$2\gamma^2+\gamma$ 　 16(43)+4F

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Efficiency of the Aluminium Counter

$$\frac{2\gamma(\gamma+1)}{2\gamma+1}=\gamma+\frac{\gamma}{2\gamma+1}$$
$$=\gamma+\frac{1}{2}-\frac{1}{2}\frac{1}{2\gamma+1}$$

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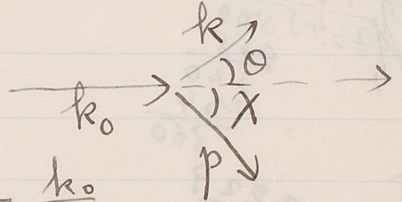
$$\frac{E}{\mu}=\frac{\cancel{2}\,2\gamma^2+2\gamma+1}{2\gamma+1}$$
$$=\gamma+\frac{\gamma+1}{2\gamma+1}$$
$$=\gamma+1-\frac{\gamma}{2\gamma+1}$$

$$\boxed{k=\frac{\gamma}{2\gamma+1}.}$$

i) Compton Effect

a) Angular distribution of Scattered Compton Electrons



$$k\cos\theta+p\cos\chi=k_0$$
$$k\sin\theta=p\sin\chi$$
$$k_0+\mu=k+E$$
$$E^2-p^2=\mu^2.$$

$$\gamma=\frac{k_0}{\mu}.$$

$$p=\frac{2k_0\mu(k_0+\mu)\cos\chi}{(k_0+\mu)^2-k_0^2\cos^2\chi}$$

$$\cancel{\ }\ \frac{p}{\mu}=\frac{2\cancel{\ }\gamma(\gamma+1)\cos\chi}{(\gamma+1)^2-\gamma^2\cos^2\chi}$$

$$E=\frac{\mu\{(k_0+\mu)^2+k_0^2\cos^2\chi\}}{(k_0+\mu)^2-k_0^2\cos^2\chi}$$

$$\frac{E}{\mu}=\frac{(\gamma+1)^2+\gamma^2\cos^2\chi}{(\gamma+1)^2-\gamma^2\cos^2\chi}$$

$$k=\frac{k_0\{(k_0+\mu)^2-(k_0^2+2k_0\mu)\cos^2\chi\}}{(k_0+\mu)^2-k_0^2\cos^2\chi}$$

$$\frac{k}{\mu}=\frac{\gamma\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}}{\cancel{k_0}(\gamma+1)^2-\gamma^2\cos^2\chi}$$

$$\frac{k}{k_0}=\frac{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}{(\gamma+1)^2-\gamma^2\cos^2\chi}=1\cancel{+}-\frac{2\gamma\cos^2\chi}{(\gamma+1)^2-\gamma^2\cos^2\chi}.$$

$$\frac{k_0}{k}=\frac{(\gamma+1)^2-\gamma^2\cos^2\chi}{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}=1+\frac{2\gamma\cos^2\chi}{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}.$$

$$\sin\theta=\frac{p}{k}\sin\chi=\frac{2(\gamma+1)\cos\chi\sin\chi}{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}$$

$$(\gamma^2+2\gamma)\,2\sin\chi\cos\chi\,d\chi$$

$$\cos\theta\,d\theta=\frac{2(\gamma+1)(2\cos^2\chi-1)\,d\chi}{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}-\frac{2(\gamma+1)\cos\chi\sin\chi}{\{\qquad\}^2}$$

$$=\frac{2(\gamma+1)\,d\chi\,\{(2\cos^2\chi-1)\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}-2(\gamma^2+2\gamma)\cos^2\chi\sin^2\chi\}}{\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}^2}$$

$$=\frac{-2(\gamma+1)\ \cancel{(1-\cos^2\chi)}\,d\chi\,\{(\gamma+1)^2-(\gamma^2+2\gamma+2)\cos^2\chi\}}{\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}^2}$$

$$\varepsilon = \frac{(\gamma+1)^2 + \gamma^2\cos^2\chi}{(\gamma+1)^2 - \gamma^2\cos^2\chi} = \frac{(\gamma+1)^2 + \frac{\gamma^2(1+x)}{2}}{(\gamma+1)^2 - \frac{\gamma^2(1+x)}{2}} = \frac{\frac{4(\gamma+1)^2}{(\gamma+4)}}{2(\gamma+1)^2 - \cancel{\frac{\gamma^2(1+x)}{2}}} - 1$$

$\gamma = 4$

$$\varepsilon = \frac{\cancel{100}\;50}{\cancel{50} - \cancel{16}(1+x)} - 1$$

$25 - 8$

$x = -1$	-0.8	-0.6	-0.4	-0.2	0
1	1.14	1.29	1.48	1.69	1.94
0.2	0.4	0.6	0.8	1.0	
2.25	2.62	3.01	3.72	4.58	

$1.8 \times 8 = 14.4$; $23.4 \overline{)\,500}$ = 2.13; 468, 320, 234, 860

$21.8 \overline{)\,500}$ = 2.29; 436, 640, 436, 2040

$9 \overline{)\,50}$ = 5.55; 45, 50

$20.2 \overline{)\,500}$ = 2.48; 404, 960, 808, 1520

$1.2 \times 8 = 9.6$

15.4

$18.6 \overline{)\,500}$ = 2.69; 372, 1280, 1116, 1640, 1674

$13.8 \overline{)\,50}$ = 3.62; $1.4 \times 8 = 11.2$; 414, 860, ~~690~~, ~~1100~~, 828, 320, 276, 440

$15.4 \overline{)\,500}$ = 3.24; 462, 380, 308, 720, 616, 1040

$17 \overline{)\,50}$ = 2.94; 34, 160, 153, 70

$12.2 \overline{)\,500}$ = 4.099; $1.6 \times 8 = 12.8$; 488, 1200, 1098, 1020

$10.6 \overline{)\,500}$ = 4.72; $1.8 \times 8 = 14.4$; 424, 760, 742, 180

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$$\cos\theta = \frac{\sqrt{\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}^2-4(\gamma+1)^2\cos^2\chi(1-\cos^2\chi)}}{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}$$

$$= \frac{(\gamma+1)^2-(\gamma^2+2\gamma+2)\cos^2\chi}{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}$$

~~$\sin\theta\, d\theta =$~~

$$d\theta = \frac{-2(\gamma+1)^2\cancel{(1-\cos^2\chi)}\,d\chi}{\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}\cancel{\{(\gamma+1)^2-(\gamma^2+2\gamma+2)\cos^2\chi\}}} \qquad \cancel{\gamma+1}$$

$$\sin\theta\, d\theta = \frac{-4(\gamma+1)^2\cos\chi\sin\chi\,d\chi}{\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}^2}$$

$$d\phi = -\frac{r_0^2}{2}d\varphi\,\frac{4(\gamma+1)^2\cos\chi\sin\chi\,d\chi}{\{(\gamma+1)^2-(\gamma^2\cancel{+2\gamma})\cos^2\chi\}^2}$$

$$\times\left\{2+\frac{2\gamma\cos^2\chi}{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi}-\frac{2\gamma\cos^2\chi}{(\gamma+1)^2-\gamma^2\cos^2\chi}-\frac{4(\gamma+1)^2\cos^2\chi\sin^2\chi}{\{(\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi\}^2}\right\}$$

