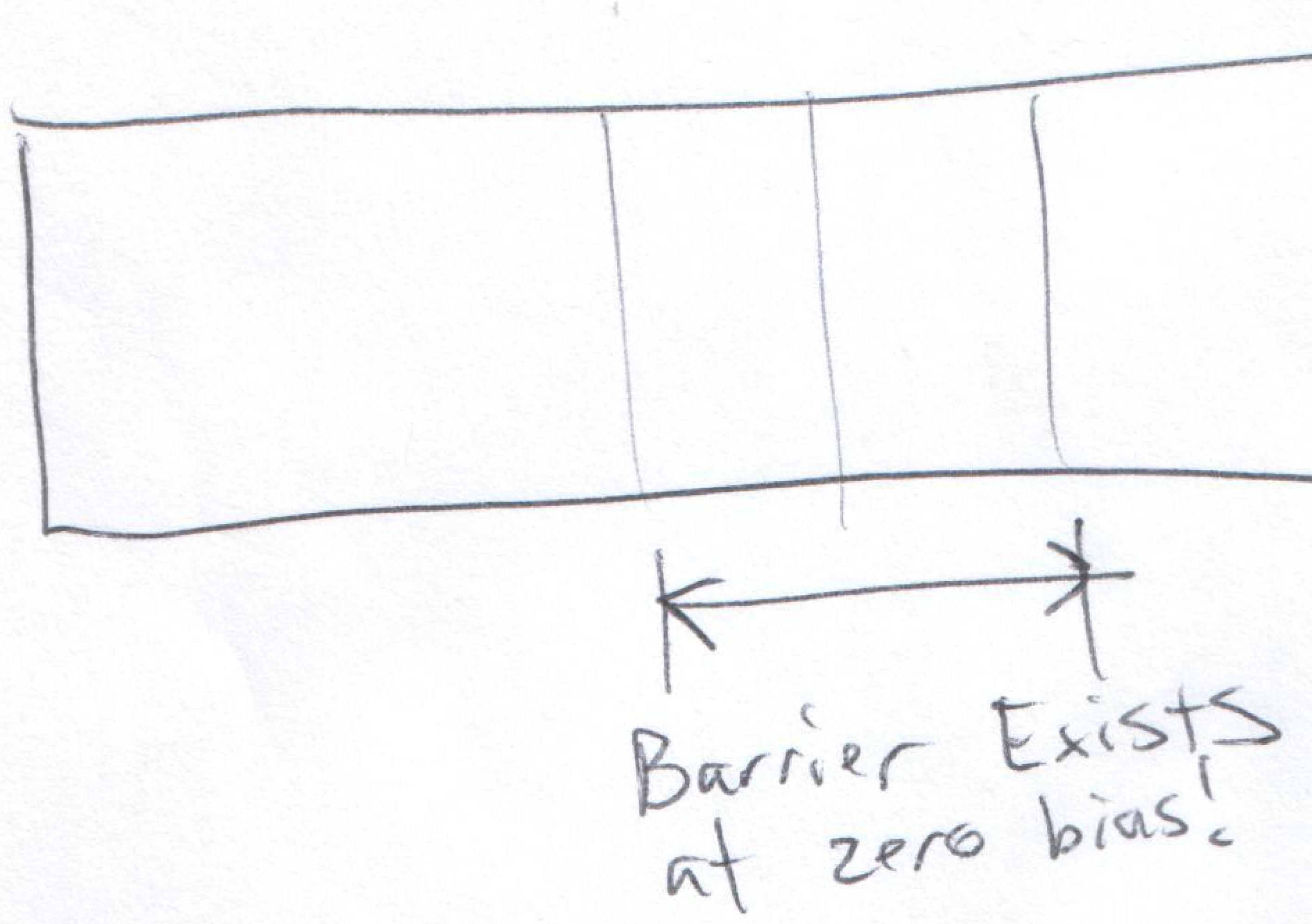
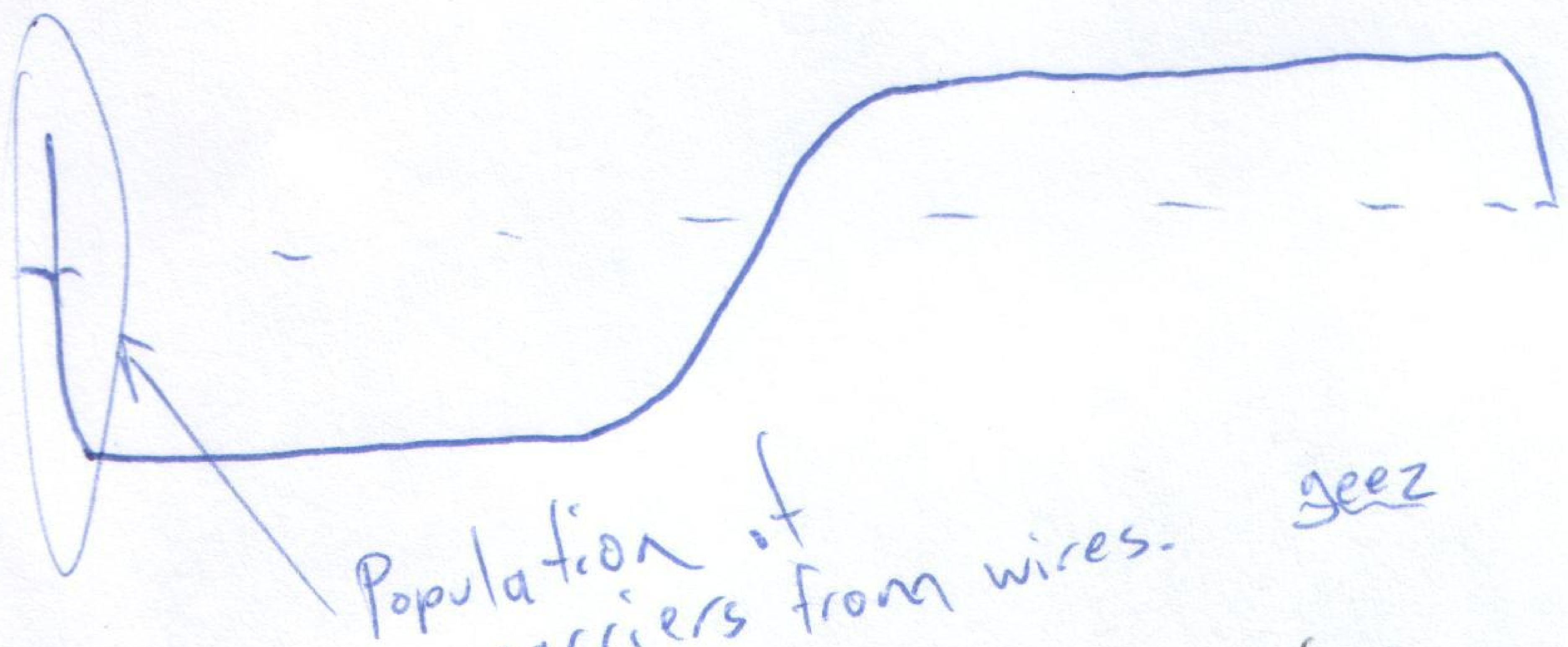
Loose Ends:





In answer to the bloody awful maths at the end of 3.1.1: $E_{MAX} = \frac{qN_AX_p}{\varepsilon}$ or $\frac{-qN_DX_n}{\varepsilon}$ ← area of a rectangle

$$\phi_j = -\int E = \frac{|E_{MAX}|(X_p + X_n)}{2}$$ ← area of a triangle

or: $\frac{E_{max}X_p}{2} + \frac{E_{max}X_n}{2}$] nice because:

$$\phi = \frac{qN_AX_p^2}{2\varepsilon} + \frac{qN_DX_n^2}{2\varepsilon}$$

$$\phi = \frac{q}{2\varepsilon}\left(N_AX_p^2 + N_DX_n^2\right)$$ →

$$Ax^2 + By^2 \overset{?}{=} (x+y)^2\frac{AB}{A+B}$$

*True for $A \neq B$, $Ax^2 = By^2$

$$\phi = \frac{q}{2\varepsilon} \cdot W^2 \frac{N_AN_D}{N_A + N_D}$$ → solve for W → $$W = \sqrt{\phi \frac{2\varepsilon}{q} \frac{N_A + N_D}{N_A \cdot N_D}}$$

$$= V_T \ln\left(\frac{N_AN_D}{n_i^2}\right)$$ ← STILL WEIRD

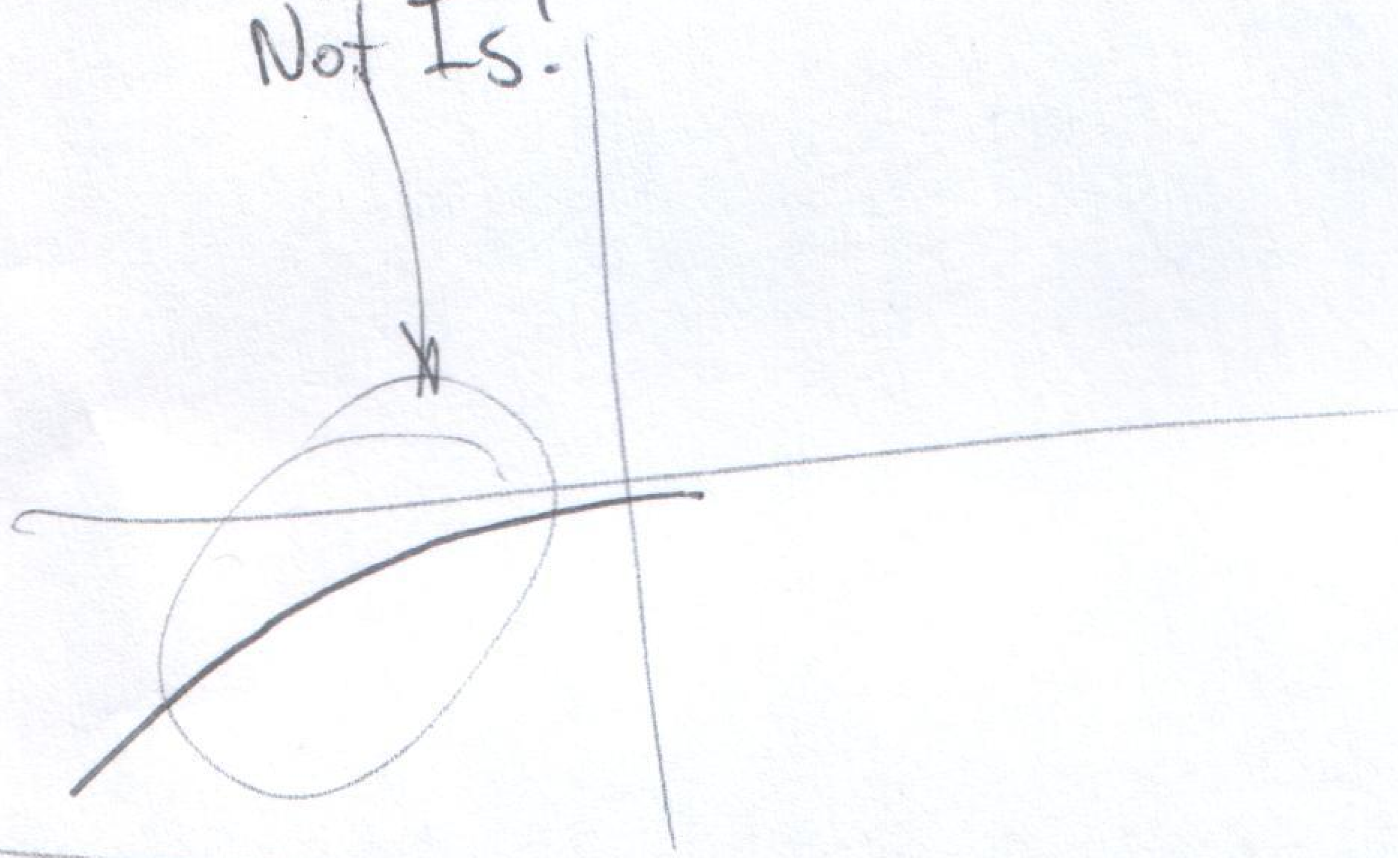
Actually Computing the IV Curve:

$$N_c \cdot q \cdot \mu \cdot E - \mu V_T \cdot \frac{dN_c}{dx} = j$$

$$E = \frac{dV}{dx}$$

Solutions to this relationship are mostly terrible, so, <u>SHORTHAND:</u>

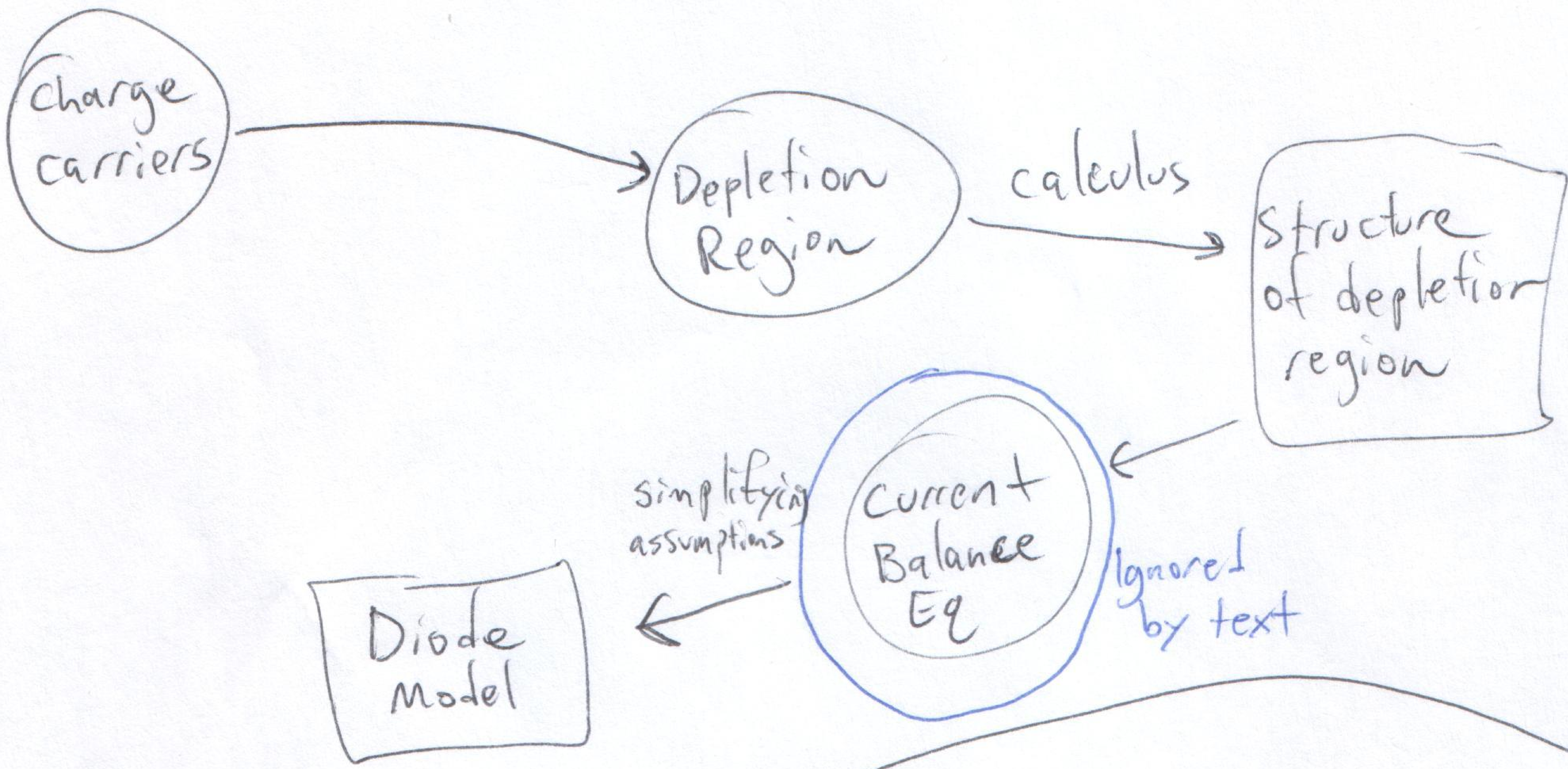
If the ~~field~~ Dep. region exists, current must flow accross it. as V-applied ~~increases~~ goes more negative, ~~so does~~ the effective R gets larger by sqrt(V).



