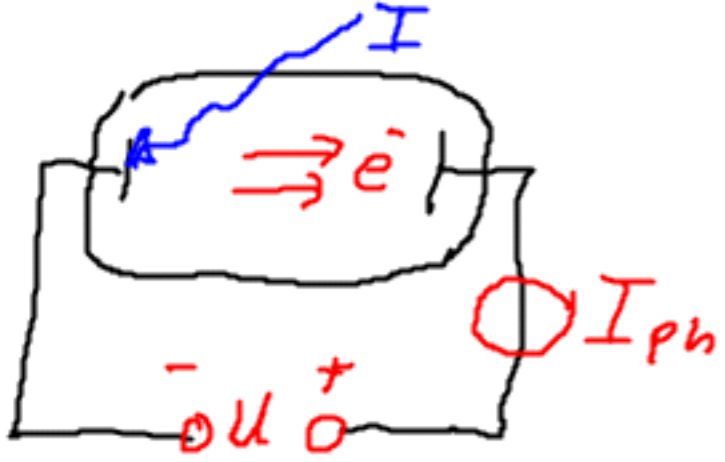
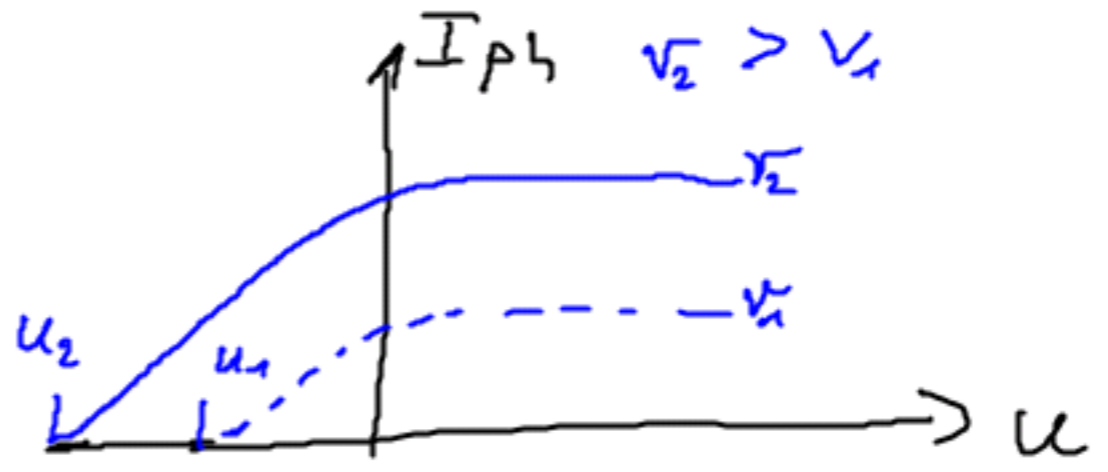
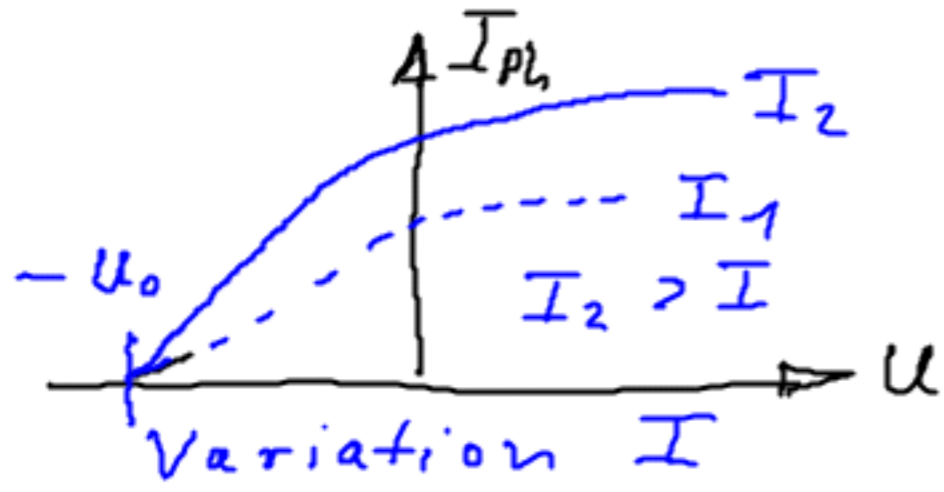


# 1.4 Photoeffekt

Planck  $E = h\nu$ , Korpuskel?



