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& this led us to studying lenses

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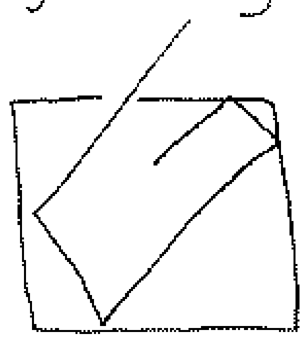
consider a very contrived case of a conductor say that exists like a box and has only a tiny hole at the top



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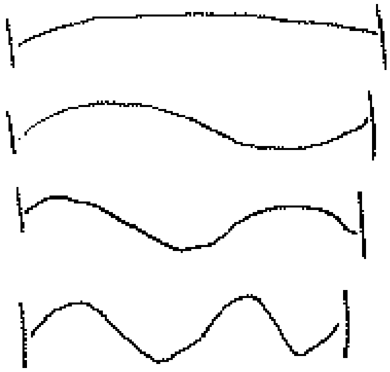

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$$\left(\frac{1}{2} m v^2 = \overset{\text{3 degree's of freedom}}{\frac{3}{2}} kT \right)$$

Now, if we do the same here, the smaller wavelengths will carry away the lions share of the energy since we can fit more of those ("degrees of freedom") into the box

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predict for a light bulb

$$\lambda_{max} = 550\,nm$$

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$$E = n h f$$

some proportionality constant

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$$E_{light} = (n_{start} - n_{Finish})\, h f$$

& since $c = \lambda f$

$$E_{light} = (n_{start} - n_{finish}) \frac{hc}{\lambda}$$

Couple of cool things to notice

The light is ~~emitted~~ emitted in discrete energy bundles (quanta)
There is a lowest energy $\frac{hc}{\lambda}$ when $n=1$

and you can no longer let $\lambda \to 0$ or $E \to \infty$

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You'll notice that if I charge a piece of zinc up with negative charge (fur on a rubber rod) and shine ultra violet light on the zinc, the charge quickly drains away.

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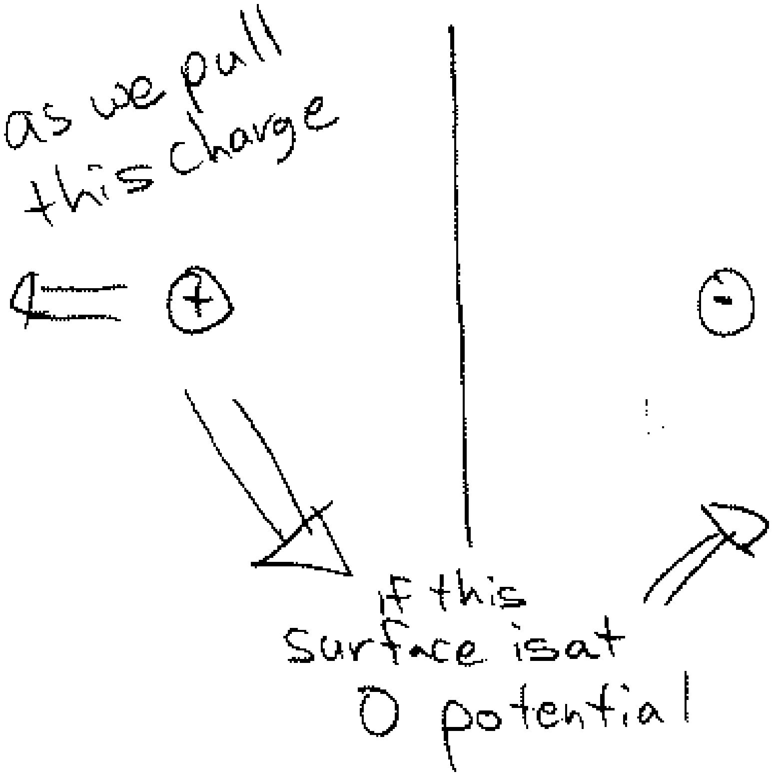

It's like there's a phantom charge on the other side that is needed to maintain $V=0$ at the surface

(this really works too)

so the charge wants to stick

now, with our old model, the charged particle would have to absorb energy enough to pull away from the surface

a few 10^{-19} J (called the work function of the surface)

Convenient unit eV

short hand for 1.6×10^{-19}C

we just use e V instead of J

So we need to absorb a few eV
how long does this take?