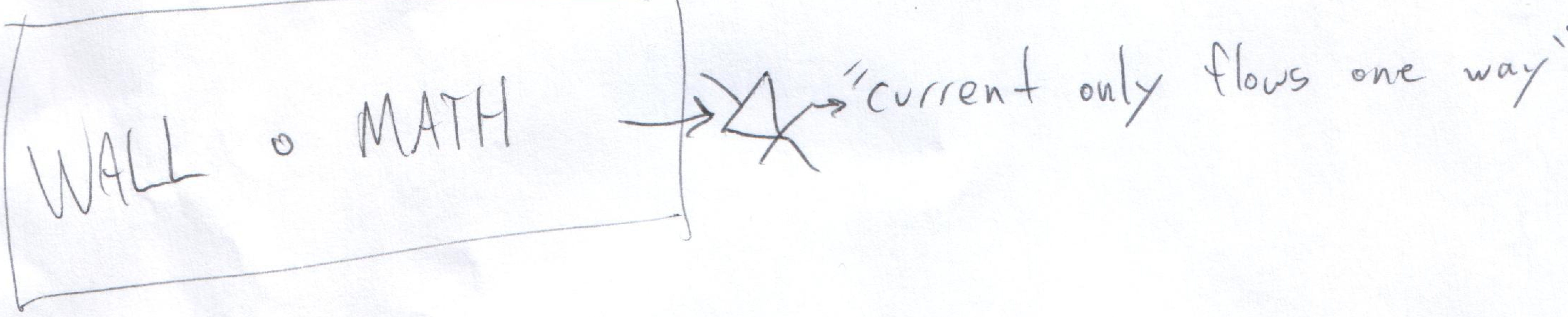
OR: Diffusion and Drift are now actually pointing in the same direction and increasing the field increases both. It is this approach that gives the exp. relationship.

Note: none of this directly gives you exactly the model $I = I_s e^{V/V_T}$.

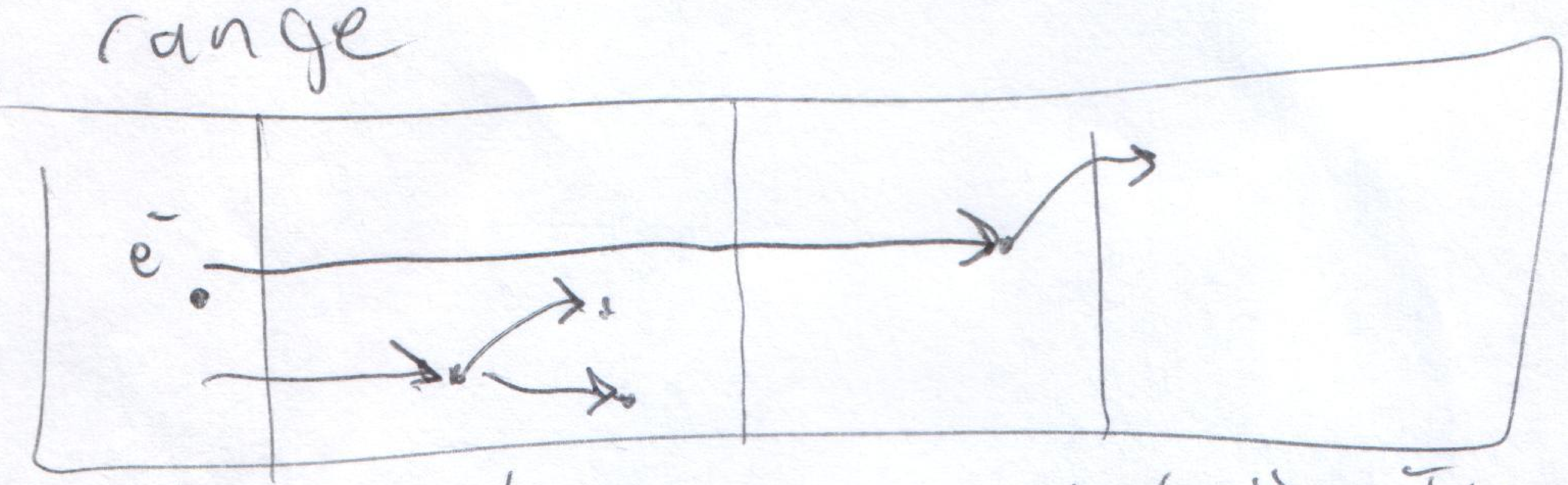
Structure of Diode Theory:



From here out, Device Physics and Circuit Theory will have a somewhat rocky relationship. We will solve circuits by stretching math over physics, often in a pretty sloppy way:

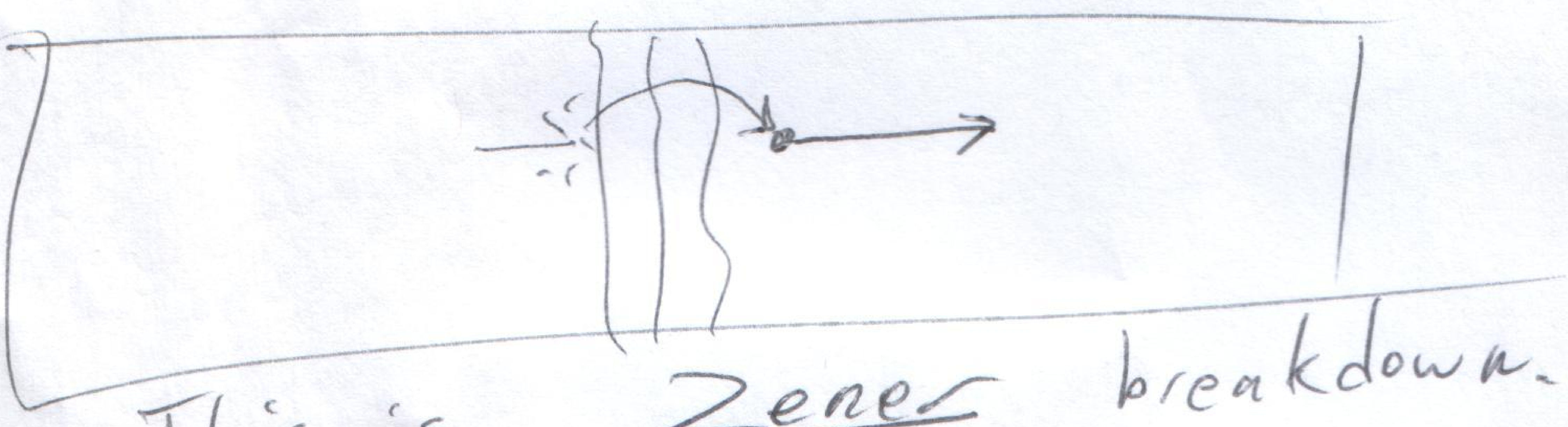


In extreme R.V. cases, the inside of the diode junction turns into a kind of electron firing range

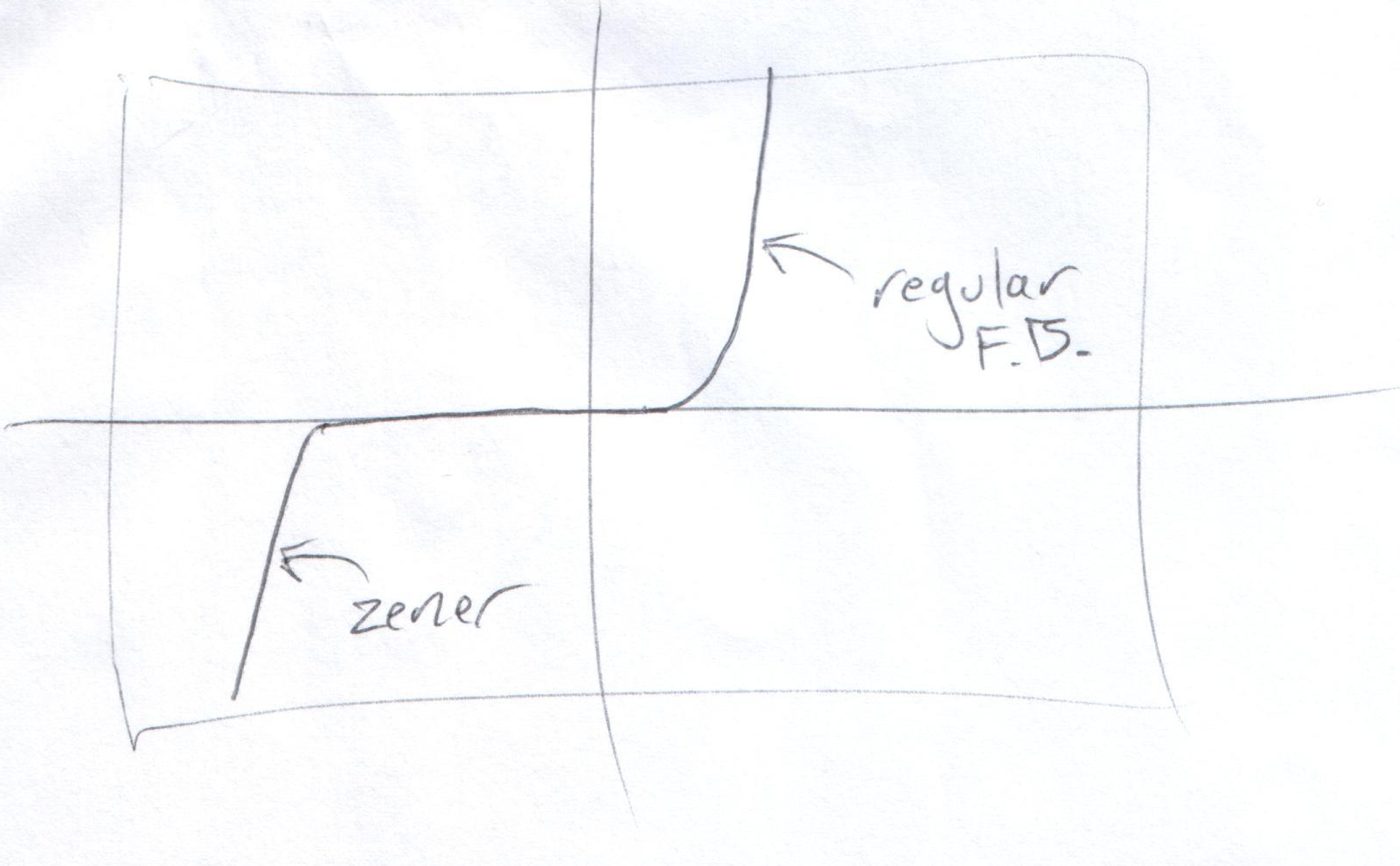


essentially "making its own holes". This is Avalanche breakdown.

Breakdown can also occur because electrons are CRAZY. Heavily-Doped diodes will have very small junction regions which means electrons are not particularly obligated to not just TELEPORT ACCROSS.



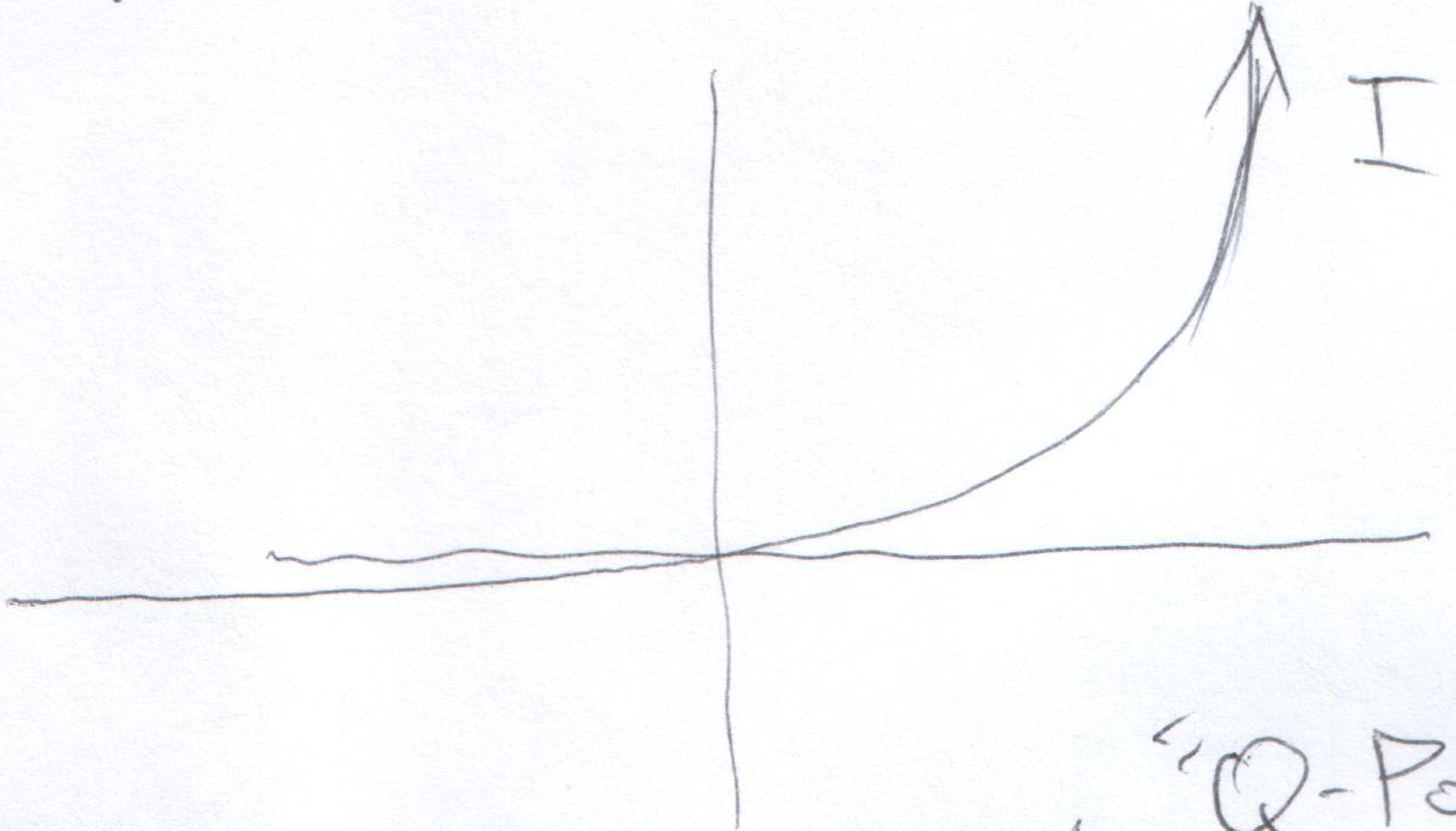
This is Zener breakdown.



Diodes in Circuits

$I = f(V)$ ← note, assumes transient behavior is <u>instantaneous</u>.

