St ard

GENERAL ATOMIC
DIVISION OF GENERAL DYNAMICS CORPORATION
POST OFFICE BOX 608
SAN DIEGO 12, CALIFORNIA

GA GENERAL ATOMIC

To Bethe
Leo Szilard
1155 E 57th Str.
Chicago 37 Ill

ON BOOK

NARROW RULED MARGINAL

SIZE 11 x 8½ No. P-2713

Bettle

Lloyd R Zumwalt Ex 608
Ulrich Merten Ex 565

Not fused $UO_2$ 1000°C $Btu\,h^{-1}\,ft^{-1}\,F^{-1} \approx 1$

$$\frac{~~30~~\ 500\,cal \;(252\,cal)}{3600\ ~~900~~\ 30}/C°\,sec = \frac{50}{10^4} = \frac{5}{1000}$$

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Don Childers
331

drafting room

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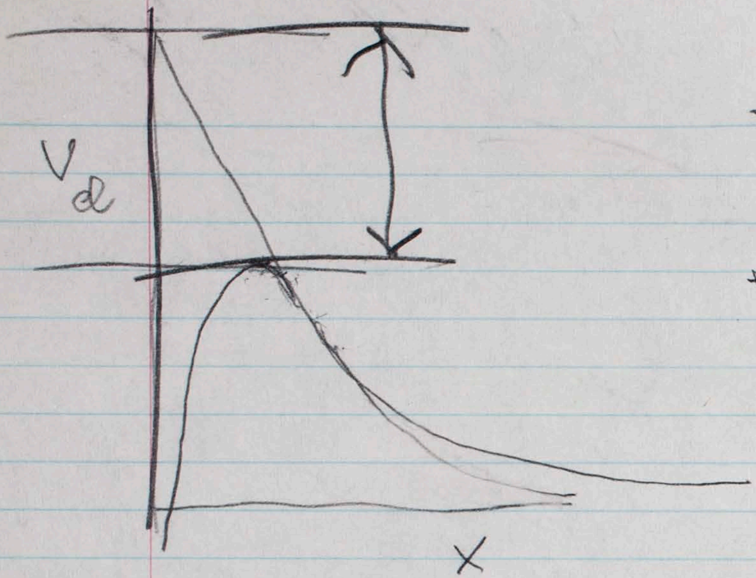



$$e\varphi - \frac{e^2}{4x}$$

$$\nabla^2\varphi = -4\pi\rho$$

$$= -4\pi e(N_i - N_e)$$

$$= +4\pi e N_{i0}\left(e^{e\varphi/kT} - e^{-e\varphi/kT}\right)$$

Expand $+\frac{8\pi e^2}{kT} N_{i0}\,\varphi$ $\quad e\varphi/kT \ll 1$

$$\varphi \sim \overbrace{\exp -\sqrt{\frac{8\pi e^2}{kT} N_{i0}}\; x}^{-\sqrt{2}\;x/\lambda_D}$$ large $x$

$$\frac{d(\ )}{dx}\quad \frac{d^2(\varphi e/kT)}{dx^2} = \frac{4\pi e^2 N_{i0}}{kT}\, e^{e\varphi/kT}\, \frac{d(e\varphi/kT)}{dx}$$

$$\frac{1}{2}\left(\frac{de\varphi/kT}{dx}\right)^2 = \lambda_D^{-2}\left(e^{e\varphi/kT} + \text{const.}\right)$$ small $x$

$e\varphi/kT \gg 1$

$$\frac{d\varphi}{dx} = -\frac{\sqrt{2}}{\lambda_D}\,\varphi$$ large $x$

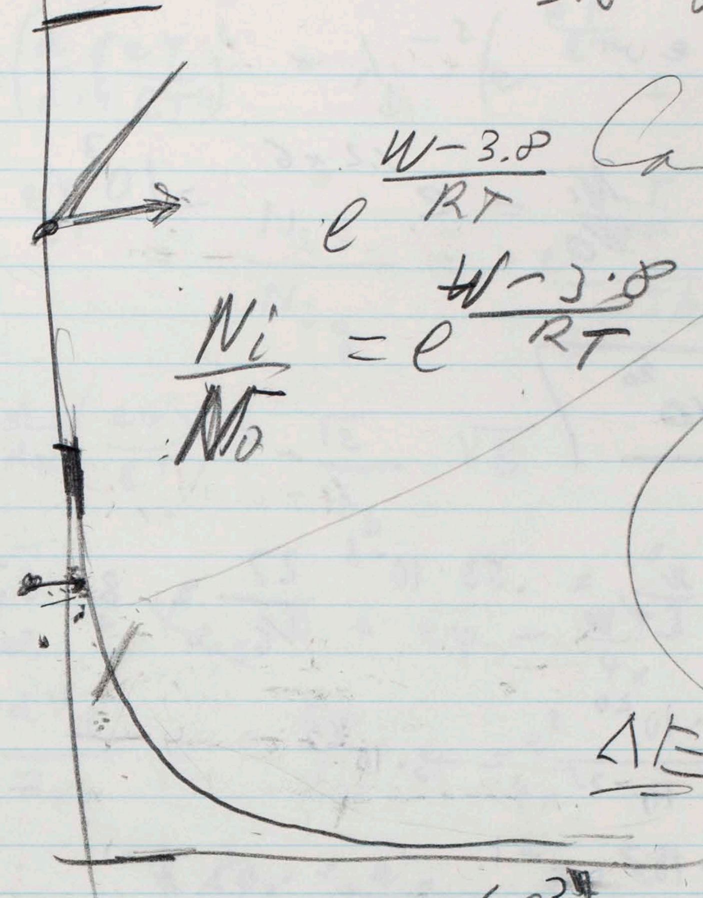
$$\frac{1}{2}(\ )^2 = \frac{1}{\lambda_D^2}\left(\frac{e\varphi}{kT}\right)^2$$