$\cos 2\chi = x,\qquad (\gamma+1)^2-(\gamma^2+2\gamma)\cos^2\chi = \frac{1}{2}\{(\gamma^2+2\gamma+2)-(\gamma^2+2\gamma)x\}$

$\cos^2\chi = \frac{1+x}{2}\qquad (\gamma+1)^2-\gamma^2\cos^2\chi = \frac{1}{2}\{(\gamma^2+4\gamma+2)-\gamma^2 x\}$

$\sin^2\chi = \frac{1-x}{2}$

$$d\phi = -\frac{r_0^2}{2}d\varphi\,\frac{4(\gamma+1)^2\,dx}{\cancel{(\gamma+1)^3}\{(\gamma^2+4\gamma+2)-\gamma^2 x\}^2}$$

$$\times\left\{2+\frac{2\gamma(1+x)}{(\gamma^2+2\gamma+2)-(\gamma^2+2\gamma)x}-\frac{2\gamma(1+x)}{(\gamma^2+4\gamma+2)-\gamma^2 x}-\frac{4(\gamma+1)(1-x^2)}{\{(\gamma^2+2\gamma+2)-(\gamma^2+2\gamma)x\}^2}\right\}$$

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$$\gamma+1=\beta.\qquad d\phi=-\frac{r_0^2}{\cancel{4}2}\,d\varphi\,\frac{\cancel{4}\beta^2\,dx}{\{(\beta^2+2\beta-1)-(\beta-1)^2x\}^2}$$

$$\times\left\{1+\frac{(\beta-1)(1+x)}{\beta^2+1-(\beta^2-1)x}-\frac{(\beta-1)(1+x)}{(\beta^2+2\beta-1)-(\beta-1)^2x}-\frac{2\beta(1-x^2)}{\beta^2+1-(\beta^2-1)x}\right\}$$

$$=-4r_0^2\,d\varphi\,\frac{(\gamma+1)^2dx}{\{(\gamma^2+4\gamma+2)-\gamma^2x\}^2}\left[1+\frac{2\gamma^2(1+x)^2}{\{(\gamma^2+2\gamma+2)-(\gamma^2+2\gamma)x\}\{(\gamma^2+4\gamma+2)-\gamma^2x\}}\right.$$

$$\left.-\frac{2(\gamma+1)^2(1+x)(1-x)}{\{(\gamma^2+2\gamma+2)-(\gamma^2+2\gamma)x\}^2}\right]$$

$$=-4r_0^2\,d\varphi\,\frac{(\gamma+1)^2dx}{\{(\gamma^2+4\gamma+2)-\gamma^2x\}^2}\left[1+\frac{2(1+x)}{\{(\gamma^2+2\gamma+2)-(\gamma^2+2\gamma)x\}}\right.$$

$$\left.\times\left\{\frac{\gamma^2(1+x)}{\{(\gamma^2+4\gamma+2)-(\gamma^2\cancel{+2\gamma})x\}}-\frac{(\gamma+1)^2(1-x)}{\{(\gamma^2+2\gamma+2)-(\gamma^2+2\gamma)x\}^{\cancel{2}}}\right\}\right]$$

$$\gamma=0;\quad d\phi=-\cancel{4}r_0^2\,d\varphi\,dx\left\{1-\overset{\cancel{\frac{1}{2}}\,4\,''}{\cancel{2}}\frac{1-x^2}{2}\right\}=-r_0^2\,d\varphi\,dx\left\{1-\frac{\sin^2(2\chi)}{2}\cancel{2\sin^2\chi}\right\}$$

~~$=-r_0^2\,d\varphi\,dx\{2\cos^2\chi-1\}$~~

$$=-r_0^2\,d\varphi\,dx\left\{\frac{1}{2}+\frac{x^2}{2}\right\}$$

$$\gamma=1;\quad d\phi=-r_0^2\,d\varphi\,dx\cdot\frac{16}{(7-x)^2}\left[1+\frac{2(1+x)}{5-3x}\left\{\frac{1+x}{7-x}-\frac{4(1-x)}{5-3x}\right\}\right]$$

$$\gamma=4;\quad d\phi=-r_0^2\,d\varphi\,dx\cdot\frac{25}{(17-8x)^2}\left[1+\frac{\cancel{2}(1+x)}{\cancel{6}13-12x}\left\{\frac{4(1+x)}{17-8x}-\frac{25(1-x)}{2(13-12x)}\right\}\right]$$

$$\gamma\approx\infty;\quad d\phi=-\frac{4r_0^2\,d\varphi\,dx}{\gamma^2(1-x)^2}$$

$\frac{9}{}$

$\frac{2}{3}$

$\frac{2\times 0.08}{1.4} = 0.06$

$$41\overline{)800}\;\;195$$
41
390
369
210

$$1.4\overline{)0.08}\;\;0.057$$
70
100

$\frac{0.08}{\cancel{2.8}\;1.4}$

$$21\overline{)200}\;\;952$$
189
110
105
50

$\frac{2}{3}$

$\frac{32}{9}$

$\frac{200}{221}$
7188

maximum energy of recoil electron $\frac{E}{\mu} = \gamma+1 - \frac{\gamma}{2\gamma+1} = 1 + \frac{2\gamma^2}{2\gamma+1}$

$\varepsilon\frac{E}{\mu}+1$ \ γ	0.2	1	4	10	20	3
$\varepsilon\frac{E}{\mu}-1$	1.057	1.67	4.56	10.52	20.5	3.6
range in Al	0.0015	0.04	1.00	2.7		0.8
τ_γ	0.43	0.223	0.116	0.0735		
$R_\varepsilon\tau_\gamma$	0.00065	0.009	0.116	0.2		

Al = 5 mm.

	γ	0.2	1	4
max range	~~ε_{max}~~	0.0015	0.04	1.00
R_γ	τ_γ	0.43	0.223	0.116
	$R_\varepsilon\tau_\gamma$	0.00065	0.009	0.116

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$d\phi \times r_0^2\, d\varphi\, dx$

$r=0$ $r\,d\varphi$ \ x	−1	−0.8	−0.6	−0.4	−0.2	0	+0.2	+0.4	+0.6	+0.8	1.0
● 0	1	0.82	0.68	0.58	0.52	0.5	0.52	0.58	0.68	0.82	1
● 0.2	0.										
● 0.4											
0.6											
0.8											
● 1.0	~~0.04~~	~~0.047~~	~~0.058~~								
1.2											
1.4											
1.6											
1.8											
⊗ 2.0						(0.8) 0.22	(1.0) 0.515-				
3.0 2.4											
● 4.0 2.8	(−1) 0.04	(−0.8) 0.047	(−0.6) 0.05~~8~~2	(−0.4) 0.060	(−0.2) 0.068	(0) 0.081	(0.2) ~~0.98~~ 0.098	(0.4) 0.120	(0.6) 0.163		
5.0 3.2											
6.0											
7.0											
8.0											
9.0											
● 10.0											
12.0											
14.0											
16.0											
18.0											
● 20.0											
● 40.0											

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i) Cross Section ϕ/ϕ_0 $\phi_0 = \frac{8\pi r_0^2}{3}$

γ	~~0.05~~ 0.2	1	4	10	20	mc^2
ϕ/ϕ_0	0.74	~~0.31~~ 0.43	0.22	0.12	0.075	

absorption coef. $\tau_c = NZ\phi = 0.518 \times \frac{\phi}{\phi_0}$ cm^{-1}

ii) Pair Creation $\phi/\bar{\phi}$ $\bar{\phi} = \frac{Z^2 r_0^2}{137}$

γ	4	10	20
$\phi/\bar{\phi}$	0.32	1.94	3.75

$\tau_M =$ ~~[illegible]~~ $N\phi = N\frac{Z^2 r_0^2}{137}\frac{\phi}{\bar{\phi}} = 0.586 \times 10^{-2}\frac{\phi}{\bar{\phi}}$

.518
.12
1036
518
0.06216

Total Absorption Coef.