Models with no reversebias beakdown:

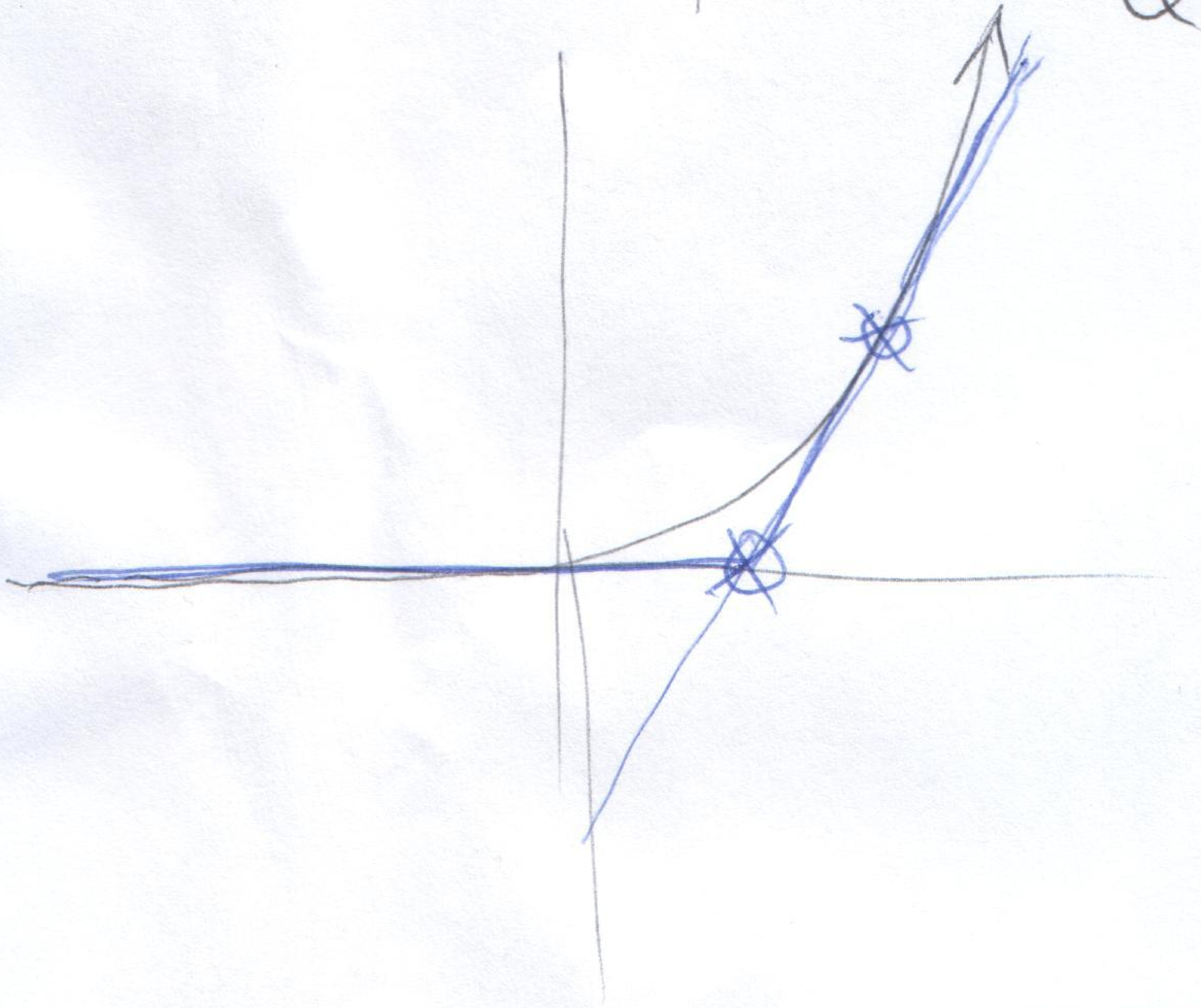


$I = I_s\left(e^{V/V_T} - 1\right)$

* pure passive
* accurate in f.b.
* quite real

(but, transcendental!)

$I = I_s e^{V/V_T}$ — mostly accurate! not -quite- true passive but algebraicly <u>way</u> easier without much error.



"Q-Point" -linearization

~~Thevanin~~

- Derive from above model with:

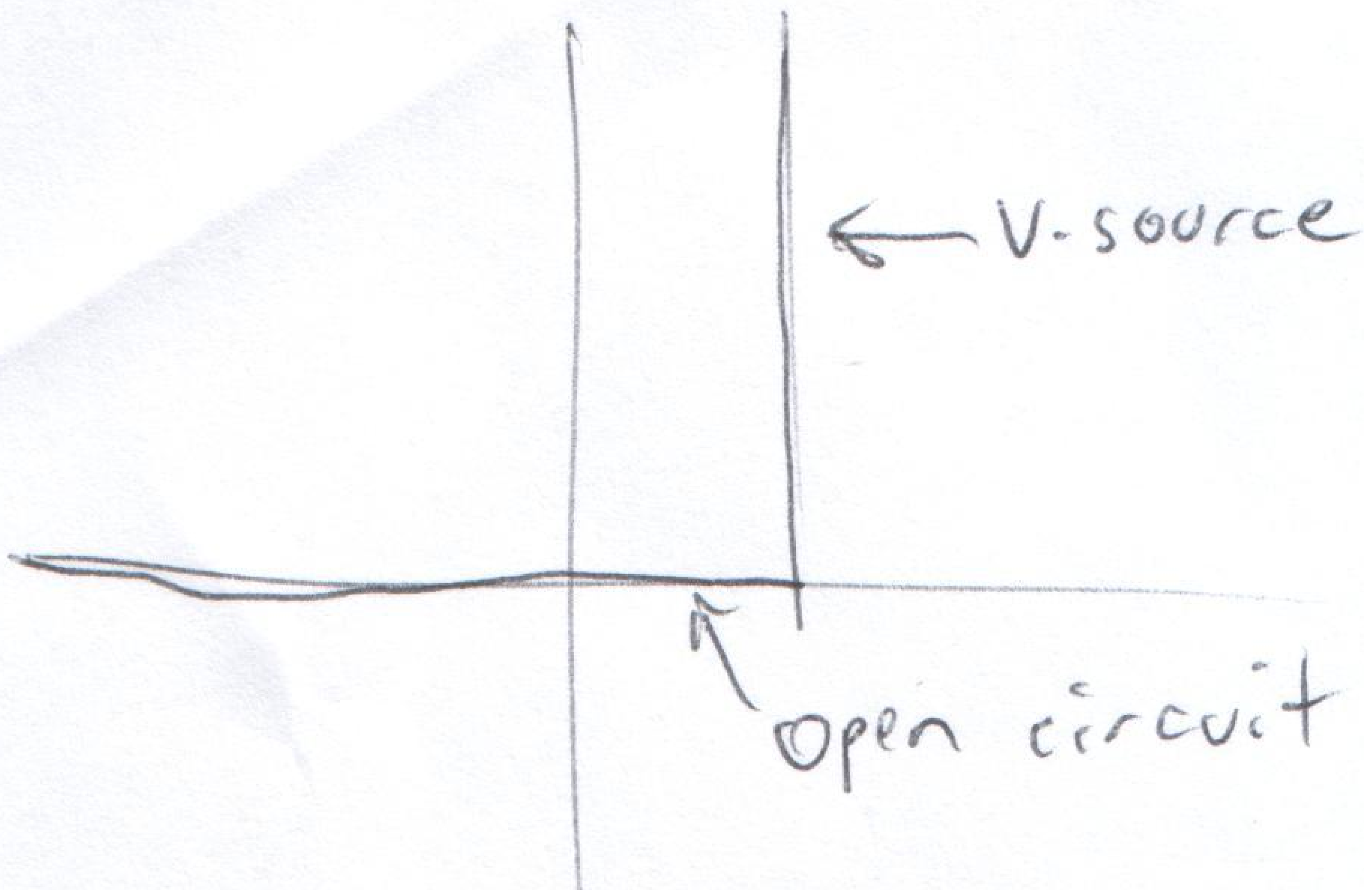
$R_m = \left(\frac{\partial}{\partial V}\left(I_s e^{V/V_T}\right)\right)\Big|_{QPOINT} =$

$V_m = $ X-intercept

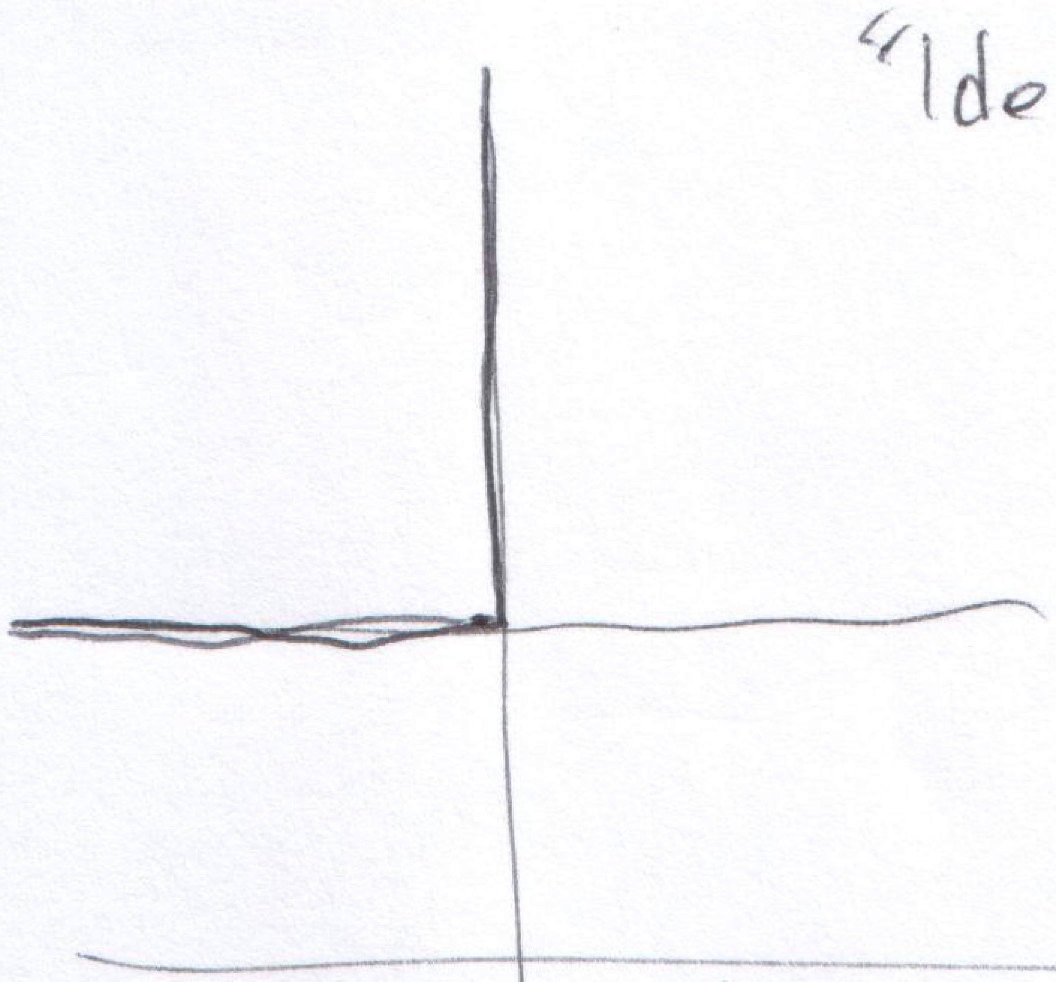
$R_m = V_T / I_{QPt}$ $\quad V_m = V_{QPt} - V_T$ (duuude)

* $V < (V_{QPt} - V_T)$, $I = 0$

Turn-on Voltage:



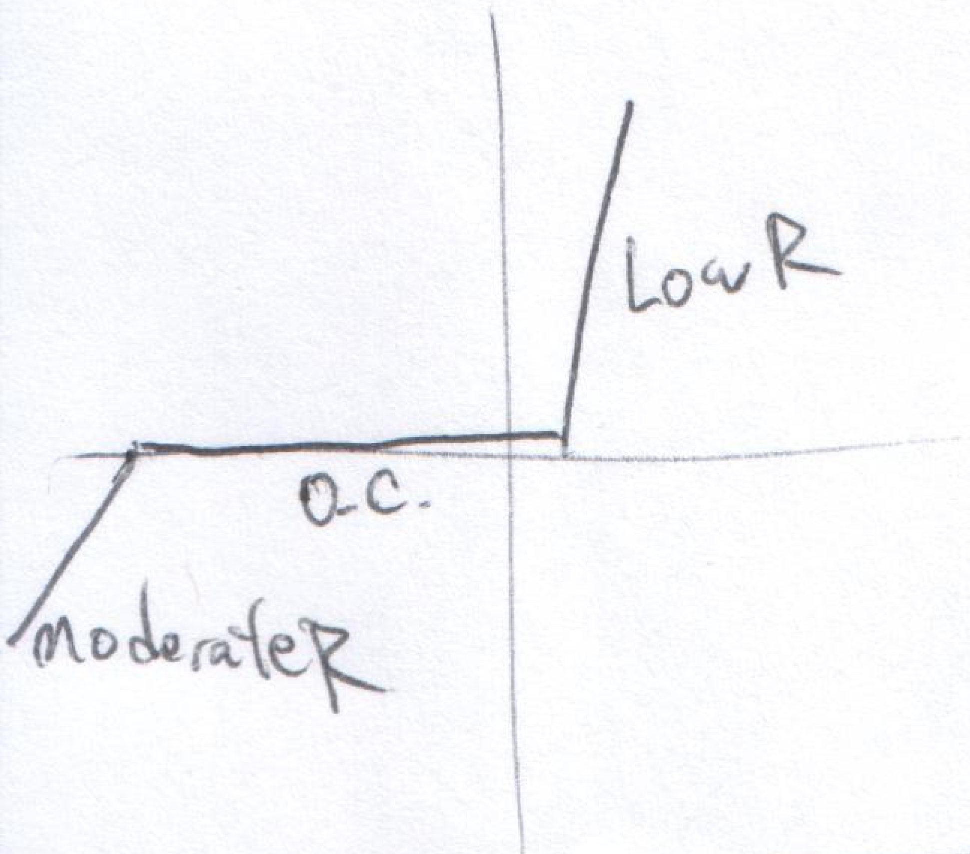
V = eh, pick something.