$$= \frac{1}{\lambda_D^2}\left[e^{\frac{e\varphi}{kT}} + \text{const.}\right]$$ true for $e\varphi/kT = 1$

const. $= -e + 1$

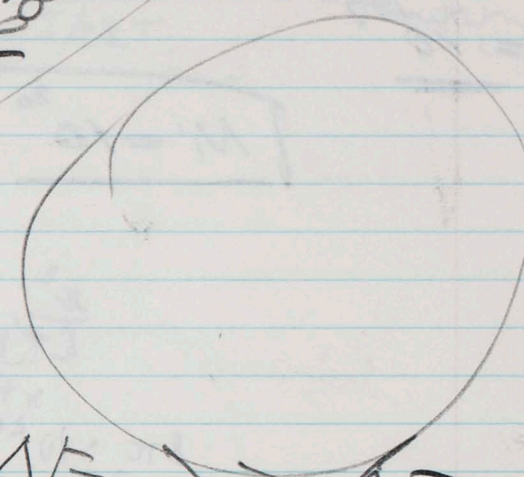
W

3.8 Volt



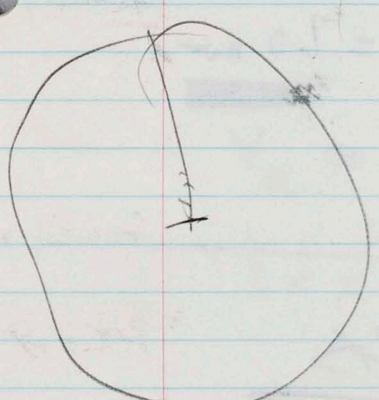
$e^{\frac{W-3.8}{RT}}$ Cal

$\frac{N_i}{N_0} = e^{\frac{W-3.8}{RT}}$



$\Delta E >> RT$

$\Delta E = \frac{1}{2}\frac{e^2}{\lambda_D}$



$\lambda_D = \sqrt{\frac{RT}{N_i e^2}}$

$\varphi(x)$ e

$N_i \sim e^{e\varphi/RT}$ $\quad N_e \sim e^{-e\varphi/RT}$

$e\varphi - \frac{e^2}{4x}$ $\quad -e\varphi - \frac{e^2}{4x}$

$\lambda = \frac{\hbar}{\sqrt{2mW}}$ $\quad e^{-x/\lambda}$

$\hbar = \frac{h}{2\pi}$

$kT = \frac{1}{6}$ ev

W

$5 - 3.8 \qquad \frac{N_i}{N_0} = e^{1.2 \times 6} = 10^3$

$N_0 = \underline{\underline{10^{17}}}$

$$\boxed{N_i = 10^{20}}$$

$$\frac{e^2}{kT} = .53 \cdot 10^{-8}\ \frac{27}{1/6} = 8 \cdot 10^{-7} \text{ cm}$$

$$\frac{8\pi \cdot 10^{20}}{8 \cdot 10^{-7}} = 3 \cdot 10^{27} \qquad \sqrt[4]{\ } \quad = .7 \cdot 10^{7} \text{ cm}^{-1}$$

$$e^2 \cdot .7 \cdot 10^{7} \text{ cm}^{-1} = e^2 \cdot .07 \text{ Å}^{-1}$$

$$= \frac{e^2}{a_0} \cdot .07 \cdot .53 = .07 \cdot .53 \cdot 27 = \underline{1.0 \text{ ev}}$$

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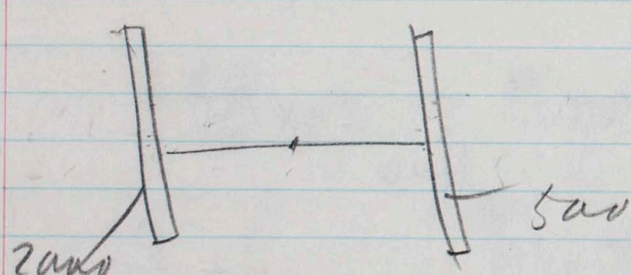



2 Volts

$$kT \int \ln \frac{T}{T_D}$$

H

$$\frac{1}{2}\left(\frac{d}{dx}\left(\frac{e\varphi}{kT}\right)\right)^2 = \lambda_D^{-2}\left(e^{\frac{e\varphi}{kT}} + 1 - e\right)$$

$$e^{\frac{e\varphi}{kT}} = \frac{N_{is}}{N_{ig}} = \frac{e^{\frac{w-I}{kT}}}{e^{-I/2kT}\dots} = B \text{ known} \gg 1$$

$$\frac{d}{dx}\left(\frac{e\varphi}{kT}\right) = -\frac{\sqrt{2}}{\lambda_D}\sqrt{B}$$

