(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

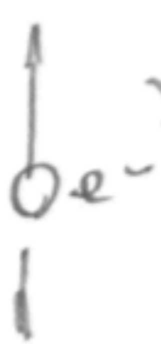
low E

Accelerates and radiates

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

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.



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

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 } X-rays: 100 eV - 100 keV; Binding e: 10eV, 13eV

- γ scattering on e- that are virtually free.

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

Compton Scattering

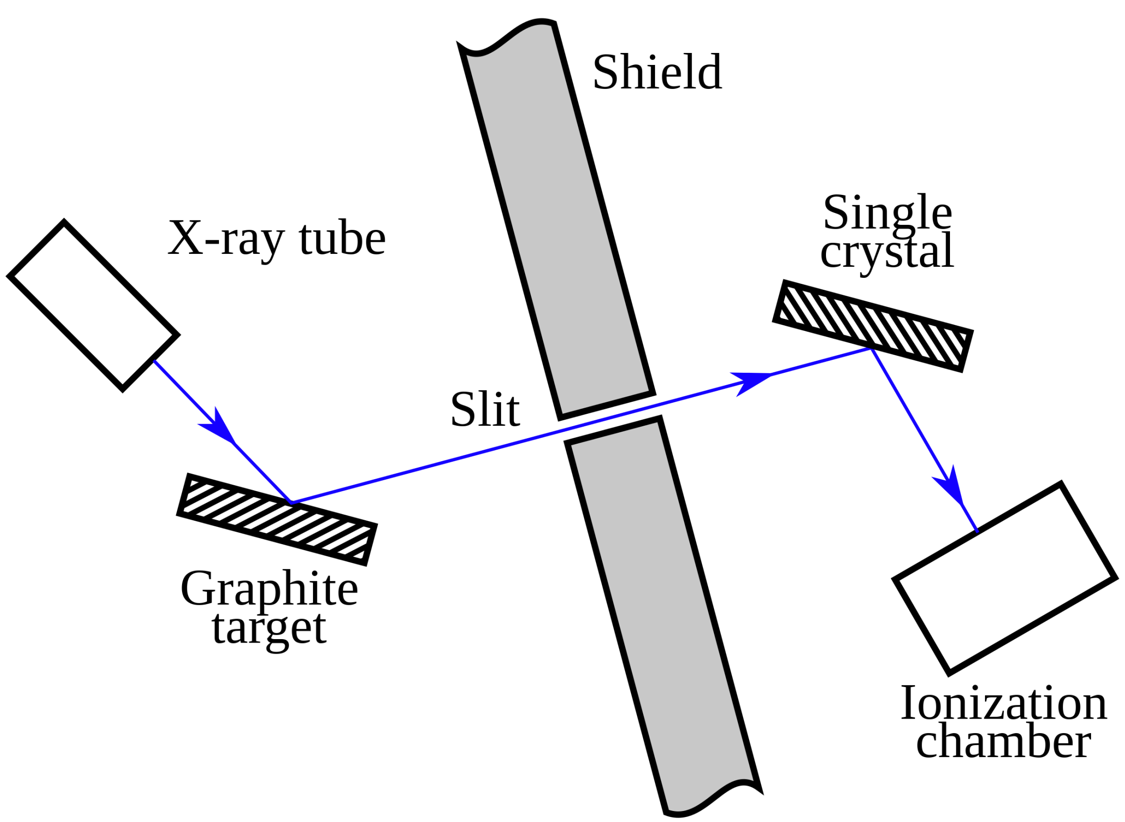
- Compton treats photons as particles:

- 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

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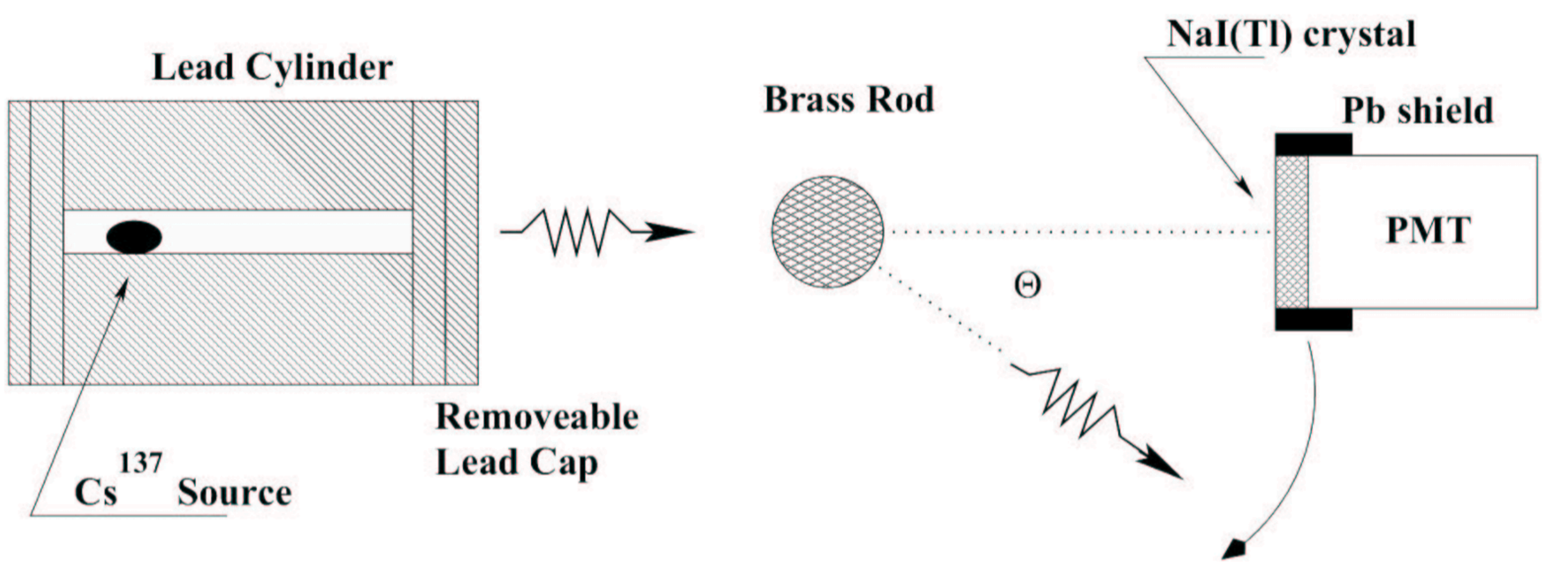

Figure 2: A schematic diagram of the experimental apparatus.

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

Compton Scattering

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Schematic diagram of Compton's experiment