"Ideal Diode"

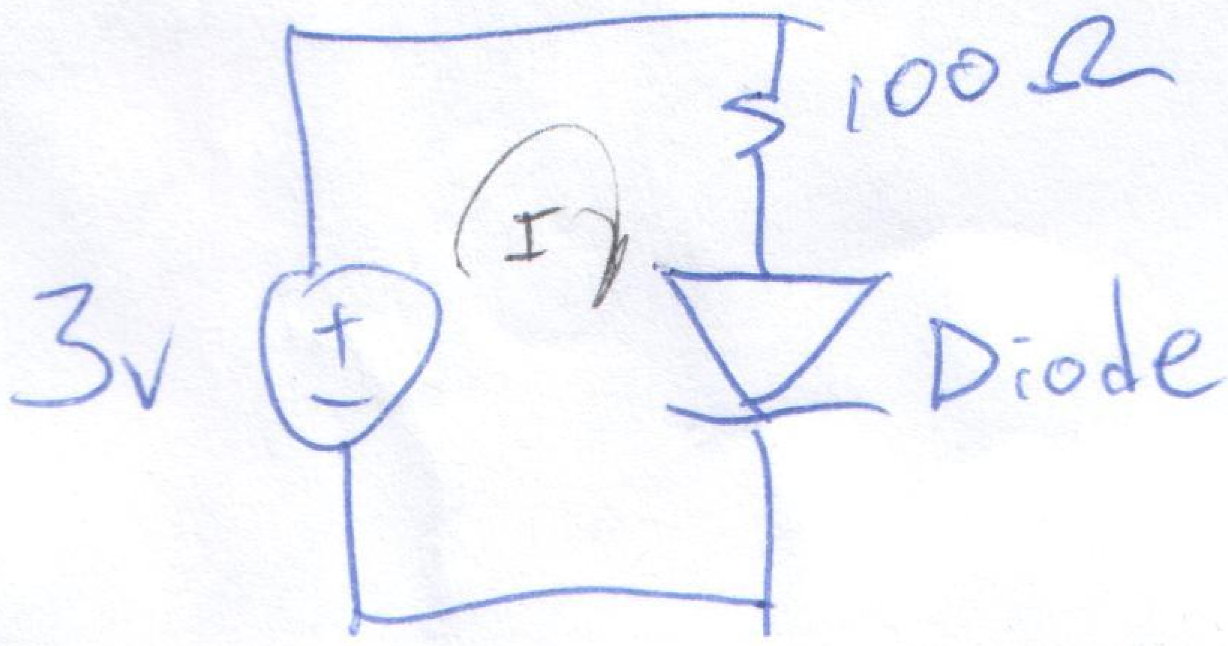
- best as a mental model or if voltages are $\gg V_{BI}$
- get used to circuits like this being "quick mental first cut"

Reverse Breakdown:



PWL ← commonly used in cheap regulators, etc

Enough models! Time for circuits:



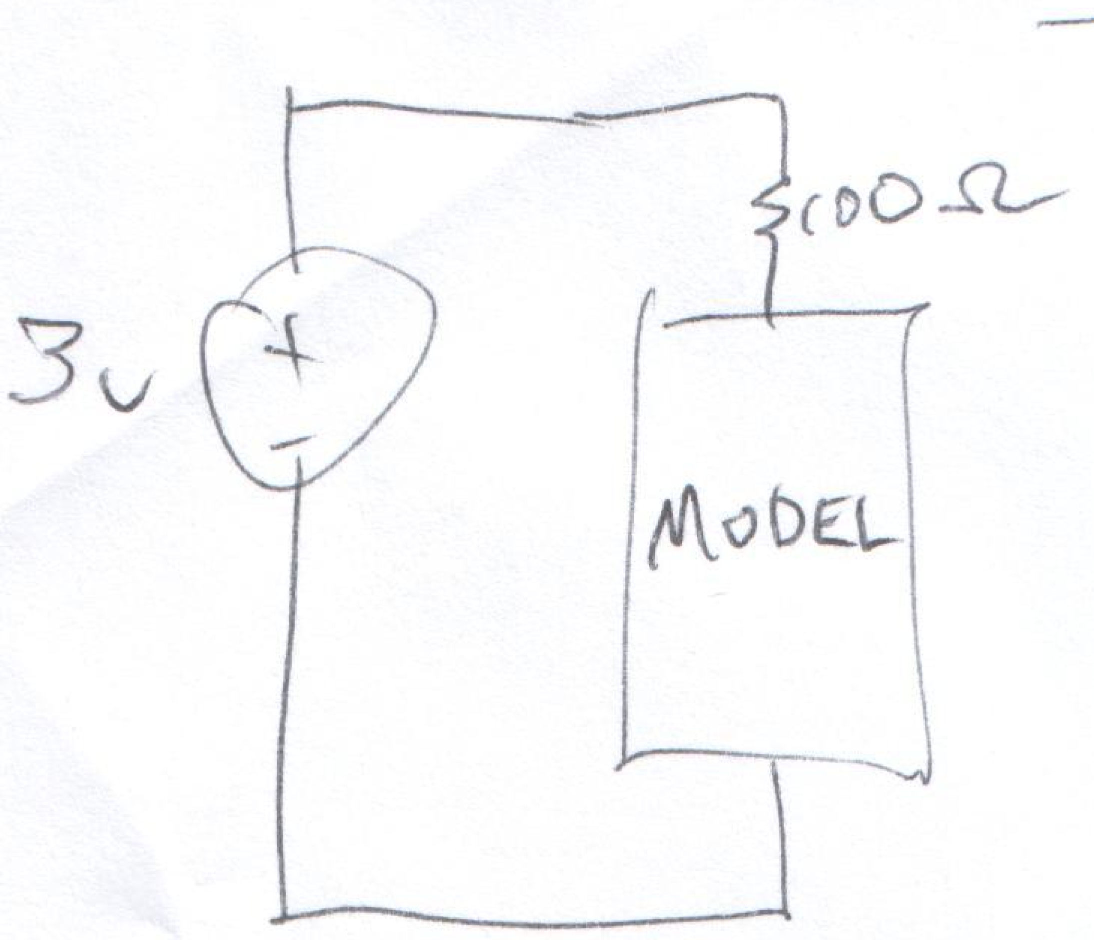
Most Accurate: <u>actually solve everything:</u>

KUL: ~~KVL~~ $3 + -100 \cdot I + V_D(I) = 0$

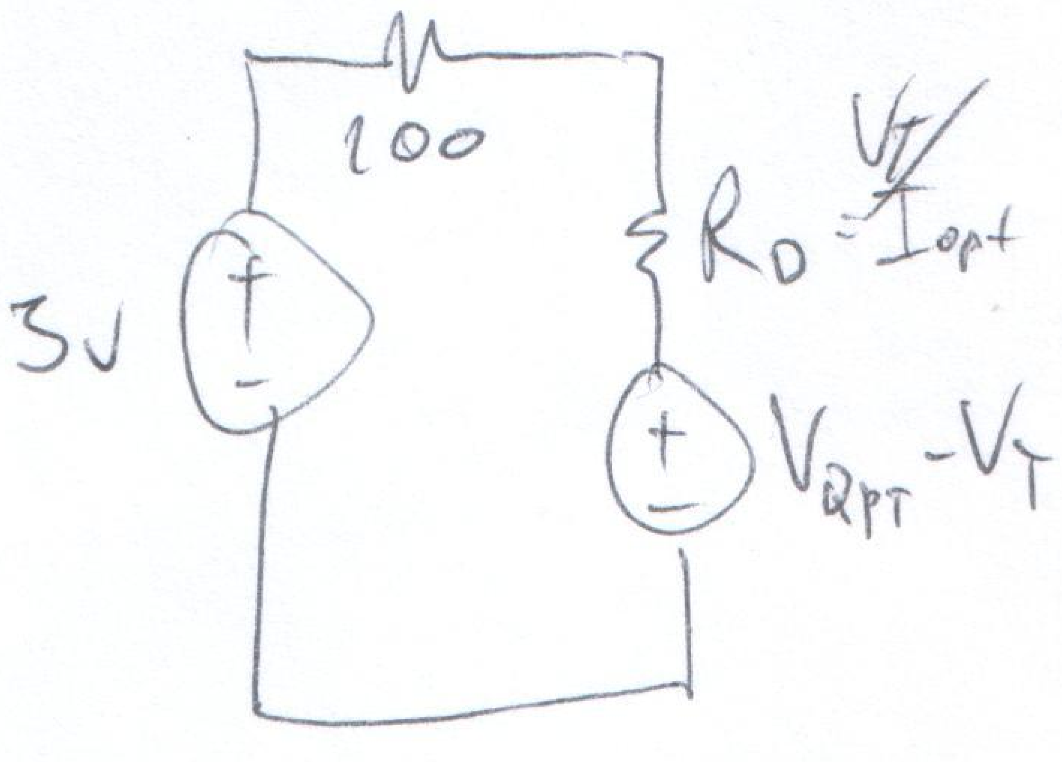
$$3 + -100I - V_T \ln \frac{I}{I_s} = 0$$

solve that.

But that's <u>irritating</u>.



Model can be any chosen ~~value~~ model type.



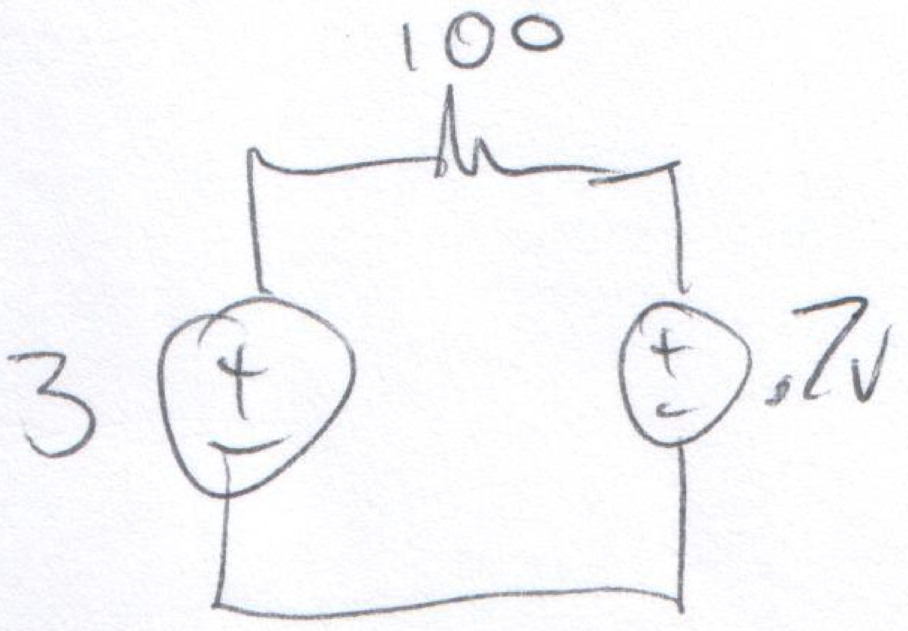
← solve this circuit.

$$3 + -100 \cdot I + -\frac{V_T}{I_Q} \cdot I - V_{QPT} + V_T = 0$$

linear!

* In <u>this</u> circuit it is obvious this is a forward bias situation

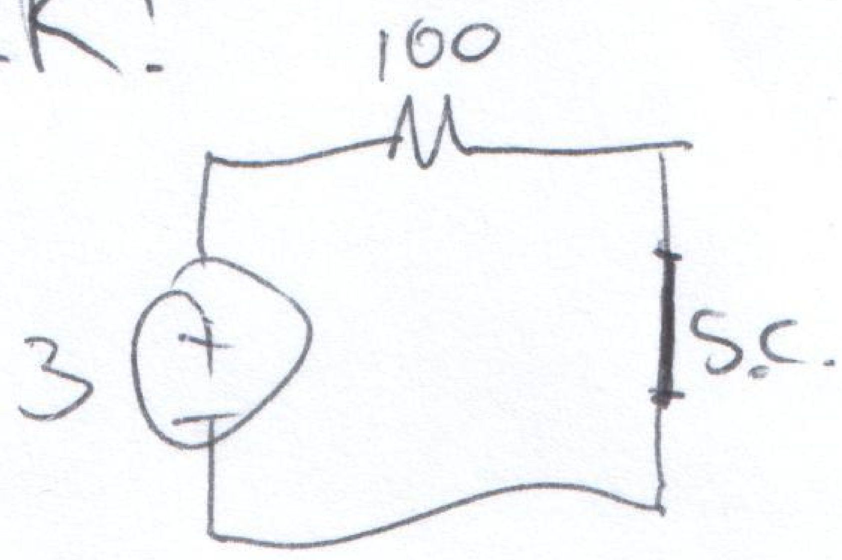
easier:



$$I = \frac{2.3v}{100\Omega} = \underline{23mA}$$

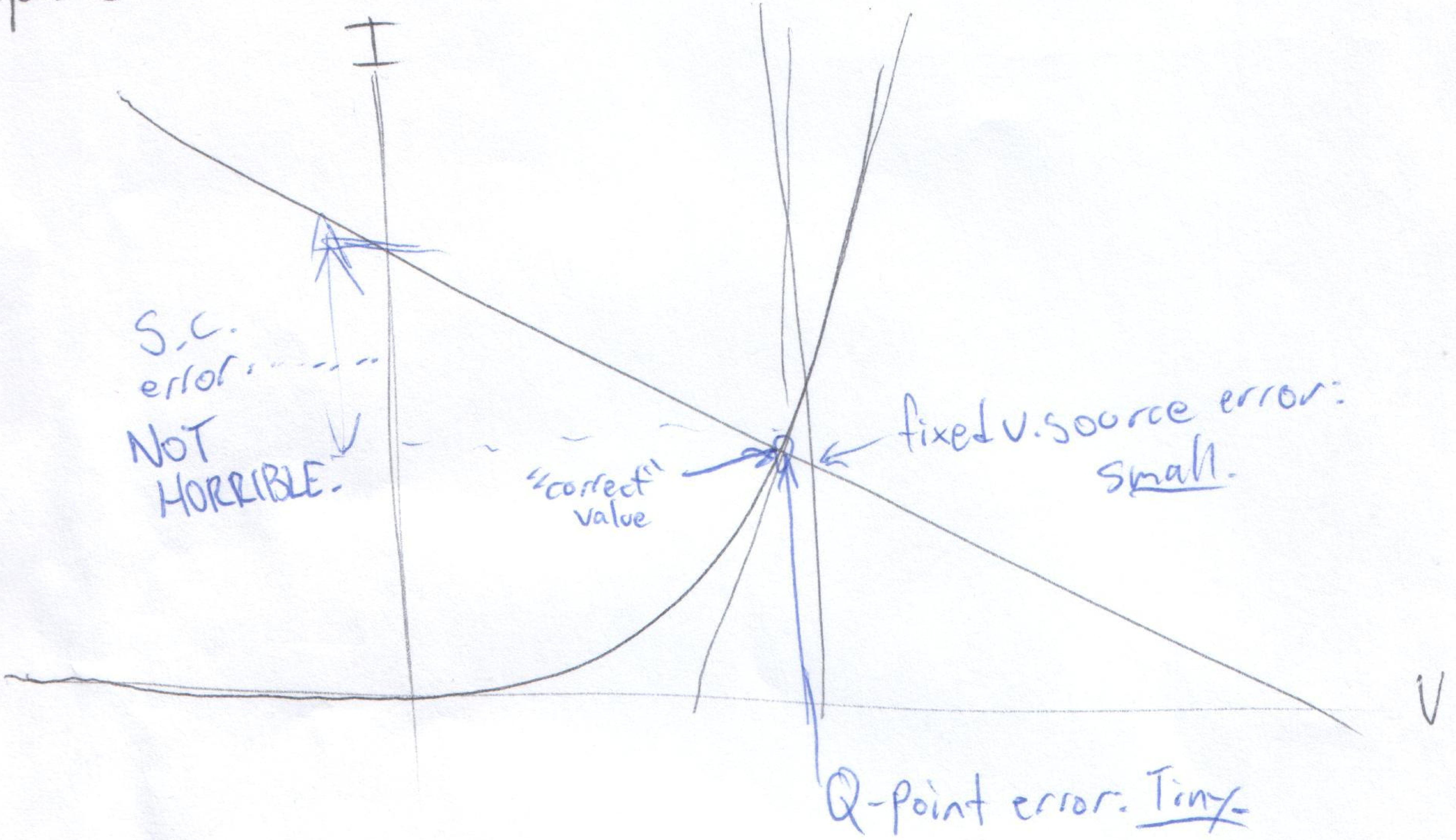
hmm.