$$V_{el} = \cancel{V_{els}}\ 0 + e\varphi - \frac{e^2}{4x}$$

$$\frac{dV_{el}}{dx} = -e\frac{d\varphi}{dx} + \frac{e^2}{4x^2} = 0$$

$$4x^2 = \frac{e^2}{e\frac{d\varphi}{dx}} = \frac{e^2\lambda_D}{\sqrt{2B}\,kT}$$

$$V_{el} \approx e\frac{d\varphi}{dx}x - \frac{e^2}{4x} = -\frac{e^2}{2x}$$

$$2x = \frac{e}{\sqrt[4]{2B}}\sqrt{\frac{\lambda_D}{kT}}$$

$$V_{el} = -e\sqrt[4]{2B}\sqrt{\frac{kT}{\lambda_D}}$$

$$\lambda_D^{-1} = \sqrt{\frac{4\pi e^2 N_{i0}}{kT}}$$

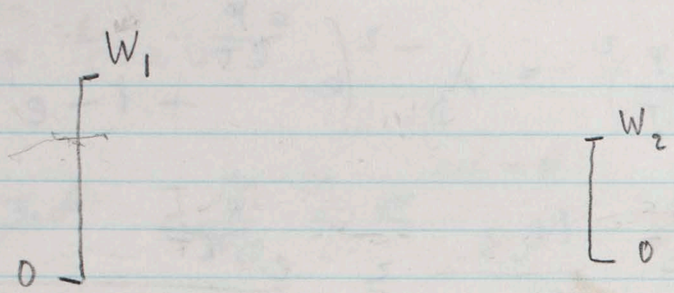
$$= -\sqrt[4]{2B\ 4\pi e^6 N_{i0}\, kT}$$