Messungen Lenard 1902  
 Erklärung Einstein 1905  
 Nobelpreis 1921



Widerspruch klass.  
 1)  $I \sim E^2$  Kraft  $eE$   
Feldstärke  
 $U_0$  sollte mit  $I$  zunehmen

2)  $U_0$  unabhängig von  $\nu$

3) keine Verzögerung beobachtet

# Erläuterung Einsteins:

a) einzelnes Photon  $E = h\nu$

b) jedes Photon Teilchen in Bündel Geschw

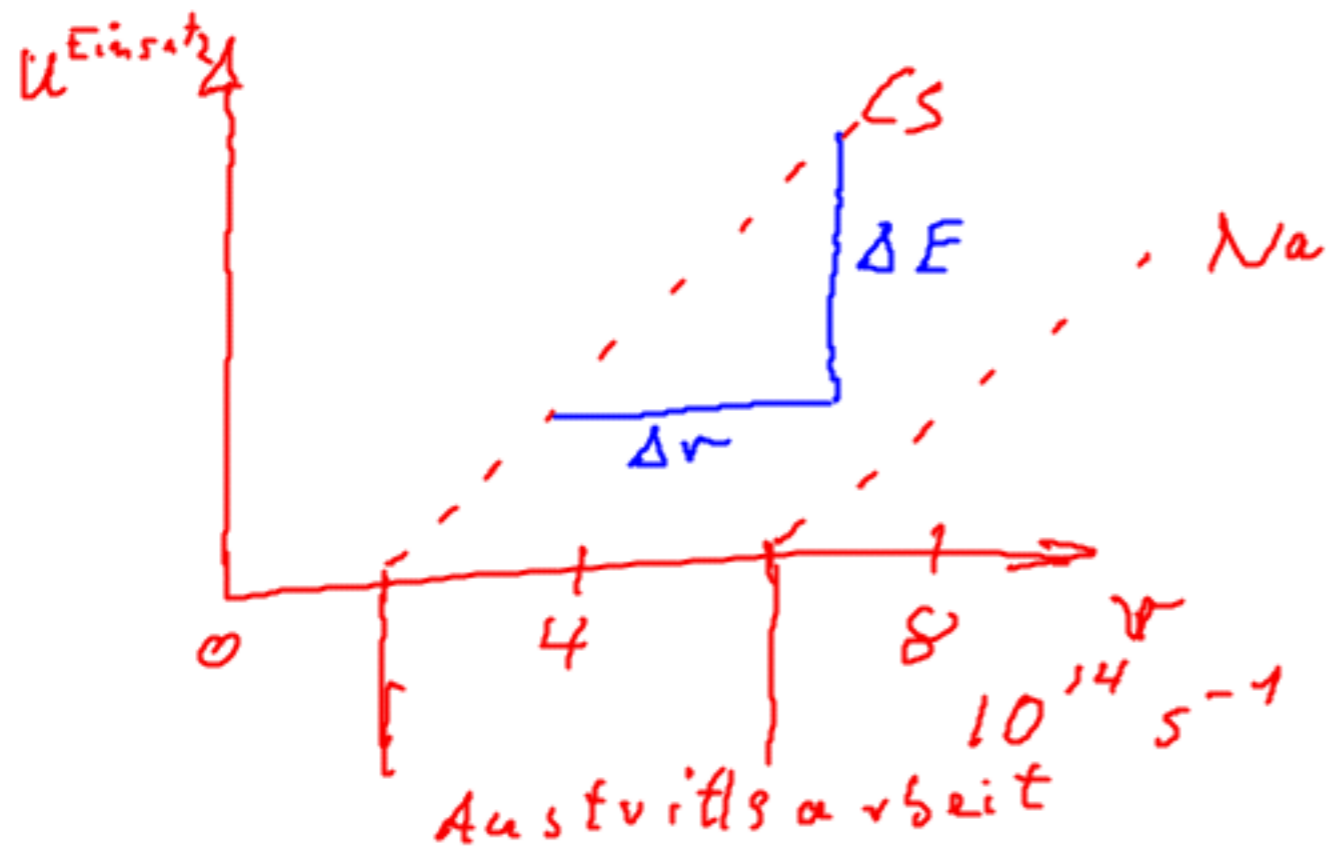
c) jedes Photon kann nur ganzes absorbiert

## Löst Widersprüche

1) mehr I

2) Austrittsarbeit  $W_a$ ;  $h\nu < W_a$  kein Photoef.