$\gamma = 10$: $\tau_c = 0.518 \times 0.12 = 0.06216$

$\tau_M = 0.586 \times 1.94 \times 10^{-2} = 0.01136$ ~~7~~

0.586
1.94
2354
5274
586
1.13694

$\tau_c + \tau_M = 0.0735$

$\gamma = 20$: $\tau_c = 0.518 \times 0.075 = 0.0389$

0.518
0.075
2590
3626
0.038850

$\tau_M = 0.586 \times 10^{-2} \times 3.75 = 0.0221$

0.586
0.0375
2930
4102
1758
0.0220750

$\tau_c + \tau_M = 0.0610$

$x = \log 9 = \dfrac{0.95424}{\cancel{0.43425}}$

$\cancel{\dfrac{\log_{10} 9}{\log_{10} e}}$

```
            2.197
0.43425 )0.95424
          86850
          ------
          85740
          43425
          ------
          423150
          390825
          ------
          323250
```

$e^x = 9 = 10^{x \log_{10} e}$

$\log_{10} 9 = x \log_{10} e$

```
    4.444
9)40
  36
```

```
   4.444
 - 2.197
 -------
   2.247
```

```
          5
64)11.235(0.176
    64
   ---
    483
    448
    ---
     355
     320
     ---
      45
```

```
  0.276
8)2.197
```

```
  0.176
  0.276
  -----
  0.452
```

```
      0.160
81)13.0
   8 1
   ---
   490
   486
   ---
     40
```

```
  0.452
  0.160
  -----
  0.292
      3
  -----
4)0.876(0.219
```

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$$\frac{\Phi}{\Phi_0} = \frac{3}{4}\left\{\frac{5}{64}\cdot\left[\frac{8\times5}{\cancel{4}\,9} - \log 9\right] + \frac{1}{8}\log 9 - \frac{13}{81}\right\}$$

$\gamma = 4.$ $\quad \tau_c = 0.518 \times 0.22$ $\quad\gg\quad$ $\tau_m = 0.586 \times 10^{-2} \times 0.32$

$\cancel{\simeq} 0.114$ $\qquad = 0.0019$

$$\begin{array}{r} .518 \\ .22 \\ \hline 1036 \\ 1036 \\ \hline 0.11396 \end{array} \qquad \begin{array}{r} .586 \\ .32 \\ \hline 1172 \\ 1758 \\ \hline .18752 \end{array}$$

$\tau_c + \tau_m = 0.116$

---

iii) Photoelectric Effect.

$\log_{10}\frac{\phi_K}{\phi_0} \simeq 0$ $\quad$ for $\gamma = 0.2$ $\quad \frac{\phi_K}{\phi_0} = 1$

$\simeq -2$ $\quad$ for $\gamma = 1$ $\quad \frac{\phi_K}{\phi_0} = 0.01$

~~$\gamma = 4$~~ :

$\tau_p = N\phi_K = NZ\phi_0 \frac{\phi_K}{Z\phi_0} = \frac{0.518}{13}\cdot\frac{\phi_K}{\phi_0}$

$= 0.04\cdot\frac{\phi_K}{\phi_0}$

$$\begin{array}{r} .0398 \\ 13\,)\,0.518 \\ 39 \\ \hline 128 \\ 117 \\ \hline 110 \end{array}$$

$\gamma = 1$;

$\tau_c = 0.518 \times 0.43 = 0.223$ ~~τ~~

$\tau_p = 0.04 \times 0.01 = 0.0004$

$\tau = 0.223$

$$\begin{array}{r} 518 \\ 43 \\ \hline 1554 \\ 2072 \\ \hline 22274 \end{array}$$

$\gamma = 0.2$;

$\tau_c = 0.518 \times 0.74 = 0.383$

$\tau_p = 0.04 \times 1 = 0.04\overset{}{\underset{5}{}}$

$\tau = 0.$~~384~~5 0.43

$$\begin{array}{r} 0.518 \\ 0.74 \\ \hline 2072 \\ 3626 \\ \hline 0.38332 \end{array}$$

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○ Range of Secondary Electrons.

Bethe, Ann. d. Phys. 5, 325, 1930. | Bethe, Handb. 24, 1, Kap. 3, IV, 1933.
Møller, ibid. 14, 531, 1932. | Heitler, chapt V, 1936
Bloch, ibid. 5, 285, 1933.
" , Zeits. f. Phys. 81, 363, 1933.

$$\frac{\Delta E}{\Delta x} = N \cdot \frac{4\pi e^2 E^2}{m_0 v^2} \sum_n f_n \left\{ \log \frac{(2)\, m_0 v^2}{\hbar \omega_n} - \frac{1}{2} \log\left(1 - \frac{v^2}{c^2}\right) - \frac{v^2}{2c^2} + \psi(1) - R\left[\psi\left(1 + i\frac{eE}{\hbar v}\right)\right]\right\}$$

$E \overset{ze}{;}$ v : ~~par~~particle of charge & v velocity.

$$= NZ\phi_0 \mu \frac{3}{4} z^2 \cdot \frac{1}{\beta^2}\left[\log \cdot \frac{\mu \beta^2 W}{(1-\beta^2) I^2 Z^2} + 1 - \beta^2 + \Psi(0) - R\Psi\left(i\frac{z}{137\beta}\right)\right]$$

IZ: average ionization energy. $I = 13.5\,eV$

$$\Psi(x) = \cancel{\hbar}\, \frac{d \log(x!)}{dx} = \frac{d \log \Gamma(x+1)}{dx}.$$

x: large $\Psi(x) = \log x + \frac{1}{2x} - \cdots$

$W = \frac{E-\mu}{2}$ for electron

$= 2\mu\beta^2$ for heavy particles

For not too slow electrons

$$\left(-\frac{dE}{dx}\right) = NZ\phi_0 \mu \frac{3}{4} \frac{1}{\beta^2}\left[\log \frac{(E-\mu)E^2\beta^2}{2\mu I^2 Z^2} + \left(\frac{\mu}{E}\right)^2\right]$$

$\beta \ll 1$: $NZ\phi_0 \mu \frac{3}{4} \frac{\mu}{(E-\mu)}\left\{\log \frac{(E-\mu)}{IZ} + \frac{1}{2}\right]$

$E \gg \mu$: $NZ\phi_0 \cancel{\mu} \frac{3}{4} \log \frac{E^3}{2\mu I^2 Z^2}.$

range.