EASIER!



$$I = \frac{3}{100} = \underline{30mA}$$

Compare with load-line:

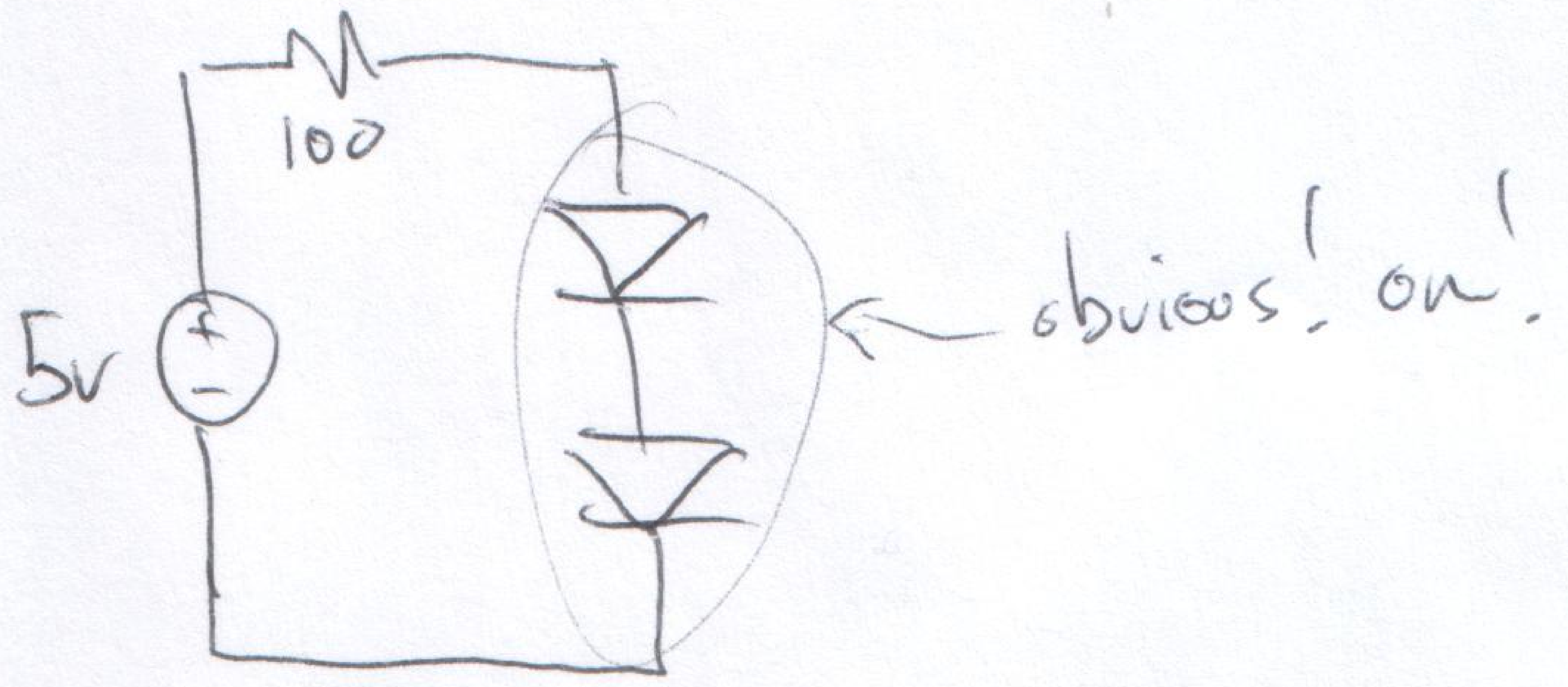


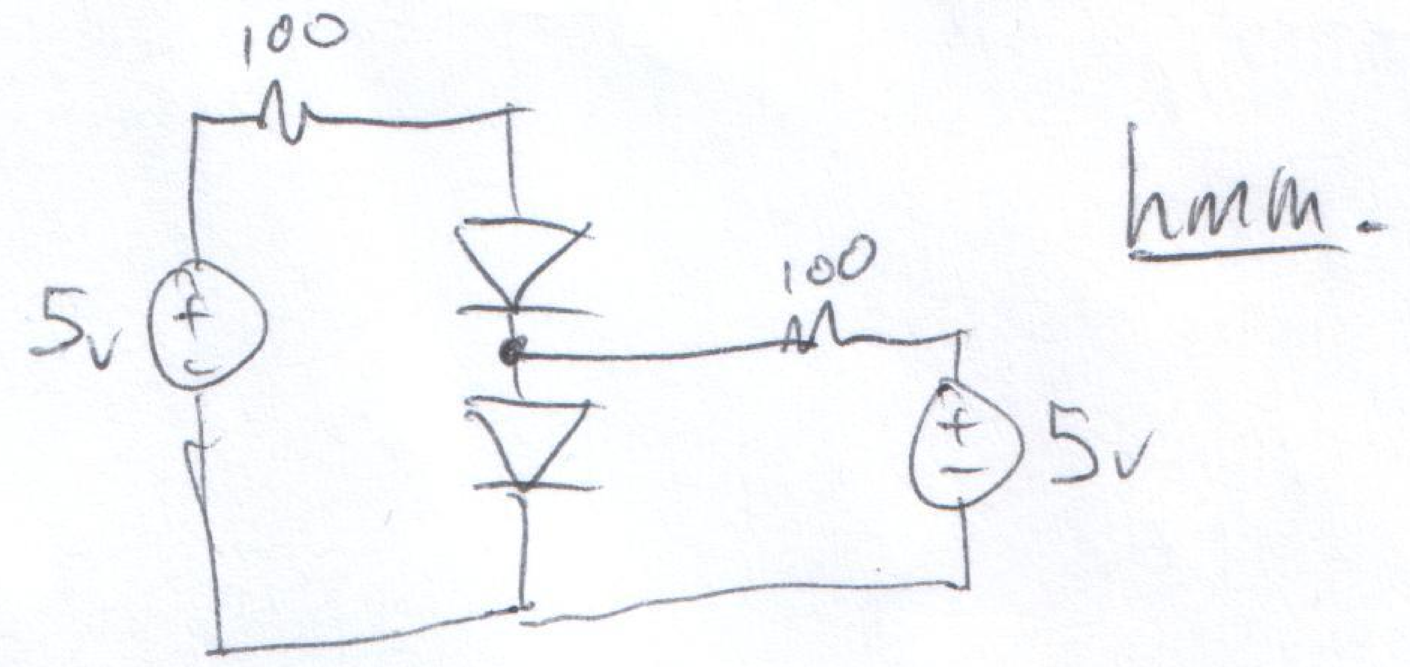
<u>All</u> of these models are <u>imperfect.</u> However, so are <u>diodes!</u> I_s can vary wildly, and temperature shifts will also have an impact.

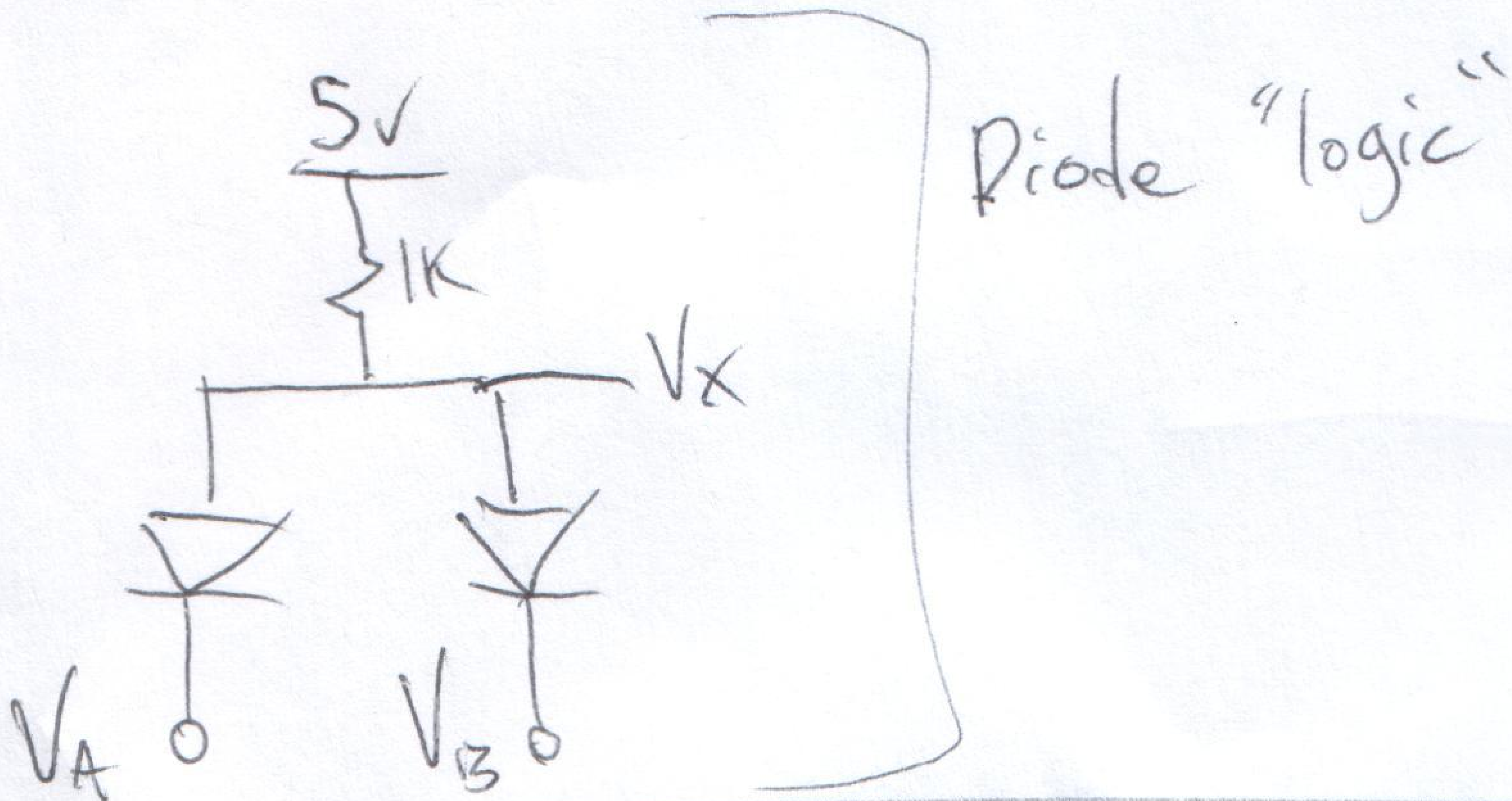
Figuring out circuits:

1 diode: <u>Obvious.</u>
2 diodes: not hard.
3 diodes: not <u>impossible</u>...
4 diodes: <u>SPICE.</u>

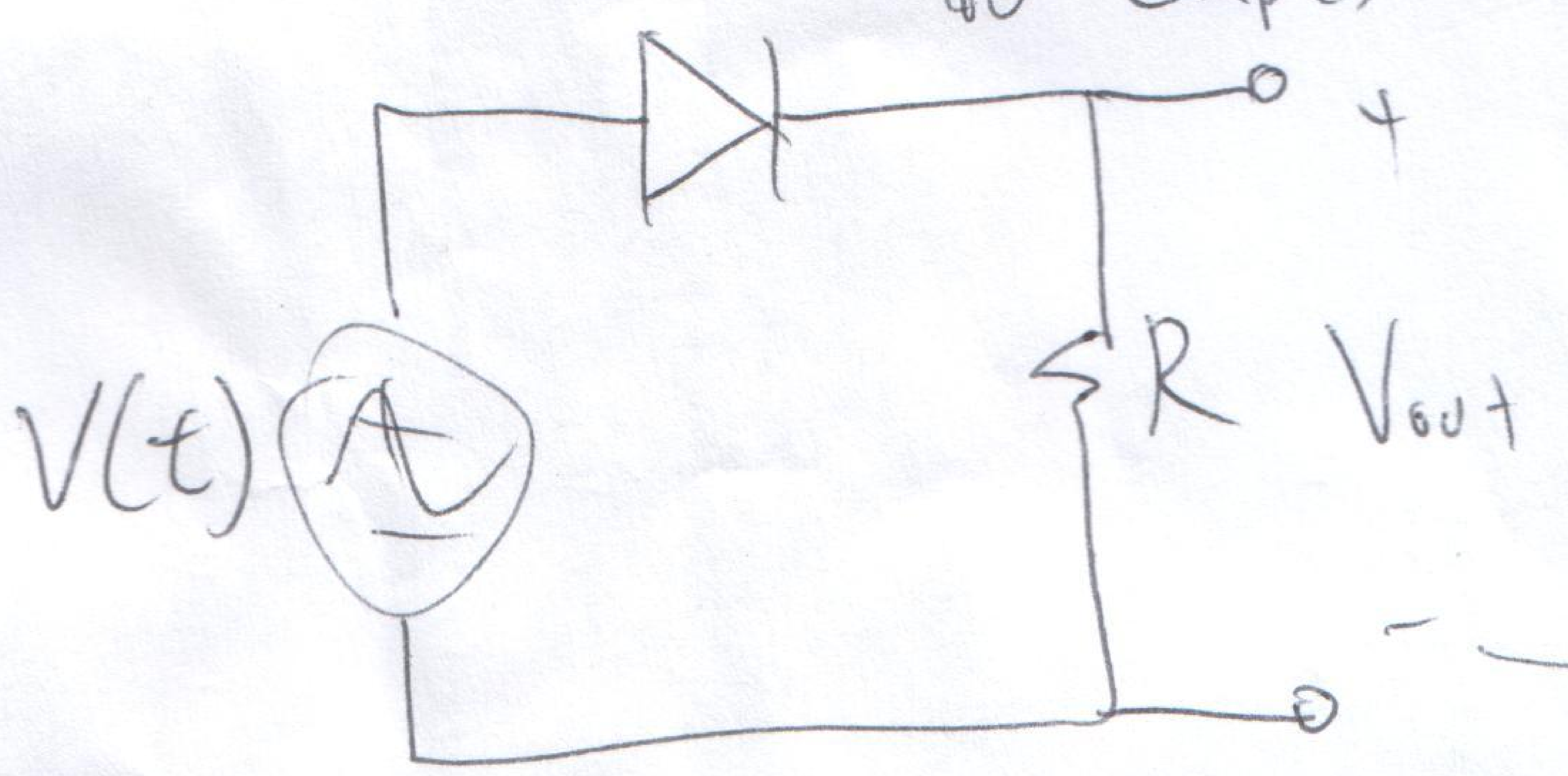
Binary search in state-space for active diodes:

