L04-Photons: Particles vs Waves

Wednesday, September 2, 2015 7:23 AM

* review
  - Planck explained blackbody spectrum by $\varepsilon = h\nu$ quantization of "oscillator modes"
  - effective UV cutoff: higher frequencies do not have enough energy for 1st excited state
    ∴ average energy/mode $\langle E \rangle \sim e^{-h\nu/kT}$
  - same for heat capacity: $C = \frac{d}{2} N_A k$
    d = # degrees of freedom - frozen out at low temp.
    quantum, not continuous states
  - only first step in development of "photon"

* history of particle vs wave theory of light
  - Aristotle - disturbance of aether
  - Democritus - indivisible atoms
  - Alhazen 11th century - refraction/reflection particles
  - Descartes 1630 - wave like
  - Newton 1670 - corpuscular (different colors)
  - Hooke, Huygen, Frenel - mathematical waves
  - Young 1803 - double slit interference
  - Poisson 1818 - "spot" observed by Arago.
  - Maxwell 1860's - wave equations for light
  - Hertz 1887 - observed wave

* what is the difference between particle & wave?

	particle		wave
position	local, point like		spread out
D.O.F.	$\vec{r}$ vector		$\Phi(\vec{r})$ field
dynamics	$\vec{F} = m\vec{a}$	$\Rightarrow$	$(\nabla^2 - \frac{1}{v^2}\partial_t^2)\Phi = 0$
quantization	mass		modes
sociality	individual		collective motion of particles
physical	m (inertia)		v, Z properties of medium

sociality:	individual	collective motion of particles
physical	m (inertia)	v, Z properties of medium
dispersion	$E = P/m$	$v = \lambda f = \omega/k$
interactions	collision/detection	reflection/refraction
interference	—	diffraction
conservation	$E, \vec{p}$	$\nabla\cdot(\vec{S}=\vec{E}\times\vec{H},\ \overleftrightarrow{T}) = 0$

* Photoelectric Effect

Irony: discovered by Hertz while showing that light is an E&M wave

properties:

a) negative charged electrons
b) cutoff frequency [not intensity!]
c) current proportional to intensity [no delay!]
d) energy of electron $\propto$ frequency [not intensity!]

"photon" of light "$h\nu$" releases electron against work function W of metal $\boxed{eV = h\nu - W}$

Millikan 1918 confirmed experimentally, didn't accept photons

* Compton effect

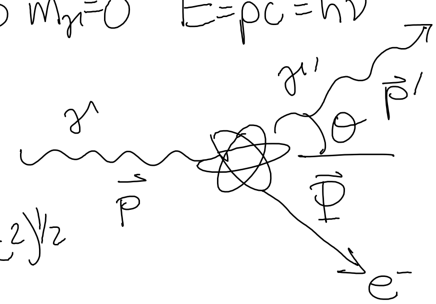
Irony: used Bragg diffraction to discover it!

classical $I(\theta) \sim 1 + \cos^2\theta$, Rayleigh scattering $\nu = \nu_0$

partical: elastic scattering, conservation of $E, \vec{p}$

$E^2 = (mc^2)^2 + (pc)^2$ but $v_\gamma = \frac{dE}{dp} = c$ so $m_\gamma = 0$ $E = pc = h\nu$

$\vec{p} = \vec{p}\,' + \vec{P} \rightarrow P^2 = (p-p')^2 = \underbrace{p^2}_{(h\nu/c)^2} + p'^2 - 2\vec{p}\cdot\vec{p}\,'$



$\Delta E = 0 \rightarrow h\nu + mc^2 = h\nu' + (m^2c^4 + P^2c^2)^{1/2}$

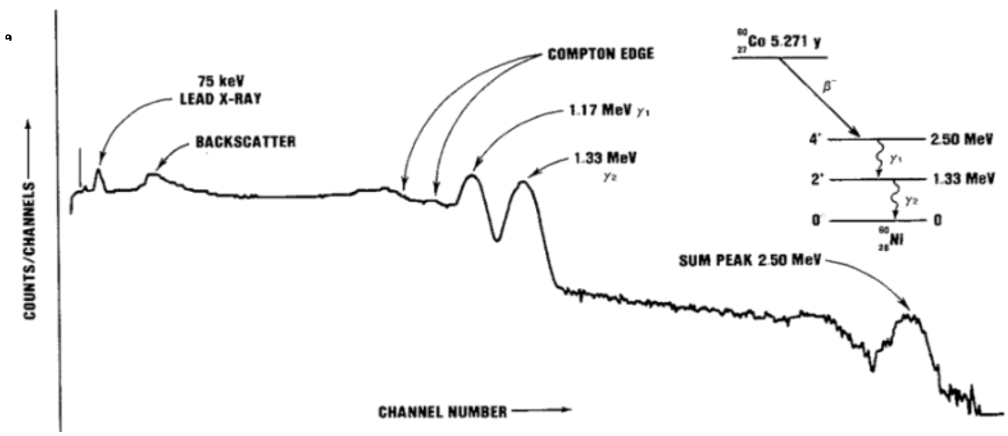
$m^2c^4 + P^2c^2 = h^2(\nu-\nu')^2 + m^2c^4 + 2h(\nu-\nu')mc^2$