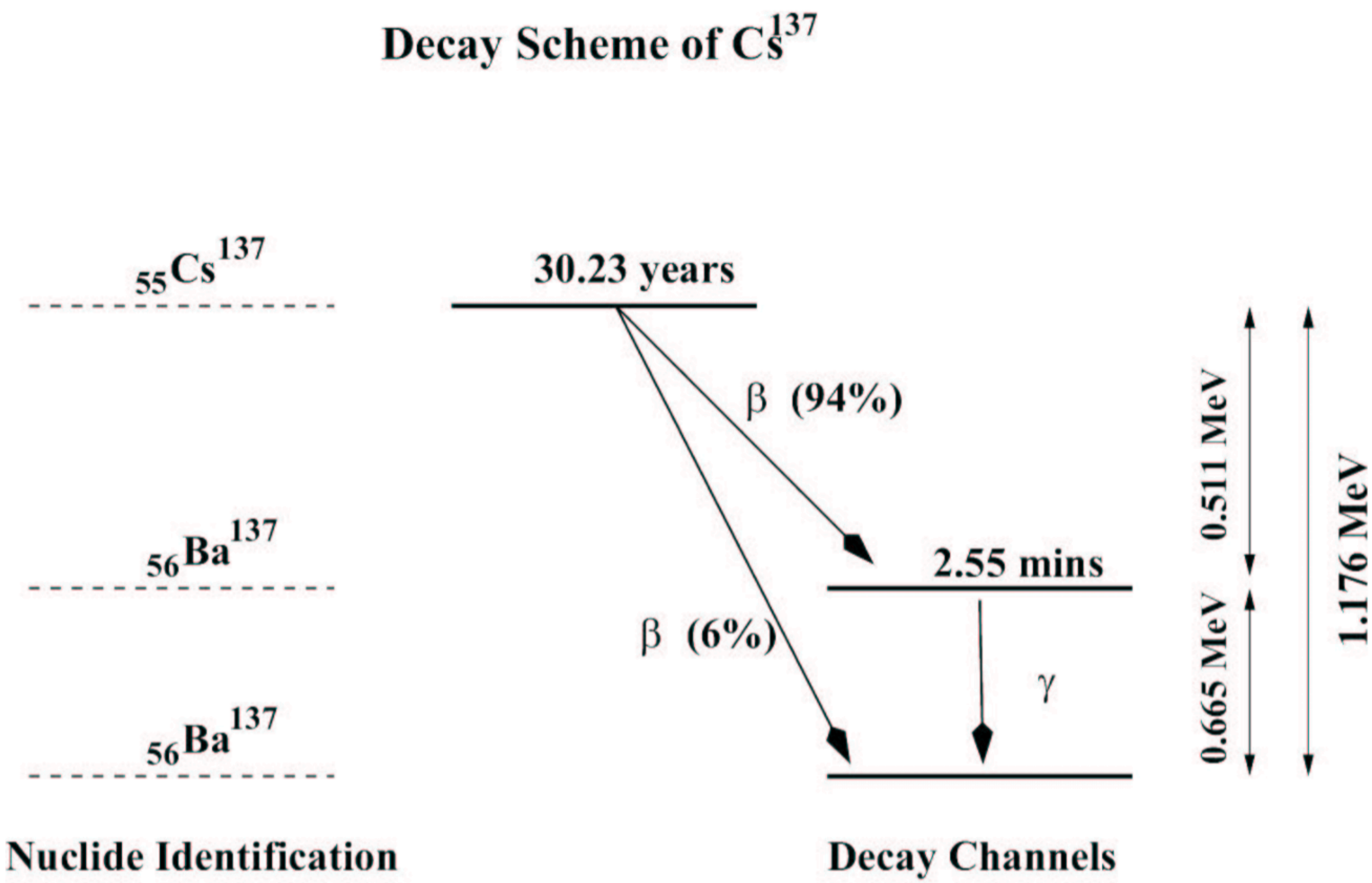

Figure 3: A schematic of the energy decay scheme of Cs^{137}.

