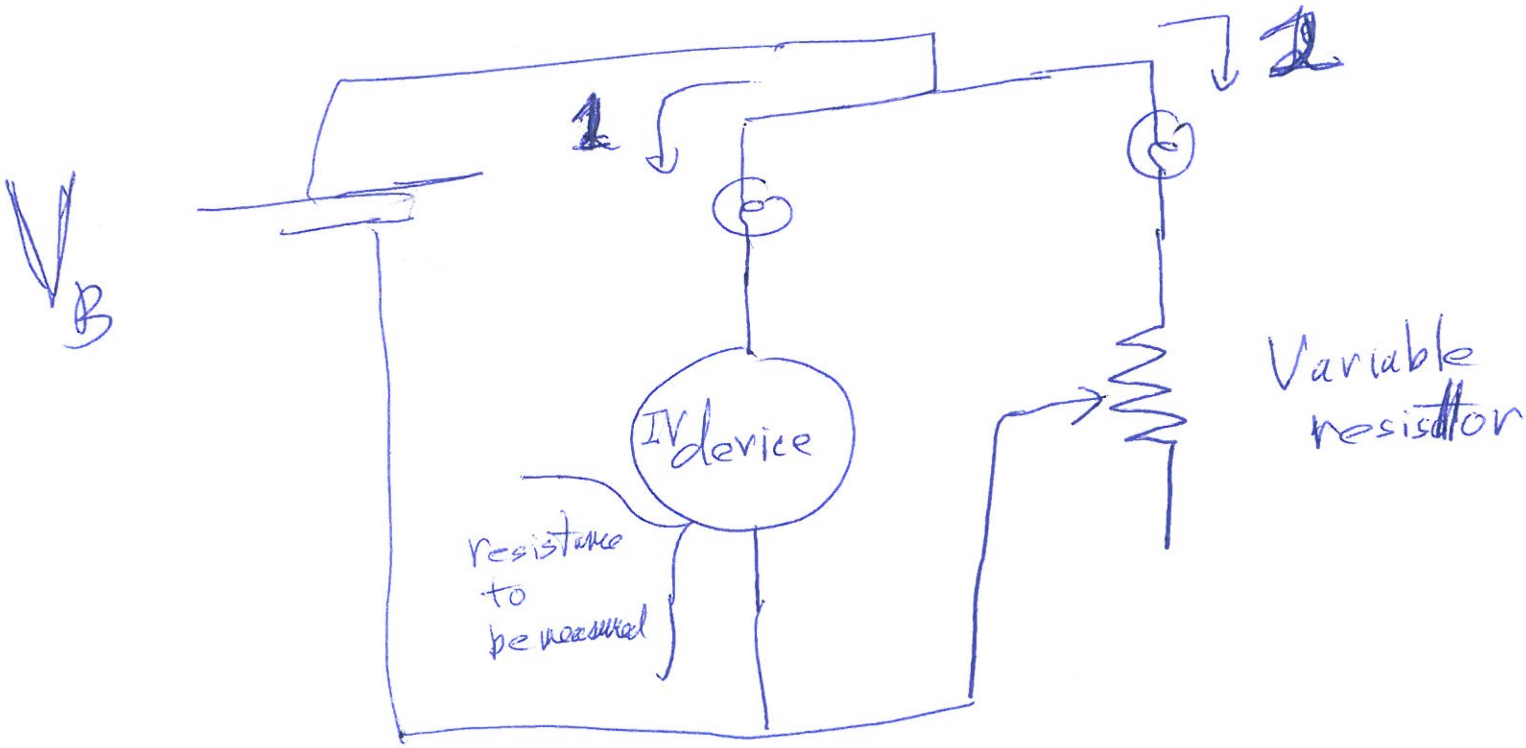
7) Nichrome Wire Resistance Measurement

Nichrome alloy of nickel and chromium
— typically 80% Ni
20% Cr
by mass

setup



— the two bulbs are identical.

— The variable ~~[illegible]~~ resistor is a length of NiCr wire with a contact ~~one~~ that slides along the wire

→ the length of wire is proportional to the resistance.