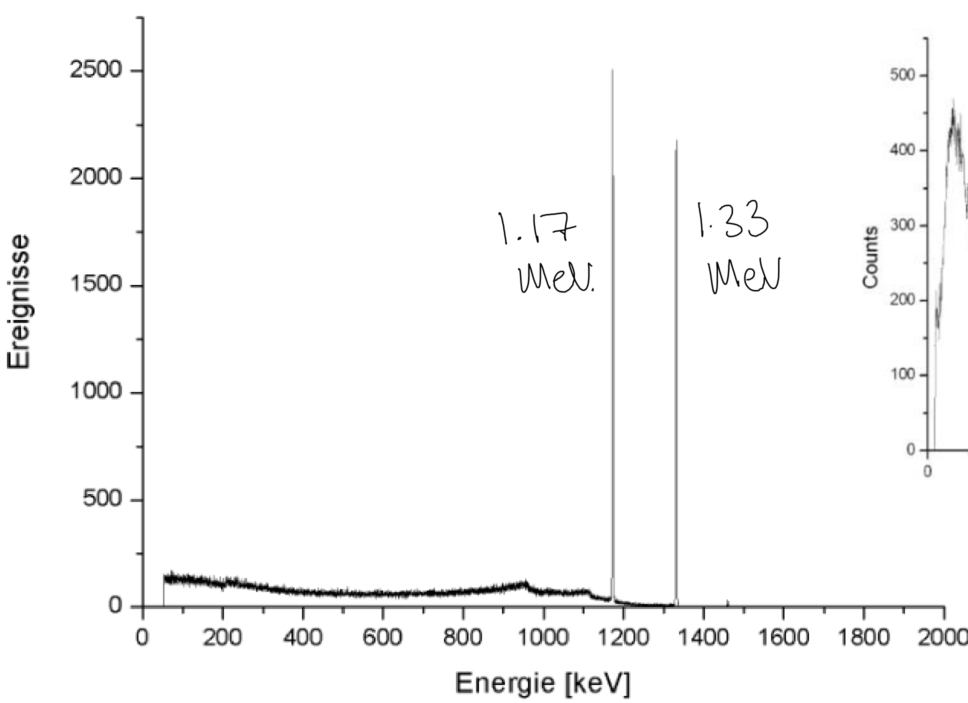
$$\left(\left(\frac{h\nu}{c}\right)^2 + \left(\frac{h\nu'}{c}\right)^2 - 2\,\frac{h\nu}{c}\frac{h\nu'}{c}\cos\theta\right)c^2 = h^2(\nu^2+\nu'^2-2\nu\nu') + 2h(\nu-\nu')mc^2$$

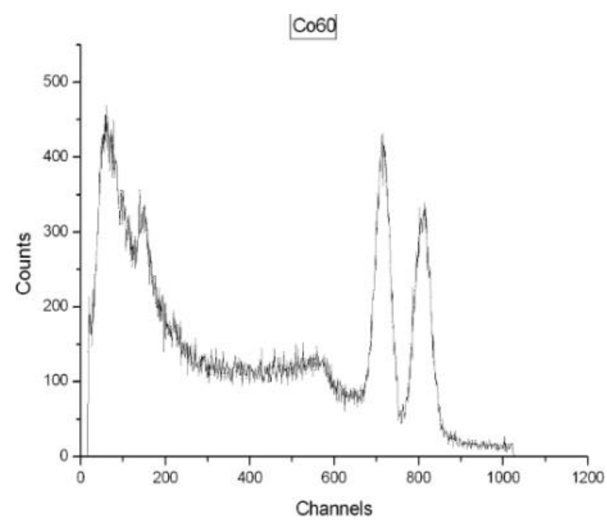
$$h\nu\nu'(1-\cos\theta) = mc^2(\nu-\nu') \qquad \boxed{\lambda'-\lambda = \lambda_c(1-\cos\theta) \quad \lambda_c = \frac{h}{mc}}$$

$$= 2.4\times10^{-12}\,\text{m}$$

* Example: ^{60}Co γ-emission spectrum







$$\lambda'-\lambda = \lambda_c(1-\cos\theta) \qquad \frac{hc}{E} - \frac{hc}{E'} = \frac{h}{mc}(1-\cos\theta)$$

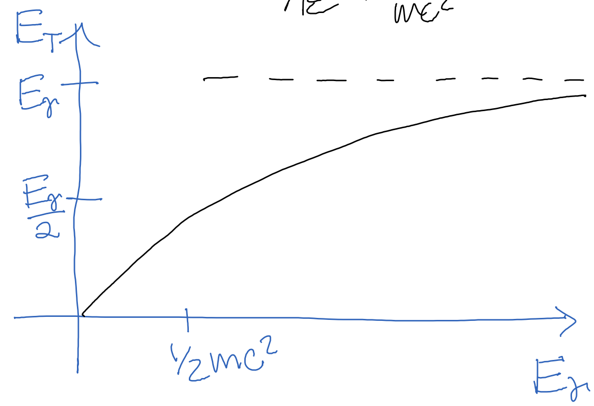
$$\frac{1}{E'} - \frac{1}{E} = \frac{1-\cos\theta}{mc^2} \qquad E' = \left(\frac{1}{E} + \frac{1-\cos\theta}{mc^2}\right)^{-1}$$

$$E_T = E - E'_{min} = E - \frac{1}{1/E + \frac{2}{mc^2}} = \frac{E\left(\frac{1}{E} + \frac{2}{mc^2}\right) - 1}{1/E + \frac{2}{mc^2}}$$

$$= \frac{2E^2}{2E + mc^2}$$

$$= E \frac{1}{1 + \frac{mc^2}{2E}}$$

$mc^2 = 0.511$ MeV.



$E_\gamma = 1.17$ MeV: $E_e = (1 + 0.218)^{-1} E_\gamma = 0.821\ E_\gamma = 960$ keV

1.33 0.192 0.839 1115 keV.