when $\hbar\omega \ll m_e c^2$, $\omega' \simeq \omega$

$\hbar\omega \sim m_e c^2$, $\omega' < \omega$

biggest.. $\theta = \pi$ by a lot..

Frequency of light not usually changed.. ie, refraction.

Antimatter, Photons (p. 158, section 27).

Every particle: e^-

p

n

has a related particle: e^+

$\bar{p}$

$\bar{n}$

known as an "antiparticle"

charge antiparticle = −(charge particle).

masses equal

$e^- + e^+$ = some number of photons

$$e^- + e^+ = \gamma \quad ???$$

no momentum

$2m_ec^2$ of Energy

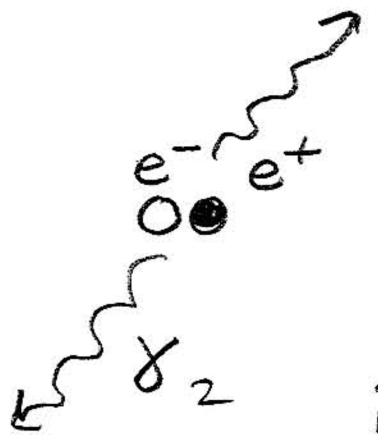
$$E_\gamma = 2m_ec^2$$

$$p_\gamma = \frac{E_\gamma}{c} = 2m_ec$$

problem !

1 photon not possible

2 photons are possible



$$\vec{p}_{\gamma_1} + \vec{p}_{\gamma_2} = 0$$

$$E_{\gamma_1} = E_{\gamma_2} = m_ec^2$$

3, 4, 5, ... all possible too

but $\dfrac{\text{Probability}(n+1)}{\text{Probability}(n)} \simeq \dfrac{1}{137} = \dfrac{e^2}{\hbar c} = \alpha$

$\gamma \to e^+ + e^-$ forbidden (mom/en).

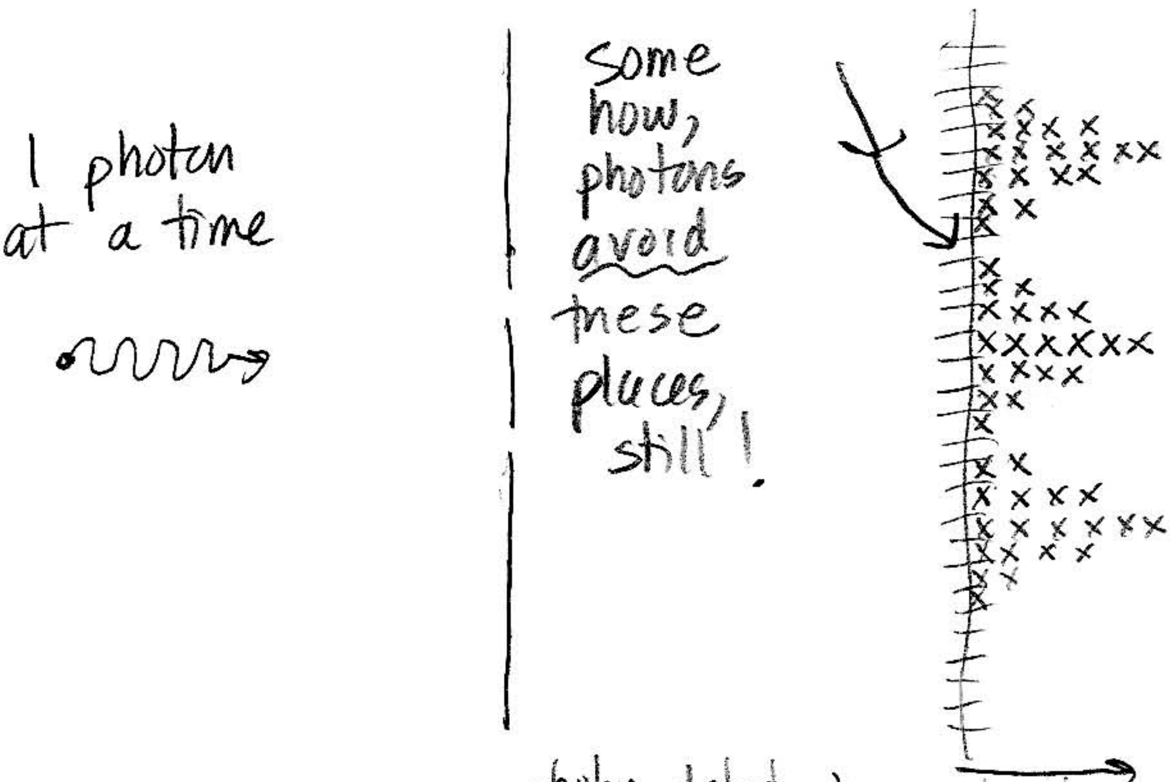
$\gamma + p \to p + e^+ + e^-$ proton allows conservation of mom/en

