Image multiplier
~~written by~~
(memo by Dr. Leo Szilard)

The following is a brief description of a photo-electric device called an "Image Multiplier".

The image of an object is projected on a semi-transparent photo cathode 7. The electrons emitted from any one point of that cathode ~~contained within the image~~ are accelerated in vacuum and have to pass through two auxiliary electrodes 1 and 2, and the grid 3 before ~~hitting~~ ~~falling on~~ reaching the fluorescent screen 5.

The electrodes 1 and 2 are cylindrical tubes having a length l_1 and l_2 respectively.

A transversal grid ~~elements are~~ is provided at both ends of each tube 1 and 2.

The potential of electrode 1 is made to oscillate around a ~~voltage~~ value V_1, the value of which ~~may~~ might be chosen around 20,000 volts, whereas the ~~voltage~~ potential of the electrode 2 is allowed to oscillate around a lower ~~voltage~~ value V_2 for which ~~e.g.~~ 10,000 volts ~~may~~ might be chosen.

V_1

V_2

Insert

~~During~~ Throughout a certain time interval (the time period of multiplication) ~~during which~~ the voltage of grid 3 is kept negative with respect to the photo cathode, and electron leaving a point of the photo cathode will move parallel to the axis through the electrodes 1 and

2 and upon reaching the grid 3 ~~will be~~ being unable to pass the same, ~~whii and~~ will return through the electrodes 2 and 1 to a point on the photo cathode which will be identical with the one from which it started, if the provisions given further below are followed.

During ~~this particular~~ the period of multiplication ~~which we are considering~~ now the ~~voltage~~ potential E_1 of the ~~first~~ electrode (1) is falling, and the ~~voltage of the second~~ potential E_2 of electrode (2) is rising. The rate at which these two ~~voltages~~ potentials change is determined by two considerations:

One consideration is that we wish to keep the time constant which it takes for a photo electron which leaves the cathode to pass through electrodes 1 and 2, and to return to the photo cathode. This consideration will fix the ratio of the rate of change of the ~~2 voltages~~ potentials E_1 and E_2. The condition which has to be met from the point of view of this requirement can be written as follows:

$$\frac{d}{dt}\left[\frac{l_1}{v_1}+\frac{l_2}{v_2}\right]=0 \quad \text{or} \quad \frac{dv_1}{dt}\Big/\frac{dv_2}{dt} = -\frac{v_1^2}{v_2^2}\frac{l_2}{l_1}$$

$$\frac{m v_1^2}{2} = \frac{V_1}{300}e; \quad \frac{m v_2^2}{2} = \frac{V_2}{300}e$$

Wherein l_1 and l_2 are the length of the two tubular electrodes 1 and 2, and ~~wherein~~ v_1 and v_2 are the velocities of an electron which is accelerated ~~from voltages V1 and V2~~ by the potentials E_1 and E_2 respectively. If for example, $V_2/V_1 = 1/2$ $E_1 = 2E_2$ ~~V2 is about one half of V1~~, then $v_1^2 = 2v_2^2$ ~~V2 will be about one half of V1~~, and if we choose ~~l_1 to be~~

~~equal to a 2, we have~~ $l_1 = l_2$ we have

$$\frac{dv_1}{dt} \Big/ \frac{dv_2}{dt} = -2$$

The other ~~consideration~~ condition which we have to meet ~~determines~~ fixes the absolute rate of change of voltages ~~V1~~ E_1 and ~~V2~~ E_2 (~~at least~~ but approximately). This ~~consideration~~ ~~second~~ condition derives from the consideration that during the ~~particular~~ time period of multiplication ~~which we are discussing now~~, we want an electron that leaves the photo cathode, passes through electrodes 1 and 2, ~~is turned around near the grid 3,~~ and returns to the photo cathode to ~~xkxrx~~ arrive at ~~a~~ the photo cathode with ~~a~~ a certain velocity of a ~~xxxxx~~ about a few hundred volts, ~~which is~~ i.e. just enough to liberate the desired number of secondary electrons upon impact with the photo cathode. ~~For instance,~~ If we wish such an electron to return with ~~a voltage of v velocities~~ at a velocity corresponding to E volts to the photo cathode ~~in a~~ the condition to be met is as follows:

$$-E = 2\frac{dE_1}{dt}\frac{l_1}{v_1} + 2\frac{dE_2}{dt}\frac{l_2}{v_2}$$

By fulfilling the first of these two conditions ~~With the provisions discussed above~~, it ~~is~~ becomes possible to have during ~~a particular time~~ the "period of multiplication" ~~which we are discussing~~ an electron which leaves a point of the photo cathode and returns to the photo cathode after passing both ways through electrodes 1 and 2, ~~and returns to the photo cathode~~

~~through the same eletrodes~~ to hit exactly the same point of the photo cathode from which it originated~~, provided~~.

In order to ~~that~~ achieve this we maintain ~~This condition will hold if there is~~ a homogenous magnetic field maintained within electrodes 1 and 2, the lines of force of which are parallel to the axis of the tubular electrodes 1 and 2, and the strength of the field thus ~~having~~ a value which is determined by (potentials ~~voltages~~ E_1 and E_2 ~~of~~ and) the lengths l_1 and l_2.

An electrode moving in a~~n~~ magnetic field described a spiral; the projection of this spiral on a plane perpendicular to the magnetic field is a circle. The time which it takes for ~~an~~ the projection of the electron to complete ~~a~~ the circle is determined by the strength of the magnetic field only, and is inverse ~~in/proprtion~~ proportional to it. ~~If we~~ We may choose a value ~~of the~~ for the magnetic field ~~in this manner, then~~ so that this time should be equal to the time which an electron emitted ~~on~~ from the photo cathode takes to return to the photo cathode. (~~a time which~~ Such a choice ~~being~~ ~~this~~ choice is possible because under the provisions stated ~~above remains constant during~~ above the time which an electron takes to return to the photo cathode does not change ~~the time interval which we are discussing~~ during the period of multiplication). ~~Under these conditions,~~ If the value of the magnetic field is thus correctly chosen an electron which leaves the photo cathode goes both ways ~~through~~ electrodes 1 and 2, ~~and returns~~ ~~when~~ will hit ~~to~~ the same point of the photo cathode from which it started.

During the "period of multiplication" ~~time interval which we are considering~~, and depending on the ~~voltages used~~ (V_1 and V_2) potentials E_1 and E_2 and the velocity which we wish ~~xxxxxxx~~ the electron to have on its return to the photo cathode, we ~~may have an arbitrarily chosen~~ shall have a smaller or larger number of returns of the electron (accompanied by its secondaries) which leave a point of the photo cathode at the beginning of the time period t of multiplication $\cdot$ t ~~which we are considering~~.

This process of repeated returns comes to an end (the end of the time period of multiplication) when the grid 3 becomes positive with respect to the photo cathode. The electrons coming from the photo cathode, upon reaching the grid will then pass through the grid, will be further accelerated by an electrode 4 and will be thrown on the fluorescent screen 5.

Before reaching the fluorescent screen the electrodes have to pass through a metal film 6, which serves to prevent the light from the fluorescent screen from reaching the photo cathode.

We saw above that ~~In~~ in order to have a focusing of ~~with~~ the image on the cathode upon itself, ~~we saw that~~ we had to choose the value of the magnetic field in ~~a specific~~ the specified manner. Any multiple of this ~~image~~ value would of ~~xxxxxx~~ course also fulfill the conditions of focusing.

Insert 1.

A homogenous magnetic field is maintained within the image multiplier tube, the lines of forces of which are parallel to the axis of the tubes 1 and 2. The ~~stress~~ strength of this magnetic field is determined by considerations which will be given below, and may be considered as fixed by the potentials $\overline{V}_1$, $\overline{V}_2$, and the ~~lay~~ lengths l_1 and l_2.

Electrons which pass the grid 3 are further accelerated by the electrode 4, pass through a metal film 6 and hits the fluorescent screen 5. The metal film 6 might be kept at 30 000 Volt with respect to the cathode which is at 0.—

During that part of the cycle of operation of the image multiplier tube during which grid 3 is positive with respect to the photo cathode, the electrons leaving the photo cathode will be allowed to pass grid 3 and will reach the fluorescent screen. [As the value of the magnetic field is fixed by considerations stated farther below, magnetic focusing of the photo cathode on the fluorescent screen ~~must be~~ is achieved by ~~proper choosing~~ adjusting of the voltage of electrode 4, ~~for~~ provided that the ~~and of the voltage of the matl film 6 for any given~~ distance between the fluorescent screen and ~~the other electrodes~~ electrode 4 has been suitably chosen.]

Assuming that we have to deal with weak images projected on the photo cathode, we shall obtain only a weak image on the fluorescent screen from the electrons which pass through grid 3 during the above considered part of the cycle of operation of the image multiplier tube.

During a period τ of the cycle of operation however, grid 3 will be kept negative with respect to the cathode. This period we shall call the multiplication period.

Under the provisions specified farther below, the following will take place during the multiplication period: An electron leaving a point of the photo cathode will pass through the tubes 1 and 2, but will not pass through the grid 3, ~~but~~ and will return through the tubes 2 and 1 to the same point of the photo cathode from which it originated. It will hit that point with a certain amount of energy which can be controlled in such a manner as to give the desired number of secondary electrons. These secondaries will then again pass through tubes 1 and 2 both ways, hit again the same point of the photo cathode, produce further secondaries and so on. In this manner we thereby obtain a multiplication of any desired degree, ~~and~~ with the multiplication process ~~will end at the end of the multiplication period~~ ending when grid 3 becomes positive with respect to the cathode and the electrons approaching grid 3 are allowed to pass through that grid, and reach the fluorescent screen.