$$\int_0^E \frac{dE}{(-\frac{dE}{dx})} = \left(NZ\phi_0 \frac{3}{4}\mu\right)^{-1} \cancel{\frac{\beta^2}{4}} \int_0^E \frac{\cancel{E}\,\beta^2\, dE}{\log\frac{(E-\mu)E^2\beta^2}{2\mu I^2Z^2} + \left(\frac{\mu}{E}\right)^2}$$

$$= (NZ\phi_0)^{-1}\cancel{\frac{3}{4}}^{-1}\cdot\frac{4}{3}\int_0^{\varepsilon}\frac{\cancel{\mu}\,\beta^2\, d\varepsilon}{\cancel{\mu}\left\{\log\frac{(\varepsilon-1)\cancel{\varepsilon^2}\mu^2(\varepsilon^2-1)}{2I^2Z^2}+\frac{1}{\varepsilon^2}\right\}}$$

$\cancel{\mu^2\beta^2 = \mu^2}$.

$$E^2 = \frac{\mu^2}{1-\beta^2} \qquad = (NZ\phi_0)^{-1}\frac{4}{3}\int_0^{\varepsilon}\frac{(\varepsilon^2-1)\,d\varepsilon}{\left\{\varepsilon^2\log\frac{\mu^2(\varepsilon-1)(\varepsilon^2-1)}{2I^2Z^2}+1\right\}}$$

$E^2 - E^2\beta^2 = \mu^2.\quad \varepsilon^2-\varepsilon^2\beta^2=1$

$\cancel{\mu^2}\beta^2 = \cancel{\mu}\left(1-\frac{1}{\varepsilon^2}\right) = \frac{\cancel{\mu}(\varepsilon^2-1)}{\varepsilon^2}$

$$\|$$

$$\varepsilon^2\left\{\log\frac{\mu^2}{2I^2Z^2}+\log(\varepsilon-1)(\varepsilon^2-1)\right\}+1\}$$

$$\log\frac{\mu^3}{2I^2Z^2} = \log\frac{(5\times10^5)^2}{2\times(13.5)^2\times13^2} = 7\log 10 - \log 2.464$$

10^7

$$= 7\times 2.30259 - 0.90179$$

$$= 15.21634$$

$$\begin{array}{r} 2.7 \\ 13 \\ \hline 81 \\ 27 \\ \hline 35.1 \\ 35.1 \\ \hline 351 \\ 1755 \\ 1053 \\ \hline 1232.01 \\ 2 \\ \hline 2464.02 \end{array} \qquad \begin{array}{r} 2.30259 \\ 7 \\ \hline 16.11813 \\ 0.90179 \\ \hline 15.21634 \end{array} \qquad \begin{array}{r} 1.05 \\ 1.05 \\ \hline 525 \\ 105 \\ \hline 0.1025 \\ 0.05 \\ \hline 0.005125 \end{array} \qquad \begin{array}{r} 2.30259 \\ 3 \\ \hline 6.90777 \\ -1.63511 \\ \hline 5.27266 \end{array} \qquad \begin{array}{r} 1.63511 \\ 6.90777 \\ \hline \end{array}$$

ε	~~0.2~~ 1.05	1.2	1.5	2.0	4.0	10.0	20.0
$(\varepsilon-1)(\varepsilon^2-1)$	0.00513						
$\log (\varepsilon-1)(\varepsilon^2-1)$	1.63511 $-3\log 10 = \cancel{6.908}$ $= -5.27266$						

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$\log \frac{\mu^2}{2I^2\varepsilon^2} = 15.21634$

ε	~~0~~ 0.25×10^5 1.05	1.2	1.5	2.0	3.0	4.0	10.0	20.0
$(\varepsilon-1)(\varepsilon^2-1)$	0.00513							
$\log(\varepsilon-1)(\varepsilon^2-1)$	-5.27266							
$\frac{(\varepsilon^2-1)}{\varepsilon^2\log\frac{\mu^2(\varepsilon-1)(\varepsilon^2-1)}{2I^2\varepsilon^2}+1}$	0.00857 6	0.02267 7	0.0365	0.0453	0.0491-	0.0491+	0.0450	0.0398
$(N2\phi_0)^{-1}x$ = $(0.518)^{-1}$	0.0166	0.0438 2	0.0705	0.0874	0.0948	0.0948	0.0869	0.0768
range $\times\frac{3}{4}$	0.00042	~~0.0014~~ 0.00495	0.01067	0.0502 0.066		0.255	0.77	1.6
	4×10^{-4} ~~0.000~~	5×10^{-3}	0.01	0.05		0.14	~~0.60~~	1.42
range in cm	5.6×10^{-4}	6.7×10^{-3}	0.013	0.067 0.08		~~0.19~~ 0.34	0.80	1.9
range in gm/cm²								
~~Radiative Energy Loss.~~				~~0.1~~ 0.24				
d=2.69	15×10^{-4}		$\frac{0.255}{3}$	~~0.18~~		0.915	~~2.4~~	

269
67
1863
1614
18003

5.6 (Hp = 540)
269
504
336
112
15.064

85
4

269
0.19
2421
269
0.5111

269
8
~~2352~~

269
0.34
1076
807
9146

67
27
469
134
18

Hp=11.370

range = 1.36 gm/cm²

Hp = 550; range = 14×10⁻⁴.

27
8
216

27
13
81
27
351

56
27
392
112
1512

34
27
238
68
918

$\overset{1}{31308}$

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eV×10⁵	0.25	1.4	2.5	~~2.0~~ 5	15	45
ε	1.05	1.2	1.5	2.0	4.0	10.0
$(NZ\phi_0)^{-1}\times\dfrac{(\varepsilon^2-1)}{\varepsilon^2\log\dfrac{m\gamma(\varepsilon-1)(\varepsilon^2-1)}{2I^2Z^2}+1}$	0.0166 ~~0.008~~	0.0438	0.0705	0.0874	0.0948	0.045
range $\times\frac{3}{4}$	4×10^{-4}	5×10^{-3}	0.01	0.06	0.255	0.77
range in cm	5.6×10^{-4}	6.7×10^{-3}	0.013	0.08	0.34	1.0
range in gm/cm²	15×10^{-4}	18×10^{-3}	0.035	0.22	0.92	2.7
	~~6000~~	~~13500~~	~~22000~~	~~35000~~	~~7500~~	~~10000~~
	500	1200	1900	2900	6500	12000
	527	1380	1930	2880	6480	11,320
	0.00117	0.020	0.064	0.17	0.72	1.36

d = 2.7

$$H\rho = \frac{mc^2}{e}(\varepsilon^2-1)^{\frac{1}{2}}$$

$$= \frac{0.9\times10^{-27}\times9}{4.77\times10^{-10}}(\varepsilon^2-1)^{\frac{1}{2}}$$

$$\sim ~~2000(\varepsilon^2-1)^{\frac{1}{2}}~~$$

$$\begin{array}{r} 0.17 \\ 48)\overline{80} \\ 48 \\ \hline 320 \end{array}$$

$$= 1200(\varepsilon^2-1)^{\frac{1}{2}}$$

$$\begin{array}{r} 17 \\ 17 \\ \hline 119 \\ 17 \\ \hline 289 \end{array} \qquad \begin{array}{r} 15 \\ 3.8 \\ 3.8 \\ \hline 304 \\ 114 \end{array}$$