1 Photon can go through 2 slits!!

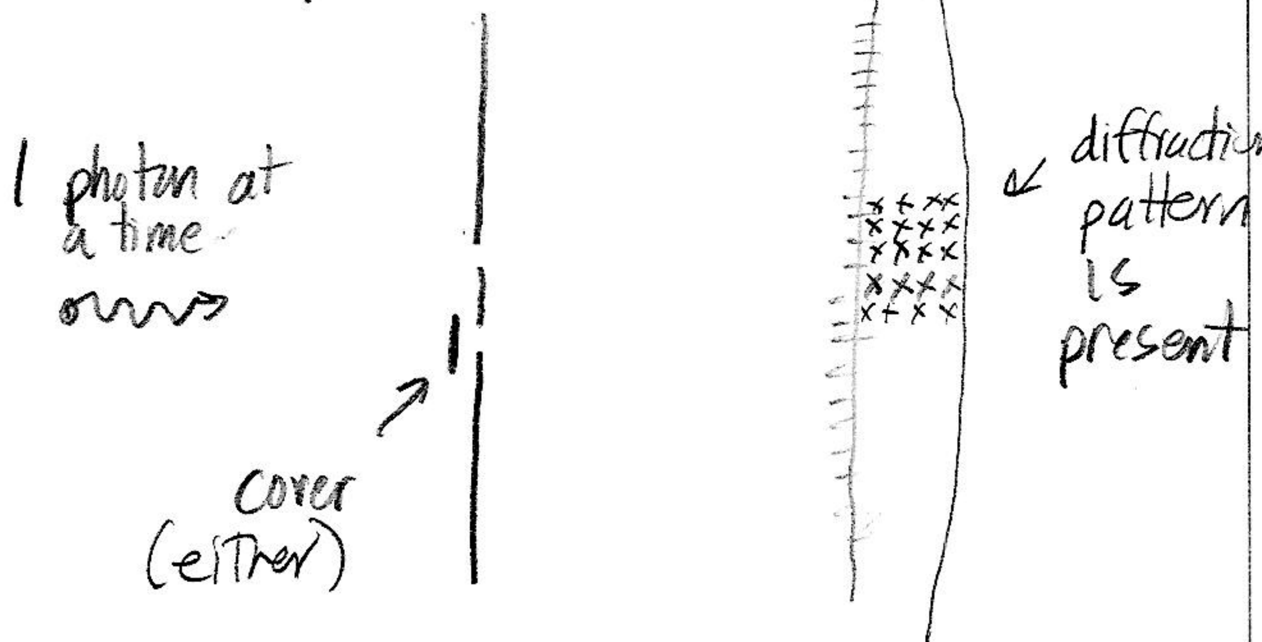
turn down intensity

replace with a detector that can detect one photon at a time

1 photon at a time



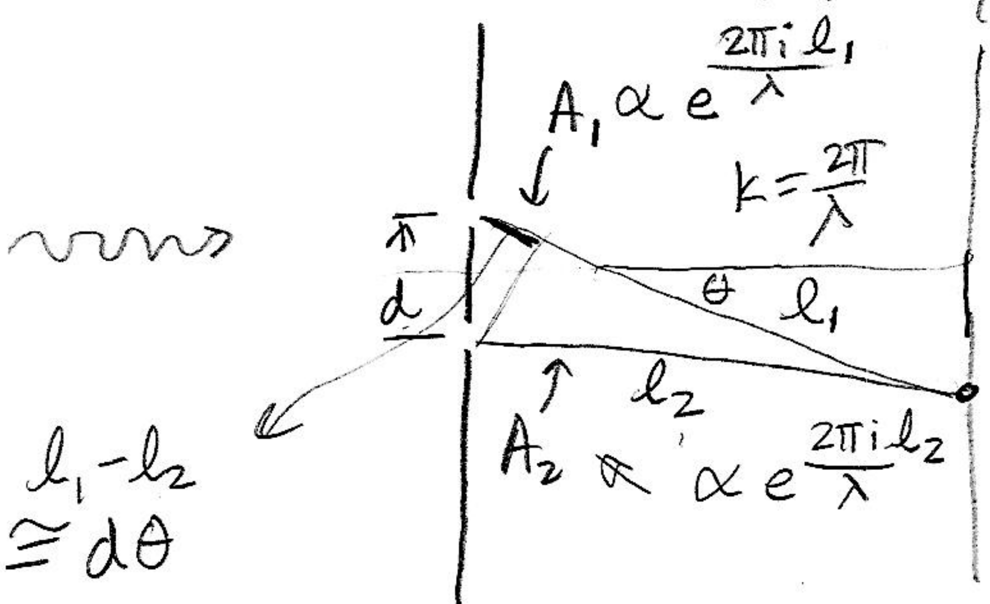
Cover Up one slit...



During journey, photon can split.
When detected, only the whole photon can be detected.

Description (Feynman).

Concept: QM "Amplitude" ← like wave, but used differently.



When slit undetermined
(both open)

$$A_{tot} = A_1 + A_2 \propto e^{\frac{2\pi i l_1}{\lambda}} + e^{\frac{2\pi i l_2}{\lambda}}$$

$$\text{Probability} \propto |A_{tot}|^2$$

$$\propto \left| e^{\frac{2\pi i l_1}{\lambda}} + e^{\frac{2\pi i l_2}{\lambda}} \right|^2$$

$$P \propto \left(e^{\frac{2\pi i l_1}{\lambda}} + e^{\frac{2\pi i l_2}{\lambda}} \right)\left(e^{\frac{-2\pi i l_1}{\lambda}} + e^{-\frac{2\pi i}{\lambda} l_2} \right)$$

$$\propto 1 + \underbrace{e^{\frac{2\pi i}{\lambda}(l_1 - l_2)} + e^{-\frac{2\pi i}{\lambda}(l_1 - l_2)}}_{2\cos\left(\frac{2\pi}{\lambda}\underbrace{(l_1 - l_2)}_{d\theta}\right)} + 1$$

$$\boxed{P \propto 2\left(1 + \cos\Big(\underbrace{\frac{2\pi d\theta}{\lambda}}_{\phi}\Big)\right)} = 4\cos^2\left(\frac{\pi d\theta}{\lambda}\right)$$

Cover Slit #2

$$P \propto |A_1|^2 = 1$$

Cover Slit #1

$$P_1 \propto |A_2|^2 = 1$$

No way to (a) "tell" which slit
(b) maintain interference pattern.