When brightness of bulbs are equal

$$R_{device} = R_{wire}$$

Proof

Given $B_1 = B_2$

~~power~~ B = brightness

$= B(P)$

$\therefore \quad P_1 = P_2$ power in bulbs

$I_1 V_1 = I_1 V_1$

$I(V_1) V_1 = I(V_1) V_1$

$\therefore \quad I_1 = I_2$

$\therefore \quad V_2 = V_2$

Also from Kirchhoff's voltage law

$V_B = V_1 + V_{device}$

$V_B = V_2 + V_{wire}$

When equal brightness $V_1 = V_2$

and therefore $V_{device} = V_{wire}$

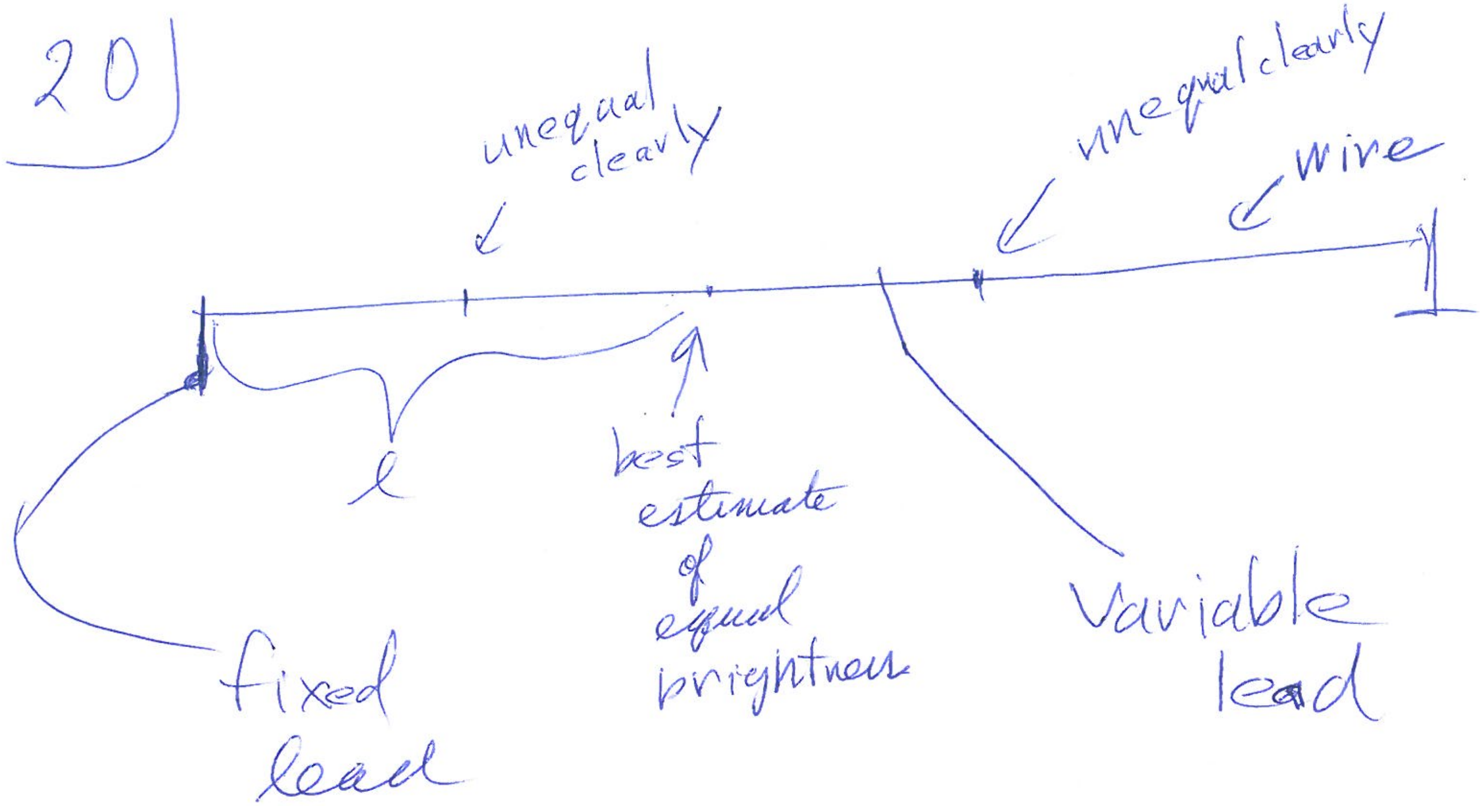
Now $R_{device} = \frac{V_{device}}{I_1} = \frac{V_{wire}}{I_2} = R_{wire}$

$\therefore R_{device} = R_{wire}$

Judging Equal Brightness

is hard

- slide the contact on the wire between locations of clearly unequal brightness and take difference



$$R_{wire} = l * R$$

(R: resistance per unit length.)

8) Practicalities of Lab

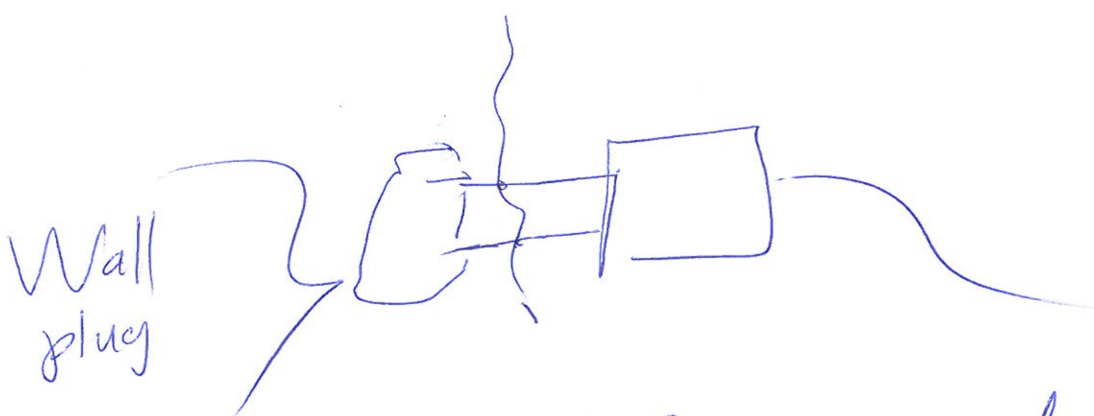
a) Dim overhead lights so that judging brightness is better.

b) Do **NOT** alligator clip the wire.

