Scattering experiments

- **1923** - A. Compton attributes X-ray shift to particle-like momentum to light quanta.
- **Compton scattering effect**, experiments of X-rays interacting with matter.

Compton scattering:

- X-rays shining on atoms $\left\} \begin{array}{l} \text{X-rays: 100 eV - 100 keV} \\ \text{Binding e: 10 eV, 13 eV} \end{array} \right.$

- γ scattering on e- that are virtually free.

- Compton experiment was in disagreement with Thompson's theory of scattering.

(Classical) Thompson Scattering

- Thompson's attributes scattering to e- vibrating as a result of the incident E field.

Thompson:

EM wave $\vec{E}$ Electric

low-ν

low E

Accelerates and radiates

$$\frac{d\sigma}{d\Omega} = \underbrace{\left(\frac{e^2}{mc^2}\right)^2 \frac{1}{2}\left(1+\cos^2\hat{\theta}\right)}_{\text{units of area}}$$

Intensity of radiation as a function of Ω

- Thompson's idea seems to work at low frequencies, but not at high frequencies.
- Predicts that outgoing photons have the same energy/frequency as the ingoing photons, which is not correct.

e- ν of $\vec{E}$ field $\Rightarrow$ $\nu_{\gamma_{out}}$ is the same

Compton Scattering

- Compton treats photons as particles:

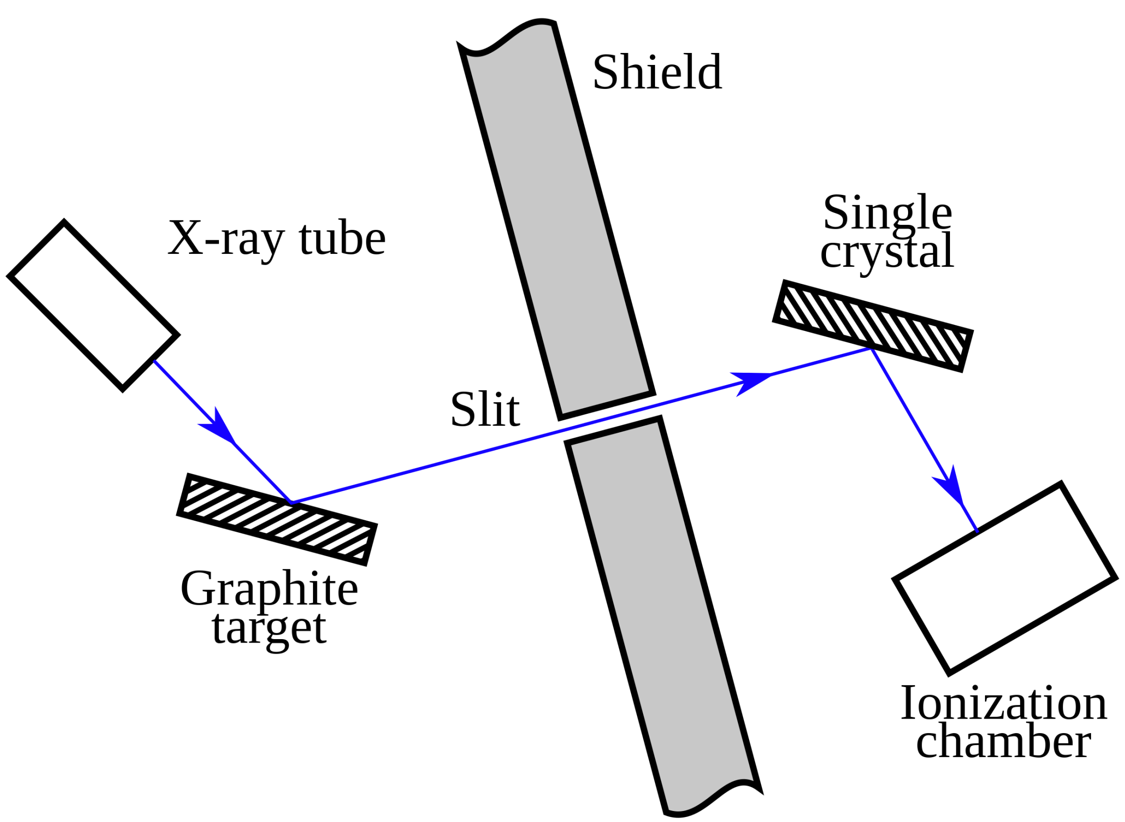
- QM tells us a beam of monochromatic light

↳ collection of particle-like γ

$$E_\gamma = h\nu$$

$$p_\gamma = \frac{h\nu}{c} = \frac{h}{\lambda}$$

Schematic diagram of Compton's experiment



Compton scattering occurs in the graphite target.

The slit passes X-ray photons scattered at a selected angle.