(1)

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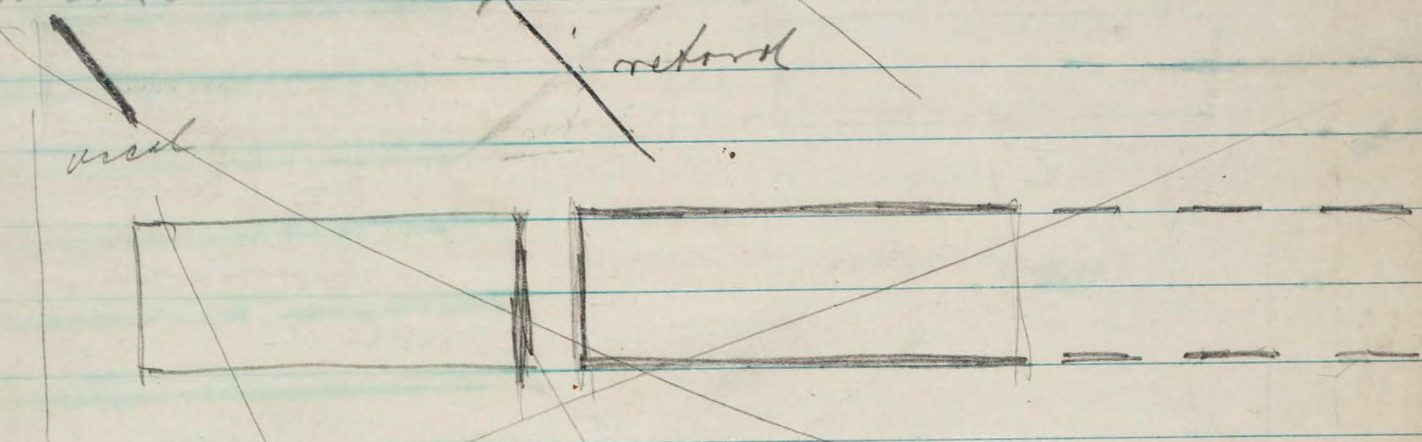
Camp Richardson (Commercialised)
Brockway Hotel (big little luxurious side)
Tamarack Lodge



$\frac{v_0}{g} = t$

$\frac{l}{v_0} + \frac{v_0}{g} = \tau$

$-\frac{l}{x^2} + \frac{1}{g} = 0 \qquad \frac{x^2}{l} = g \qquad v_0 = \sqrt{gl}$

$g(x)$

$\frac{dv}{dt} = g(x)$

$x = \int_0^t v\,dt$

$\frac{dv}{dt} = ax$

$\cancel{v = axt + c}$

$\frac{dv}{dt} = av$

$\frac{dx}{dt} = v$

$\frac{d}{dt}\left(\frac{dv}{dt}\right) =$

$y'' = ay$

$\alpha^2 e^{\alpha x} = a e^{\alpha x}$

$v = e^{\alpha x}$

$1 - ce^{\alpha t}$

$\frac{dv}{dt} = -ce^{ax}$

$v'' = -a$

$\frac{dv}{dt} = f(x)$

$y'' = \frac{df}{dx} v$

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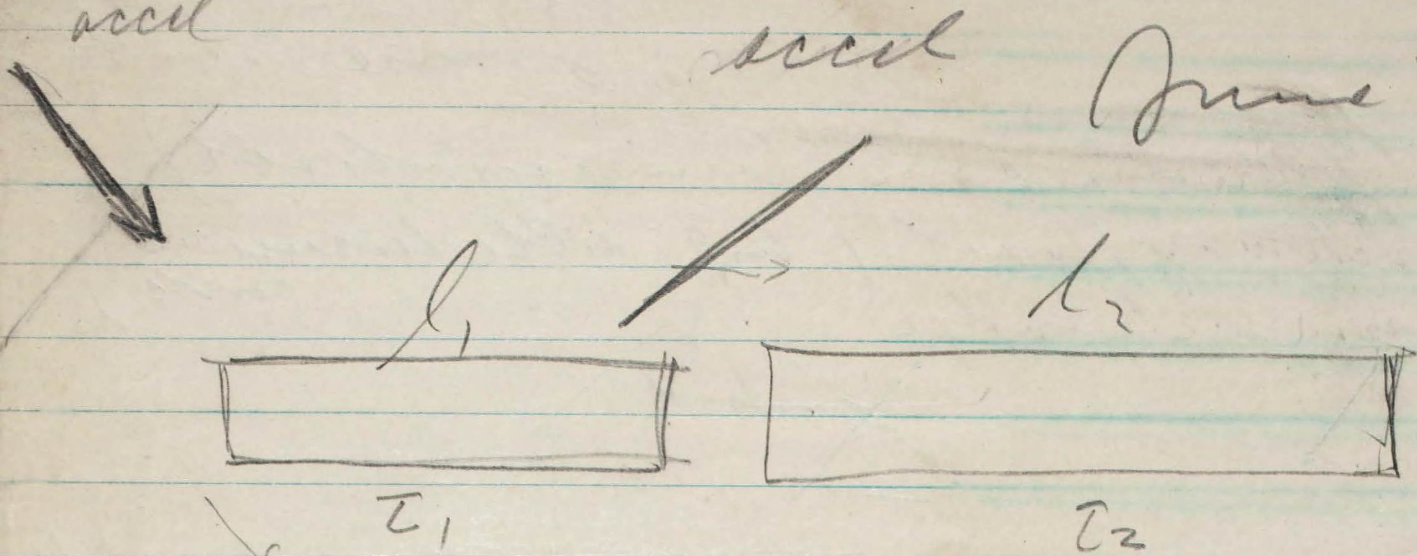
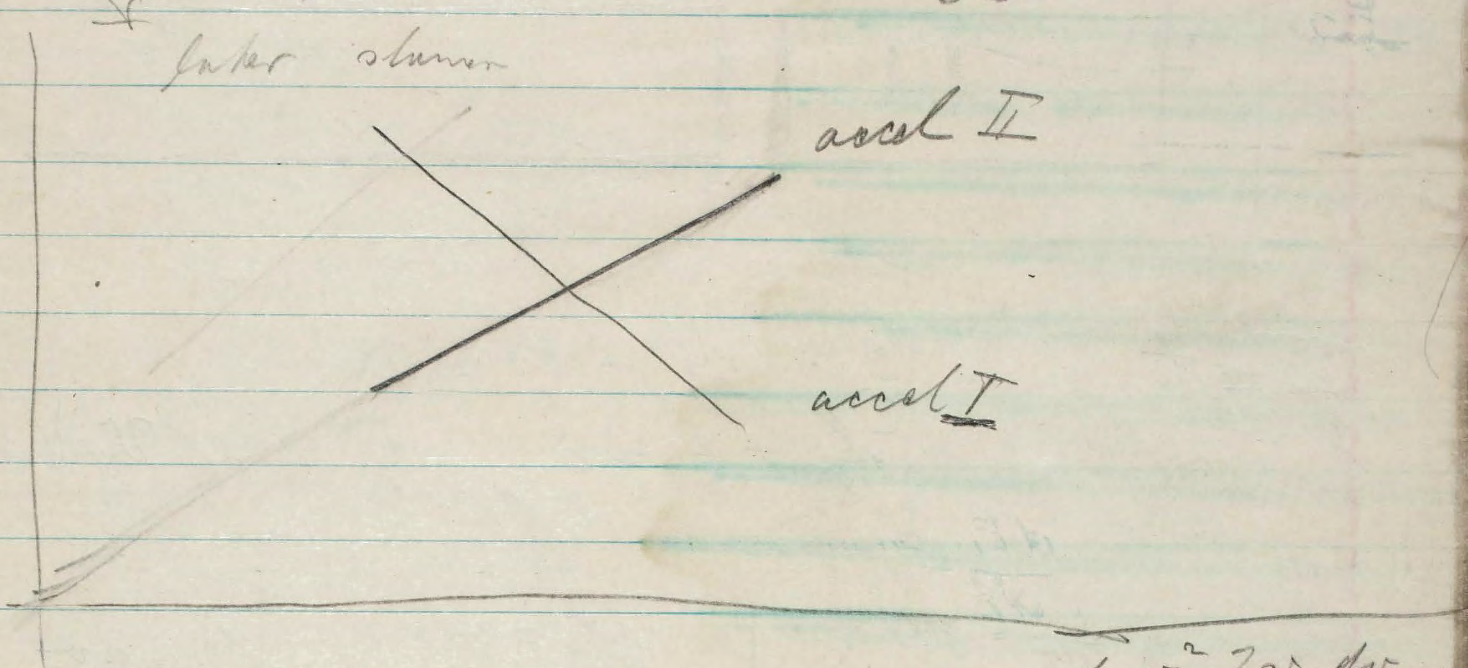