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

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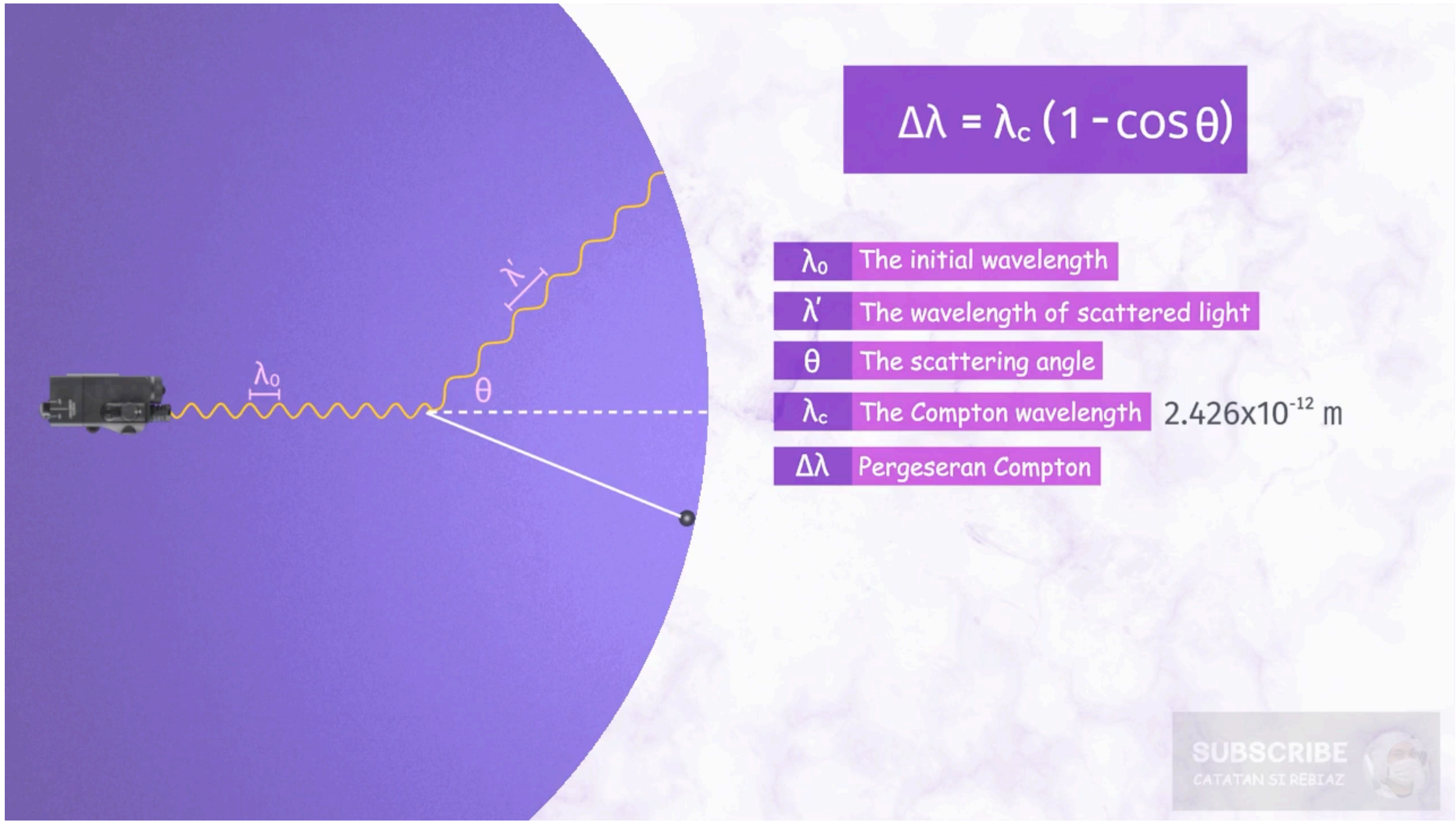
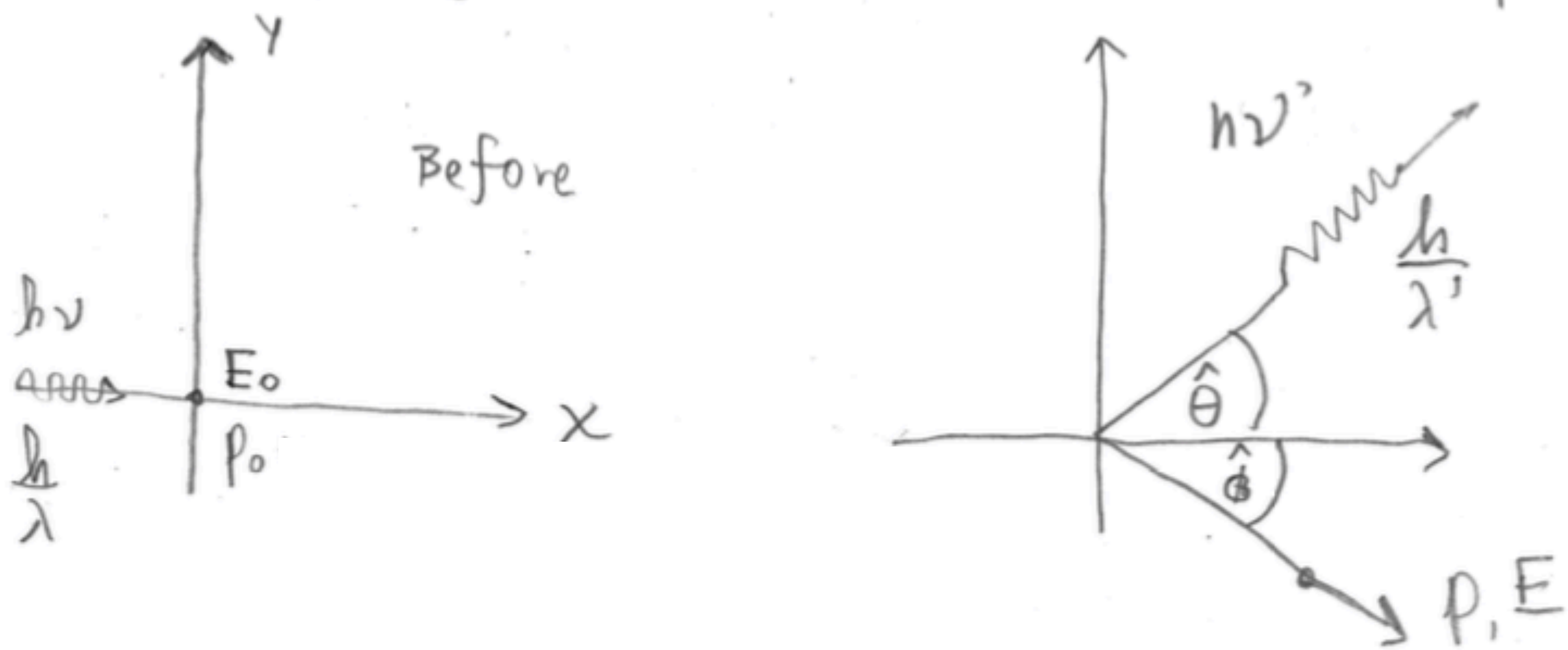