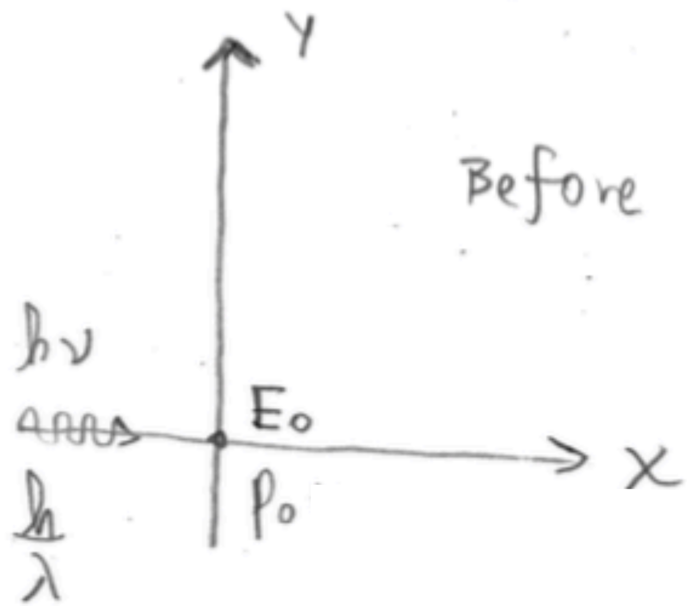
The energy of a scattered photon is measured using Bragg scattering in the crystal on the right in conjunction with the ionisation chamber.

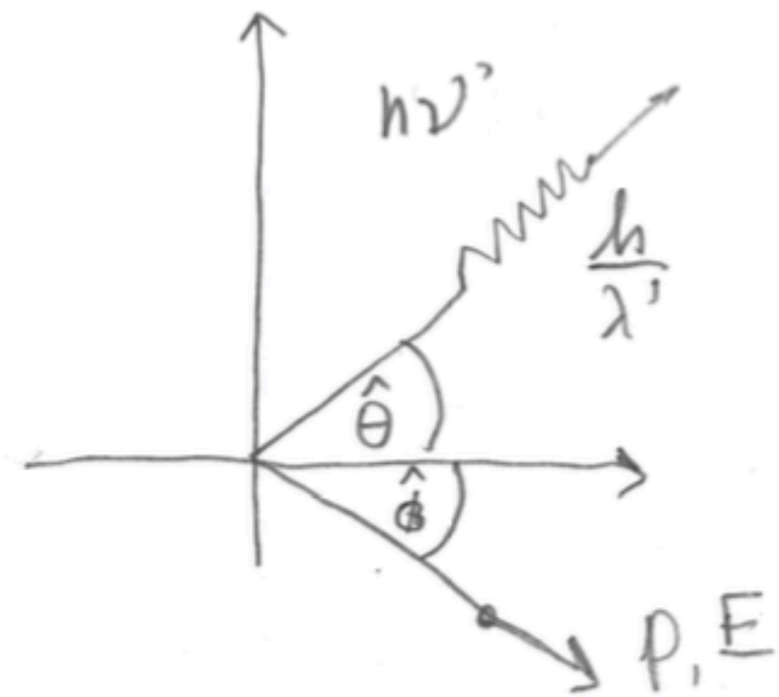
The chamber measures total energy deposited over time, not the energy of single scattered photons.

Reference: https://en.wikipedia.org/wiki/Compton_scattering

Compton Scattering

- Compton Scattering: collision of γ with charged particle





Compton shift:

$$\boxed{\Delta\lambda = \lambda' - \lambda = \frac{h}{m_0 c}\left(1 - \cos\hat{\theta}\right)}$$

Compton wavelength of the charged particle (e.g. e-)

QM predicts that ν decreases
λ increases

$\hat{\theta}$ is the scattering $\measuredangle$.

γ loses energy $\lambda' > \lambda$

Photons are particles

1916 : quanta of E, p

$$\left.\begin{aligned} E &= \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}} \\ \vec{p} &= \frac{m\vec{v}}{\sqrt{1-\frac{v^2}{c^2}}} \end{aligned}\right\} \quad E^2 - p^2c^2 = m^2c^4$$

Non-relativistic case:

$$E = \frac{1}{2}mv^2, \ \vec{p} = m\vec{v} \Rightarrow E = \frac{p^2}{2m}$$

Photon: $m_\gamma = 0$, $E_\gamma = p_\gamma c \quad \Rightarrow p_\gamma = \frac{E_\gamma}{c} = \frac{h\nu_\gamma}{c} = \frac{h}{\lambda_\gamma}$

↳ looks like a particle.

De Broglie and Compton wavelengths

de Broglie wavelength:

$$\boxed{\lambda = \frac{h}{p}} = \lambda_{dB}$$

m → Rest energy : mc^2

↳ not moving → $\gamma = mc^2$ → natural length

Compton wavelength:

$$\boxed{\lambda_c = \frac{h}{mc}}$$ → Compton λ of a particle of mass "m".

↳ Length associated to any particle of mass "m".

De Broglie and Compton wavelengths

The rest energy of the particle is: $E = mc^2$

What is the λ of a γ whose energy is the rest mass of a particle?

$$mc^2 = E_\gamma = h\nu = h\frac{c}{\lambda} \Rightarrow \lambda_c = \frac{h}{mc}$$

The Compton λ is the λ of light that has that rest energy.

If we have an e^- with a Compton λ_e and we shine on it a γ with that size, that γ is carrying the same energy as the rest energy of the e^-.

Experimental implication $\rightarrow$ particle creation
particle destruction

It's difficult to isolate particles in sizes smaller than their λ_c.

De Broglie and Compton wavelengths

Definitions:

① de Broglie λ: the length / size at which the wavelike nature of particles become apparent.

② Compton λ: the length/size at which the concept of a single pointlike particle breaks down completely.

See: https://asafpeer2.ph.biu.ac.il/wp-content/uploads/2020/08/Introduction_QFT.pdf