$$\begin{array}{r} 38 \\ 17 \\ \hline 266 \\ 38 \\ \hline 646 \end{array}$$

$$\phi_0 = \frac{8\pi r_0^2}{3} = \frac{4}{3}(2\pi r_0^2)$$

efficiency $NZ\int \left(\frac{d\phi}{r_0^2\,d\varphi\,dx}\right)\cdot r_0^2\,2\pi\,dx\cdot R(x)\left(\frac{1+x}{2}\right)^{\frac{1}{2}}$

$$= NZ\phi_0\cdot\frac{3}{4}\frac{1}{\rho}\int\left(\frac{d\phi}{r_0^2\,d\varphi\,dx}\right)\cdot R\rho\cdot\left(\frac{1+x}{2}\right)^{\frac{1}{2}}dx.$$

$$= 0.588\,\frac{3}{4\times2.7}\int\cdots$$

$$= ~~0.16~~\ \underset{0.144}{}\times\int\cdots\ ~~=0.16~~$$

$$\begin{array}{r} 0.16 \\ 3.6)\overline{0.586} \\ 36 \\ \hline 226 \end{array} \qquad \begin{array}{r} 0.144 \\ 36)\overline{0.518} \\ 36 \\ \hline 158 \\ 144 \\ \hline 140 \end{array}$$

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Pi
$$\begin{array}{r} 235 \\ \underline{144} \\ 940 \\ 940 \\ \underline{235} \\ 33840 \end{array} \qquad \begin{array}{r} 144 \\ \underline{21} \\ 144 \\ \underline{288} \\ 3024 \end{array}$$

◯ Compton Effect

$\gamma = 1$: $\mathrm{eff}_\theta = 0.1\overset{44}{6} \times 0.021 = 0.003\overset{0}{4}$ ~~%~~

~~0.34%~~ 0.30% ($\cos\theta$)

$\mathrm{eff}_0 = 0.1\overset{44}{6} \times 0.0235 = 0.003\overset{4}{7}6$ $0.3\overset{2}{8}\%$

$0.3\overset{4}{8}\%$

$\gamma = 0.4$: $\mathrm{eff}_\theta = 0.0\cancel{5}8\%$ eff (Photo) $\begin{array}{r} 0.15 \\ \underline{68} \\ 0.22 \end{array}$ 0.063%

$\mathrm{eff}_0 = 0.068\%$

$\gamma = 4$: $\mathrm{eff}_\theta = \mathrm{eff}_0 = 2.1\%$

$\gamma = 2$: ~~$\mathrm{eff}_0 = 0.16 \times 0.0098 = 15.7\%$~~ 0.0 ~~= 1.6%~~ ~~1.57%~~

$= 0.1\overset{}{\underset{44}{6}} \times 0.0706 = 0.0113 = 1.0\%$

$\mathrm{eff}_\theta = 0.1\underset{44}{6} \times 0.064 = 0.0101 =$ ~~1.0%~~ 0.92%

$$\begin{array}{r} 144 \\ \underline{7} \\ 1008 \end{array} \qquad \begin{array}{r} 144 \\ \underline{64} \\ 576 \\ \underline{864} \\ 9216 \end{array}$$

T.R

$\gamma = 10$: $\mathrm{eff}_0 = \mathrm{eff}_\theta = 3.8\%$ eff (Pair)

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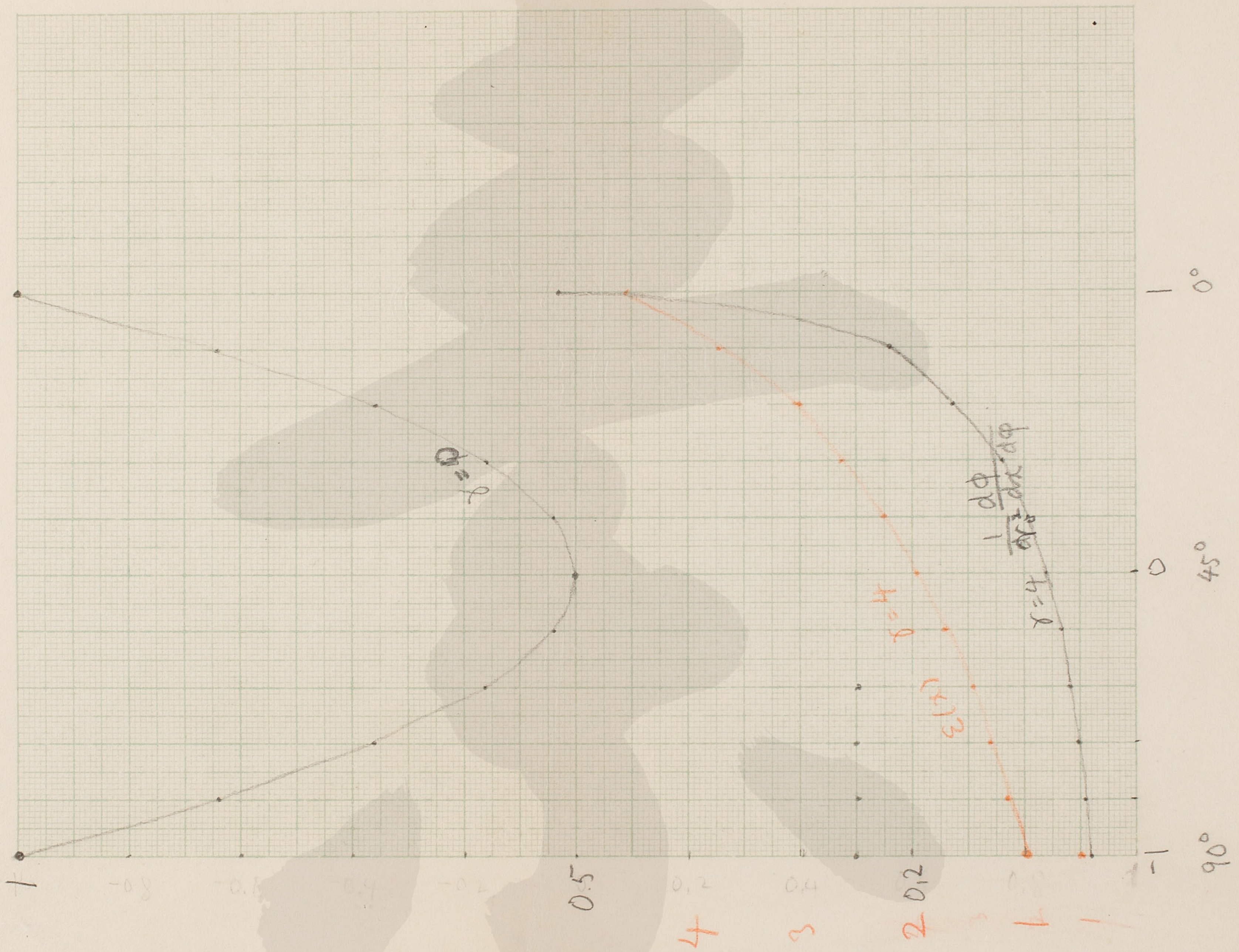