It can snap.

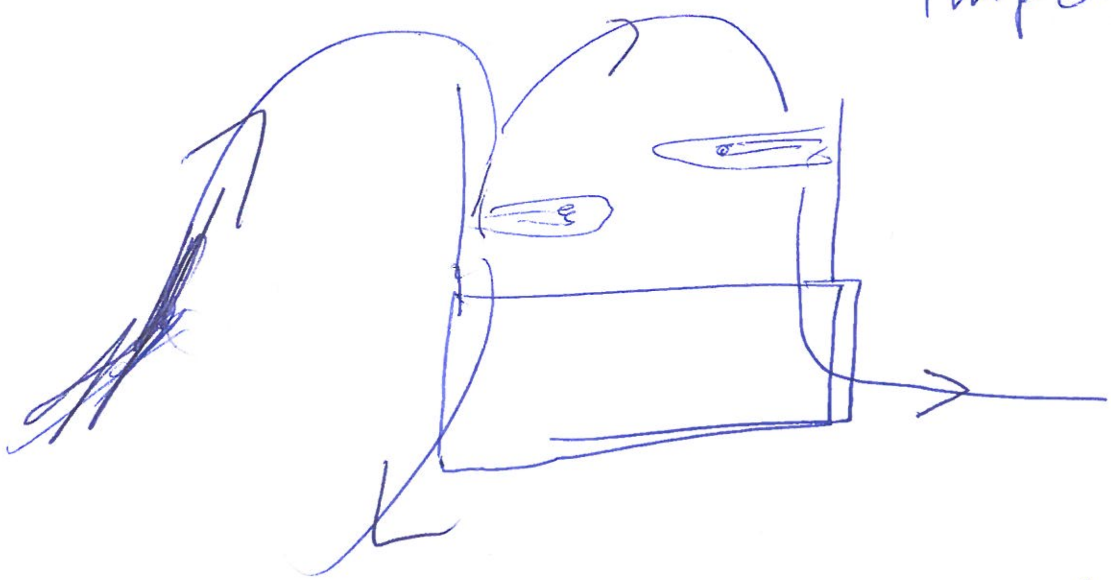
Just touch with the variable lead.

c) Don't let a dangling NiCr wire contact plug prongs



— a large and slightly dangerous current can flow.
between prongs

d) Use <u>bulb holders</u> for parallel bulbs (if they arn't impossible)



e) <u>Constructed Circuits</u> often do not look much like schematic diagrams.

wires curling all over, etc.

You should try to make your circuit

look as transparent
as reasonably
possible.

In any case make the
right connections

"The battery's connected to the node
The node's connected to the bulbs
The bulb 1 is connected
to the device

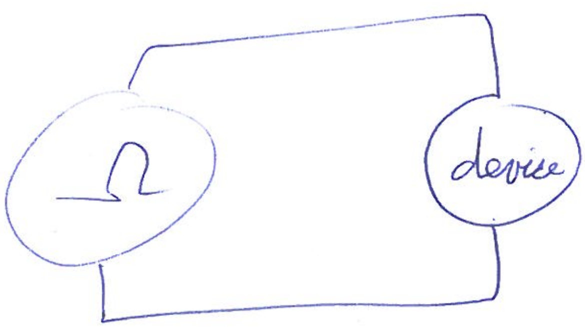
The bulb2 is connected to
the wire

The ....

and that's how the
circuit is made."

9) Ohmmeters

Our Ohmmeters (a function of the multimeter) read resistance for a device **NOT** in circuit.



The ohmmeter itself sets a circuit and passes a fixed small current I through the device and reads the potential drop across the device.

$$R_{\text{ohmmeter}} = \frac{V}{I_{\text{fixed}}}$$

The ohmmeter assumes I_{fixed}.

If another current I_{other} is running through the device, then V does NOT correspond to I_{fixed} but ~~that~~ to $I_{fixed} + I_{other}$

$$R_{ohmmeter} = \frac{V}{I_{fixed}} \neq \frac{V}{I_{fixed} + I_{other}} = R_{actual}.$$

So the ohmmeter gives the wrong Resistance in this case.

26)

Ohmmeters only read
small current, small
potential drop
resistance R_{small}.

If the device is Ohmic

$R_{actual} = R_{small}$ for
all
cases
(where the
device
behaves
ohmically)

If the device is
non-ohmic,

$R_{actual} \equiv R_{small}$ only for I_{fixed}

and

$R_{actual} \neq R_{small}$ usually and
usually for $I \gg I_{fixed}$.