$$= -e^2\sqrt[4]{8\pi \underbrace{N_{i0}}\,\frac{kT}{e^2}\underbrace{B}}$$

$$= -e^2\sqrt[4]{8\pi\frac{kT}{e^2}N_{is}}$$

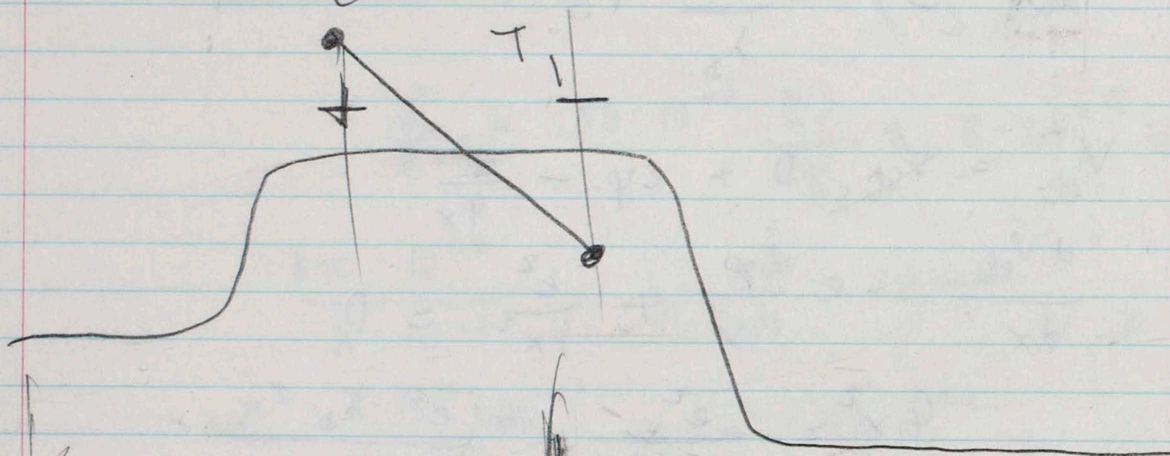
$\frac{kT}{e^2}$

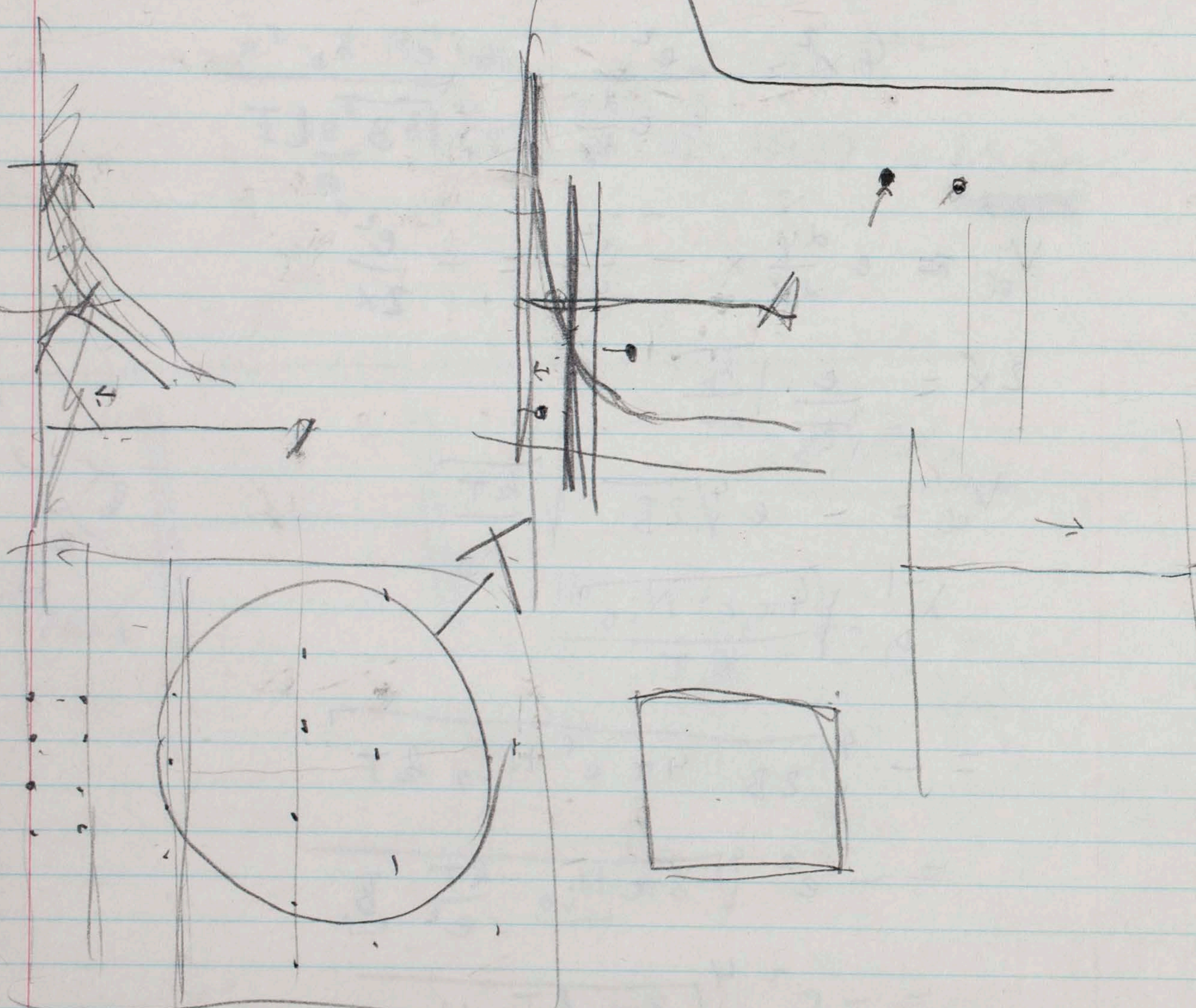
$N_{is}$



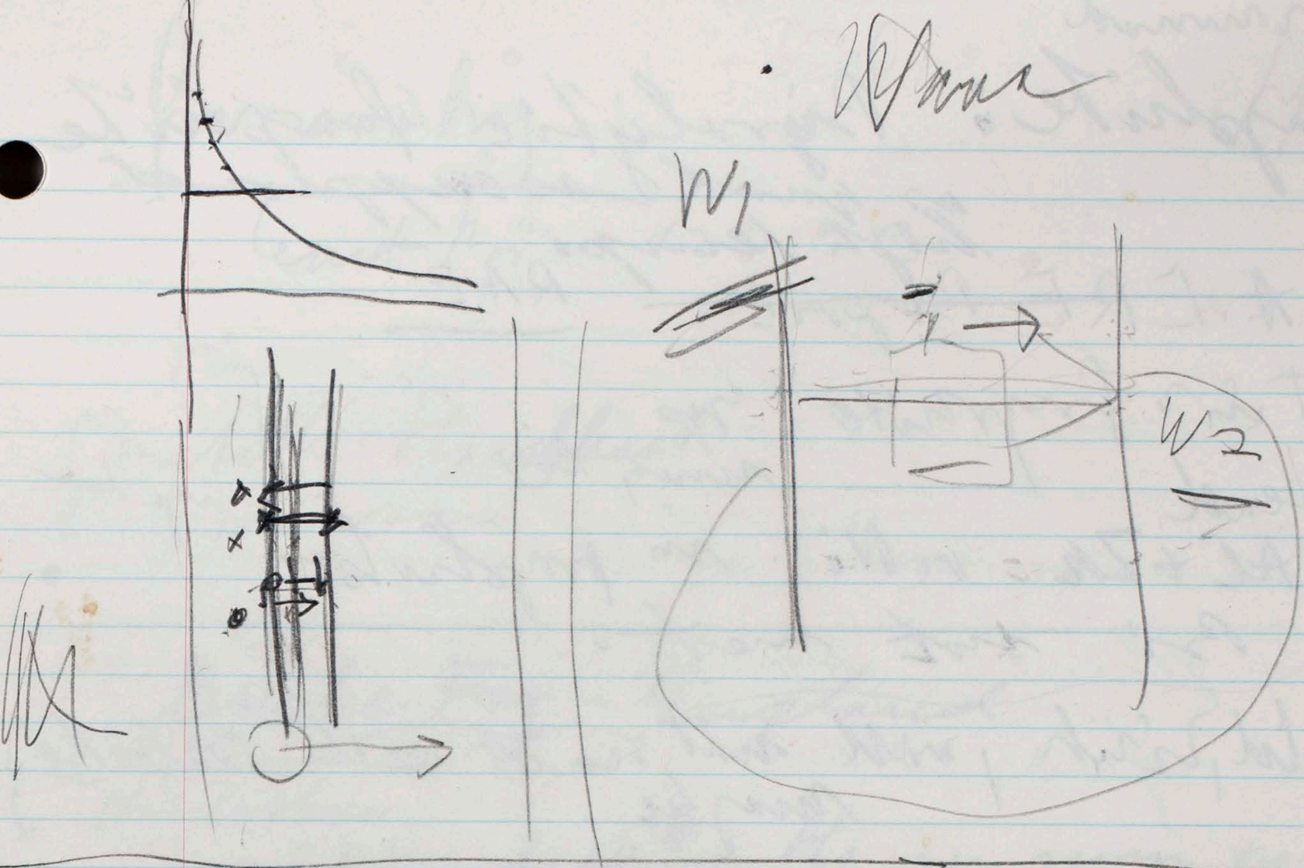

$e^{-W_1/kT_1}$ $e^{-W_2/kT_2}$

$e^{-V/kT}$



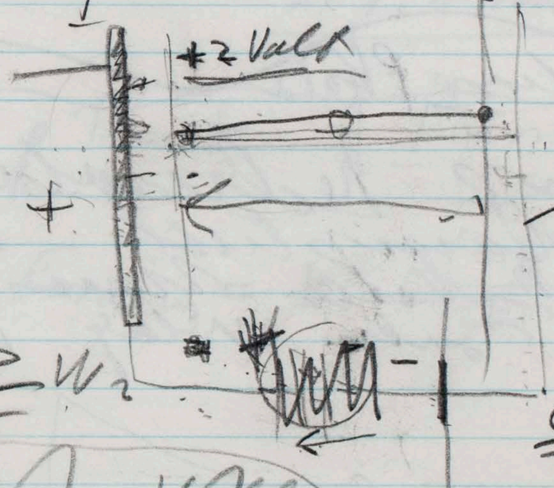
Wave




$V = 2$ Volts

$W_1$

$+\Delta$




$W_2$

$W_2 > W_1$

$W_2 - W_1 =$

$\Delta$

$W_1 + 1 \geq W_2$

$0$

$\Delta - 2$ Volt

$\Delta - 2$ Volt

$e^{-\frac{W}{kT}}$

$\Delta - 1$ Volt

$kT \ln \frac{I}{I_0}$

Simmod

Graphite: Pyrolytic graphite as good as copper at high temp.

~~A.ERE Report~~ RAE

Tried graphite yes
Lead may be
Al + Zn or Ni in graphite
Bi not met.

up to

Cd, Zinc, will not react with carbide
maybe

Pu C Sealing Plate
High Temp Technology
I.E. Campbell
Battelle Memorial
John Wiley 1956

Pu Oxide
$UO_2$

$CaO_2 + ZnO$ 15%
2400 C°
el cond : thermal cond
0.005 at room C known

yes
C° 385 700

$1 \times 10^{12}$ $10^{10}$ $2.2 \times 10$

C ± 1200, $3.6 \cdot 10^{-2}$
2000 $10^6$

Gurinsky 530 M.