100 W light bulb

- lets say I (intensity) @ surface is 1 $\frac{W}{m^2}$

- each electron or atom if you like takes up 10^{-10} m of space

- Energy for each atom

$$\sim \frac{W}{m^2}(10^{-10} m)^2 \sim 10^{-20} \frac{J}{s}$$

- takes a few seconds to energize
  - doesn't depend on the light source
- we put more power in, get stuff faster
- if we wait long enough, should absorb enough energy to come off no matter what the charge is

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now, Einstein said, and this is where he got his 1st nobel prize, that this was happening because light is composed of those discrete bundles of energy described by Plank, & individual photons were colliding with individual e^-'s

It takes a certain amount of energy to kick out an electron (due to the image charge if you like) that is characteristic of the material. He called this ϕ the work function

To just begin to kick out electrons you need

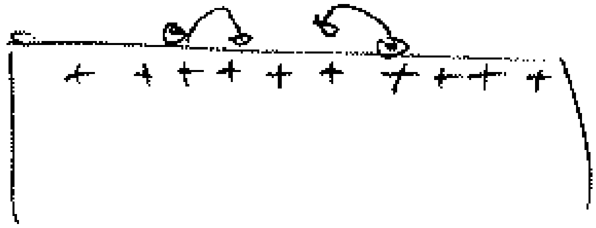
$$E_{photon} \geq \phi$$

$$h f_{cutoff} = \phi$$

Planks constant 6.626×10^{-34} Js (also useful $hc = 1240$ eVnm

maximum kinetic energy of ejected electrons $K_{max} = hf - \phi$

So, we can understand what is happening with our zinc (must be clean!)



put a + charge on surface (really remove e's)

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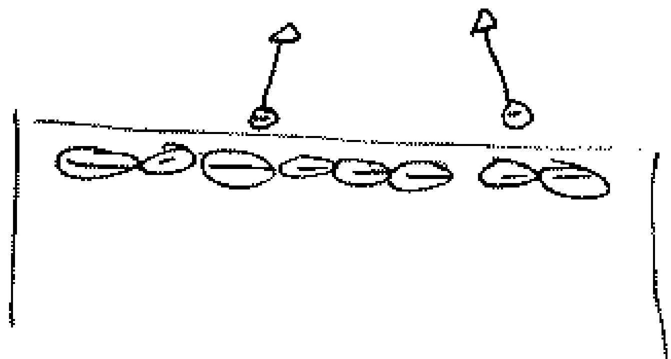


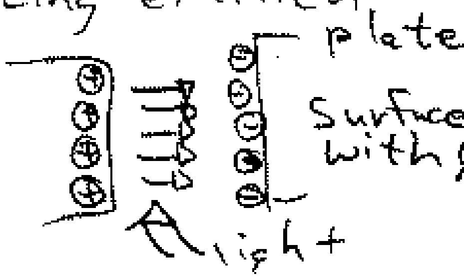
put more e's on, e's more likely to come out (less reverse potential)

but still need energetic enough photons to do the job

<u>lets do an example</u>

sometimes it's easier to determine K_{max} by finding what the potential difference is to try and stop electrons from being emitted