$\frac{d}{dt} v_1^2 = 2 v_1 \frac{dv_1}{dt}$

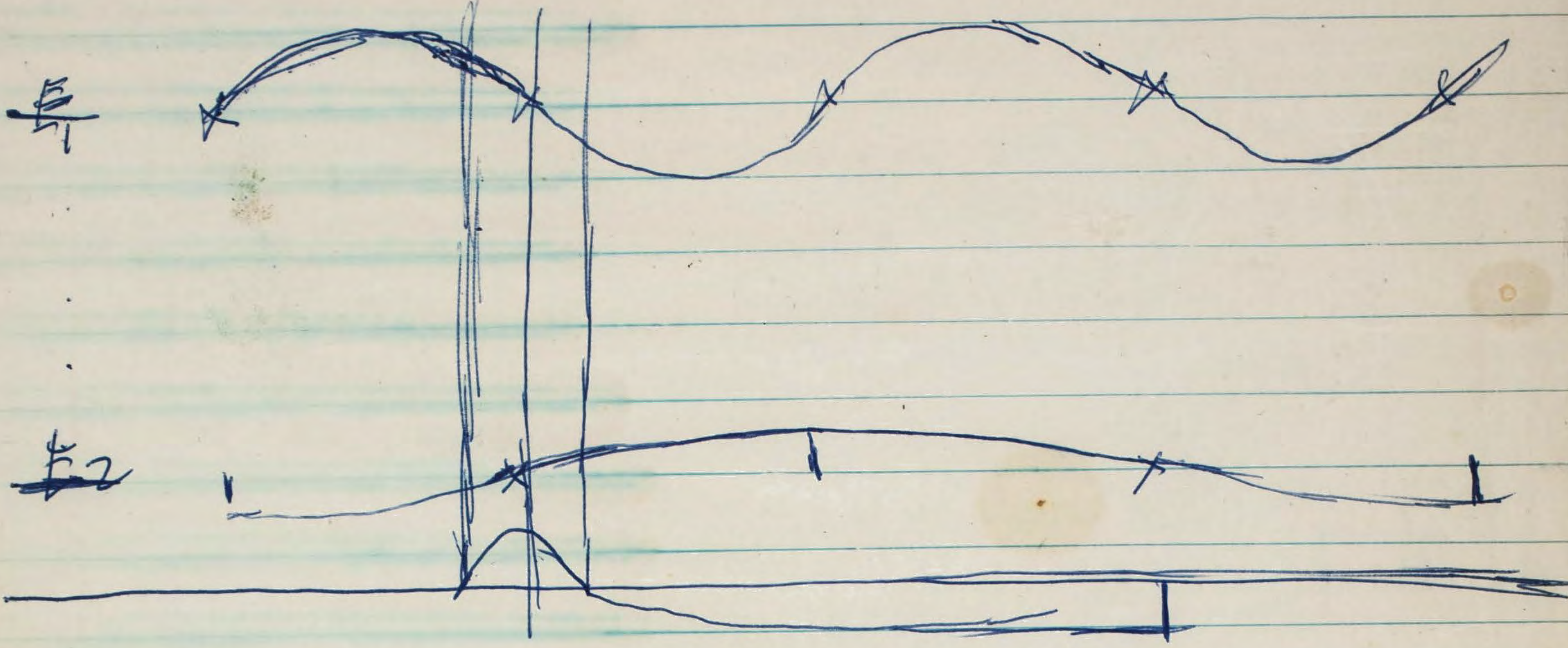
$l_1 =$ $\qquad$ $\underline{l_2 = n l_1}$ $\qquad$ $\cancel{\frac{1}{l_1}\frac{dE}{dt}}$

$v_2' \tau_2 <$

$\tau_1 = l_1 / v_1 \qquad \tau_2 = \boxed{n l_1 / v_2}$ $\qquad \frac{v_2' \, n l_1}{\cancel{n l_1}} < v_1' \tau$

$$\frac{l_1}{v_1} + \frac{n l_1}{v_2} = \tau \; \text{Const}$$

$$+ \frac{l_1 v_1'}{v_1^2} = \frac{n l_1 v_2'}{v_2^2} \qquad \frac{v_1'}{v_2'} = n \frac{v_1^2}{v_2^2}$$



$$\frac{E_1 v_1'}{\frac{v_1^2}{l_1}} = -\frac{E_2 v_2'}{\frac{v_2^2}{l_2}}$$

$$\frac{dE_1}{dt} = a v_1 \cancel{v_1'} \frac{v_1^2}{l_1} \qquad \frac{dE_1}{dt}\Big/E = b\sqrt{E}\,\frac{1}{l_1}$$

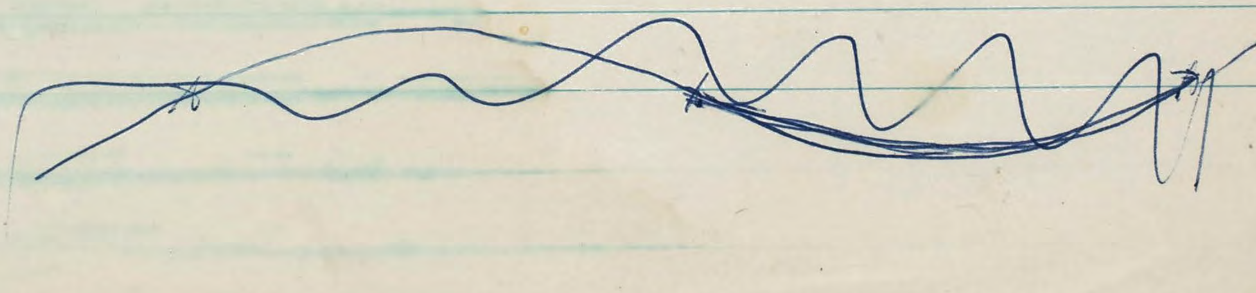
$$\frac{dE_2}{dt} = a v_2 \frac{v_2^2}{l_2} \qquad w_1 = b\frac{\sqrt{E_1}}{l_1}$$

$$w_2 = \frac{\sqrt{E_2}}{l_2}$$

to

$$w_1 = w_2 \quad \sqrt{E_1} = \frac{\sqrt{E_2}}{n}$$

$$n = \sqrt{E_2/E_1}$$



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2

$$v_2' \frac{nl}{v_2} < v_1'\left[\frac{l}{v_1}+\frac{nl}{v_2}\right]$$

$$\frac{nl}{v_2} < n\frac{v_1^2}{v_2^2}\left[\frac{l}{v_1}+\frac{nl}{v_2}\right]$$

$$\frac{l}{v_2} < \frac{l v_1}{v_2^2} + l\frac{v_1^2}{v_2^3}$$

$$1 < \frac{v_1}{v_2} + \frac{n v_1^2}{v_2^2}$$

$$\frac{v_1'}{v_2'} = n\frac{v_1^2}{v_2^2}$$

$$\frac{v_2' v_2}{n l_1} < v_1'\left[\frac{l_1}{v_1}+\frac{n l_1}{v_2}\right]$$

$$\frac{v_2}{n l_1} < \frac{v_1'}{v_2'}\left[\frac{l_1}{v_1}+\frac{n l_1}{v_2}\right]$$

$$\frac{v_2}{n l_1} < n\frac{v_1^2}{v_2^2}\left[\frac{l_1}{v_1}+\frac{n l_1}{v_2}\right]$$

$$\frac{v_2^2}{n l_1} < \frac{n l_1}{v_2}\left[v_1+\frac{n}{v_2}\right]$$

$$v_2^3 = (n l)^2\left[v_1+\frac{n}{v_2}\right]$$

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conditions of "resonance"

l

$$\tau_1 = \frac{2l_0}{v_0}$$

$$\tau_2 = \frac{2\pi r}{v_x}$$

$$\frac{v_x^2}{r} = \frac{e v_x H}{mc}$$

$$\frac{v_x}{v_y} = \frac{e}{m}\frac{H}{c} r$$

$$\tau_2 = \frac{2\pi c}{\frac{e}{m} H} \sim \frac{6 \times 3\,10^{10}}{\cancel{1.77\,10^{7}}\ \ 4 \times 10^{+17} H} = \boxed{4.5\ 10^{-7}}$$

$$\frac{1}{6 \times 10^{23}} \frac{1}{1000} = \frac{1}{1.08} \frac{5 \cdot 10^{-10}}{10^{27}} = \cancel{\ }$$

$$4.5\ 10^{-10}\ \ 0.9\ 10^{27} = 4\ 10^{+17}$$

$$\tau_1 = \frac{2l}{v_0} \qquad \cancel{\ } v_0 = \sqrt{\frac{\cancel{\ }eV}{300}}$$

$$\tau_1 = \frac{2l}{\sqrt{\frac{2 e/m V}{300}}} = \frac{2\pi c}{\frac{e}{m} H}$$

$$\frac{l}{\sqrt{V}} = \frac{\pi c\ \cancel{\ }\ \sqrt{2}}{\sqrt{\frac{e}{m}} H\ \ \sqrt{300}}$$