Cent Pt ~ 125 °C

Tin

{ Metals Handbook
Hansen

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Burke Fry - England

Nat. Carbon

CEY $3 \times 10^{-4}$ cc He per min per cm$^2$
at 1 Atm.

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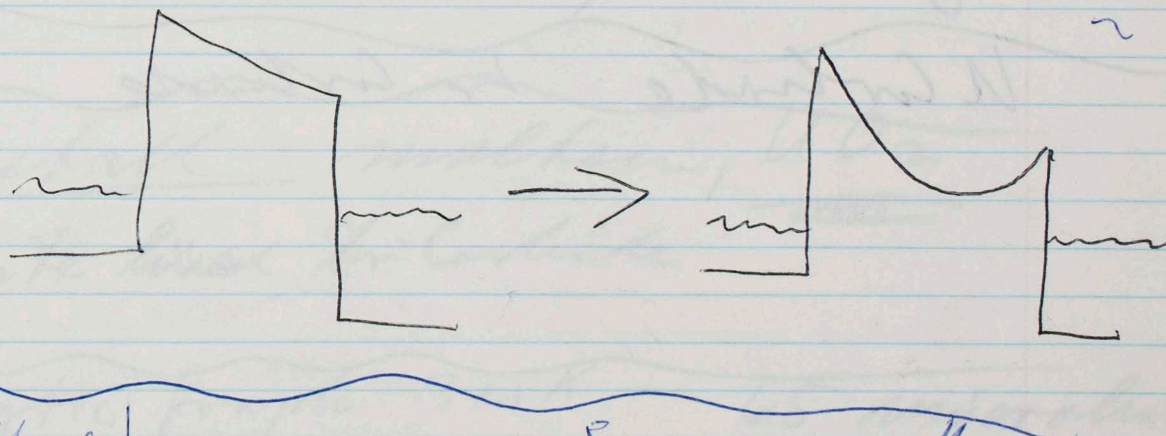
Lewis & Reeder [Plasma Anode]

$$E_{addition} = kT \ln\left[\frac{nh^3}{2(2\pi m k T)^{3/2}}\right] = \frac{3}{2} kT \ln\left(\frac{T_d}{T}\right)$$



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Exp limit for
Gas pressure
$10^{-6}$ Hg gag

$\frac{32}{100}$ m/m $\frac{32}{1000}$ cm

$\frac{4}{10}$ m/m

$\rho = 10^{-4}$ Ω cm

$d = \frac{15}{1000}$ 2.5 cm

$d =$

Ledge length short
comp d.

$\boxed{UO_2}$ reacts with graphite at 1200 C°, !

BeO and ThO stand up to carbon to 1700 or 1800 C°

~~$UO_2$ contain in BeO, ThO~~

Graphite compatible w BeO, $ThO_2$ up to 1800

ZrO. (melts 2400)

$UO_2$, ~~Z~~ in BeO (2570) $Al_2O_3$ → melts 2050

CaO (2570

try $UO_2$ in ~~Zr~~ Carbide

U Carbide Zr Carbide

Refractory hard materials, by Schwarzkopf / Kiefer
for carbides
1956-57 ?