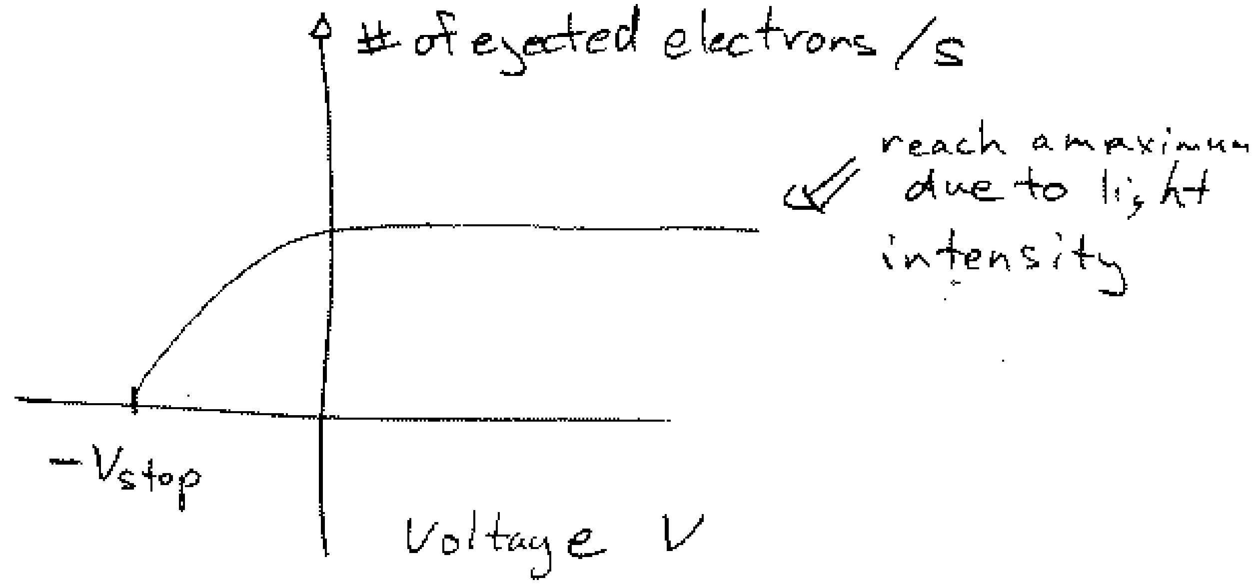
Surface with ϕ_{low}



Surface with ϕ_{high}

electrons collect here until $V_{diff} = \left(\frac{K_{max}}{e}\right)$

or, if you maintain a potential difference across the plates, you can prevent some of the electrons from being ejected



none get out when $V_{stop} = \frac{K_{max}}{e}$

choose this because it is easier to measure

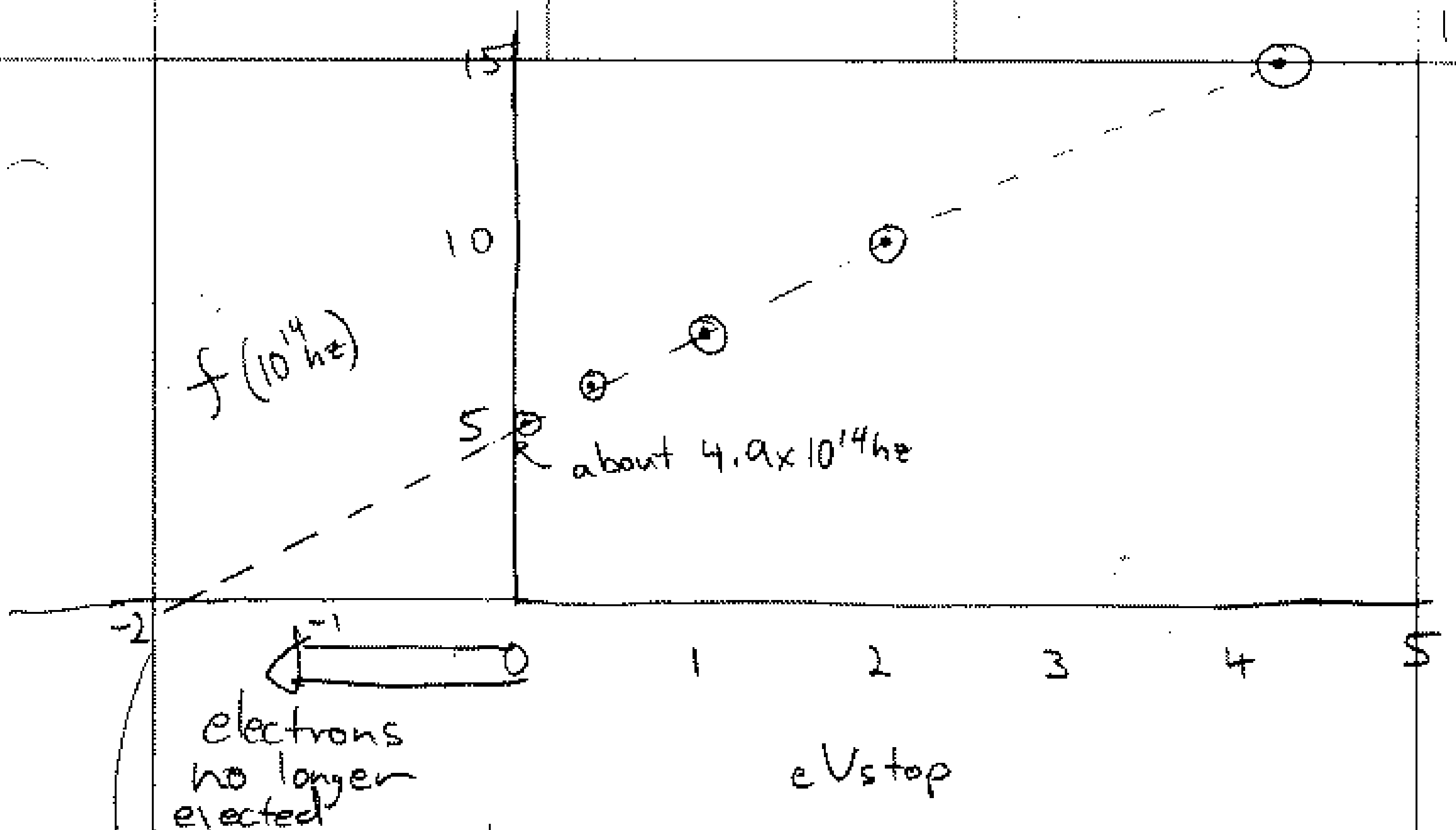
ex I have several lasers on hand and can determine how much voltage I need to stop electrons being ejected fore each one