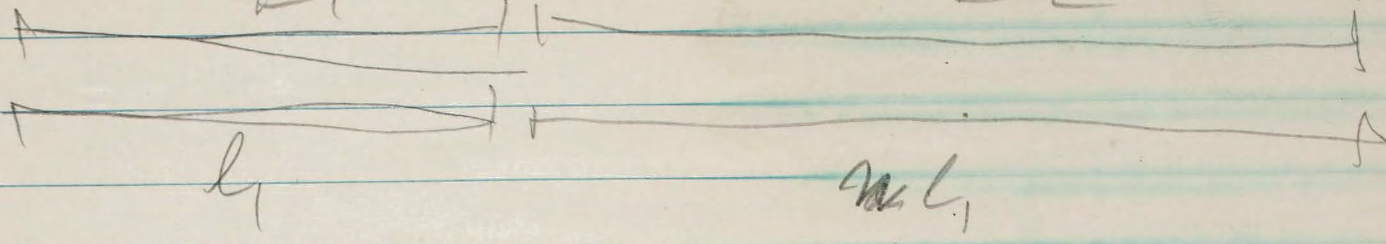
$$\frac{H}{\sqrt{V}} = \frac{1}{l} \frac{3 \times 10^{10}\ \ \pi \sqrt{2} / \cancel{\sqrt{300}}}{\underbrace{6.3 \times 10^{8} \times 17.3}_{103}} \approx \frac{3\pi/\sqrt{2}}{l} = \frac{6.7}{l}$$

or for $l = 6.7$ cm

$V = 10^4$

$H = 10^2$ talks ord for larger l, H smaller

Check



$$\tau = 2\left[\frac{l_1}{v_1} + \frac{l_2}{v_2}\right]$$

$$\frac{l_1 v_1'}{v_1^2} = -\frac{l_2 v_2'}{v_2^2}$$

$$\frac{v_1'}{v_2'} = -\frac{v_1^2}{v_2^2} n$$

If v_1' is negative
v_2' is positive

we should have deceleration

$$2 v_2 \quad v_2' \quad \frac{nl}{v_2} <$$

$E = \frac{m v_2^2}{2}$

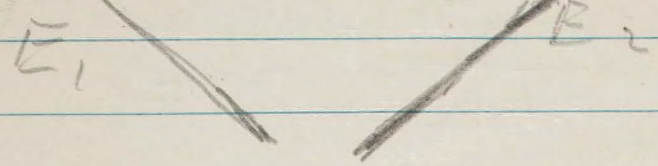
$dE = m \underline{v_2 \Delta v_2}$

$$E_1 = \frac{m v_1^2}{2} \qquad \Delta E_1 = v_1 \Delta v_1$$

$$E_2 = \frac{m v_2^2}{2} \qquad \Delta E_2 = v_2 \Delta v_2$$

$$E_1(t_a) - E_1(t_b) + E_2(t_b) - E_2(t_c) + E_1(t_c) - E_1(t_d)$$

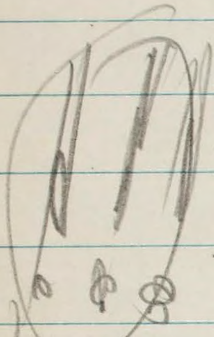
found is $\Delta E_1 t_1 + \Delta E_2 t_2$



and a_1) retard Pot. increase

$\Delta E_1 t_1 = \cancel{v_1} v_1' \frac{l}{\cancel{v_1}}$

$\Delta E_2 t_2 = v_2'$



$-[l v_1' + n v_2' l]$ is gain in Energy

$-l\left[\frac{v_1'}{v_2'} + n\right] v_2' =$ gain $= + l n \left[\frac{v_1^2}{v_2^2} - 1\right] v_2'$

but $\frac{v_1'}{v_2'} = -n \frac{v_1^2}{v_2^2}$

is condition for constancy

$l(n v_2' + v_1') = \varepsilon < 0$

is condition for gain

$$l n |v_2'| = \varepsilon + |v_1'|$$

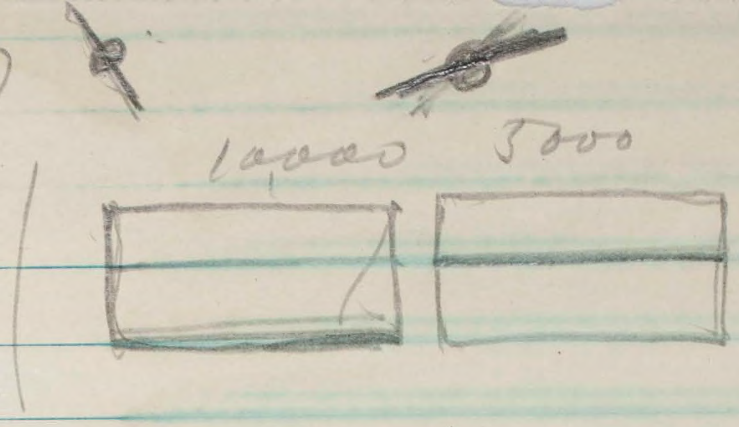
$$n = \frac{\varepsilon}{l} \left|\frac{v_1'}{v_2'}\right|$$

$$n = \frac{\varepsilon}{l} \left| n \frac{v_1^2}{v_2^2} \right|$$

$$1 = \frac{\varepsilon}{l}$$

6

for Inst. n=1

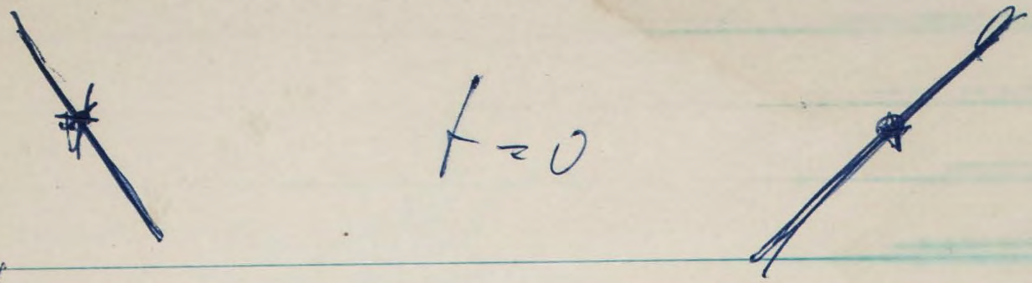


$$v_1' = -2v_2'$$

$$dE_1 = v_1 v_1' \qquad dE_2 = v_2 v_2'$$

$$2[v_1' - v_2']$$

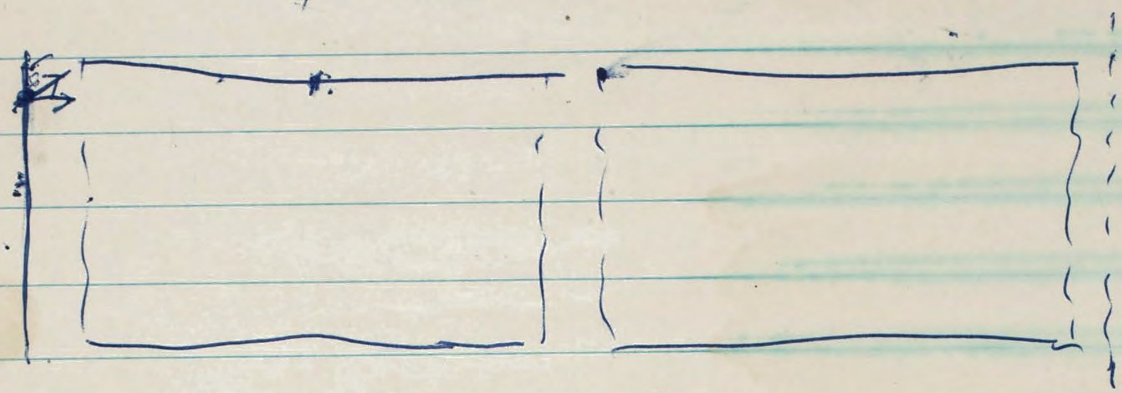
$$2\left|\frac{v_1'}{v_2'} - 1\right| v_2'$$



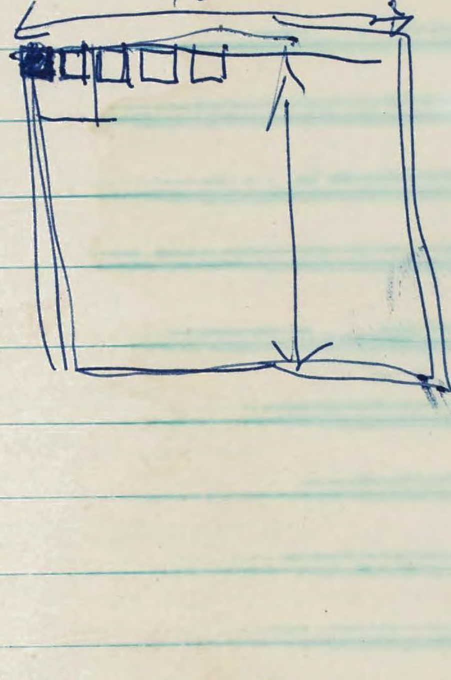
$t = 0$

t_{-}

10,000 5000



4,0 10 $\underline{2,500}$



~~40~~

(nt) refresh | T looks

$\frac{(nt)}{T} < 20\%$

τ lowering out a multiplication

mass time $\tau/5$ ~~[illegible]~~ or faster

τ say $1/4\ 10^{-3}$ sec / (possibly ten times faster but not urgent)

$$\frac{l_1}{v_1} + \frac{l_2}{v_2}$$

$$\frac{l_1}{v_1^2} v_1' = - \frac{l_2}{v_2^2} v_2'$$

$$\frac{v_1'}{v_2'} = \frac{v_1^2}{v_2} \frac{l_2}{l_1}$$

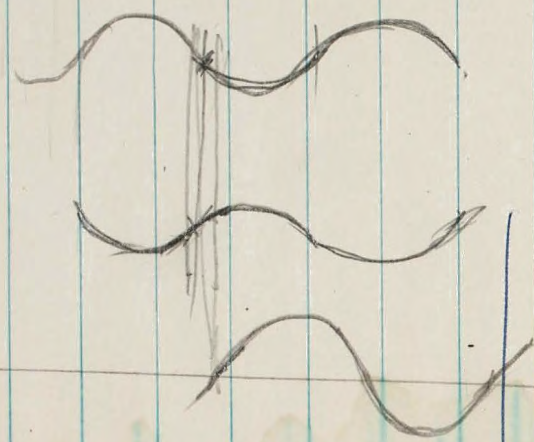
$$\frac{dV_1}{dt} = \frac{2m}{h} v_1 \frac{dv_1}{dt}$$

