

Effect of a slight change in polarization on light shift

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1 Goal

Vector and tensor light shift from an optical tweezer can cause coupling between different angular momentum states that were not allowed without it. This effect can be different if the tweezer polarization changes between site.

While it's fairly easy to control when there's only vector light shift, just use linear polarization, the effect can be much more complex when tensor light shift terms. It's of course always possible to turn off all of the coupling with perfect π polarization (since it doesn't break rotational symmetry around z and therefore doesn't couple different m_F states) but non- π linear polarization could still have nontrivial effects in the experiment.

Questions to answer,

1. Can the solution for vector light shift, i.e. using pure linear polarization, eliminate all the unwanted coupling in the presence of tensor light shift (section 2).
2. For a single tweezer, can the effect from different source, e.g. circularity of polarization, angle of polarization, angle of B field, cancel out each other and to what level, i.e. is it possible to achieve "optimal" result without π polarization.
3. If yes, is it possible to have local optimal (e.g. cancellation of some terms at a condition that doesn't cancel all terms), and if that's the case, what is the best way to align everything.
4. In general, what is the condition for the coupling to the wrong state being insensitive to certain type of change in the polarization. E.g. is there a magic certain polarization that is at least first order insensitive to arbitrary small angle rotation (i.e. linear polarization when there's only vector shift).

We'll mainly (only) consider the state mixing for a single state. This is fine since the system we want to study here, ^{171}Yb neutral, has a $J = 0, I = 1/2$ ground state that should have a very small (if any) vector shift. Any existing vector shift should also be factored into a slightly tweaked excited state vector shift (at least to the first order).

We'll also mostly consider the coupling for spontaneous emission. For darkness of state during OP, one could almost always adjust the OP polarization to cancel out any unwanted coupling. With the ground state setting the quantization axis, the presence of unwanted coupling/decay path is simply proportional to any non-diagonal element in the Hamiltonian.

2 Linear polarization

Assuming the polarization of the tweezer is linear and selecting the quantization axis for the ground state, we'd like to see what coupling could be caused by a linear polarization that is not pure- π . As mentioned above, this can only be caused by the tensor term. Tensor shift hamiltonian,

$$H \propto \frac{3}{2} \left\{ \vec{u}^* \cdot \vec{F}, \vec{u} \cdot \vec{F} \right\} - \vec{F}^2 \quad (1)$$

For linear polarization $\vec{u} = \vec{u}^*$

$$H \propto 3 \left(\vec{u} \cdot \vec{F} \right)^2 - \vec{F}^2 \quad (2)$$

If the polarization is very closed to π but off by a small angle θ in the x direction (can also be any other direction in the x - y plane without loss of generality)

$$\vec{u} = \cos \theta \hat{z} + \sin \theta \hat{x} \quad (3)$$

$$\begin{aligned} H &\propto 3(\cos \theta F_z + \sin \theta F_x)^2 - \vec{F}^2 \\ &= 3(\cos^2 \theta F_z^2 + \sin \theta \cos \theta (F_z F_x + F_x F_z) + \sin^2 \theta F_x^2) - \vec{F}^2 \\ &\approx 3 \left(\cos^2 \theta F_z^2 + \frac{1}{2} \sin \theta \cos \theta (F_z F_+ + F_z F_- + F_+ F_z + F_- F_z) \right) - \vec{F}^2 \\ &= 3 \left(\cos^2 \theta m_F^2 + \frac{1}{2} \sin \theta \cos \theta ((2m_F + 1)F_+ + (2m_F - 1)F_-) \right) - F(F + 1) \\ &= 3 \cos^2 \theta m_F^2 - F(F + 1) + \frac{3}{2} \sin \theta \cos \theta ((2m_F + 1)F_+ + (2m_F - 1)F_-) \end{aligned} \quad (4)$$

Here we've ignored the second order term (in θ) and calculated the matrix element in the z basis.

The result shows that the tensor light shift can cause a first order coupling between the neighboring m_F state when the polarization is not π even if it remains linear. This is different from vector light shift which only have non-trivial effect for circular polarization.