f (hz)	1.5×10^{15}	1.0×10^{15}	7.5×10^{14}	6.0×10^{14}	5.0×10^{14}
λ nm	200	300	400	500	600
V_{stop}	4.20	2.06	1.05	0.41	0.03

now if

$$K_{max} = hf - \phi = eV_{stop}$$

I should be able to plot K_{max} vs f and find both h & ϕ (eV_{stop} vs f)



at each spot

$$eV_{stop} = hf - \phi$$

expect if $f = 0$ $\quad eV_{stop} = -\phi$

$$\phi = -(-1.8\,eV) \Rightarrow 1.8\,V$$

{ h is slope of line

$$\frac{1}{h} \approx \frac{1.5\times10^{15}\,hz - 5\times10^{14}\,hz}{4.20\,eV - 0.03\,eV}$$

$$h = 4.17\times10^{-15}\,eVs$$

e ↑ $1.6\times10^{-19}\,C$

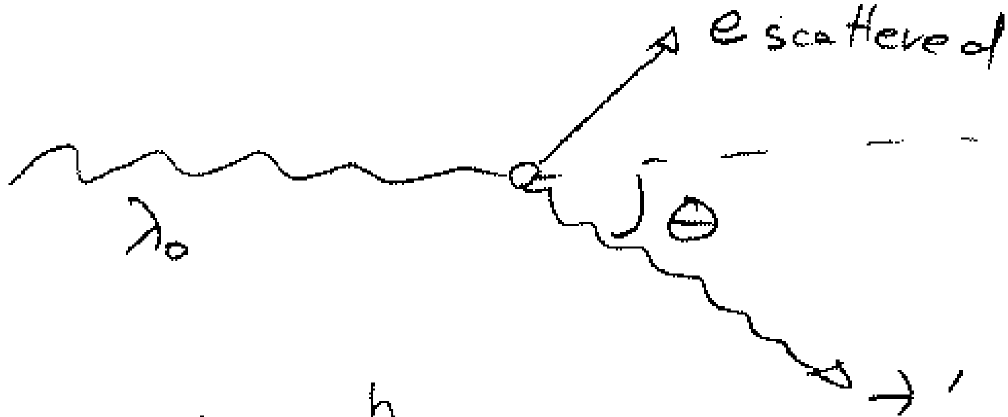
$$= 6.67\times10^{-34}\,Js \quad \text{ok!}$$

{ this is how h <u>was</u> measured about 10 years <u>after</u> Einsteins prediction

The real nail in the coffin occured when it was observed that some times x-rays bounced off electrons in a material as if the x-ray and the electron were billiard balls,

Using relativistic Kinematics you find

$$\lambda' - \lambda_0 = \lambda_c (1 - \cos\theta)$$



$\lambda_c = \frac{h}{m_e c}$ ⟵ foreshadowing!