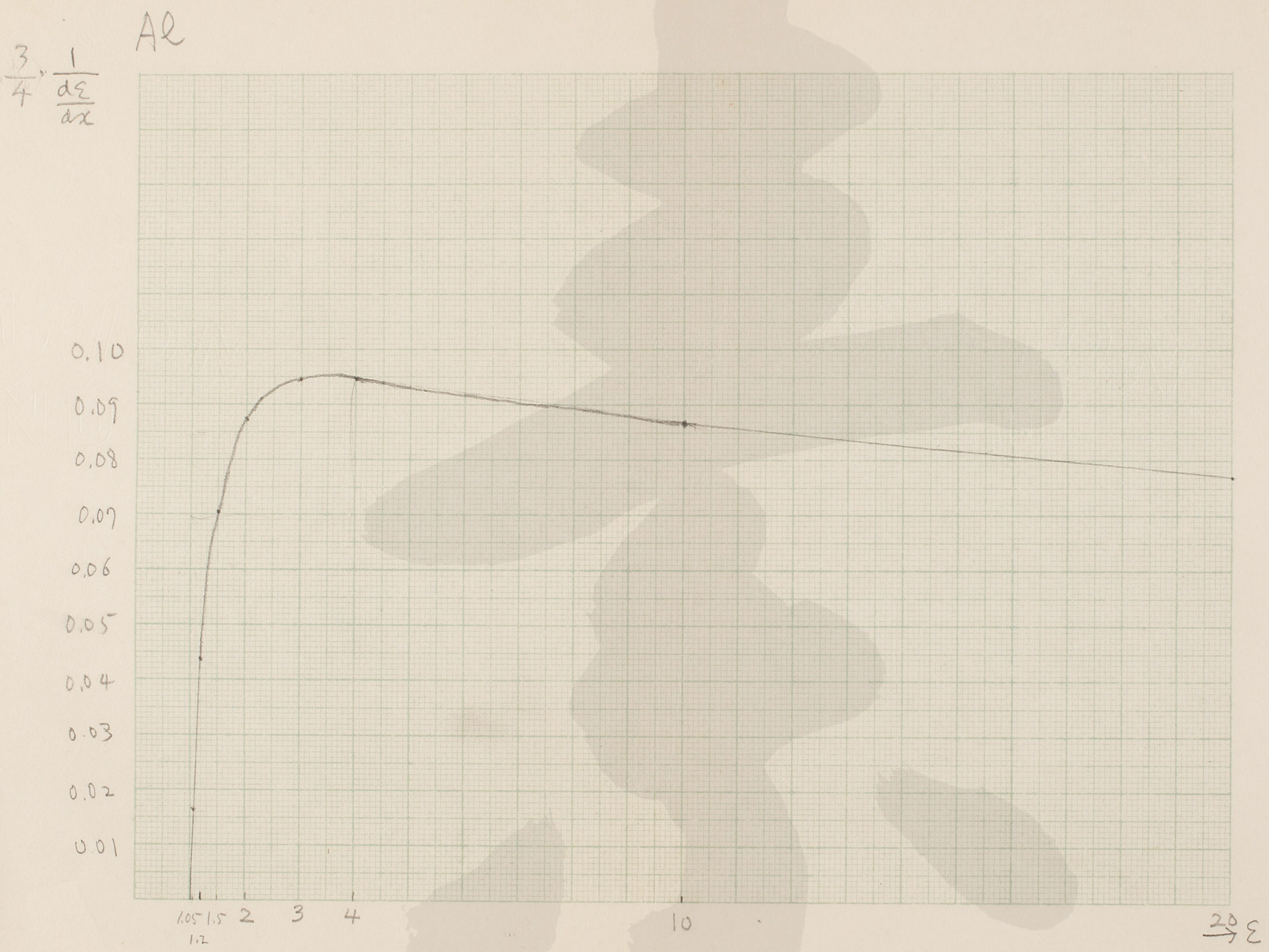

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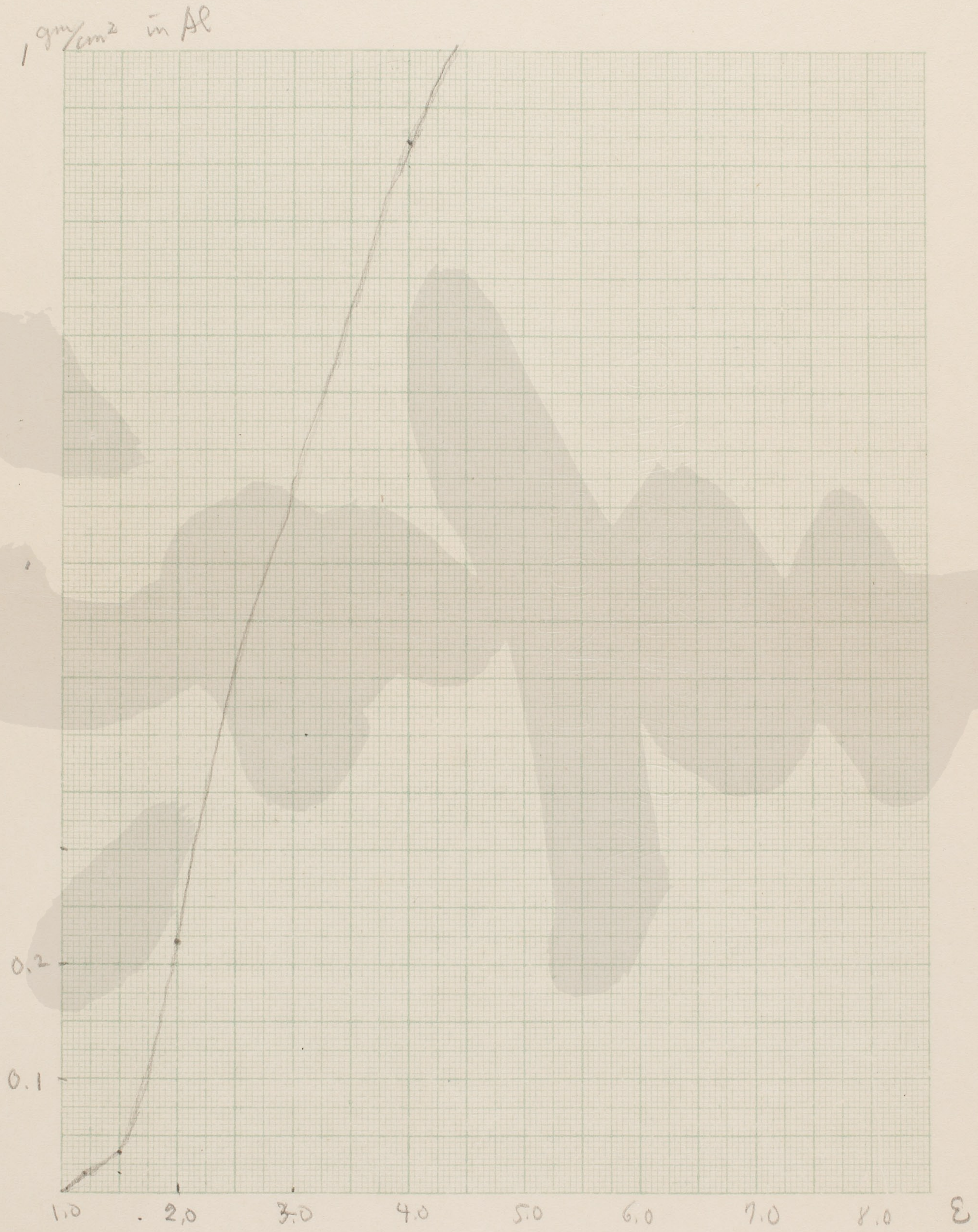