3) keine Verzögerung; Photon trifft Elektron



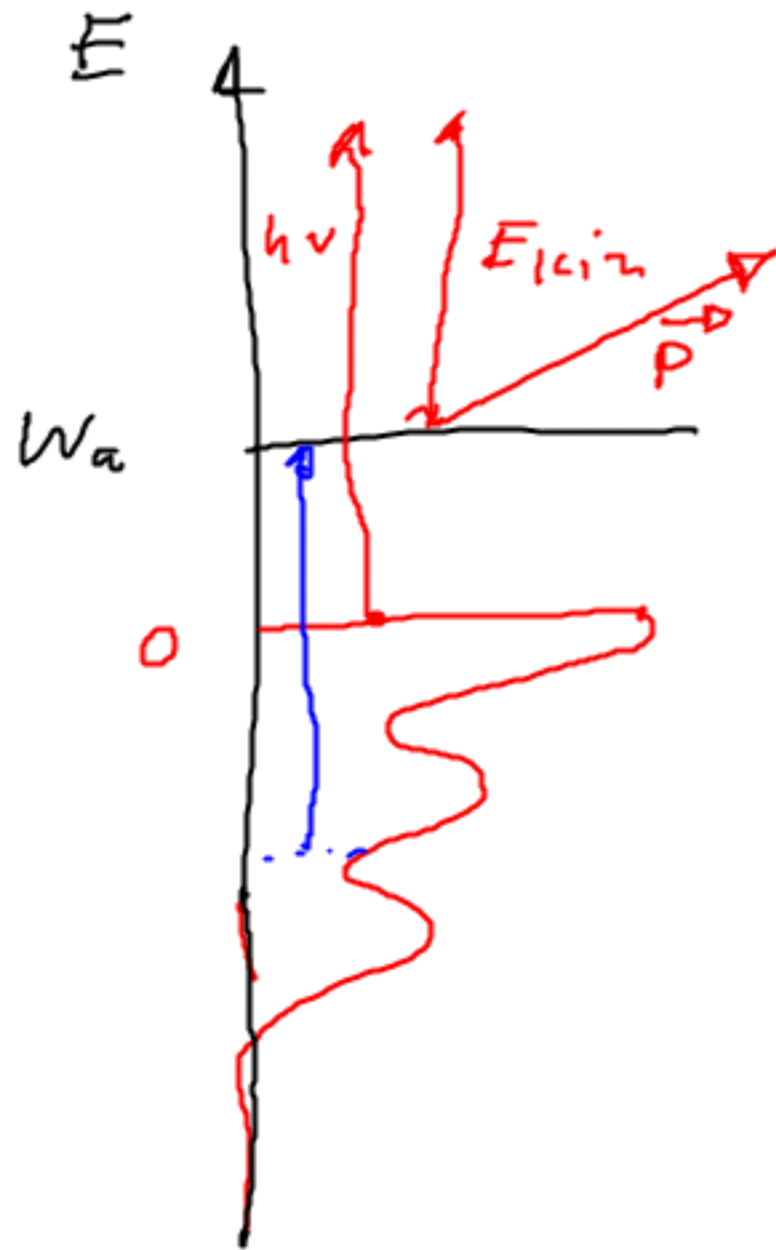
4) Steigung

$$h\nu = E_{\text{kin}} + W_a$$

$$\frac{\Delta E_{\text{kin}}}{\Delta \nu} = h$$

Photo

elektrorenspektroskopie



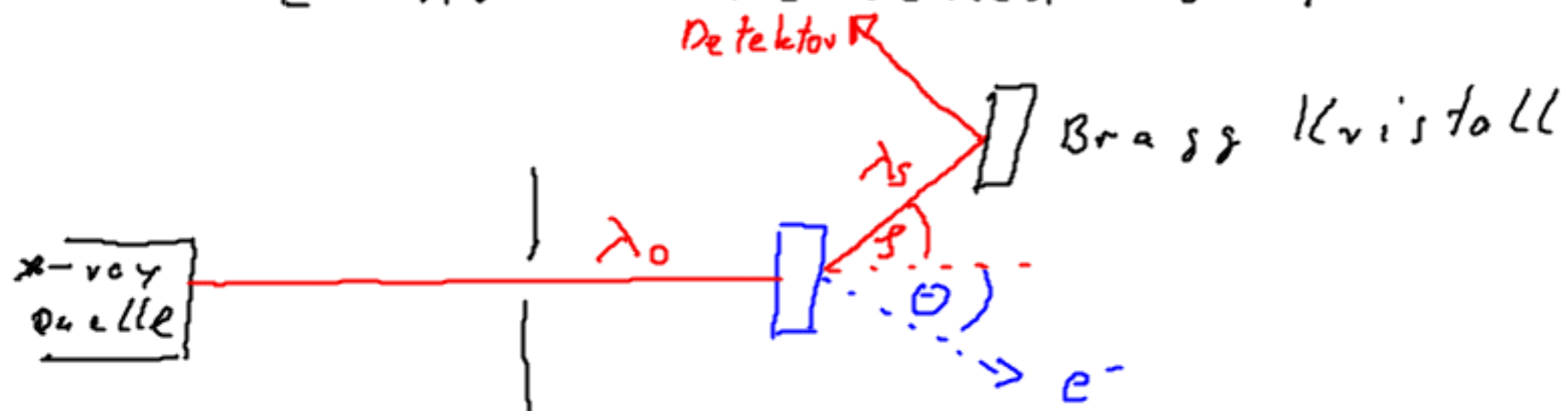
ESCA

Siegbahn 1975

Richtungsverteilung

# 1.5 Compton effekt 1923

$E = h\nu$  Teilchen - Impuls



klassisch:  $\lambda_0 = \lambda_s$  erzwingend Schwingung

Messung:  $\lambda_s - \lambda_0 = \Delta\lambda = \lambda_c (1 - \cos\phi)$

$\lambda_c = 2.4262 \times 10^{-12} \text{ m}$  (unabh.  $\lambda_0$ )

relativ. Energie  $E$  gegen Ruhemasse  $m_0$  und  $v$

$E = m_0 c^2 / \sqrt{1 - v^2/c^2}$   $v \rightarrow c \rightarrow \frac{1}{\sqrt{\quad}} \rightarrow \infty$