& this is what was seen

now recall from your relativity

$E^2 = p^2c^2 + m^2c^4$ (need to add in $E_0 = mc^2$)

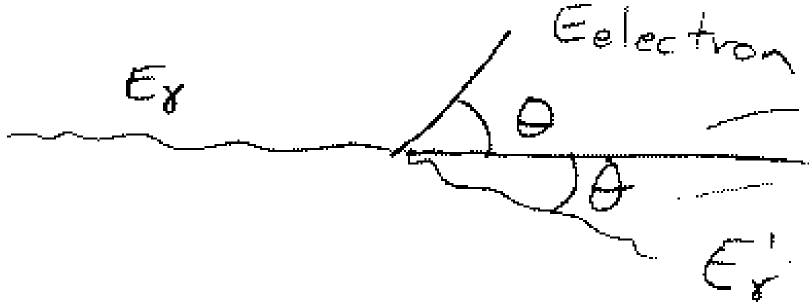
↑ $(KE + mc^2)$

example

Suppose you could measure the angle where the Θ of the emitted photon is the same as the angle the electron was emitted.

What angle should you have if $E_\gamma = \frac{hc}{\lambda_0} = 0.880\ \text{MeV}$? & E_γ' ? $E_{electron}$?

Know momentum must be conserved & Energy must be conserved



in this case!

$$P_{electron} \cancel{\sin\Theta} = P_\gamma' \cancel{\sin\Theta}$$

Careful!

$$P_\gamma = P_{elec}\cos\Theta + P_\gamma' \cos\Theta = 2P_\gamma' \cos\Theta$$

$$E_{before} = E_\gamma + m_e c^2$$

$$E_{after} = E_\gamma' + KE_{elect} + m_e c^2$$

$$KE_{elec} = E_\gamma - E_\gamma'$$

& since $\lambda' - \lambda_0 = \lambda_c(1-\cos\Theta)$ & $\underbrace{\frac{h}{\lambda_0}}_{P_\gamma} = 2\underbrace{\frac{h}{\lambda'}}_{P_\gamma'}\cos\Theta$

$$\lambda' = 2\lambda_0\cos\Theta$$

$$\Rightarrow \quad 2\lambda_0\cos\theta - \lambda_0 = \lambda_c(1-\cos\theta)$$

$$\lambda_0(2\cos\theta - 1) = \lambda_c(1-\cos\theta)$$

$$2\cos\theta - 1 = \frac{\lambda_c}{\lambda_0}(1-\cos\theta)$$

$$2\cos\theta + \frac{\lambda_c}{\lambda_0}\cos\theta = 1 + \frac{\lambda_c}{\lambda_0}$$

$$\cos\theta = \frac{1+\frac{\lambda_c}{\lambda_0}}{2+\frac{\lambda_c}{\lambda_0}}$$

$$\frac{\lambda_c}{\lambda_0} = \frac{\frac{\cancel{h}}{m_e c}}{\frac{\cancel{h}c}{E}} = \frac{E}{m_e c^2}$$

$$\theta = \cos^{-1}\left(\frac{1+\frac{.880\,\text{MeV}}{.511\,\text{MeV}}}{2+\frac{.880\,\text{MeV}}{.511\,\text{MeV}}}\right)$$

$$= 43^\circ$$

$$\frac{hc}{\lambda'} = \frac{hc}{\lambda_0}\,\frac{1}{2\cos\theta} = \frac{.880\,\text{MeV}}{2(\cos 43^\circ)}$$

$$= .602\,\text{MeV}$$

$$KE_{electron} = 0.880\,\text{MeV} - 0.602\,\text{MeV}$$
$$= .278\,\text{MeV}$$

check $cP_e = P_\gamma c$? $\quad P_e c = \sqrt{(.278+.511)^2 - .511^2} = .601\,\text{MeV}$ pretty good!