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$\Sigma \simeq 2$
$\beta \simeq 0.86$
$R\rho = 0.165$

ii) Photoelectric Effect

$\gamma = 1$. cross section $\phi_K = \frac{\phi_0}{100}$

efficiency. > $\frac{N\phi_K}{\rho} . R\rho = \frac{NZ\phi_0}{Z\rho} \cdot \frac{R\rho}{100} = \frac{0.518 \times 0.165}{13 \times 2.7 \times 100}$

$= \frac{0.024}{100} = 0.02\%$

```
   54
 .259        2.7
  .33         13
 ----        ---
  777         81
 777         27            0.024
 -------     ----      ----------
 0.08547     3.51 ) 0.08547
                        702
                       ----
                       1527
```

$\gamma = 0.4$ ~~0.~~ effic. =

eff 0	eff 0
~~0.126 %~~	~~0.242 %~~
~~0.058~~	~~0.068~~
~~0.218~~	~~0.308~~

effic total. mean 0.263 %

effic. =

eff 0	eff 0
0.145	0.22
0.058	0.068
~~0.184~~	0.288
0.203	

mean = 0.256
4

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iii) Pair ~~Pro~~ Creation.

$\gamma = 4$: $\tau_M = 0.0019$ $\qquad \bar{\varepsilon}_M = 1+1$

$R_M = \frac{0.9}{2.7}$

$\tau_M R_M = \frac{0.0019 \times 0.9}{2.7} = 0.00063 = 0.06\%$

eff pair $\gtrless 0.1\%$

$\gamma = 10$: $0.35\% \sim 0.5\%$

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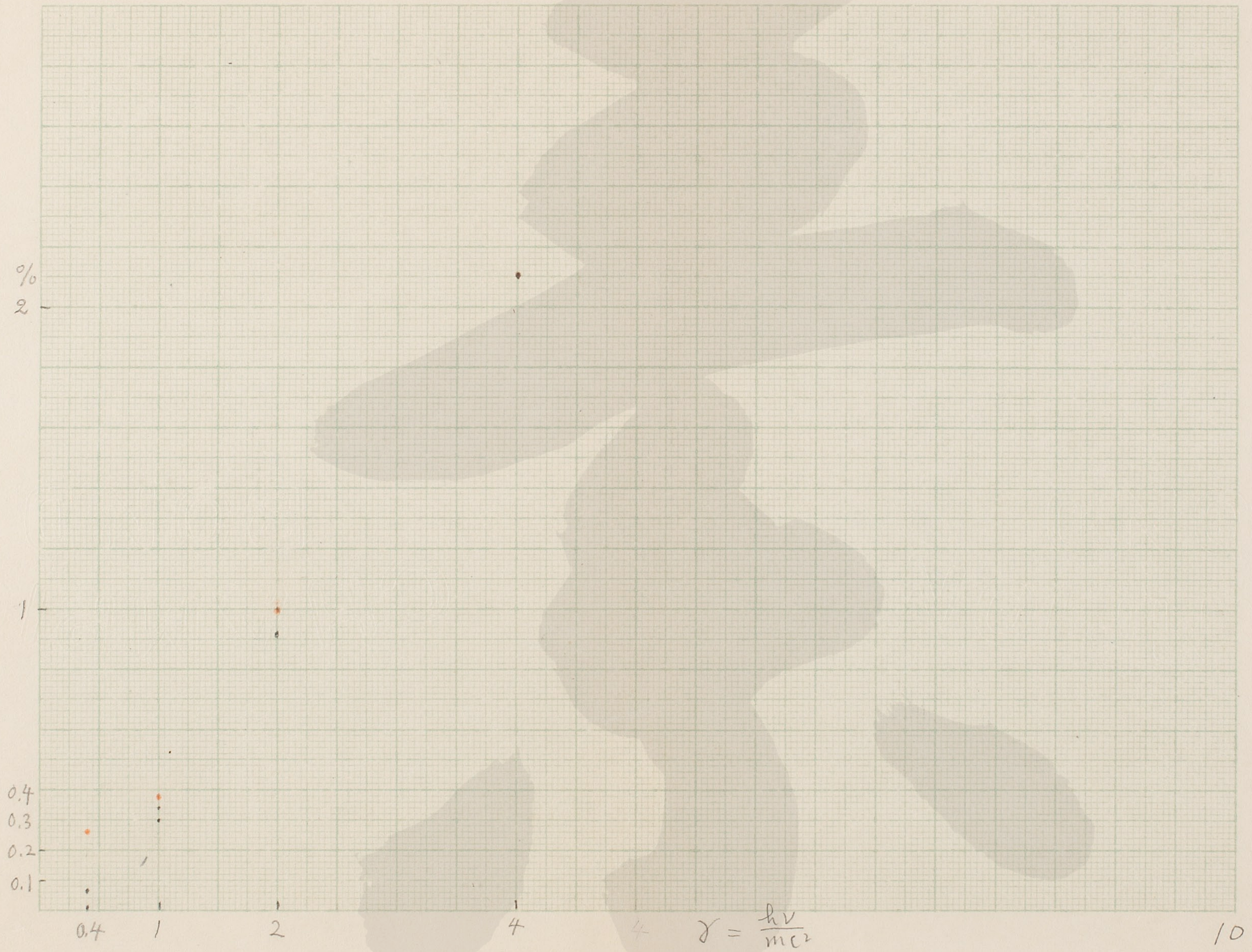

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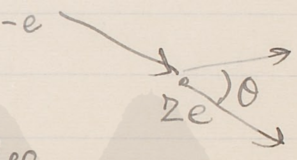
○ Effect of Scattering of Recoil Electrons

$$dQ = \frac{Z^2e^4}{4m^2v^4}\left(1-\frac{v^2}{c^2}\right)\left(1-\frac{v^2}{c^2}\sin^2\frac{\theta}{2}\right)\frac{\cancel{\sin\theta}\,d\Omega}{\sin^4\frac{\theta}{2}}$$

$$= \frac{1}{4}\left(\frac{Ze^2}{mc^2}\right)^2\frac{1-\beta^2}{\beta^4}\left(1-\frac{\beta^2(1-x)}{2}\right)\frac{dx\,d\varphi}{\left(\frac{1-x}{2}\right)^2}$$