$m_0 = 0$  ! Ruhemasse!

rel.  $E$  gegen  $m_0$  und Impuls  $p$

$E^2 = c^2 p^2 + (m_0 c^2)^2 \rightarrow 0$

$E = c \cdot p \rightarrow p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$

Photon : Teilchen  $E = h\nu$   $p = \frac{h}{\lambda} = \hbar k$

Energie



$$E_0 + m_0 c^2 = E_1 + E_{kin} + m_0 c^2$$

$$E_0 - E_1 = E_{kin}$$

$$c(p_0 - p_1) = E_{kin} \quad (2)$$

E-Satz  $e^-$

$$(E_{kin} + m_0 c^2)^2 = c^2 p_e^2 + (m_0 c^2)^2$$

$$E_{kin}^2 + 2 E_{kin} m_0 c^2 = c^2 p_e^2$$

$$p_e^2 = E_{kin}^2 / c^2 + 2 E_{kin} m_0$$

↙ (1)

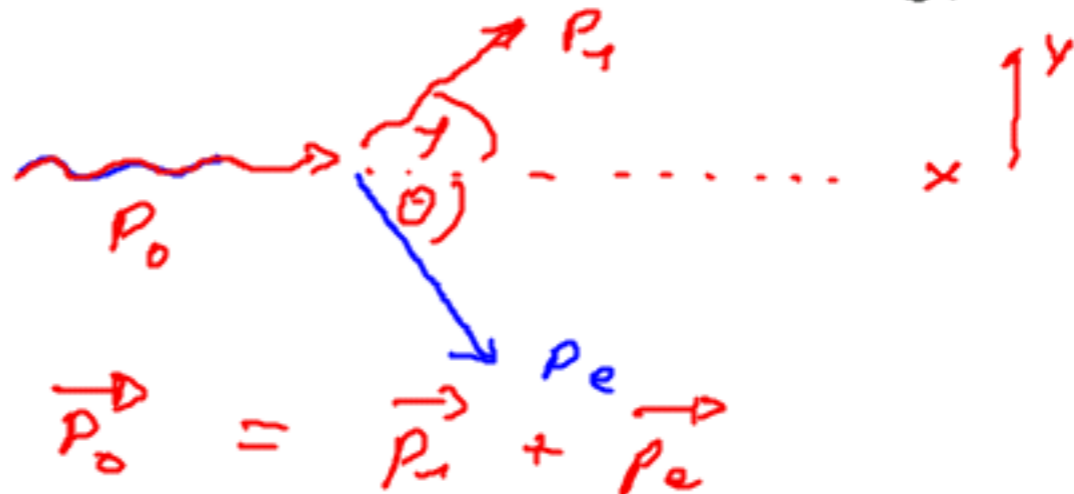
↘ (2)

$$p_0^2 + p_1^2 - 2 p_0 p_1 \cos \varphi = (p_0 - p_1)^2 + 2 m_0 c (p_0 - p_1) : 2$$

$$p_0 p_1 (1 - \cos \varphi) = m_0 c (p_0 - p_1) \quad / p_0 p_1$$

$$\frac{1}{p_1} - \frac{1}{p_0} = \frac{1}{m_0 c} (1 - \cos \varphi)$$

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



$$\vec{p}_0 = \vec{p}_1 + \vec{p}_e$$

$$x: p_0 = p_1 \cos \varphi + p_e \cos \theta$$

$$p_0 - p_1 \cos \varphi = p_e \cos \theta$$

$$y: p_1 \sin \varphi = p_e \sin \theta$$

$$p_0^2 + p_1^2 - 2 p_0 p_1 \cos \varphi = p_e^2 (\sin^2 \theta + \cos^2 \theta) \quad \text{quad. + add}$$