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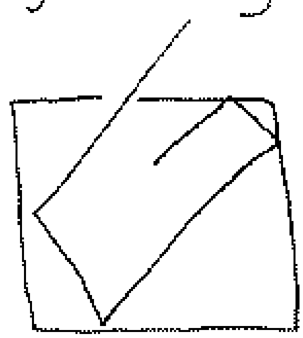

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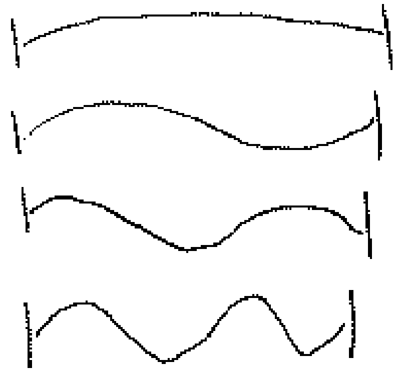

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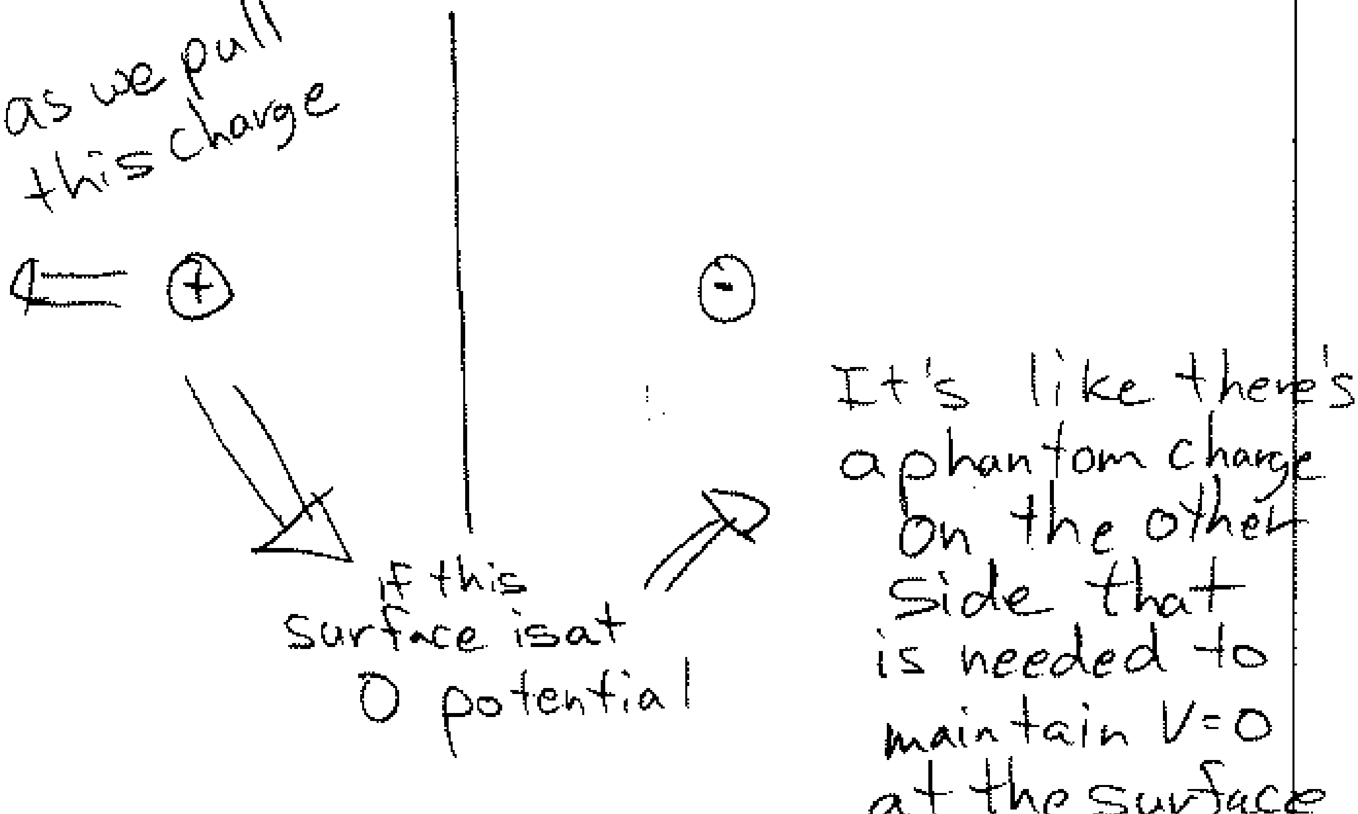