$$\frac{dE_1}{dt} = v_1 v_1'$$

$$\frac{F'}{E_2'} =$$

$$\frac{dE_1}{dt}\Big/E = \sqrt{E}$$

$$\frac{l_1}{v_1} + \frac{l_2}{v_2} = \text{konst}$$

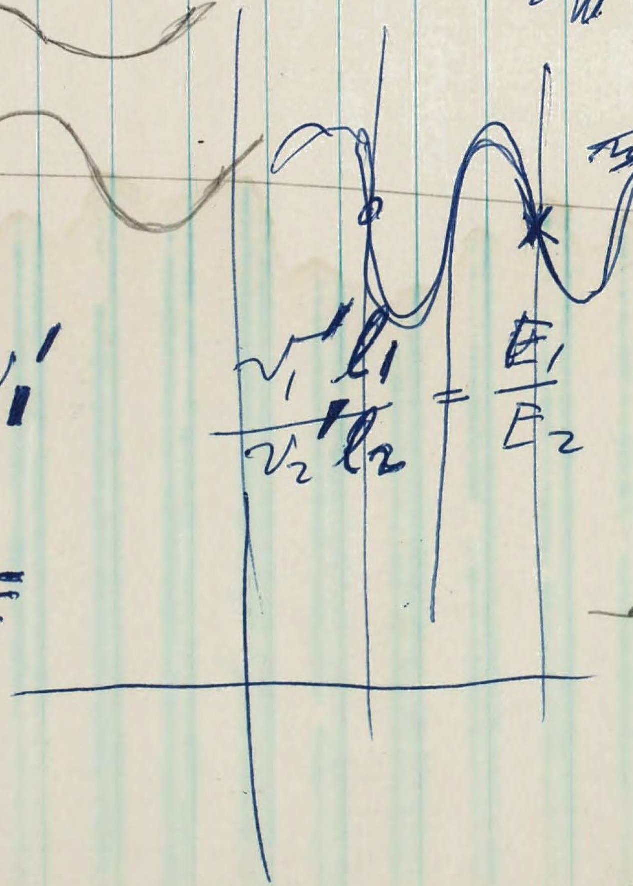


$$\frac{v_1' l_1}{v_1^2} = -\frac{v_2'}{v_2^2} l_2$$

20,000 : 5000

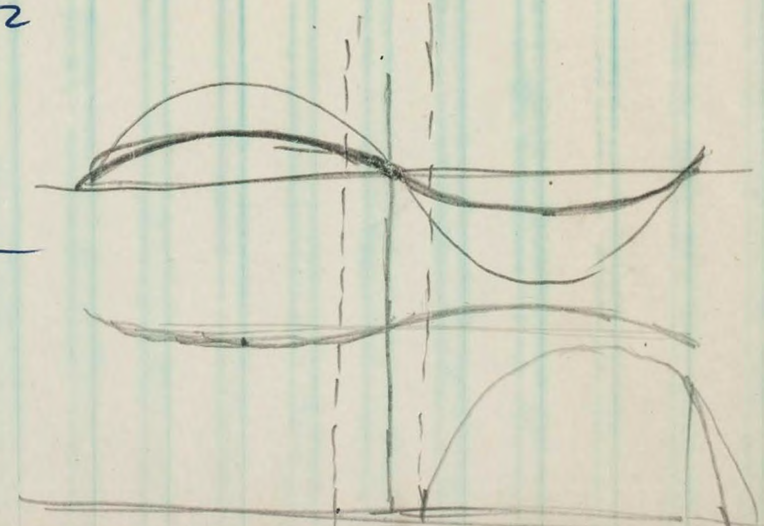
$$v_1^2 = a V_1$$

$$2 v_1 v_1' = a V_1'$$



v_1'

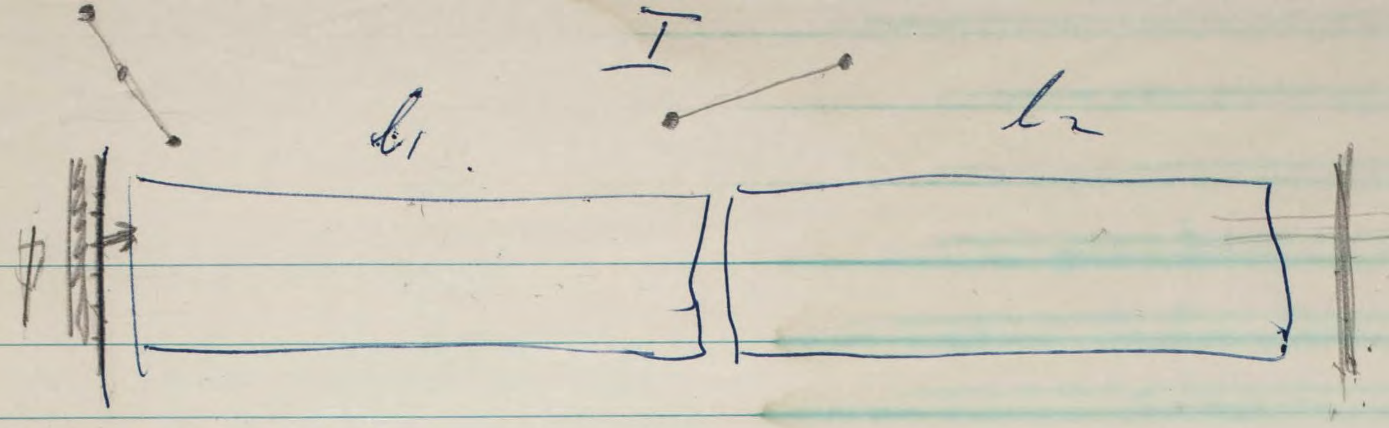
$$\frac{v_1' l_1}{v_2' l_2} = \frac{E_1}{E_2}$$



$$a E_1' = v_1 v_1' E$$

$$\frac{E'}{E} = v.$$

I



total time

$$2\left(\frac{l_1}{v_1}+\frac{l_2}{v_2}\right)$$

if this is constant

$$\frac{l_1 v_1'}{v_1^2} = -\frac{l_2 v_2'}{v_2^2}$$

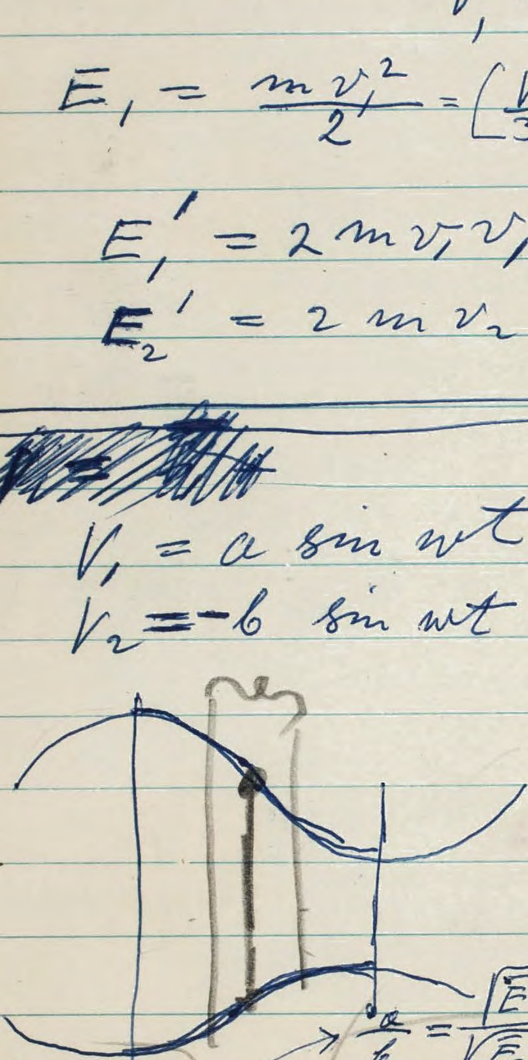
$$E_1 = \frac{m v_1^2}{2} = \left[\frac{V_1}{300} e\right]$$

$$E_1' = 2 m v_1 v_1'$$

$$E_2' = 2 m v_2 v_2'$$

$$V_1 = a \sin wt + \overline{V_1}$$

$$V_2 = -b \sin wt + \overline{V_2}$$



$$\frac{a}{b} = \frac{\sqrt{\bar{E}_1}}{\sqrt{\bar{E}_2}}\,\frac{\bar{E}_1}{\bar{E}_2}\,\frac{l_2}{l_1}$$

$$\frac{a}{b} = \frac{v_1}{v_2}\,\frac{\bar{E}_1}{\bar{E}_2}\,\frac{l_2}{l_1}$$

or

$$-\frac{v_1'}{v_2'} = \frac{l_2}{l_1}\,\frac{v_1^2}{v_2^2} = \frac{l_2}{l_1}\,\frac{E_1}{E_2}$$

and working for

$$v_1' = \frac{E_1'}{2 m v_1}$$

$$-\frac{E_1'}{E_2'}\,\frac{v_2}{v_1} = \frac{l_2}{l_1}\,\frac{E_1}{E_2} \quad \text{Nrl}$$

or $-\frac{E_1'}{E_2'} \Big/ \frac{E_2'}{E} = \frac{v_1}{v_2}\,\frac{l_2}{l_1}$

or $\frac{E'}{E_1} = -\frac{E_2'}{E_2}$ if

$$\frac{l_2}{l_1} = \frac{v_2}{v_1} = \frac{\sqrt{E_2}}{\sqrt{E_1}}$$

In the special case of $\frac{l_2}{l_1} = \frac{\sqrt{E_2}}{\sqrt{E_1}}$

$$\frac{a}{b} = \frac{E_1}{E_2}$$

or if we wish to make $a = b$ or $a/b = 1$
we must choose

$$\frac{l_1}{l_2} = \left(\frac{E_1}{E_2}\right)^{3/2}$$

Energy with which electron returns to cathode

$$-E = \frac{2l_1}{v_1}\frac{dE_1}{dt} + \frac{2l_2}{v_2}\frac{dE_2}{dt}$$

Nr 1 $\quad -\frac{E_1'}{E_2'}\,\frac{v_2}{v_1} = \frac{l_2}{l_1}\,\frac{E_1}{E_2}$ or

$$+\frac{E_1'}{v_1}l_1 = -\frac{E_2' l_2}{v_2}\,\frac{E_1}{E_2}$$

so $\boxed{+E = 2\left[\frac{E_1}{E_2} - 1\right]\frac{dE_2}{dt}\,\frac{l_2}{v_2}}$ No 2