$$= p_e^2$$

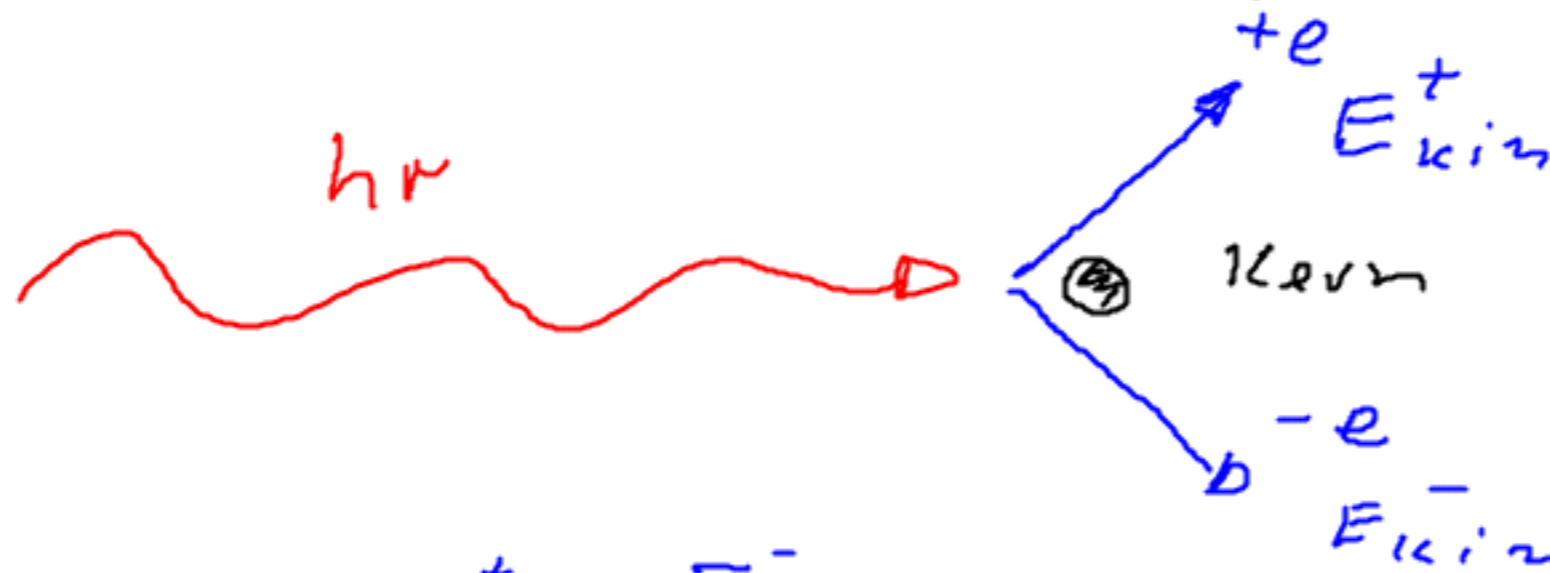
↙ (1)

= p\_e^2

$$\Delta \lambda = \lambda_s - \lambda_0 = \lambda_c (1 - \cos \varphi)$$

$$\lambda_c = \frac{h}{m_0 c} = 0,0024 \text{ nm}$$

1.6 Paarbildung, Gravitation (Möbbauev)



$$h\nu = E^+ + E^- = (m_0 c^2 + E_{kin}^+) + (m_0 c^2 + E_{kin}^-)$$

$$= E_{kin}^+ + E_{kin}^- + 2m_0 c^2$$

Schwelle:  $h\nu = 2m_0 c^2 \hat{=} 1,02 \text{ MeV}$

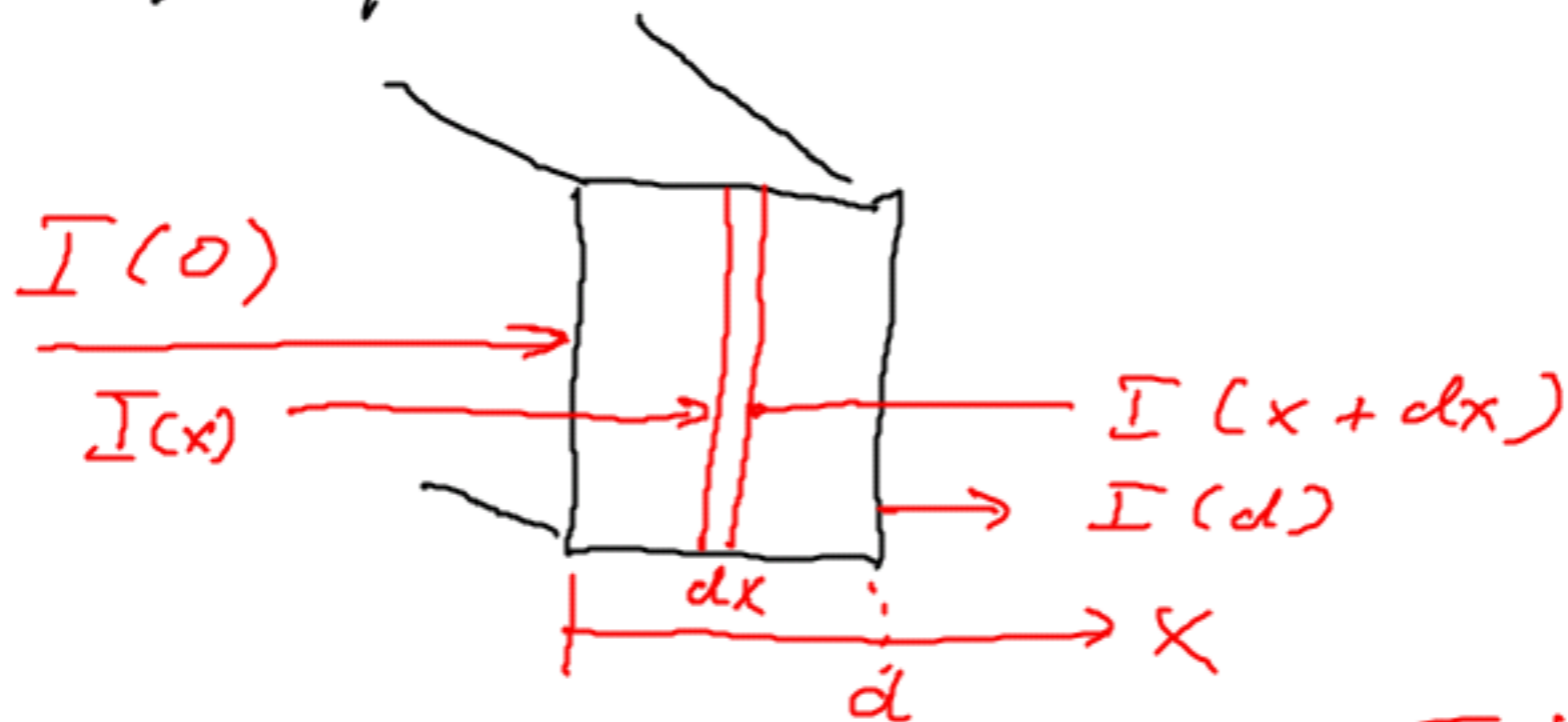
Paarvernichtung  $\rightarrow$  2 Photonen