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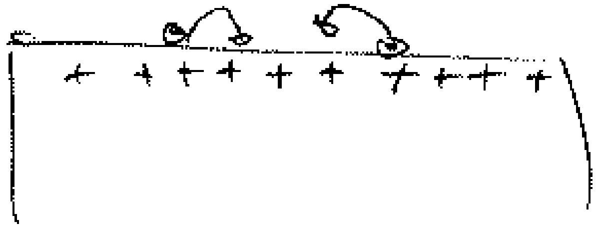

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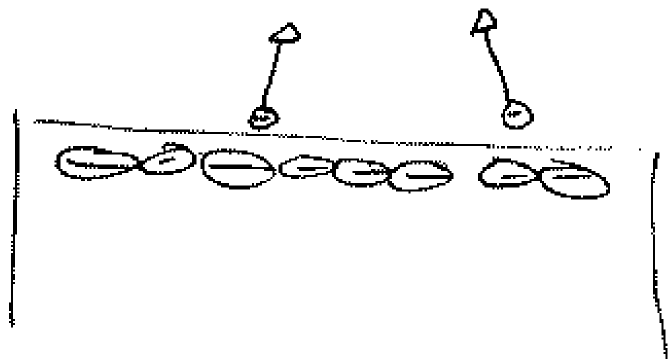

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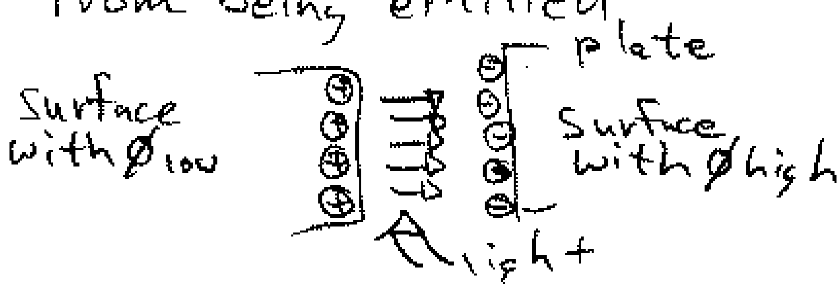

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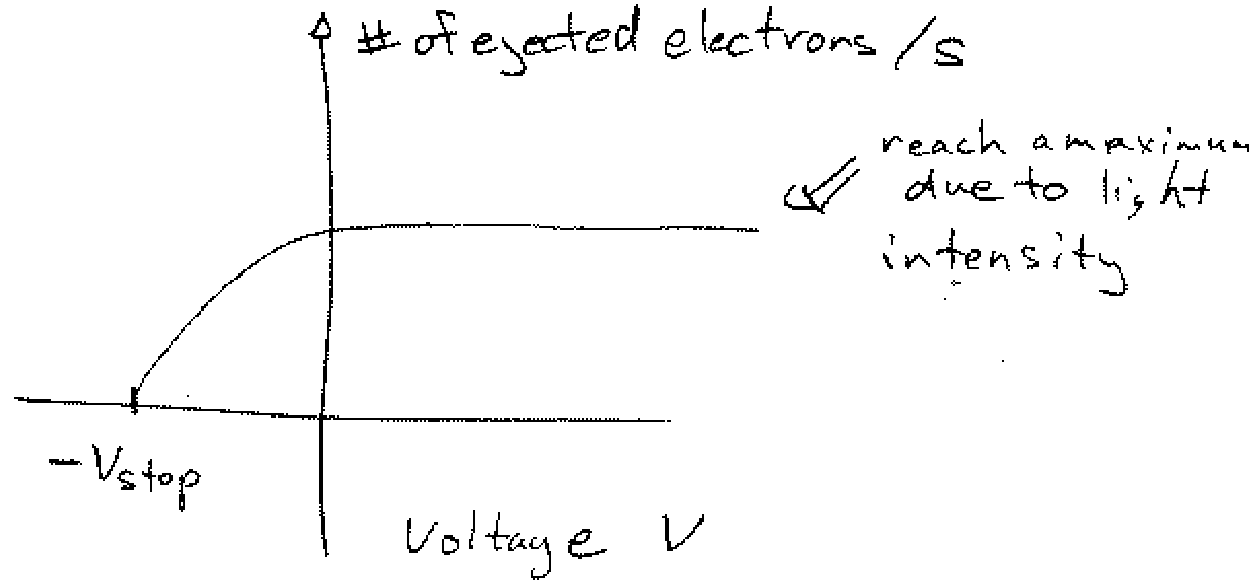

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