$\underline{III}$

Focussing condition for cathode

$$\frac{Hve}{c} = \frac{mv^2}{r}$$

$$\frac{2\pi r}{v} = \frac{2\pi}{e/m} \quad c\cancel{f} = \text{time} = \frac{2\pi c}{e/m\, H}$$

$$\cancel{\frac{2\pi\, 3\, 10^{10} \times 10^{-27}}{4.5\, 10^{-10}\, H} = \frac{1}{H}\sqrt{3\, 10^{27}}}$$

$$\frac{1}{H}\frac{2\pi c}{e/m} = 2\left(\frac{l_1}{v_1} + \frac{l_2}{v_2}\right)$$

$$\frac{mv_1^2}{2} = \frac{V_1 e}{300}\,; \quad v_1 = \left(\frac{V_1}{150}\, e/m\right)^{1/2}$$

writing $\frac{l_1}{v_1} + \frac{l_2}{v_2} = \alpha \frac{l_1}{v_1}$ $\qquad \alpha > 1$

$$\frac{\pi c}{H}\frac{1}{e/m} = \frac{\alpha l_1}{\sqrt{e/m\; V_1/150}}$$

or

$$\frac{H\, e/m}{\pi c} = \frac{\sqrt{e/m}\sqrt{V_1}}{\sqrt{150}\,\alpha l_1}$$

$$\boxed{\frac{4.5\, 10^{-10}}{10^{-27}} = 4.5\, 10 \qquad \frac{1}{6\, 10^{23} \times 1800} = 0.9\, 10^{-27}}$$

$$\frac{H}{\sqrt{V_1}} = \frac{1}{\alpha l_1}\frac{\pi c}{\sqrt{e/m}\sqrt{150}} \approx \frac{1}{\alpha l_1}\frac{9.5\, 10^{10}}{7 \times 10^{8}\ \sqrt{150}} = \frac{1}{\alpha l_1}\frac{9.5 \times 10^{10}}{12.2 \times 7 \times 10^{8}}$$

$$\frac{H}{\sqrt{V_1}} \approx \frac{1}{\alpha l_1}\frac{9.5 \times 10^{10}}{0.85\ 10^{10}} = \frac{11}{\alpha l_1} \qquad e/m = 5\, 10^{17}$$

for $V_1 = 10000$ Volts

$$H = 100 \times \frac{11}{\alpha l_1} \qquad \text{for } l_1 = 11 \text{ cm} \quad H = 100\,\frac{1}{\alpha}$$

IV

v linear

repeat

$$2\left\{\frac{l_1}{v_1} + \frac{l_2}{v_2}\right\}$$

$$2\left[\frac{l_1}{v_1^2}(v_1')^2 + \frac{l_2}{v_2^2}(v_2')^2\right]$$

$$d\tau = \frac{d^2\tau}{dt^2}(\tau)^2$$

$$\Delta\tau = 2\left[\quad\right]\left[\cancel{4}\,\frac{l_1}{v_1}\right]^2$$

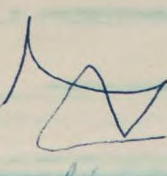
$$\frac{\Delta\tau}{4\frac{l_1}{v_1}} = 2\left[\frac{l_1}{v_1^2}(v_1')^2 + \frac{l_2}{v_2^2}(v_2')^2\right] 4\frac{l_1}{v_1}$$

cm

sec

$$\frac{1}{v_1^2}\; v_1' \qquad x^{-2} \qquad -2x^{-3} v_1'$$

IV



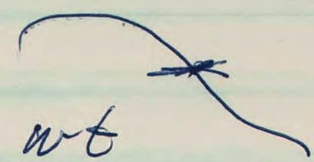
for line

second order

$$\frac{l_1}{v_1} + \frac{l_2}{v_2}$$

$$\frac{l_1}{v_1^2} v_1' + \frac{l_2}{v_2^2} v_2' = 0$$

$$-\frac{l_1}{v_1^2} v_1' v_1' - \frac{l_2}{v_2^2} (v_2')^2$$



$= a \sin wt$

$$\frac{l_1}{v_1^2}\left(v_1'' - (v_1')^2\right) + \frac{l_2}{v_2}(\quad) = 0 \quad b \sin wt$$

$= a w \cos wt$

$$v_1 = \beta\sqrt{E_1}$$

$$v_1' = \beta \tfrac{1}{2}\frac{1}{\sqrt{E_1}}\, dE_1/dt$$

$$(v_1')^2 = \beta^2 \tfrac{1}{4}\frac{1}{E_1}\left(dE/dt\right)^2$$

$$l_1 \frac{(v_1')^2}{v_2} = l_1\left(\frac{dE_1}{dt}\right)^2 \frac{1}{4}\,\frac{1}{E_1^2}$$

assume both times equal

$$\frac{l_1}{v_1} = \frac{l_2}{v_2} \qquad \frac{l_1}{l_2} = \frac{\sqrt{E_2}}{\sqrt{E_1}}$$

$$\frac{dE_1}{dt}\frac{1}{E_1} = \frac{dE_2}{dt}\frac{1}{E_2}$$

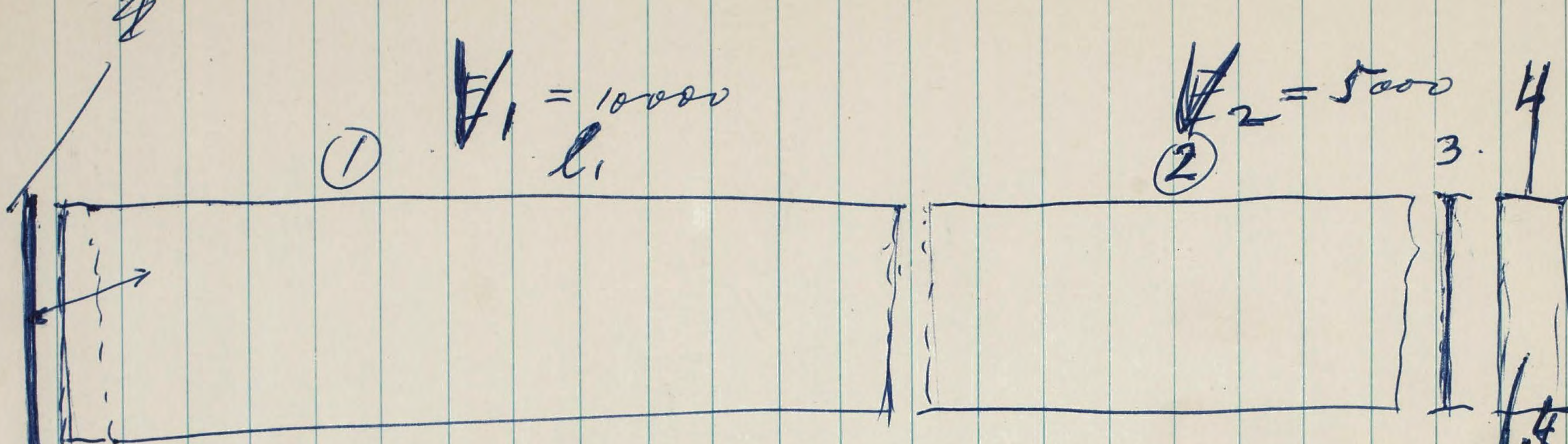
$$\frac{\Delta T}{\frac{l_1}{v_1} + \frac{l_2}{v_2}} = \left\{ l_1\left(\frac{dE_1}{dt}\right)^2 \frac{1}{4}\frac{1}{E_1^2} + l_2\left(\frac{dE_2}{dt}\right)^2 \frac{1}{4}\frac{1}{E_2^2} \right\} \left(\frac{l_1}{v_1} + \frac{l_2}{v_2}\right)$$

$$= \left[l_1\left(\frac{dE_1}{dt}\Big/E_1\right)^2 + l_2\left(\frac{dE_2}{dt}\Big/E_2\right)^2 \right] \frac{l_2}{v_2}$$