Impulserhaltung  $0 = p_1 + p_2$   
 $h\nu_1 = h\nu_2$

Wesellkammer	Wilson	Nobelpreis 1927
Blasenkammer	Glaser	" 1960
Drahtkammer	Charpak	1992

# Wirbelungsquerschnitt



Teilchendichte  $n$   $\left(\frac{\text{Teilchen}}{\text{m}^3}\right)$   
effektiver  $\sigma$  (in  $\text{m}^2$ ) pro Teilchen für Prozeß

1)  $dx$  so klein, nicht verdecken?  
abgedeckte Fläche:  $n \cdot \sigma \cdot dx$

$$2) \text{Trage (für } dI(x) = -I(x) \cdot \sigma \cdot n \cdot dx$$

$$\frac{dI}{I} = -\sigma n dx$$

$$\ln \frac{I(x)}{I(0)} = -\sigma n x$$

$$I(x) = I_0 e^{-\sigma n x}$$



$\sigma$  Wirkungsquerschnitt

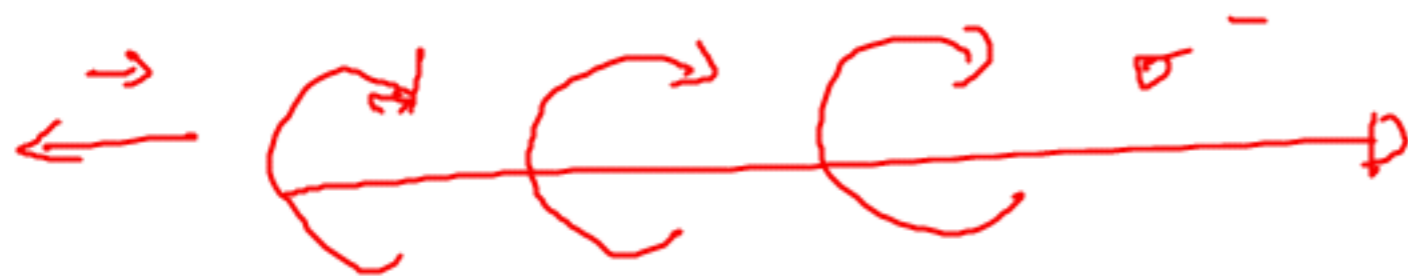
$\sigma \cdot n$  Schwächungskoeffizient