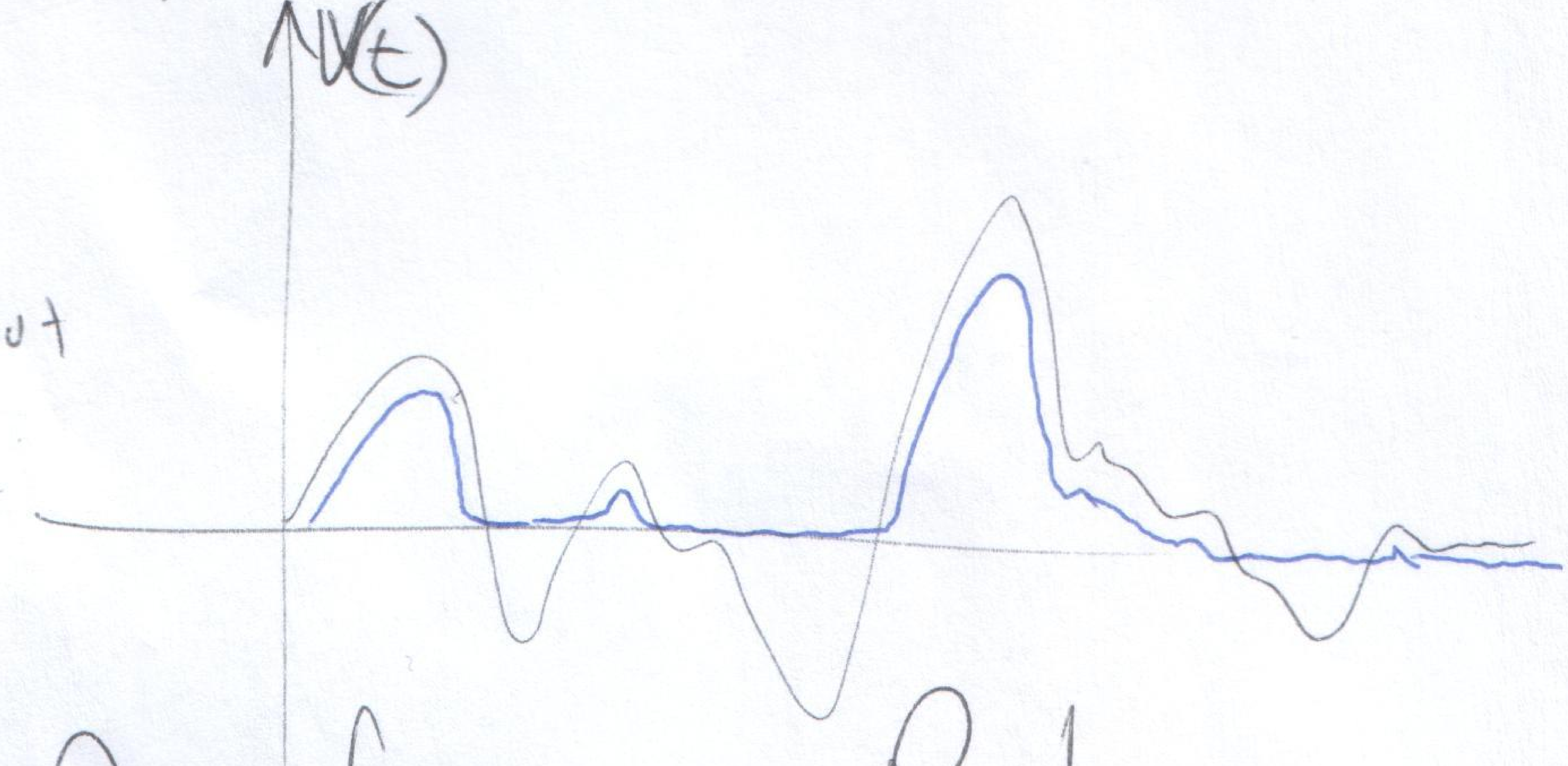






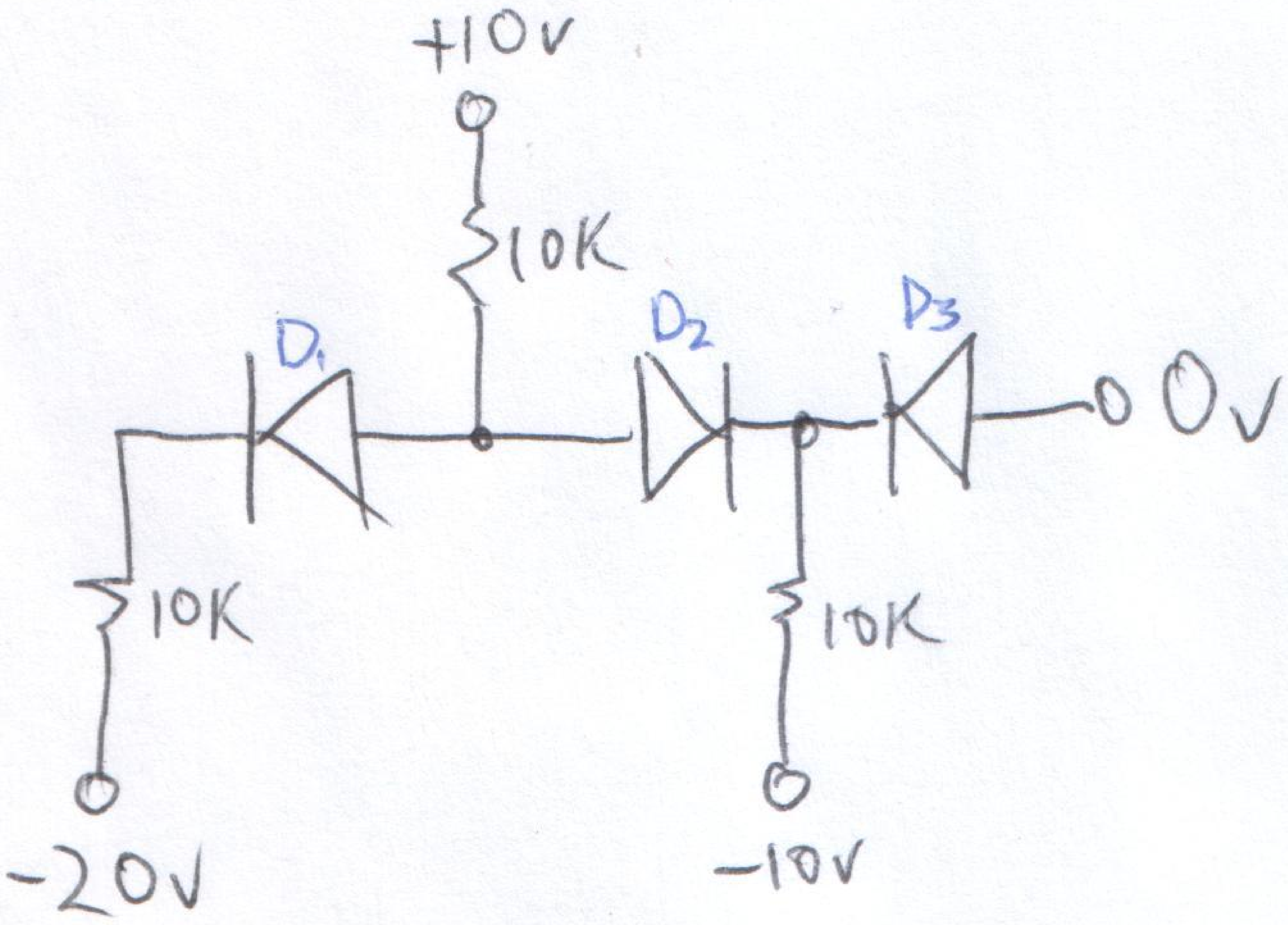
Transients: yeah definitely don't do exp() in your head...





AC vs DC, Rectifiers & Radio

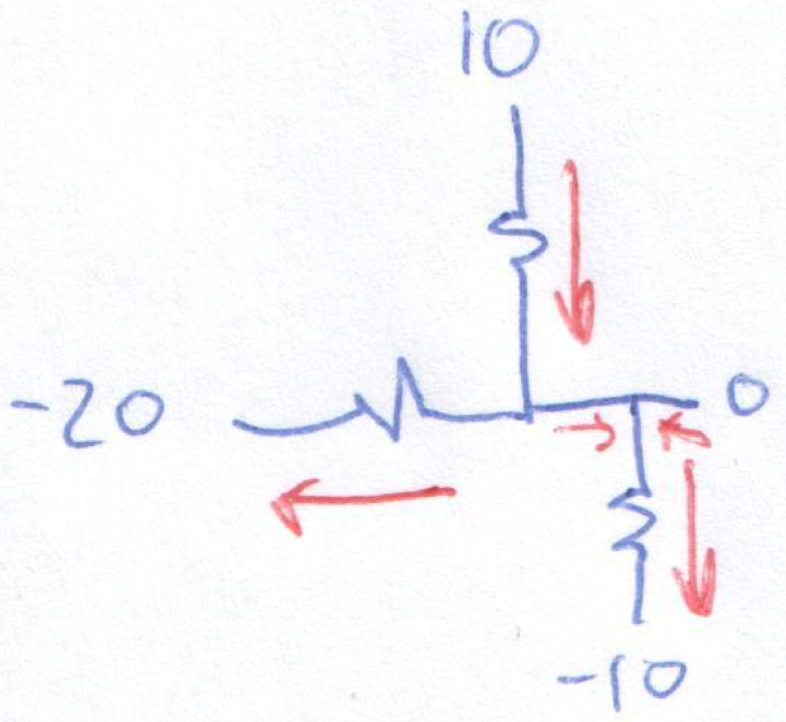
Diodes in Circuits



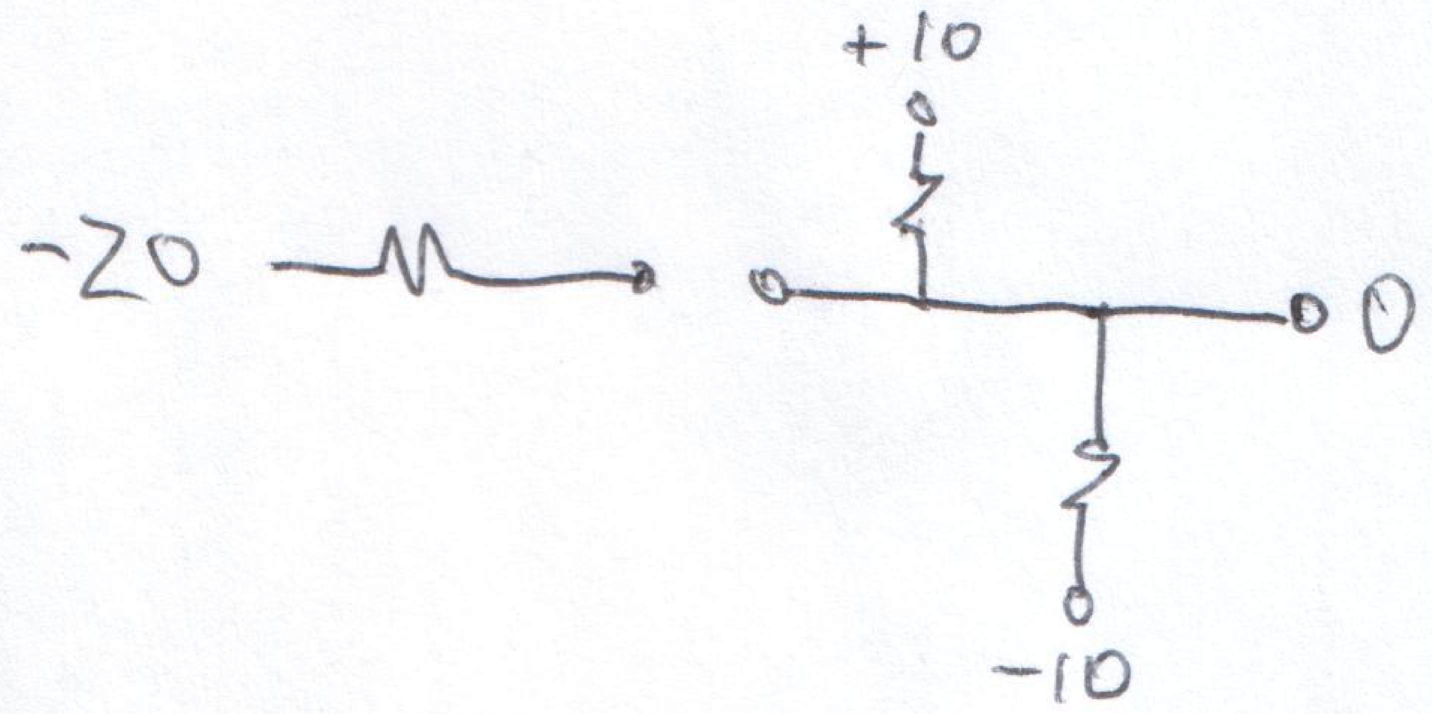
Possible Set of Modes:

D_1	D_2	D_3
off	off	off
off	off	on
off	on	off
off	on	on
on	off	off
on	off	on
on	on	off
on	on	on

However, intuition can help a lot here.

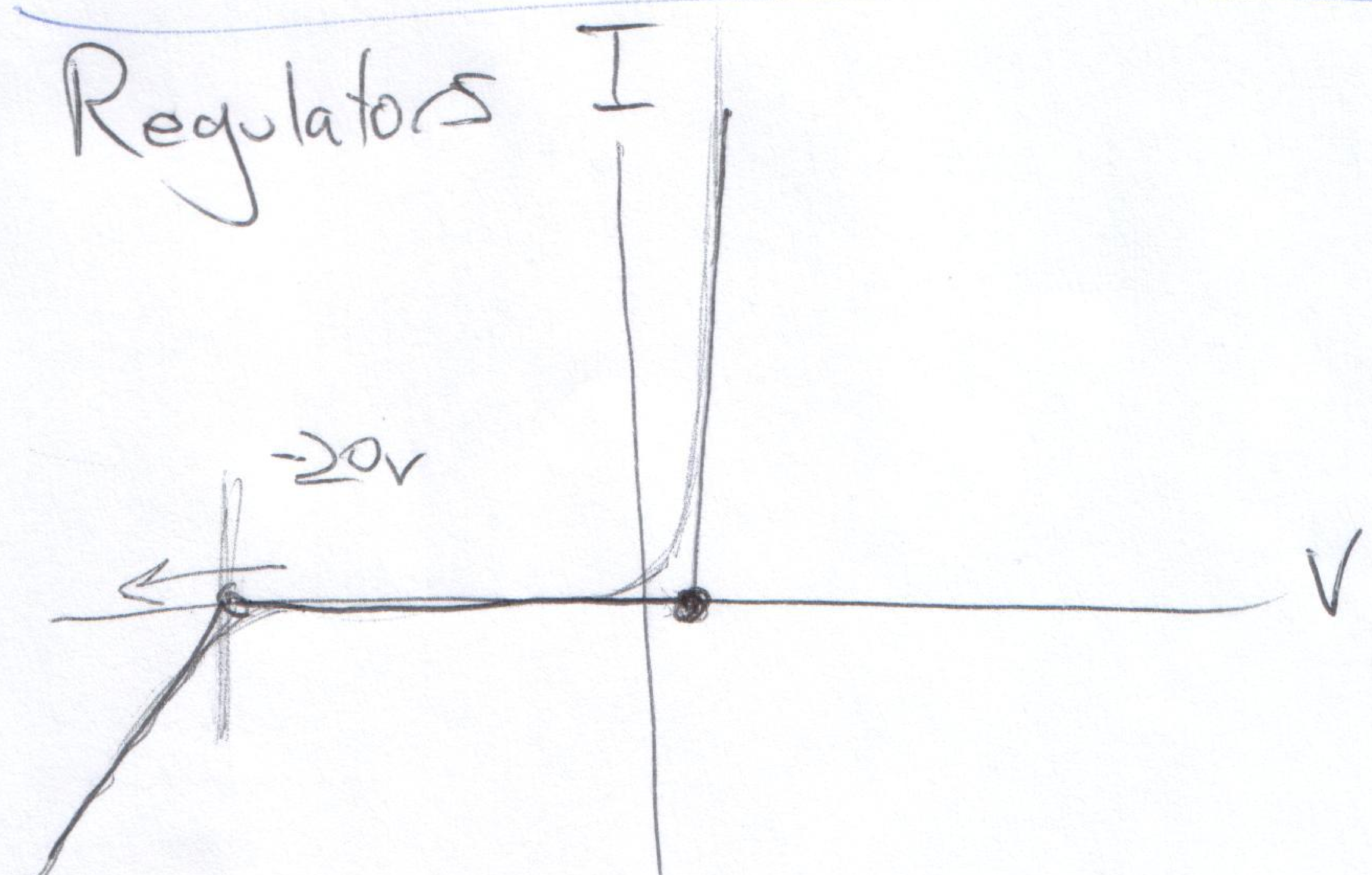


→ Sounds Legit.

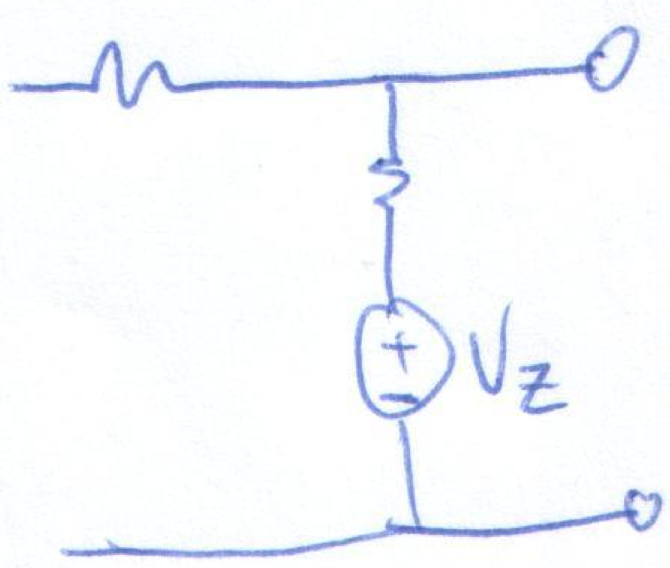


Practice: choosing ~~resistors~~ different diode mode will show +30v across one, obviously F.B.

