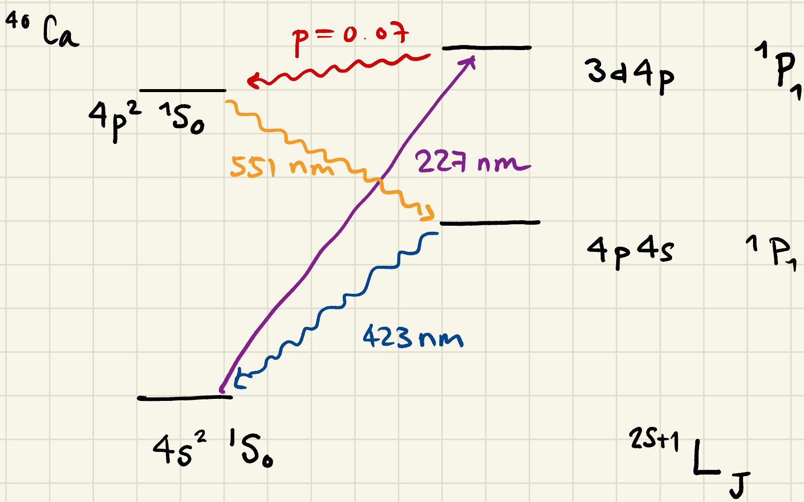
ESPERIMENTO DI FREEMAN E CLAUSER (1972)

Sorgente di fotoni entangled



Cascata radiativa $p \simeq 1$, emissione di 2 fotoni

giallo a 551 nm e blu a 423 nm

REGOLE DI SELEZIONE NELLA CASCATA RADIATIVA

Hamiltoniana dipolo elettrico

$$\hat{H}_I = -\vec{d} \cdot \vec{E}$$

vettore di polarizzazione

$$\vec{E}(\vec{r},t) = i \sum_{\mu} \sqrt{\frac{\hbar\omega}{2\epsilon_0 V}} \left[\vec{\epsilon}_\mu a_\mu(t) e^{i\vec{k}\vec{r}} - \vec{\epsilon}_\mu^{\,*} a_\mu^{\dagger} e^{-i\vec{k}\vec{r}} \right]$$

$\omega = ck$

operatore distruzione

$|i\rangle$ nel primo decadimento $|i\rangle = |4p^2\ {}^1S_0\rangle \otimes \underbrace{|0\rangle}_{\text{non ci sono fotoni}}$

$$|f\rangle = |4p\,4s\ {}^1P_1\rangle \otimes |\hbar\omega, \mu\rangle$$

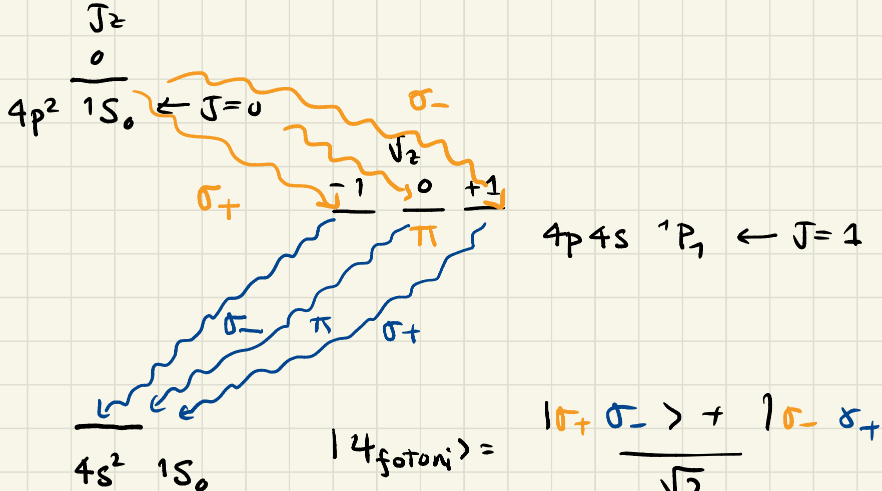
$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{\omega}c = 551\ nm$$

$$A_{fi} = \langle f|\hat{H}_I|i\rangle$$

$$= -\langle f|\vec{d}\cdot\vec{E}|i\rangle = i\vec{\epsilon}_\mu^{\,*}\sqrt{\frac{\hbar\omega}{2\epsilon_0 V}}\langle 4p4s\ {}^1P_1|\vec{d}|4p^2\ {}^1S_0\rangle$$

Elemento di matrice del dipolo elettrico non è nullo se

- $\Delta J = \Delta L = \pm 1$
- $\Delta J_z = \Delta L_z = -1, 0, +1$



$$|4_{fotoni}\rangle = \frac{|\sigma_+\sigma_-\rangle + |\sigma_-\sigma_+\rangle}{\sqrt{2}}$$

Fotone π : $\vec{\epsilon} = \hat{z}$

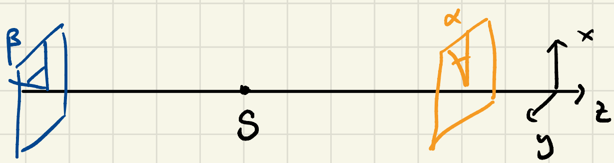
σ_+ : $\vec{\epsilon} = \frac{1}{\sqrt{2}}(\hat{x} + i\hat{y})$

σ_- : $\vec{\epsilon} = \frac{1}{\sqrt{2}}(-\hat{x} + i\hat{y})$

$$|\psi_{fotoni}\rangle = -\frac{|\hat{x}\,\hat{x}\rangle + |\hat{y}\,\hat{y}\rangle}{\sqrt{2}}$$

Rate coincidenze $\equiv R(\varphi) \propto \frac{1}{4}[1+\cos 2\varphi]$

φ angolo $= \alpha - \beta$



$$P(\alpha,\beta) = \langle \psi_{fotoni} | \Pi_\alpha \Pi_\beta | \psi_{fotoni} \rangle$$

$$= \frac{1}{2}(\cos\alpha\cos\beta + \sin\alpha\sin\beta)^2$$

$$= \frac{1}{4}[1+\cos(2(\alpha-\beta))]$$

$$= \frac{1}{4}[1+\cos 2\varphi]$$

$$\Delta(\varphi) \equiv \frac{3R(\varphi)}{R_0} - \frac{R(3\varphi)}{R_0} - \frac{R_1+R_2}{R_0}$$

R_0 rate di coincidenze senza polarizzatori

R_1, R_2 " senza polarizzatore 1/2

$$-1 \leq \Delta(\varphi) \leq 0$$

DISEGUAGLIANZA DI BELL
TESTATA DA FREEMAN & CLAUSER

$$-1 \leq \Delta(\varphi_1) - \Delta(\varphi_2) \leq 1$$

$$|\Delta(\varphi_1) - \Delta(\varphi_2)| \leq 1$$

Scelgo angolo $\varphi_1 = \frac{\pi}{8}$, $\varphi_2 = \frac{3\pi}{8}$

$$|\Delta(\varphi_1) - \Delta(\varphi_2)| = \left| 4\frac{R(\frac{\pi}{8})}{R_0} - 4\frac{R(\frac{3\pi}{8})}{R_0} \right| \leq 1$$

$$\delta \equiv \left| \frac{R(\pi/8)}{R_0} - \frac{R(\frac{3\pi}{8})}{R_0} \right| - \frac{1}{4} \leq 0$$