$x=\cos\theta$

$$= \left(\frac{Ze^2}{mc^2}\right)^2\frac{(1-\beta^2)(2-\beta^2+\beta^2x)}{2\beta^4(1-x)^2}\,dx\,d\varphi$$

$$\cancel{\frac{dQ}{dx\,d\varphi} = Z^2r_0^2}$$

$$\frac{1}{dx}\int_{\varphi} dQ = \cancel{4\pi}Z^2r_0^2\,\frac{\pi(1-\beta^2)\cancel{(2-\beta^2)}(2-\beta^2+\beta^2x)}{\cancel{2}\beta^4(1-x)^2}\,dx.$$

$$Q(x_0)\int_{x=-1}^{x_0}\int_{\varphi=0}^{2\pi} dQ = Z^2r_0^2\,\frac{\pi(1-\beta^2)}{\beta^4}\cdot\int_{-1}^{x_0}\frac{2-\beta^2+\beta^2x}{(1-x)^2}\,dx$$

$$= \frac{Z^2r_0^2\pi(1-\beta^2)}{\beta^4}\cdot\cancel{4}\left\{\frac{2}{(1-x)}+\cancel{\frac{\ }{(1-x)^2}}\beta^2\log(1-x)\right\}_{-1}^{x_0}$$

$$= \frac{Z^2r_0^2\pi(1-\beta^2)}{\beta^4}\left\{\frac{2}{1-x_0}+\beta^2\log(1-x_0)-1-\beta^2\log 2\right\}$$

$$= \frac{Z^2r_0^2\pi(1-\beta^2)}{\beta^4}\left\{\frac{2}{1-x_0}-1-\beta^2\log\cancel{\frac{1-x_0}{2}}\left(\frac{2}{1-x_0}\right)\right\}$$

mean free path for the scattering $(x_0 > x > -1)$,

$$\lambda^{-1}(x_0) = NZ\phi_0\cdot\frac{3Z}{8}\,\frac{(1-\beta^2)}{\beta^4}\left\{\frac{2}{1-x_0}-1-\beta^2\log\frac{2}{1-x_0}\right\}$$

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$\varepsilon^2 = \frac{1}{1-\beta^2}$

$1-\beta^2 = \frac{1}{\varepsilon^2}$

$\beta^2 = 1 - \frac{1}{\varepsilon^2} = \frac{\varepsilon^2-1}{\varepsilon^2}$

$\boxed{\log 2 = 0.69315}$

$x_0 = 0.\ (\theta = \frac{\pi}{2})$

Al : $\lambda^{-1}(0) = 0.518 \times \frac{39}{8} \times \frac{\varepsilon^2}{(\varepsilon^2-1)^2} \{ \cancel{\frac{2}{1-1}} \cancel{1-\beta^2 \log 2)}$

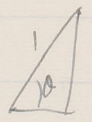
$\{1 - \frac{\varepsilon^2-1}{\varepsilon^2} \log 2\}$

~~8=1~~ $\varepsilon = 2,\quad \lambda^{-1}(0) = \frac{0.518 \times 39}{8} \times \frac{4}{9} \{1 - \frac{3}{4} \log 2\}$

$= \frac{0.259 \times \overset{13}{\cancel{39}} \times \overset{0.16}{\cancel{0.48}}}{\cancel{9}3} = 0.54$

$\lambda(0) = 1.85$ cm

$$\begin{array}{r} .69315 \\ 3 \\ \hline 4)2.07945 \\ 0.52 \end{array} \qquad \begin{array}{r} 0.26 \\ 13 \\ \hline 78 \\ 26 \\ \hline 3.38 \\ 0.16 \\ \hline 2028 \\ 338 \\ \hline 0.5408 \end{array} \qquad \begin{array}{r} 1.85 \\ 0.54)\overline{100} \\ 54 \\ \hline 460 \\ 432 \\ \hline 28 \end{array}$$



$2\sqrt{2} = 2.828$

~~$\frac{2\sqrt{2}}{\sqrt{2}-1}$~~

$\frac{2(1+\frac{1}{\sqrt{2}})}{\frac{1}{2}} = 4 + 2\sqrt{2}$

$x_0 = \frac{1}{\sqrt{2}}\quad (\theta = \frac{\pi}{4})\qquad \varepsilon = 1$

Al $\quad \lambda^{-1}(\frac{1}{\sqrt{2}}) = \frac{0.518 \times 39 \times 4}{8 \times 9} \{ \frac{2}{1-\frac{1}{\sqrt{2}}} - 1 - \frac{3}{4} \log \frac{2}{1-\frac{1}{\sqrt{2}}} \}$

$= \frac{0.26 \times 13}{3} \{ \cancel{4} 3 + 2\sqrt{2} - \frac{3}{4} \log(4 + 2\sqrt{2}) \}$

$\log 6.828 = 1.9213$

$= \frac{0.26 \times 13 \times 3.39}{\cancel{3}3} = 4.495$

$\lambda(\frac{1}{\sqrt{2}}) \doteqdot 0.202$ cm

$$\begin{array}{r} 1.9213 \\ 3 \\ \hline 4)5.7639 \\ 1.441 \end{array} \qquad \begin{array}{r} 5.828 \\ 1.9213 \\ \hline 3.907 \end{array} \qquad \begin{array}{r} 5.828 \\ 1.441 \\ \hline 3.637 \\ 4.387 \end{array}$$

$$\begin{array}{r} 4.387 \\ \times \cancel{3.639} \end{array} \qquad \begin{array}{r} 3.38 \\ 1.2 \\ \hline 10\ 4 \\ 338 \\ \hline 4394 \end{array} \qquad \begin{array}{r} 3.38 \\ 1.2 \\ \hline 6 \end{array}$$

$$\begin{array}{r} 0.202 \\ 4.95)\overline{1000} \\ 990 \\ \hline 100 \end{array} \qquad \begin{array}{r} 3.38 \\ \cancel{1.39} \\ 1.46 \\ \hline 2228 \\ 1352 \\ 338 \\ \hline 49548 \end{array}$$

0.49
0.25
0.24
0.24
96
48
0.0576

$\frac{0.49}{4}$

$0.49\overline{)0.24}$ 0.49
196
440
441

$\varepsilon = 1.4$

$$\lambda^{-1}(0) = 0.518 \times \frac{39}{8} \times \frac{(1.4)^2}{((1.4)^2-1)^2}\left\{1 - \frac{(1.4)^2-1}{(1.4)^2}\log 2\right\}$$

$\frac{(1.4)^2-1}{(1.4)^2} = 0.49$

$$= \frac{\overset{2.59}{\cancel{0.518}} \times \overset{13}{\cancel{39}} \times 0.49}{\underset{4}{\cancel{8}} \times \underset{0.0192}{\cancel{0.0576}}} \times 0.66$$

$$= 21.4 \times 0.66 = 14.1$$

3.38
0.49
3042
1352
16562

0.192
4
0.768

$0.768\overline{)16.562}$ 21.4
1536
1202
768
4340

0.69315
0.49
6237
2772
0.339657
0.66043

21.4
0.66
1284
1284
14124

$14.1\overline{)100}$ 0.071
987
130

$$\lambda(0) = 0.071\ \text{cm}$$
$$= 0.71\ \text{mm}.$$

$\varepsilon = 1.4$

$$\lambda^{-1}\left(\frac{1}{\sqrt{2}}\right) = ~~cm~~\ 21.4\left\{~~2mm~~\ 5.828 - 0.49 \times 1.9213\right\}$$
$$= 104$$

1.9213
94

5.828
0.94
4.888

21.4
4.9
1926
856
104.86

$$\lambda\left(\frac{1}{\sqrt{2}}\right) = 0.01\ ~~mm~~\ \text{cm} = 0.1\ \text{mm}$$