$1/\sigma \cdot n = \Lambda$  Absorptionslänge

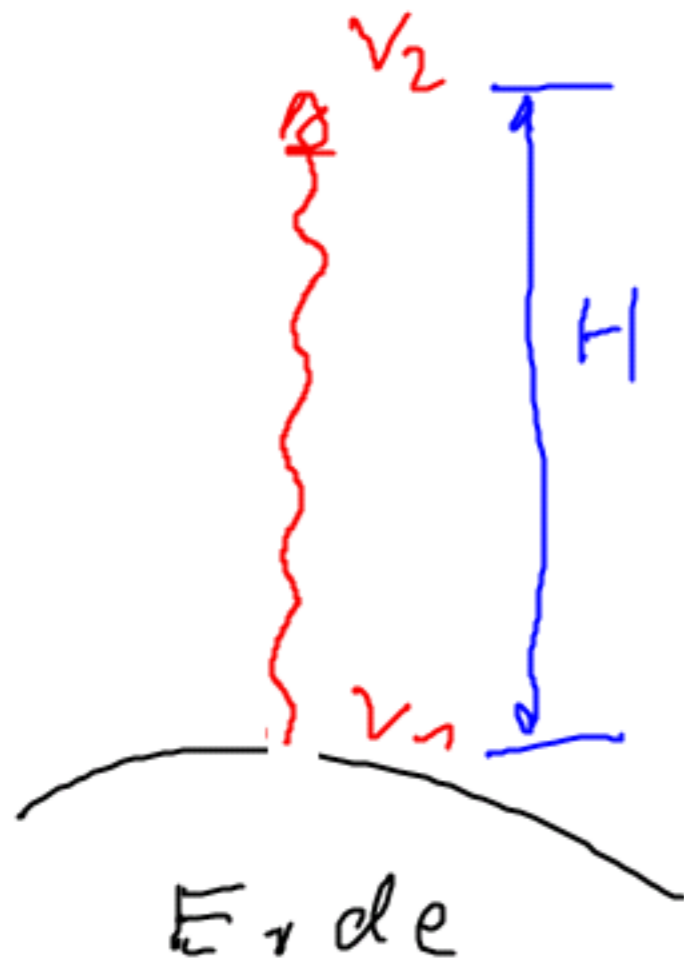
Polarisation + Drehimpuls  
(Spin)

