Response to Bryce's questions

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I. BACKGROUND

Considering an atom in a uniform static electric field, the dynamic dipole polarizability can be written as

$$\alpha_1(\omega) = \alpha_1^S(\omega) + A\cos\theta_k \frac{M_{J_0}}{2J_0}\alpha_1^V(\omega) + [\frac{3\cos^2\theta_p - 1}{2}]\frac{3M_{J_0}^2 - J_0(J_0+1)}{J_0(2J_0-1)}\alpha_1^T(\omega) \tag{1}$$

where $\alpha_1^S(\omega)$, $\alpha_1^V(\omega)$, and $\alpha_1^T(\omega)$ present the scalar, vector and tensor polarizabilities, θ_k is the angle between the wave vector of the electric field and z-axis, θ_p relates to the polarization vector and z-axis, θ_k and θ_p satisfy the relation of $\cos^2\theta_k + \cos^2\theta_p \le 1$. A is the forth Stokes parameter, which represents the degree of polarization. $A = 0$ is for the linearly polarized light, $A = 1$ and $A = -1$ are for the right and left handed circularly polarized light.

For experimental measurement, the magnetic field $\mathbf{B}$ direction is taken as z-axis, so θ_k is the angle between the laser propagation director $\mathbf{k}$ and $\mathbf{B}$ director, θ_p is the angle between the laser polarization director and $\mathbf{B}$ director.

If the probe laser is linear polarization laser, then $A = 0$, for the $M_J = \pm 1$ sublevel of $2\,^3S_1$ state of helium, the Eq.(1) can be simplified as

$$\alpha_1(\omega) = \alpha_1^S(\omega) + \frac{3\cos^2\theta_p - 1}{2}\alpha_1^T(\omega) \tag{2}$$

which is dependent on the θ_p angle.

Generally, it's difficult to adjust the laser polarization director to be parallel to the $\mathbf{B}$ director, and also it's difficult to make sure the laser is pure linearly polarized, so the systematic shifts caused by uncertainty of θ_p, θ_k, and parameter A should be evaluated.

II. QUESTION 1:

How to avoid the painful progress of aligning the probe beam angle perfectly with the magnetic field?

I think your measurement approach is feasible: To measure the dependence of the tune-out wavelength on the linear polarization angle θ_p by changing the angle θ_p until the measured tune-out wavelength reaches to the maximum(minimum). But the sign of your formula is wrong, please see the following formulas.

if the polarization is perpendicular to the magnetic field, then $\cos^2\theta_p = 0$, we have

$$\alpha_1(\omega) = \alpha_1^S(\omega) - \frac{1}{2}\alpha_1^T(\omega) \tag{3}$$

Otherwise, if the polarization is parallel to the magnetic field, then $\cos^2\theta_p = 1$, we have

$$\alpha_1(\omega) = \alpha_1^S(\omega) + \alpha_1^T(\omega) \tag{4}$$

At your request, we also study the dependence of the tune-out wavelength on the θ_p angle, please see the Fig.1, We find that if the θ_p change from 0 degree to 90 degree, it brings 3pm shift for the 413nm tune-out wavelength. Assuming the shift from θ_p is approximative taken as a straight line, then if the θ_p increases 1 degree, which will decrease about 0.033pm on the 413 nm tune-out wavelength.

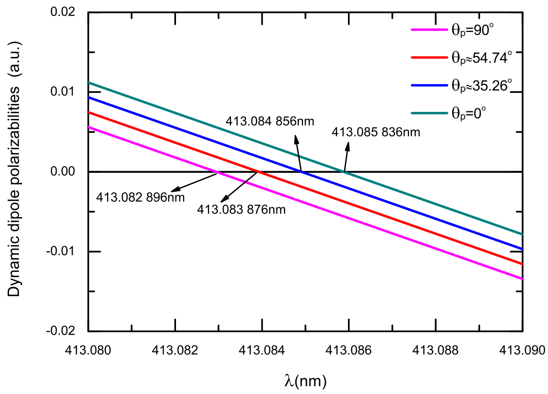

FIG. 1: (Color online) Dynamic dipole polarizability $\alpha_1(\omega)$ (in a.u.) for the $2\,^3S_1(M_J = \pm 1)$ state of the ^{4}He as the ω increased. Four different curves represent different θ_p angle.

III. QUESTION 2:

Is this term A independent of the alignment of the probe beam with the magnetic field and equal to zero for linearly polarized light? How exactly is the term A defined, is it one of the Stokes parameters?

The stokes parameter A is zero for linearly polarized light, since laser polarization is impossible to achieve 100% linear polarization, so A does not strictly equal to zero due to some reason in the measurement, which will bring the contribution of vector polarizability (contribution of circularly polarized light).

In order to study the systematic shifts caused by uncertainty of θ_k and A, according to the Eq.(1), I think we can measure the tune-out wavelength difference for $M_{J_0} = 1$ and $M_{J_0} = -1$ by changing θ_k angle, it will be found that the difference comes to 0 when $\theta_k = 90$ degrees, which indicates the $A\cos\theta_k$ term no longer contribute systematic shifts.

In our calculation, in the Eq.(1), when the $A\cos\theta_k$ is adjusted from -1 to $+1$, then we find this adjustment will produce 0.4pm-6pm correction on the 413 nm tune-out wavelength.