Reference: www.youtube.com/watch?v=zTzJJ9lGP0U

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

↳ 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

De Broglie's proposal: matter waves

· de Broglie relations (1924)

↳ De Broglie's proposal.

- γ are particles — definite amount of E, packets, cannot be broken. — & momentum p
- γ is also a wave — interferes / described by waves, ν

therefore ⟹ this could be a more general property.

Is this universal?

de Broglie:

↳ All "matter particles" behave as waves, not just the γ's.

↳ There is a wave associated to a matter particle.

De Broglie's proposal: matter waves

QM: probability amplitude to be somewhere
probability waves

Matter waves are introduced:

↳ Matter waves → probability amplitudes. $\mathbb{C}$ #'s
↳ Associate to a particle a wave that depends on the momentum.

For a particle of momentum p, we associate a plane wave $\boxed{\lambda = \frac{h}{p}}$ which is the de Broglie λ.

QM arises as a theory

- **1925** - Schrödinger/Heisenberg wrote the governing equations of QM.
- QM is almost a 100 years old!

What is QM?

QM is a (mathematical) framework to do physics.

Quantum physics

- QM replaces classical mechanics CM. CM is a good approximation but it is not accurate when describing some experiments.
- **Quantum physics:** principles of QM applied to physical phenomena.
- **Branches of QM:**
  - **QED:** QM + EM
  - **QCD:** QM + Strong interaction
  - **Quantum optics:** QM + photons
  - **Quantum gravity:** QM + gravitation -> String theory (QM of gravity)