$ThO_2$ thermal 0.008
1000°C
3800°C

H

UC heat cond el cond

$UC_2$

| | atomic el res | thermal |
|---|---|---|
| HfC | $1.09 \times 10^{-4}$ | |
| NbC | $7.4 \times 10^{-5}$ | .034 |
| TaC | $2 \times 10^{-5}$ | .053 |
| TiC | $1.05\ 10^{-4}$ | 0.041 |
| WC | $1.2\ 10^{-5}$ | |
| VC | $1.56\ 10^{-4}$ | |
| ZrC | $6.34\ 10^{-5}$ | 0.049 |

Niob ~~10~~ 10/lb better fabrication
W less
Mo less
Ta several times higher

U metall molten; $UO_2$

graphite lined Zr Carbide

Pyrolytic graph. 30 $\times$ 10 65 microohm

Artif. graphite 1,375 "
at room temp.

Nuclear Eng. Aug 58 (Vol 3) H

$UO_2$ ~~U density~~ Emp[?] U density 10.5 gm

m.p. 2740°C

cond 0.0060 cal

lin expand 0.8% at 1000°C

vap. press 1 mm at 2363°C

compatible

Stainless Steel ~~& lead~~

Nickel slow attack at 1400°C

Copper short test up to melting point.

~~U~~ Carbide U density 13 gm/cc

m.p. 2350

cond 0.04 cal/cm

U-Silicide [$U_3Si$]

dens. 15 gm/cc

decomp. 930°C

U. Silicide [$U_3Si_2$]

m.p. 1665°C

cond .035

Th-oxide

m.p. 3220

heat cond .0076 at 1200°C

$$\sqrt{\frac{N_0}{N_i}} = \sqrt{\frac{N_0}{N_w}} + x\sqrt{\frac{2\pi N_0 \varepsilon^2}{kT}}$$

$N_0$ = ion density in uniform medium is immaterial

$$\frac{1}{\sqrt{N_i}} = \frac{1}{\sqrt{N_w}} + x\sqrt{\frac{2\pi\varepsilon^2}{kT}} \qquad N_i \gg N_a$$

~~Elect~~ Potential $\varphi$ is related to $N_i$, viz. ($\varphi_0$ = wall potential)

$$e^{y_0 - y} = e^{\frac{\varepsilon}{kT}(\varphi_0 - \varphi)} = \frac{N_w}{N_i}$$

$$\varphi_0 - \varphi = \frac{kT}{\varepsilon} \ln \frac{N_w}{N_i}$$

We need $\varepsilon\varphi - \frac{\varepsilon^2}{4x}$ = electron potential energy

$$= kT \ln \frac{N_w}{N_i} - \frac{\varepsilon^2}{4x}$$

Derivative: $\frac{kT}{N_i}\frac{dN_i}{dx} + \frac{\varepsilon^2}{4x^2} = 0$

$$\frac{1}{N_i}\frac{dN_i}{dx} = -2\sqrt{N_i}\,\frac{d(1/\sqrt{N_i})}{dx} = -2\sqrt{N_i}\sqrt{\frac{2\pi\varepsilon^2}{kT}} = -\frac{\varepsilon^2}{4x^2 kT}$$

∴ at maximum potential energy:

$$\frac{1}{\sqrt{N_i}} = \frac{8x^2 kT}{\varepsilon^2}\sqrt{\frac{2\pi\varepsilon^2}{kT}} = \frac{8x^2}{\sqrt{2\pi}}\sqrt{\frac{kT}{\varepsilon^2}}$$

$$= x\sqrt{\frac{2\pi\varepsilon^2}{kT}} + \frac{1}{\sqrt{N_w}}$$

If depression of work function is large, then $N_i \ll N_w$, so

at the max.

$1/\sqrt{N_w}$ negligible, so

$$x = \frac{2\pi}{8}\frac{\varepsilon^2}{kT}$$

$\varphi$ = − electrostatic potential

Density of positive ions $N_i = N_0\, e^{\varepsilon\varphi/kT}$

" " electrons $N_e = N_0\, e^{-\varepsilon\varphi/kT} \ll N_i$

$$\nabla^2\varphi = +4\pi\rho = \pi N_0\, \varepsilon\, e^{\varepsilon\varphi/kT}$$

a) neglecting $N_e$ compared with $N_i$

b) " image force on ions

$$e^{\varepsilon\varphi/kT} = e^{y}, \quad \frac{\varepsilon\varphi}{kT} = y$$

$$\frac{d^2}{dx^2}\, y = \frac{\varepsilon}{kT}\nabla^2\varphi = \frac{4\pi N_0\,\varepsilon^2}{kT}\, e^{y}$$

Multiply both sides by $2\frac{dy}{dx}$

$$2y'y'' = \frac{8\pi N_0\,\varepsilon^2}{kT}\, e^{y}\, y' = 2\, b^{-2}\, e^{y}\, y'$$

$b$ = Debye length

$$y'^2 = 2b^{-2}\left(e^{y} + \text{const.}\right)$$

$y' = 0$ for $y = 0$ (approx.)