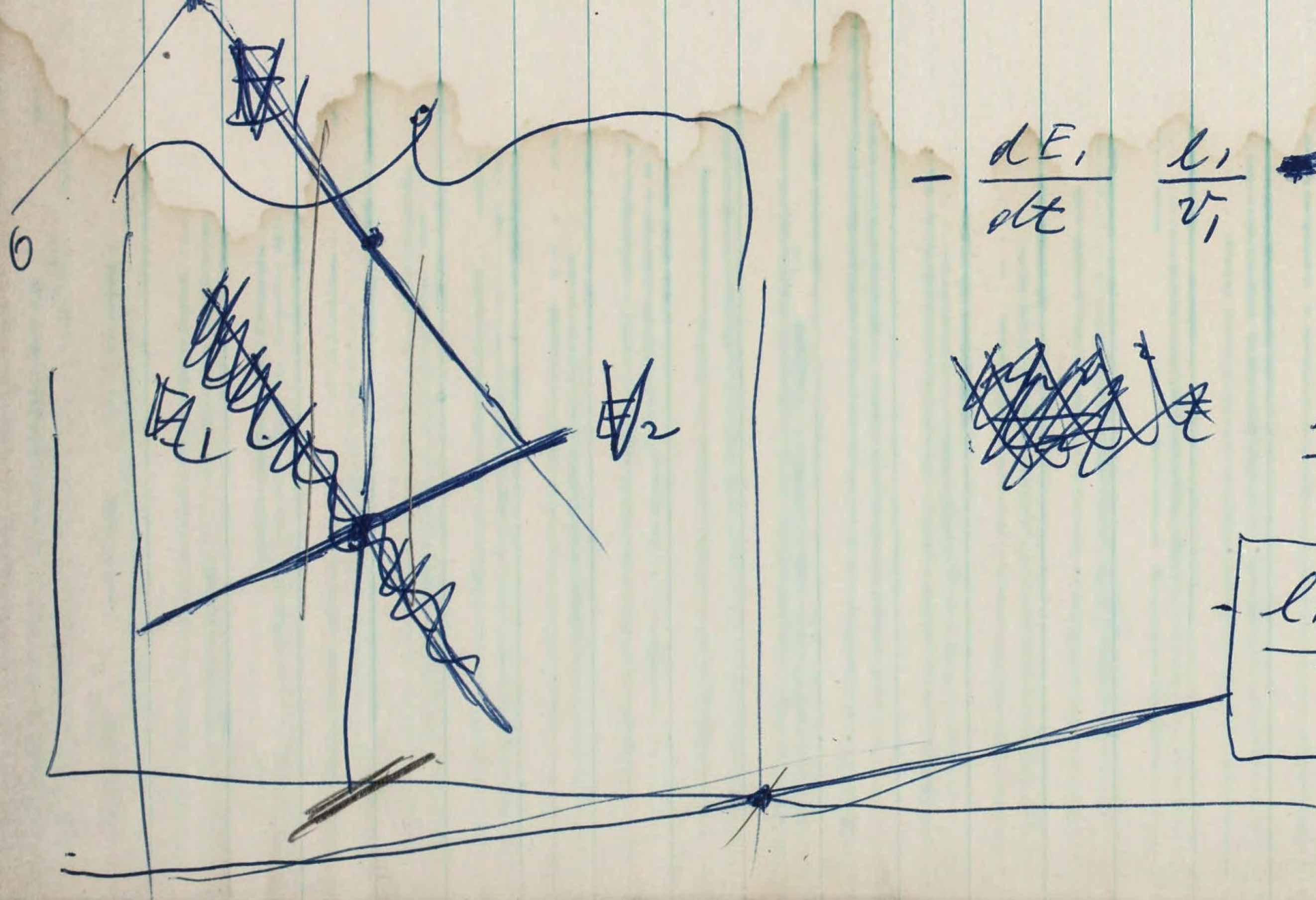
$$(l_1 + l_2)\left(\frac{dE_2}{dt}\Big/E\right)^2 \frac{l_2}{v_2}$$

assume $\frac{E_1}{E_2} = 2$

$E/E_2 = 1/50$



$$-\frac{dE_1}{dt}\,\frac{l_1}{v_1} = \frac{dE_2}{dt}\,\frac{l_2}{v_2}$$



$$\frac{l_1}{v_1} + \frac{l_2}{v_2} = \text{Const.}$$

$$\boxed{-\frac{l_1 v_1'}{v_1^2} = -\frac{l_2 v_2'}{v_2^2}}$$

VI

$$\frac{1}{2}\left[\frac{1}{v_1^2} - \frac{1}{v_2^2}\right] \frac{l_1 v_1'}{E_1} aw +$$

$$+ 2\frac{l_1}{v_1}\frac{(v_1')^2}{v_2^2} + 2\frac{l_2}{v_2}\frac{(v_2')^2}{v_2^2}$$

$$\frac{1}{E}\frac{v_1'}{v_1^2} = \cancel{\beta}\frac{1}{\sqrt{E}}\ \cancel{v_1^2}\ \frac{1}{E}\ \frac{1}{\beta \cancel{E}} = \frac{1}{v E^2}$$

$$\frac{1}{v}\frac{[v_1']^2}{v_2^2} = \frac{\beta/E}{\beta^2 E}\frac{1}{v} = \frac{1}{\beta E^2}\frac{1}{v}$$

$$\frac{m v^2}{2} = E$$

$$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2}{m}}$$

Hubel Jerome

a sin wt $\cancel{+}$ $E_0 = E\, a w^2 \sin wt$

$$v = \beta\sqrt{E_0 + a \sin wt}$$

$$\frac{dv}{dt} = \beta \frac{1}{2} \frac{1}{\sqrt{E_0 + a \sin wt}}\; a w \cos wt$$

$$\frac{dv'}{dt} = \beta \frac{1}{2} \frac{1}{\sqrt{E_0 + a \sin wt}}\; a w^2 \sin wt +$$

$$\beta \frac{1}{4} \frac{1}{\left(\sqrt{E_0 + a \sin wt}\right)^3} \left[a w \cos wt\right]^2$$

$$\frac{d^2 v_1}{dt^2} = -\frac{dv_1}{dt}\frac{1}{2}\frac{1}{E_1}\left[a w\right]$$

$$\frac{l_1}{v_1} + \frac{l_2}{v_2}$$

$$\boxed{\begin{aligned} \frac{l_1 v_1'}{v_1^2} &= -l_2 \frac{v_2'}{v_2^2} \\ l_1 \frac{v_1'}{E_1} &= -l_2 \frac{v_2'}{E_2} \end{aligned}}$$

$$-\left[\frac{l_1}{v_1^2} v_1' + \frac{l_2}{v_2^2} v_2'\right]$$

$$+2\frac{l_1 (v_1')^2}{v_1^3}$$

$$+\left[\frac{l_1}{v_1^2} v_1' \frac{1}{2}\frac{1}{E_1} + \frac{l_2}{v_2^2} v_2' \frac{1}{2}\frac{1}{E_2}\right] a w$$

pos $\frac{1}{2}\left[\frac{1}{v_1^2} - \frac{1}{v_2^2}\right] \underset{\text{neg}}{a w} + 2\frac{l_1}{v_1}\frac{(v_1')^2}{v_1^2} + \frac{2 l_2}{v_2}\frac{(v_2')^2}{v_2^2}$

IV

repeat → II

for $v_1'' = 0$
$v_2'' = 0$

$\frac{l_1}{v_2} = \frac{l_2}{v_2}$

$$T = 2\left[\frac{l_1}{v_1} + \frac{l_2}{v_2}\right]$$

$$\frac{dT}{dt} = -2\left[\frac{l_1 v_1'}{v_1^2} + \frac{l_2 v_2'}{v_2^2}\right]$$

$$\frac{dT}{dt^2} = +2\times 2\left[\frac{l_1}{v_1^3}(v_1')^2 + \frac{l_2}{v_2^3}(v_2')^2\right]$$

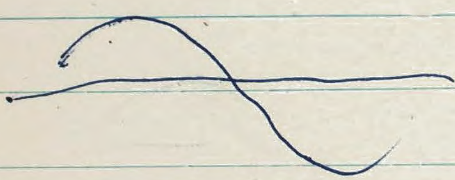
$$\frac{\Delta T}{4\frac{l_1}{v_1}} = 2\times 2\left[\frac{l_1}{v_1^3}(v_1')^2 + \frac{l_2}{v_2^3}(v_2')^2\right] 4\frac{l_1}{v_1}$$

$$16\left[\frac{l_1}{v_1}\frac{(v_1')^2}{v_1^2} + \frac{l_2}{v_2}\frac{(v_2')^2}{v_2}\right)$$

$$16\left[\frac{l_1}{v_1}\right]^2\left(\frac{(v_1')^2}{v_1^2} + \frac{(v_2')^2}{v_2^2}\right)$$

$$v = \beta\sqrt{E} \qquad \frac{dv}{dt} = \beta \tfrac{1}{2} \frac{dE/dt}{E^{1/2}}$$

$$\tfrac{1}{2}\left[\frac{dE_1/dt}{E_1}\right]^2$$



$$\frac{\Delta T}{4\frac{l_1}{v_1}} = 16\ \frac{l_1}{v_1}\ \frac{\frac{dE_1}{dt}}{E_1}\ \frac{l_1}{v_1}\ \frac{\frac{dE_1}{dt}}{E_1} \sim 16\ 10^{-4}$$