Regulators

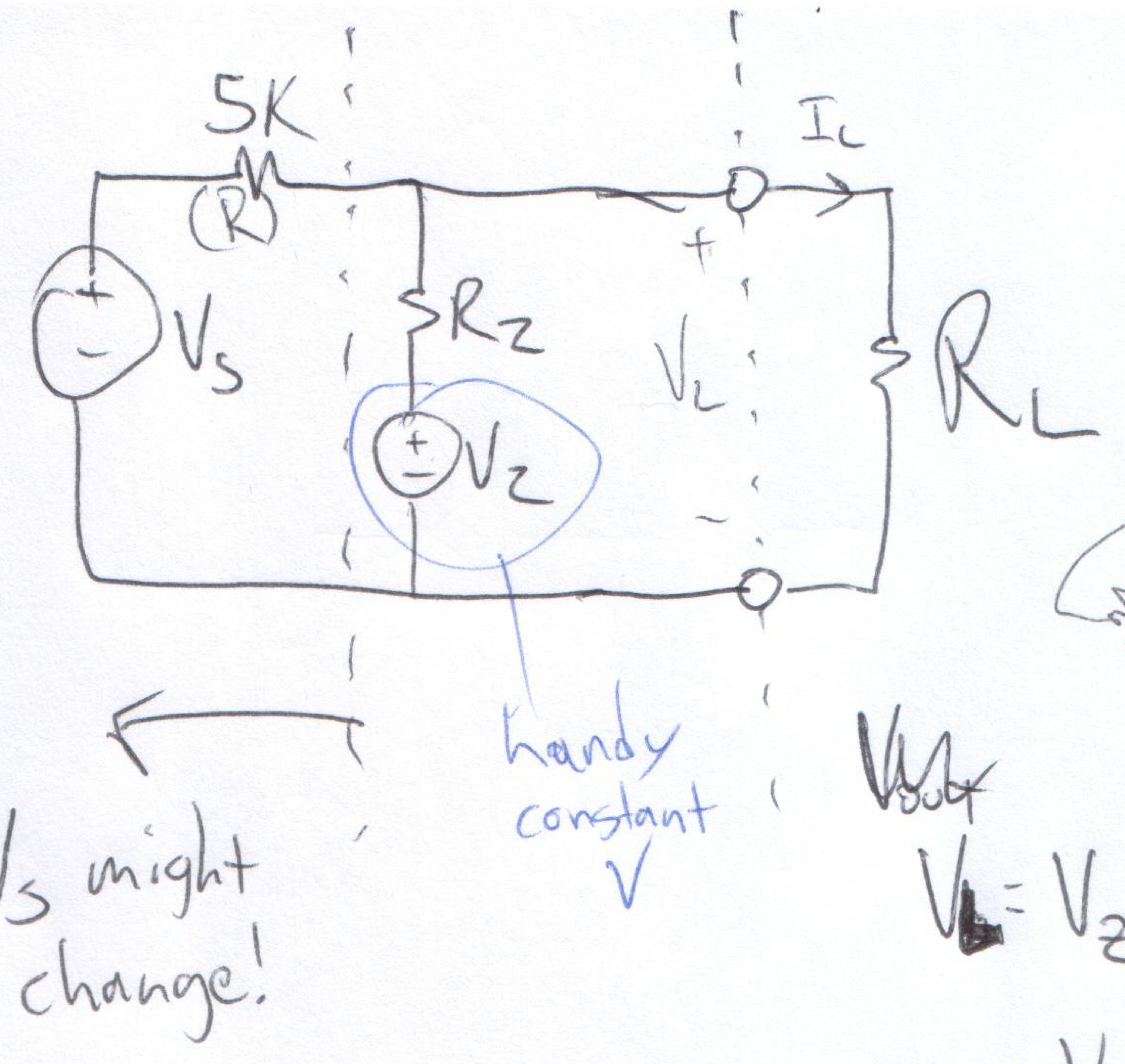


→ Potential use as regulator:



A diode that is Zenering acts at least a little like a voltage source, so maybe we could use it to effectively reduce the output Z of a power supply....

Or hold it steady over input V_S



Line Regulation

$$\frac{\partial V_L}{\partial V_S}$$

assume $R_L \to \infty$

Load Regulation

$$\frac{\partial V_L}{\partial I_L}$$

~~V_{out}~~

$$V_L = V_Z + R_Z \cdot \frac{V_S - V_Z}{R + R_Z}$$

$$= V_Z\left(1 - \frac{1}{R+R_Z}\right) + V_S \underbrace{\frac{R_Z}{R+R_Z}}_{\text{slope!}}$$

$$\frac{\partial V_L}{\partial V_S} = \frac{R_Z}{R+R_Z}$$

good reg: $R_Z << R$

$\frac{\partial V_L}{\partial I_L}$: R_L, varying -

$$V_L = V_S - R\left(I_L + (V_L - V_Z)/R_Z\right)$$

~~$V_L \to V_Z$~~

~~$V_L - V_S - RI_L - RR_Z V_L + RR_Z V_Z$~~

~~$V_L(1 + RR_Z) = V_S - RI_L + RR_Z V_Z$~~

~~$V_L = \frac{1}{1+RR_Z} V_S + \frac{RR_Z}{1+RR_Z} V_Z - \frac{R}{1+RR_Z} I_L$~~

reciprocal err ← oops

$$V_L = V_S - RI_L + \frac{R}{R_Z} V_Z - \frac{R}{R_Z} V_L$$

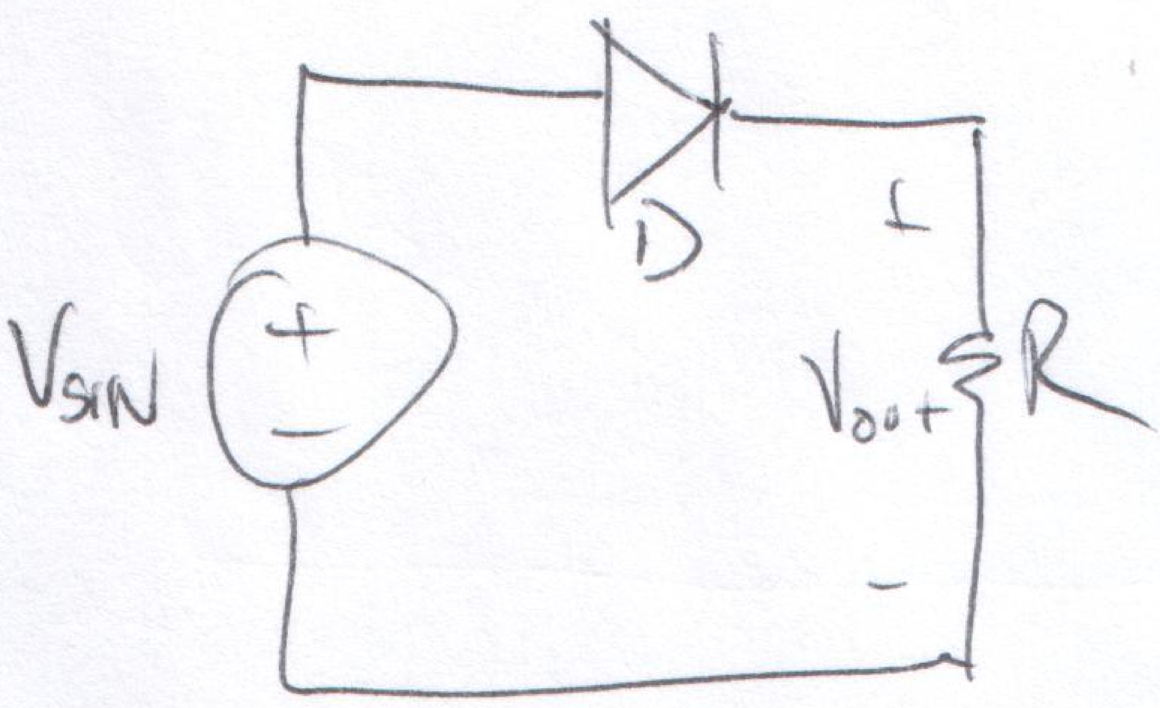
$$V_L\left(1 + \frac{R}{R_Z}\right) = V_S - RI_L + \frac{R}{R_Z} V_Z$$

$$V_L = \frac{1}{1+R/R_Z} V_S - \underbrace{\frac{R}{1+R/R_Z}}_{\text{Slope!}} I_L + \frac{R/R_Z}{1+R/R_Z} V_Z$$

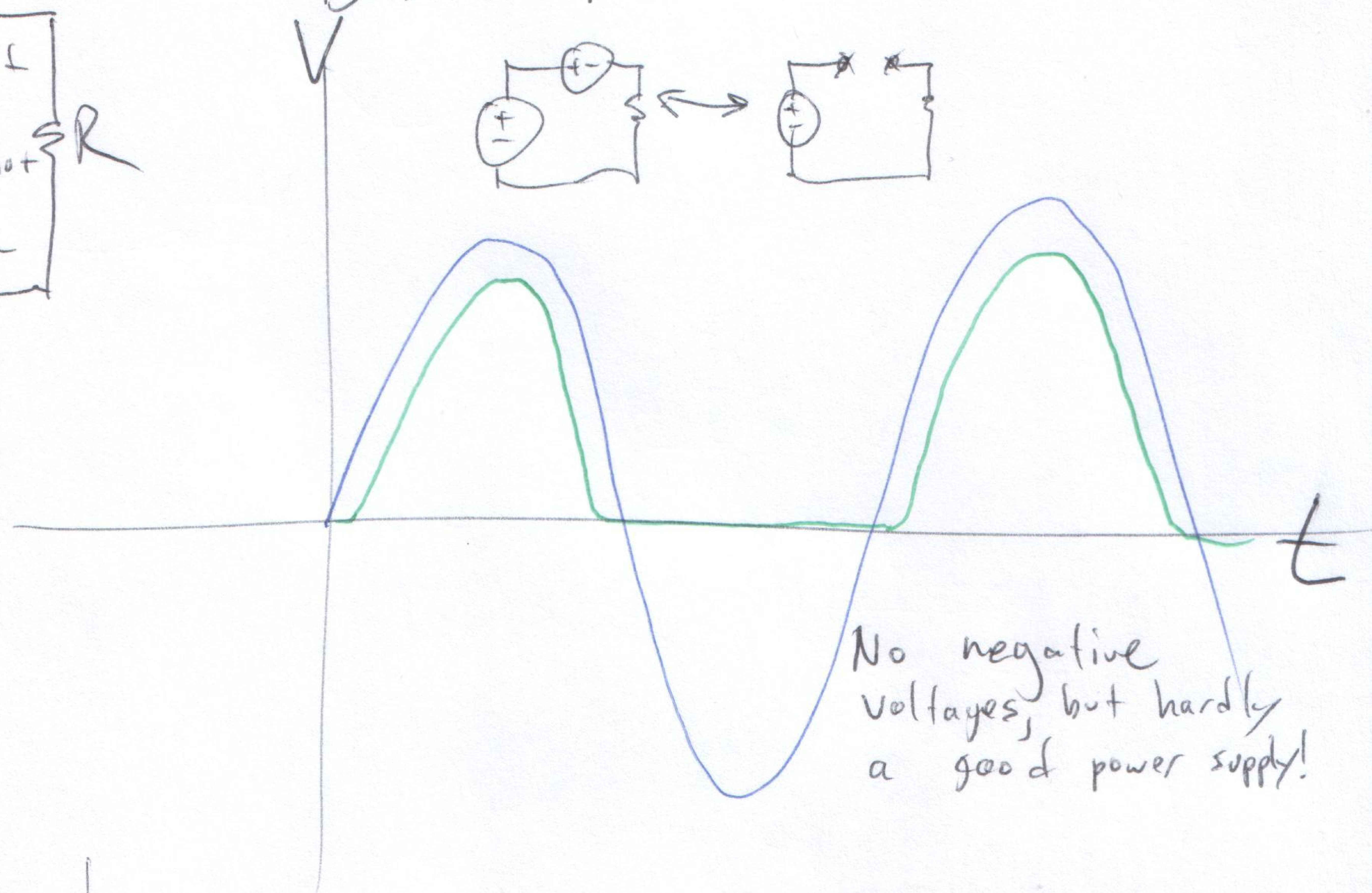
$$\to -\frac{RR_Z}{R+R_Z} \text{ IE } R \parallel R_Z$$