$$y'^2 = 2b^{-2}\left(e^{y} - 1\right) \simeq 2b^{-2}\, e^{y} \qquad \text{for } y \gg 1$$

$$x = \int \frac{dy}{y'} = \pm \frac{b}{\sqrt{2}} \int \frac{dy}{e^{y/2}} = -b\sqrt{2}\int \frac{d(y/2)}{e^{y/2}}$$

$$= b\sqrt{2}\left(e^{-y/2} - e^{-y_0/2}\right)$$

$y_0$ at metal surface

$$~~y/2 =~~ \quad e^{-y/2} = \frac{x}{b\sqrt{2}} + e^{-y_0/2}$$

Density of ions $N_i = N_0\, e^{+y}$, $\quad e^{-y/2} = \sqrt{\dfrac{N_0}{N_i}}$

$N_w = N_i$ at wall

Assume $T = 2000°K = .17$ ev

$$\frac{\varepsilon^2}{kT} = \frac{4.8 \cdot 10^{-10}}{.17/300} \frac{\text{e.s.u.}}{\text{e.s.u.}} = .8_5 \cdot 10^{-6} \text{ cm}$$

$$N_{atom} = 10^{16} \text{ per cm}^3 \simeq \frac{1}{5000} \text{ NTP}$$

$\frac{\pi^3}{8} \approx 4$, $\therefore$ $4 N_{atom} \cdot \left(\frac{\varepsilon^2}{kT}\right)^3 = 4 \cdot .6 \cdot 10^{16-18} = \frac{1}{40}$

ln of this $\sim -3.7$

so

$$W_{eff} \approx I + 3.4\, kT$$

condition: $\Delta = W - I - 3.4\, kT > 4.6\, kT$

$$W - I > 8\, kT \qquad (1)$$

On the other hand, density at wall:

$$\ln N_w = \ln N_a + \frac{W-I}{kT}$$

$$\frac{W-I}{kT} = \ln \frac{N_w}{N_a} < \ln 10^6 = 14 \qquad (2)$$

In other words:

$$8\, kT < W - I < 14\, kT$$

which is a rather narrow range. For $W - I > 14\, kT$, we get monolayer, $\therefore$ Cs work function (?)

Wall condition generally:

$$\Delta = kT \ln N_{wall} \frac{\pi^3}{8} \left(\frac{\varepsilon^2}{kT}\right)^3 + \frac{kT}{\pi}$$

$$\frac{\Delta}{kT} < \ln 4 \cdot 10^{22} \cdot .6 \cdot 10^{-18} + \frac{1}{\pi} = 10.1 + .3 = \underline{10.4}$$

Then

$$\frac{1}{\sqrt{N_i}} \simeq x\sqrt{\frac{2\pi\varepsilon^2}{kT}} = \frac{(2\pi)^{3/2}}{8}\left(\frac{\varepsilon^2}{kT}\right)^{3/2} \quad ; N_i = \frac{8}{\pi^3}\left(\frac{kT}{\varepsilon^2}\right)^3$$

$$\frac{\varepsilon^2}{4x} = \frac{1}{\pi} kT$$

Depression of electron work function

$$\Delta = \varepsilon\varphi_0 - \left(\varepsilon\varphi - \frac{\varepsilon^2}{4x}\right) = \varepsilon(\varphi_0 - \varphi) + \frac{\varepsilon^2}{4x}$$

$$= kT \ln \frac{N_w}{N_i} + \frac{kT}{\pi}$$

$$= kT \ln \frac{N_w \pi^3}{8}\left(\frac{\varepsilon^2}{kT}\right)^3 + \frac{kT}{\pi}$$

$$N_w = N_{atom}\, e^{(W-I)/kT}$$

$$\Delta = kT \ln N_{atom} \frac{\pi^3}{8}\left(\frac{\varepsilon^2}{kT}\right)^3 + \frac{kT}{\pi} + W - I$$

$$W^* = I - kT \ln(\ \ ) - \frac{kT}{\pi}$$

with the restriction that $N_w <$ density of monomolecular layer of Cs $\sim 10^{22}$ or so

Validity condition

$N_w \gg N_i$, i.e.

$$N_a\, e^{(W-I)/kT} \gg \frac{8}{\pi^3}\left(\frac{kT}{\varepsilon^2}\right)^3$$