$1.6\ 10^{-3}$

$E_1 = 2E_2$

$$\frac{1}{50} = \frac{E}{E_2} = 2\ \frac{E}{E_2}\ 2\ \frac{dE_2}{dt}\Big/E_2\ \frac{l_2}{v_2}$$

$$\frac{\frac{dE_2}{dt}}{E_2}\ \frac{l_2}{v_2} = \frac{1}{100}$$

Louis E. Hosch
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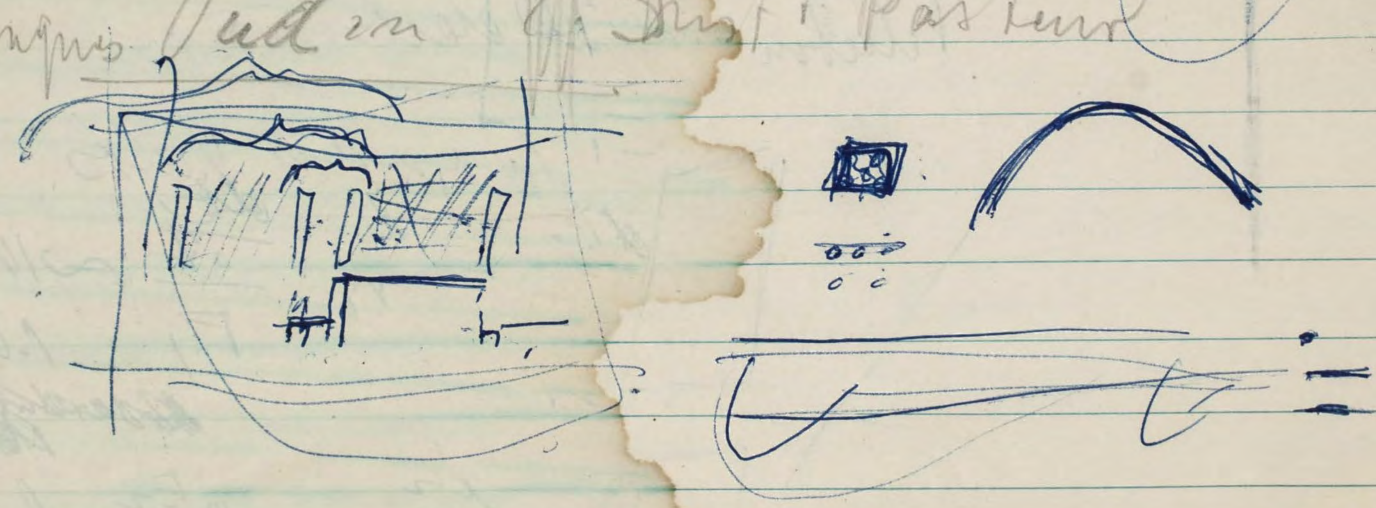
49

Ingres Oud in Ghent : Pasteur



10^{-1} ~~60~~ 10^{-6} sec 100 10^{-6} Amp x | 10^{4} Volt

500

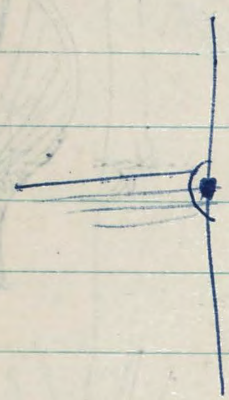
10^{-11} Amp sec

$10^{-11}\ 3\ 10^{9} = 3\ 10^{-2}$ e Shot

10 %

$5\ 10^{-10}$

$\frac{3}{5}\ 10^{8}$ el



100

10^{5}

X100

10^{-6} Amp 1000 Volt

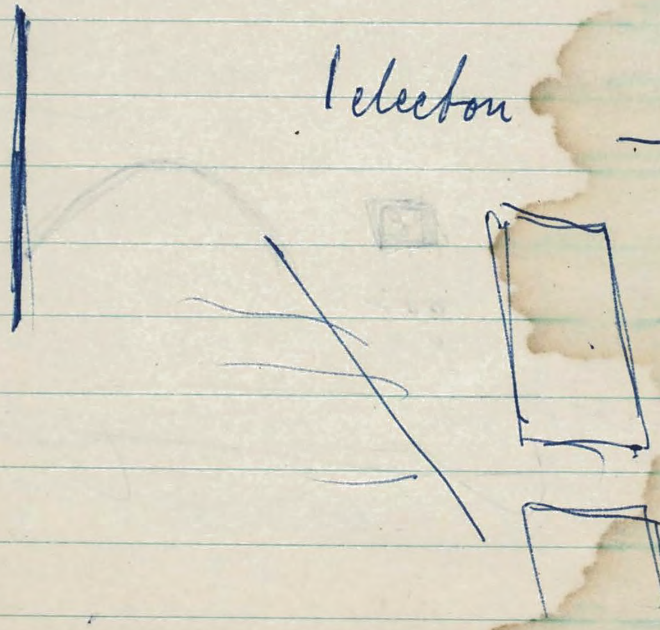
~~$3\ 10^{9}$ bout~~

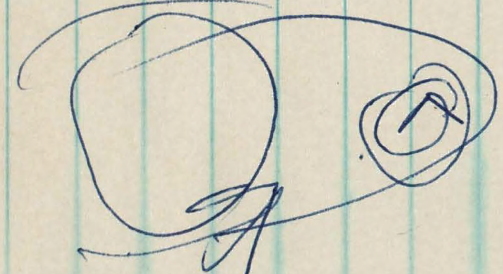
$3\ 10^{9}$ el Shot /sec

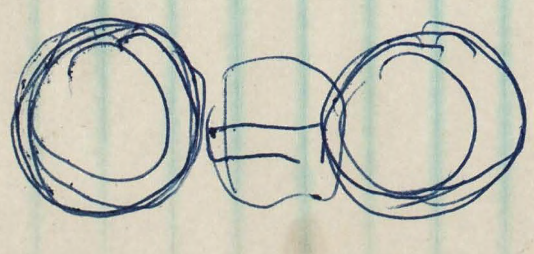
1 electron

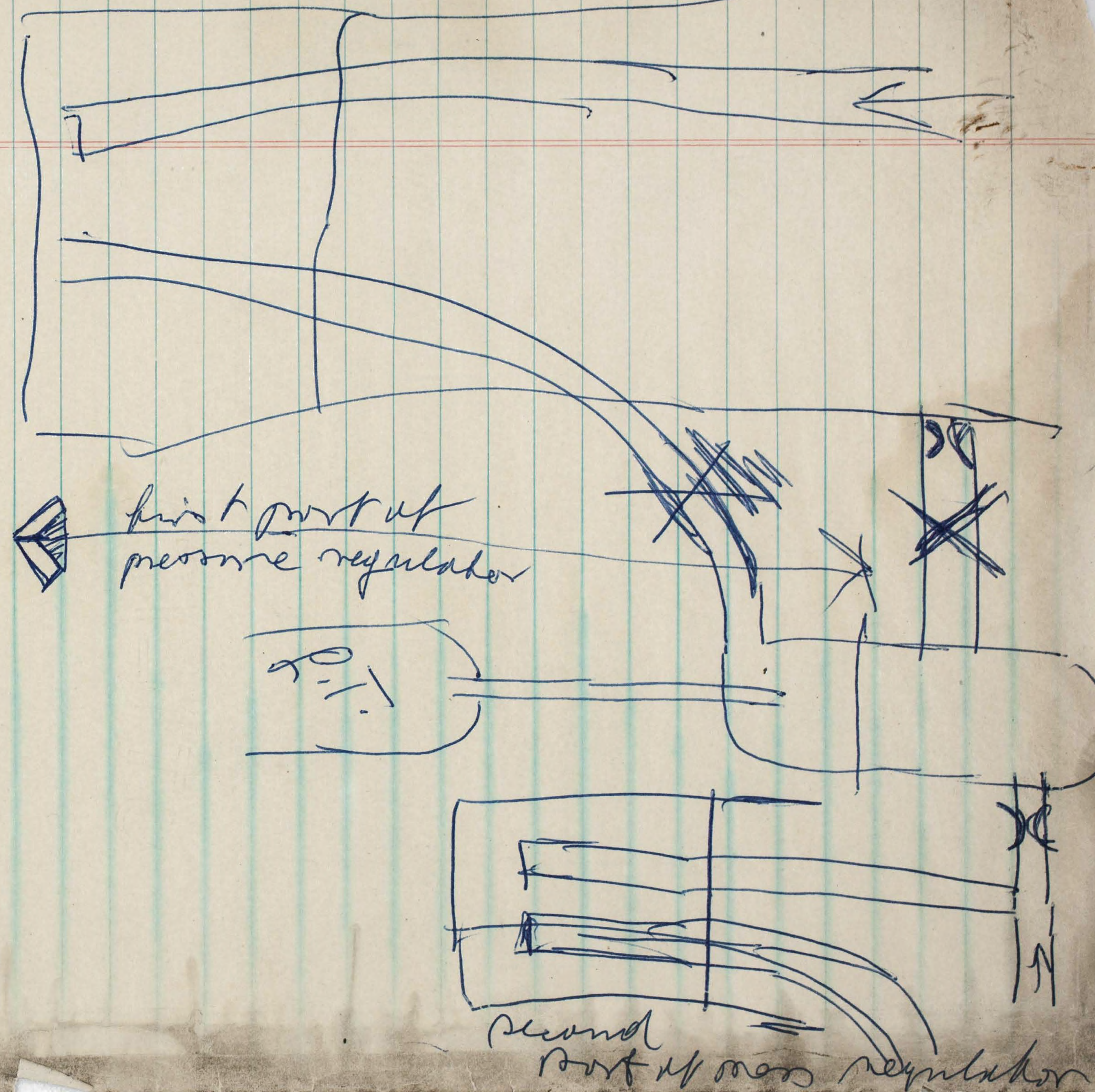
10 electrons

1000000 Volts








first part of
pressure regulator
second
Part of mass regulator