The Landau-Yang theorem

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Selection Rules for the Dematerialization of a Particle into Two Photons

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(Received August 22, 1949)

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The Landau-Yang theorem

- A spin 1 particle cannot decay into 2 photons
- A result which was already long known
- Landau (1948) and Yang (1949) proved independently that it is a consequence of rotational symmetry alone (does not involve parity)

The photon spin

Quantum	*Classical*
Photon = spin 1 particle	*Electromagnetic fields* $\vec{E}, \vec{B}$ = *vectors*
For a photon moving in the x direction, the spin component S_x can be +1, -1, not 0	$\vec{E}, \vec{B}$ *are transverse to the direction of motion x*

2 photon decay

In the rest frame of the decaying particle

Angular momentum along x:

Initial: spin of decaying particle J_x

Final: $S_{1x}+L_{1x}+S_{2x}+L_{2x}$

2 photon decay

In the rest frame of the decaying particle

Angular momentum along x:

Initial: spin of decaying particle J_x

Final: $S_{1x}+S_{2x}$ because

orbital momentum $L_x=yp_z-zp_y=0$

Conservation $\Rightarrow J_x=S_{1x}+S_{2x}$

2 photon decay

S_{1x} and S_{2x} can be either +1 or -1: 4 spin states

$|+1, +1\rangle$ $J_x = +2$

$|-1, +1\rangle$ $J_x = 0$

$|+1, -1\rangle$ $J_x = 0$

$|-1, -1\rangle$ $J_x = -2$

2 photon decay

S_{1x} and S_{2x} can be either +1 or -1: 4 spin states

~~$|+1, +1\rangle$ $J_x = +2$~~

$|-1, +1\rangle$ $J_x = 0$

$|+1, -1\rangle$ $J_x = 0$

~~$|-1, -1\rangle$ $J_x = -2$~~

$|J_x| \leq J$

2 states forbidden if $J = 1$

2 photon decay

S_{1x} and S_{2x} can be either +1 or -1: 4 spin states

$| -1, +1 \rangle$ $J_x = 0$

$| +1, -1 \rangle$ $J_x = 0$

Only 2 states allowed if $J=1$. *Both have $J_x=0$*

Transformation under 180° rotation about z

- Spin = vector: $S_x \leftrightarrow -S_x$
- Left-moving photon ↔right-moving photon

$$| s_1 , s_2 \rangle \rightarrow | -s_2, -s_1 \rangle$$

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$$| s_1 , s_2 \rangle \rightarrow | -s_2, -s_1 \rangle$$

$$| -1, +1 \rangle \rightarrow | -1, +1 \rangle$$

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Transformation under 180° rotation about z

- Spin = vector: $S_x \leftrightarrow -S_x$

- Left-moving photon ↔ right-moving photon

$$| s_1 , s_2 \rangle \rightarrow | -s_2, -s_1 \rangle$$
$$| -1, +1 \rangle \rightarrow | -1, +1 \rangle$$
$$| +1, -1 \rangle \rightarrow | +1, -1 \rangle$$

Both allowed states are unchanged

Transformation of J=1 states

$|m\rangle \equiv$ eigenstate of J_z

180° rotation about z:

$|m\rangle \rightarrow e^{im\pi}|m\rangle$

$|-1\rangle \rightarrow -|-1\rangle$

$|0\rangle \rightarrow |0\rangle$

$|+1\rangle \rightarrow -|+1\rangle$

Transformation of J=1 states

$|m\rangle \equiv$ eigenstate of J_z

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$|+1\rangle \rightarrow -|+1\rangle$

In this basis, the $J_x=0$ state is $|\Psi\rangle = (|-1\rangle - |+1\rangle)/\sqrt{2}$

[recall $J_x=(J_+ + J_-)/2$].

Transformation of J=1 states

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In this basis, the $J_x=0$ state is

$|\Psi\rangle = (|-1\rangle - |+1\rangle)/\sqrt{2}$

[recall $J_x=(J_+ + J_-)/2$].

Hence $|\Psi\rangle \rightarrow -|\Psi\rangle$

Conclusion

- Allowed two-photon states have J_x=0 and are even under a rotation by 180° around z
- J=1, J_x=0 state is odd under the same rotation
- *Therefore a J=1 particle cannot decay into two photons*