in other words $\Delta > kT$

Must have about $\Delta > 5kT$, then $\sqrt{N_i} < .1\sqrt{N_w}$

Effective work function determined by $I$, not $W$

$$10^{-14} = \frac{1.6\,10^{-12} \times 10^{20}}{\pi \times 100\,N}$$

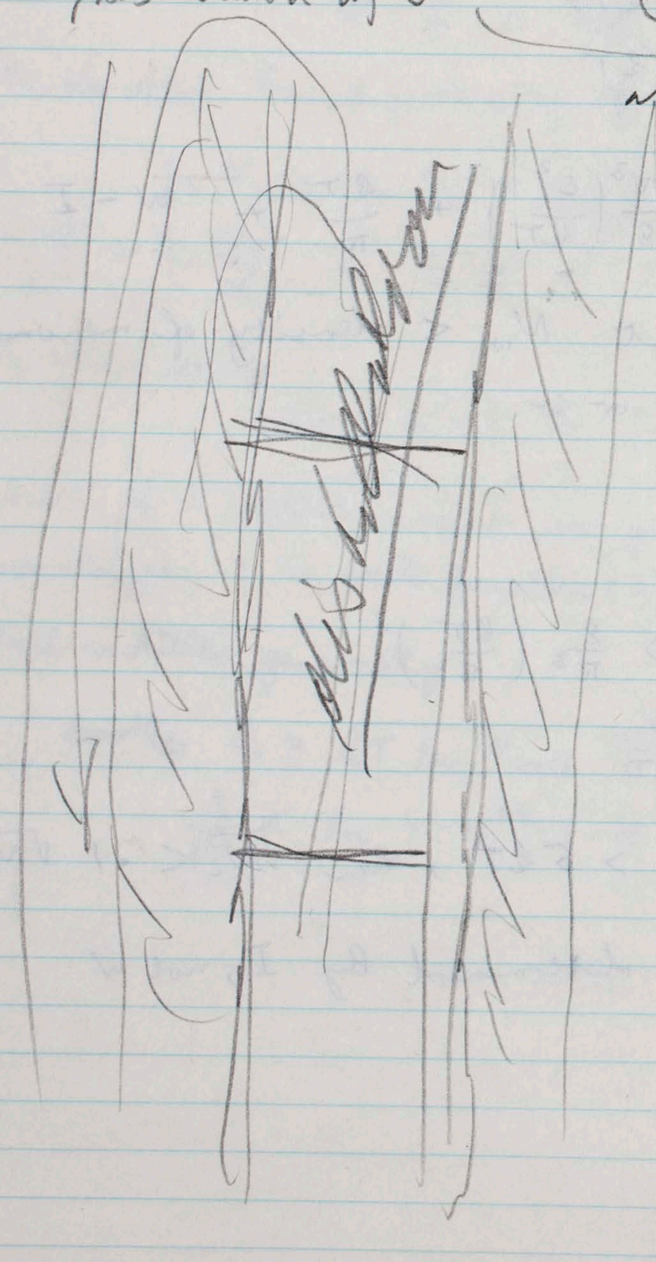
$$N = \frac{1.6}{\pi} \times 10^{20} \simeq \frac{1}{2}\,10^{20} = 5\,10^{19}$$

$$1\ \text{Atm} = \frac{6\,10^{23}}{2.2\,10^{4}} = 3\,10^{19}$$

$$\lambda_i^2 = \frac{kT}{4\pi N_i e^2} \quad \Big| \quad N_i = \frac{kT}{\lambda^2\,4\pi e^2}$$

if $\lambda_i$ doubled and $kT_i$ divided by 2

$N_i$ goes down by 8 to $N = \frac{5}{8}\,10^{19}$ or $\frac{1}{6}$ th of Atm at normal temp or



100 20

$\frac{80}{3} = 26.6$

46.6

1 Atm at 2000 C

or 2 1/2 Atm at 5,000 C° $\simeq \frac{1}{2}$ Volt $= kT$

Stanford (?)

$$\Delta E = \frac{1}{2}\frac{e^2}{\lambda_D}$$

$$\lambda_D = \sqrt{\frac{kT}{4\pi N_i e^2}}$$

M

$$\lambda_D = \frac{1}{2}\frac{e^2}{\Delta E}$$

$$\lambda_D^3 \times 4\pi N_i \cancel{e^2} = kT\,\lambda_D$$

$$= \frac{1}{2} kT \frac{e^2}{\Delta E}$$

Saha

$$\frac{f^2}{1-f^2} = 2.4\times10^{-4}\,\frac{T^{5/2}}{p_{mm}}\,e^{-\frac{V_i}{kT}}$$

$T = 10^4$

$$= 2.4\;10^{-4} \times \frac{1}{60}\,10^{10}\,\frac{1}{p_{mm}}$$

$$= 2.4\times10^{6}\times\frac{1}{60}\,\frac{1}{p_{mm}}$$

$$= \frac{4}{p_{mm}}\times10^{4}$$

$$10^{-14} = \frac{kT}{4\pi N\,25\,10^{-20}}$$

$kT \approx 1\,eV$

$f = \frac{1}{2}$ $\quad \frac{1/4}{3/4} =$

$p_{mm} = 12\;10^4$ mm

for $p = 1$ Atm

$N_i$

$\Delta E =$

$$1\,eV = 1.6\;10^{-12}\ \text{erg}$$

$$\Delta E = 1.6\;10^{-12}\,\text{erg} = \frac{1}{2}\frac{e^2}{\lambda_D} = \frac{B}{2}$$

$$\lambda_D = \frac{1}{1.6}\,10^{12}\,\frac{1}{2}(4.8)^2\,10^{-20} = \frac{1}{3.}\,10^{-8}\,25 \approx 10^{-7}$$

$\cancel{kT = \frac{1e^2}{2\lambda_D}}$

$\lambda = \frac{e^2}{2kT} = \frac{25\ 10^{-20}\ 6\ 10^{23}}{8000 \times 4 \times 10^7} =$

$= 150 \times 10^3 = \frac{1.5\ 10^5}{3.2\ 10^{11}} = \frac{1}{2}\ 10^{-6}$ cm

$5 \times 10^{-7}$

$125\ 10^{-21}$

$1.2\ 10^{-19}$ 1V $1.2 \times 10^{-7}$ cm.

$\underline{10^{19}}$

$\cancel{2.2\ 10^2}$

$\frac{2.2\ 10^4 \times 10^{19}}{6\ 10^{23}}$

$5V\ \frac{r}{\lambda_D}$ - - - $r$

$-5V$

$5V e^{-r/\lambda_D}$

$5V\left[1 - \frac{r}{\lambda_D}\right]$

$\frac{1}{3}$

$1.2 \times 10^{-7}\ \sqrt{\frac{\frac{1}{2}10^{-6}}{r \times 5}} = r$

$1.2 \sqrt{\frac{1}{r}} = r$

$y = r / 10^{-7}$ cm

$r \approx 1$