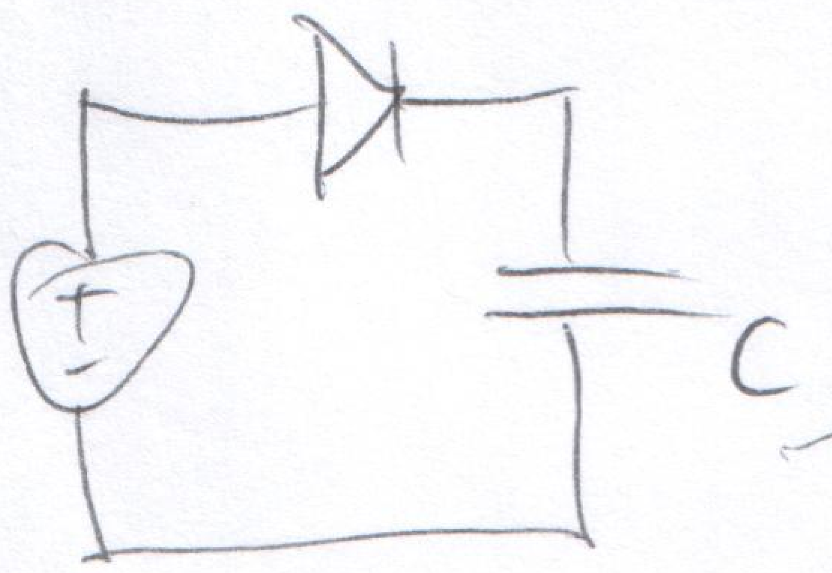
good reg: <u>both small</u>

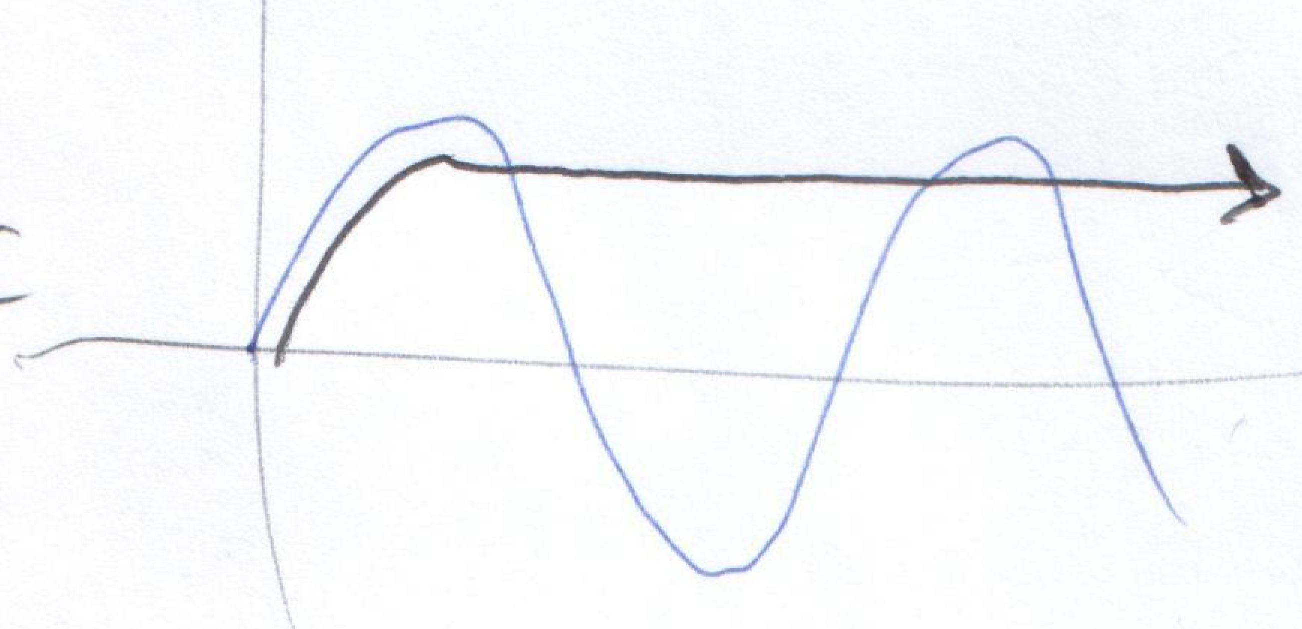
Half-Wave Rectifier



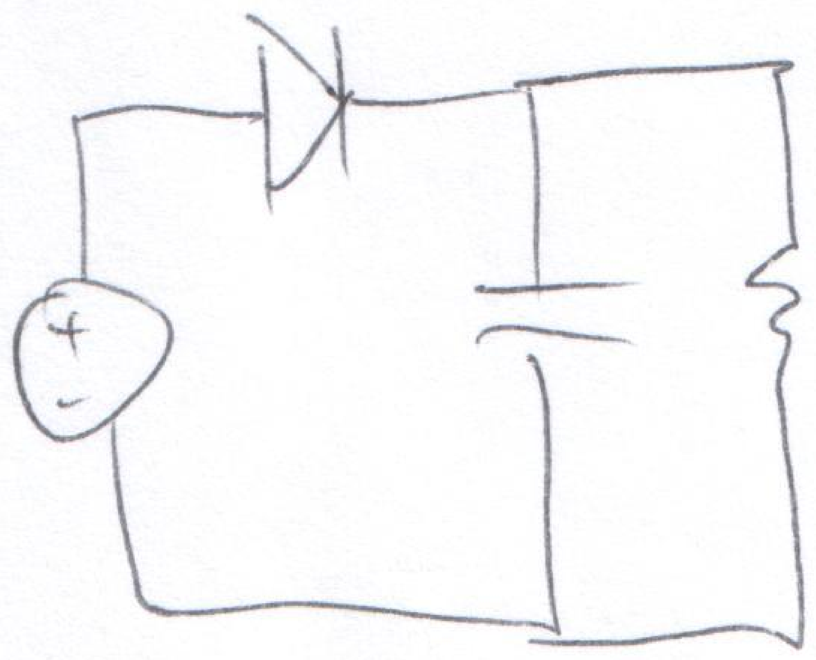
Basic Operation:

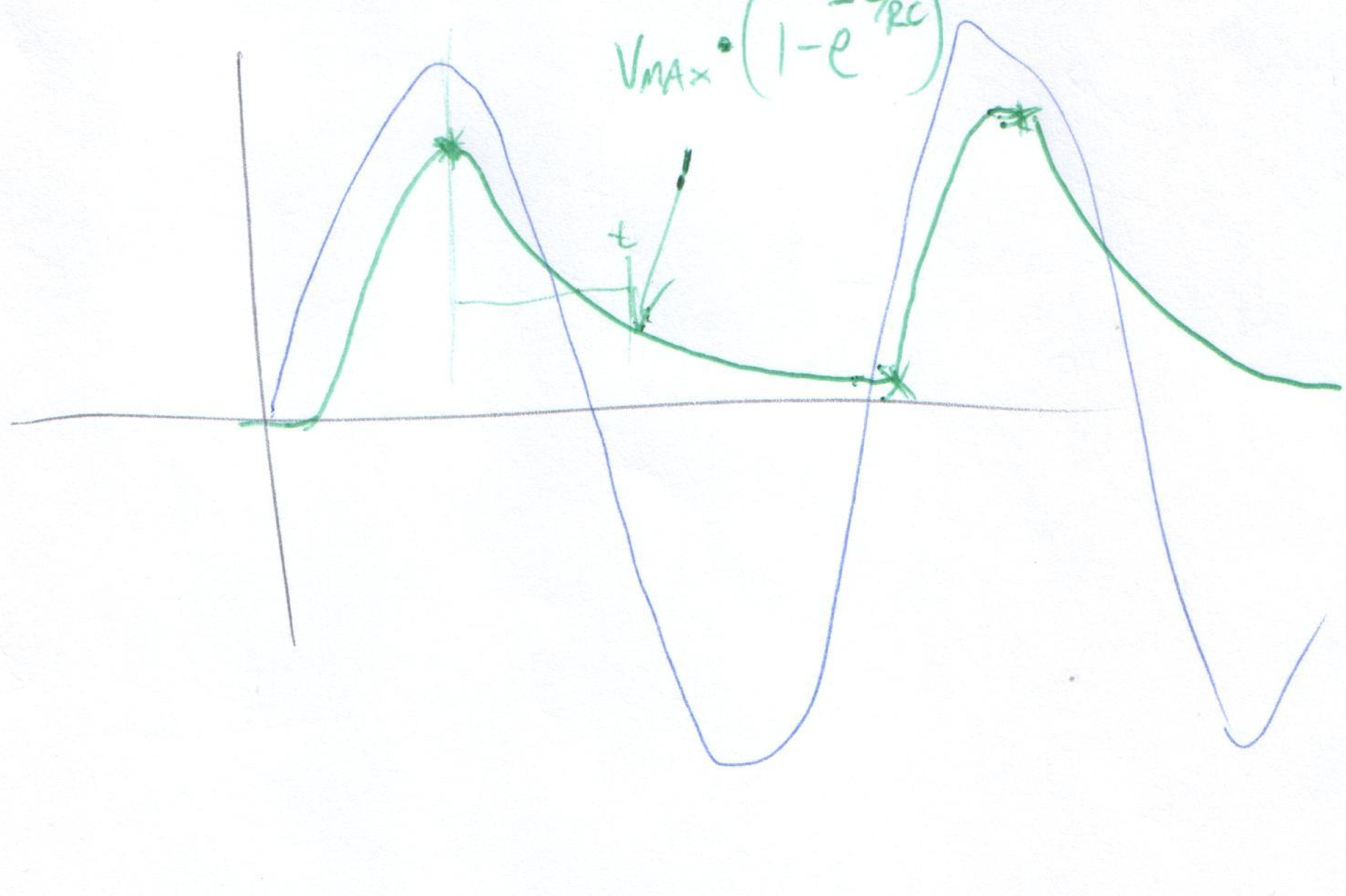




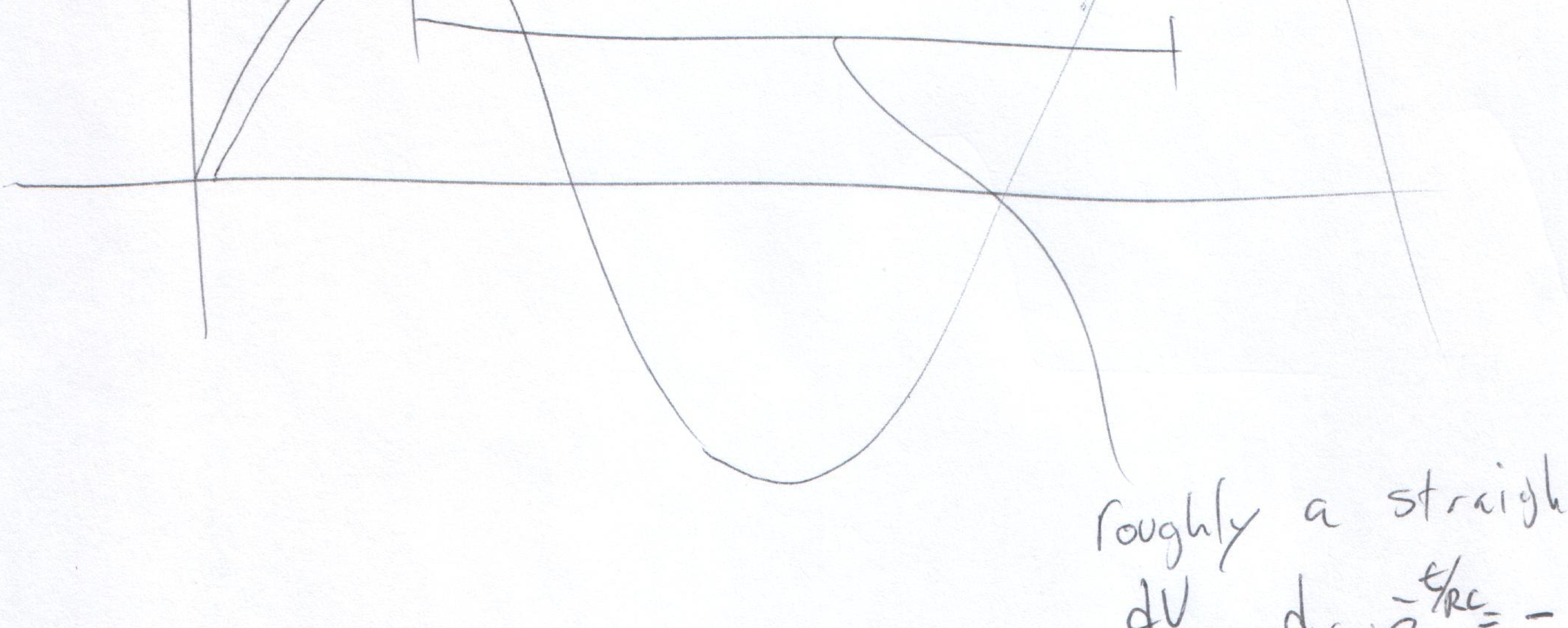


current never leaves C, so flat at max!



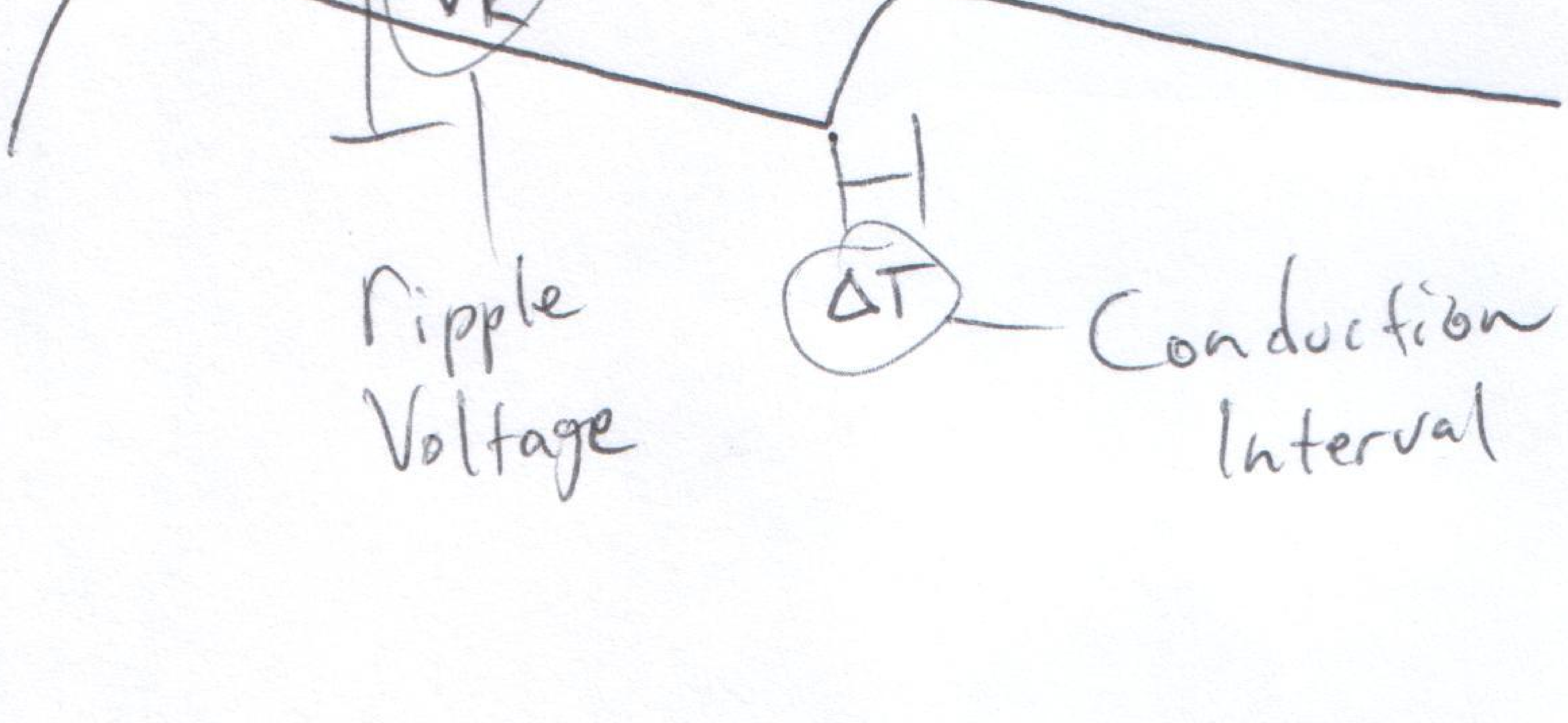


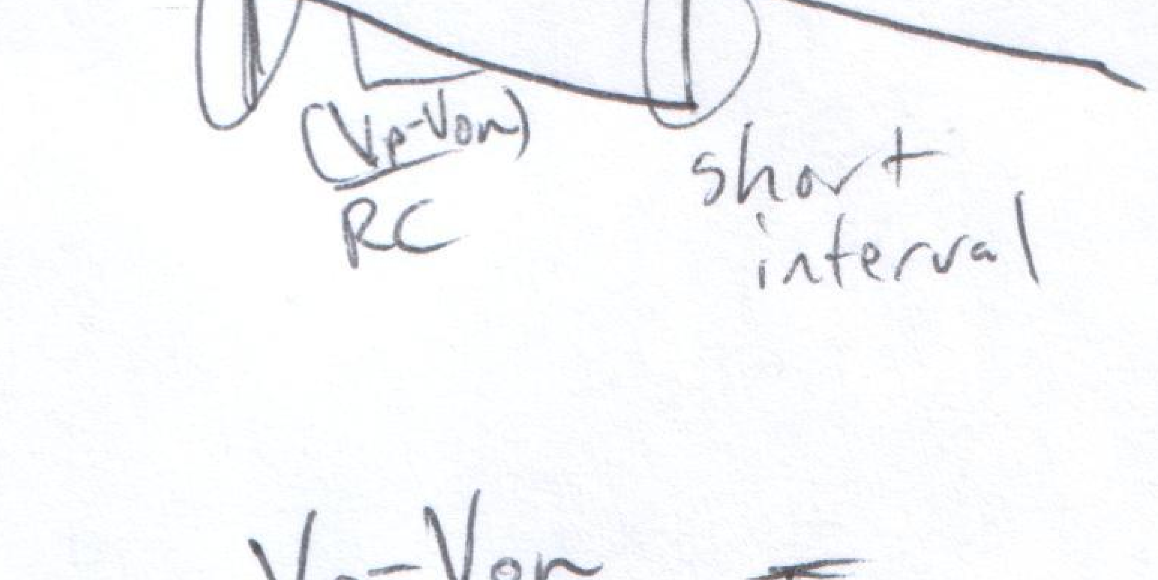
Special Case: $RC \gg \frac{1}{f_{pwr}}$



roughly a straight line

$$\frac{dV}{dt} = \frac{d}{dt}(V_p - V_{on})e^{-t/RC} = -\frac{(V_p - V_{on})}{RC}$$





$$V_r = \frac{V_p - V_{on}}{RC} \cdot T$$

— Note: half the power doesn't go anywhere, the AC only pushes a little bit, and C should be very big for heavy loads.

Power brick LED: goes out after you unplug — faster for laptop plugged in.