$\sigma^+$  (rechtszirkular):  $S = +\hbar$  parallel  $\vec{k}$

$\sigma^-$  (links)  $S = -\hbar$  antiparallel  $\vec{k}$



# Photon in Gravitational field

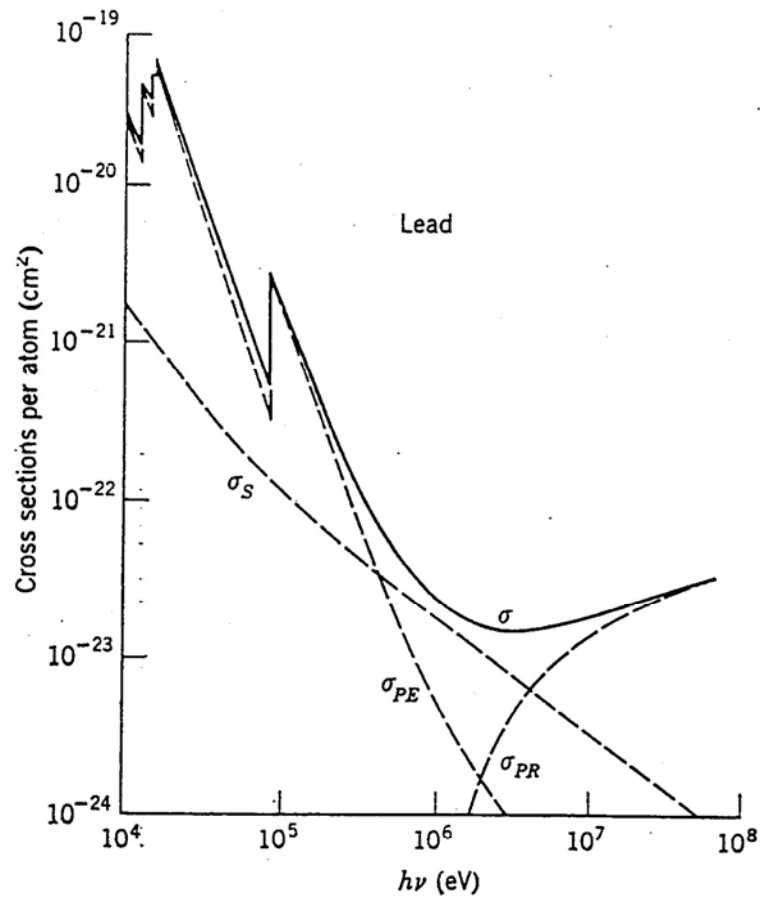


$$h\nu = mc^2$$

$$m = \frac{h\nu}{c^2}$$

$$h\nu_2 = h\nu_1 - m \cdot g \cdot H$$

$$\nu_2 = \nu_1 \left( 1 - \frac{g \cdot H}{c^2} \right)$$

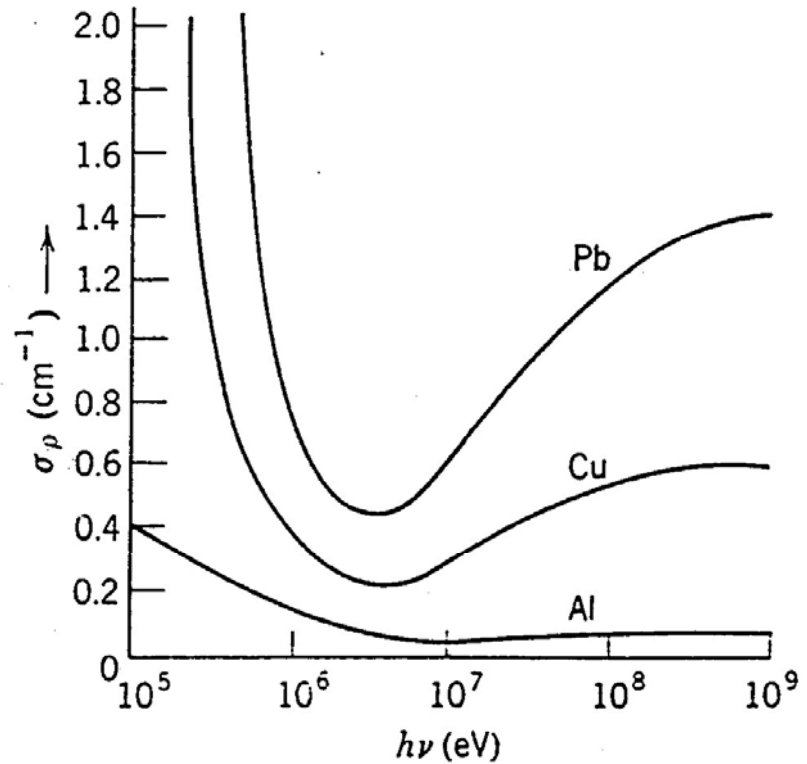


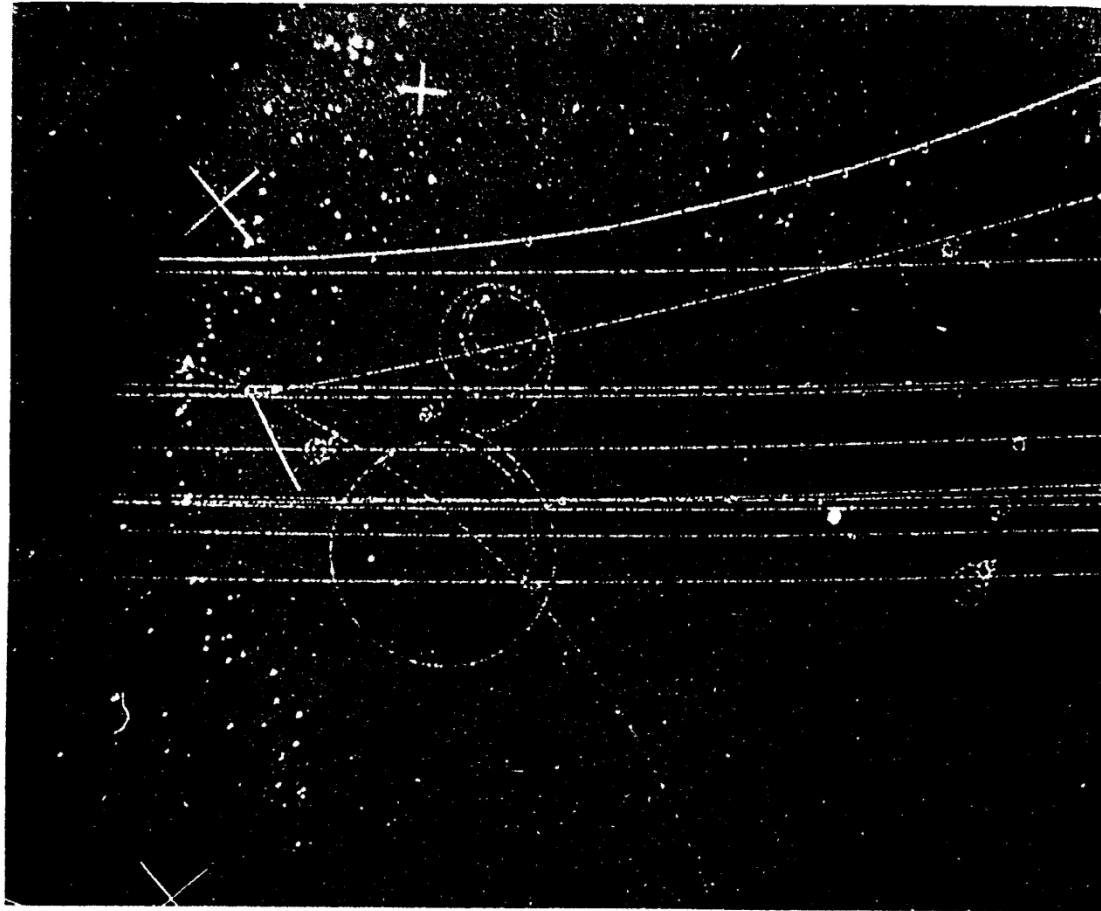
**FIGURE 2-17**

The scattering, photoelectric, pair production, and total cross sections for a lead atom.

**FIGURE 2-18**

The attenuation coefficients for several atoms and a range of photon energies.





**FIGURE 2-13**

Electron pair production, as seen in a bubble chamber. The electron and positron tracks are the two spirals meeting at the point where the production took place in the liquid filling of the chamber. The student can determine which of the two spirals belongs to the positron by knowing that the long tracks are primarily positively charged deuterons which are incident from the left. (Courtesy of C. R. Sun, State University of New