Weak Transition Measurement through coherent control

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Motivation: selection rules govern that some transitions are dipole-forbidden, which means interaction Hamiltonian for the dipole operator vanishes. However, the transitions may have non-zero magnetic dipole or electric quadruple moment that can allow for transition, though, at weaker levels. In order to measure the transition strength of magnetic dipole (M1) and electric quadruple (E2) separately, appropriate coherent control needs to be imposed. Experimental measurements of such transition have been demonstrated in atomic Rubidium in the magneto-optical trap (MOT) [1], and in Cesium atomic beam [2, 3]. Measurement of microwave hyperfine ground state transition in Francium has been also proposed [4].

In Rubidium 87, the transition of $8p_{3/2} \rightarrow 8p_{1/2}$ is dipole-forbidden due to selection rules. The excited state of D1 line transition in Rubidium 87 contains four fine levels, namely $F' = 0, F' = 1, F' = 2$, and $F' = 3$. The state $8p_{1/2}$ contains two fine levels, $F'' = 1$ and $F'' = 2$. In the experiment by Pires et al. [1], atomic spectroscopy was performed for the transitions $F' = 0 \rightarrow F'' = 1$ to measure M1 transition, and $F' = 0 \rightarrow F'' = 2$ for E2 transition.

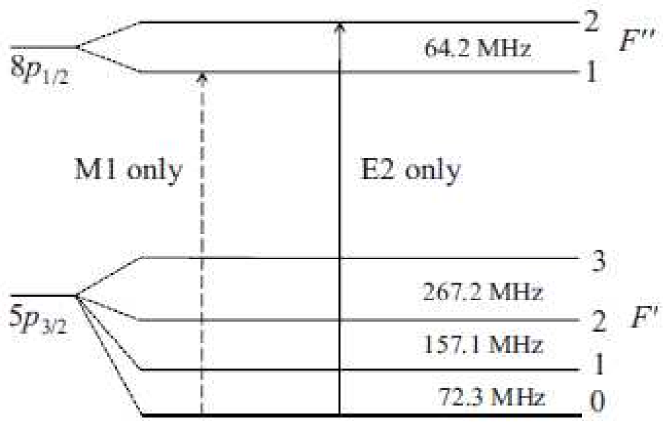

Figure 1: Dipole-forbidden Hyperfine Transition from $5P_{3/2} \rightarrow 8P_{1/2}$. Frequency locking to a certain hyperfine transition allows for measuring the relative amplitude of M1 and E2 transitions separately.

First, atoms were prepared in $5s_{1/2}\ F = 1$ state by emptying $5s_{1/2}\ F = 2$ state with an optical pumping laser tuned to $5s_{1/2}\ F = 2 \rightarrow\ 5p_{3/2}\ F = 2$ transition. Then excite the atoms from $5s_{1/2}\ F = 1$ state to $5p_{3/2}\ F' = 1$. Then the 587.6 nm laser was used to excite the atoms to

$8p_{1/2}$ state. This laser was scanned over a 100 MHz range to effect both $5p_{3/2}\ F' = 0 \rightarrow 8p_{1/2}\ F'' = 1$ and $5p_{3/2}\ F' = 0 \rightarrow 8p_{1/2}\ F'' = 2$ transitions.

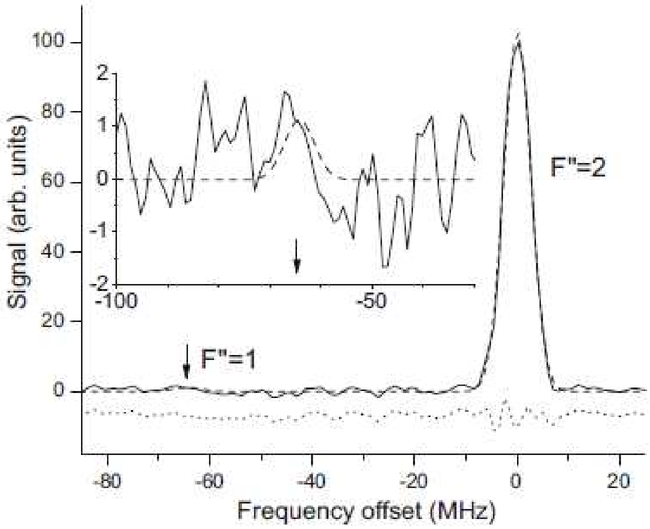

Figure 2: Spectroscopic results for $5P_{3/2} \rightarrow 8P_{1/2}$ transition with 587.6 nm laser

Figure 2 shows the scanning results of the 587.6 nm laser over a 100 MHz range. The peak due to E2 transition is clearly visible (at zero frequency offset) but M1 transition is not visible in the plot. The authors conclude that the measurement of M1 transition, as theory predicted, was a few orders magnitude smaller than the E2 transition strength so that it was overshadowed by noises in the signal.

In a similar fashion, M1 and E2 measurements in Cesium 133 from $6p_{3/2} \rightarrow 8p_{1/2}$ was proposed [2]. The measurement setup uses an atomic beam in a vacuum chamber instead of a MOT. However, all transitions from $6p_{3/2} \rightarrow 8p_{1/2}$ support E2 and M1 transitions and therefore separating E2 and M1 requires careful calculations. In Figure 3, two transitions are shown that support either only E2 or M1 transition. In order to measure the transition strength, atoms need to be prepared at $6p_{3/2}\ F' = 5, m = -3$ and $6p_{3/2}\ F' = 5, m = +3$ Zeeman sublevels. Once this is done, a right or left circular polarized 997 nm laser is used to excite the atoms to the respective states.

This experiment was halted in 2010 because the theoretical calculation for M1 transition yielded a negligible value.

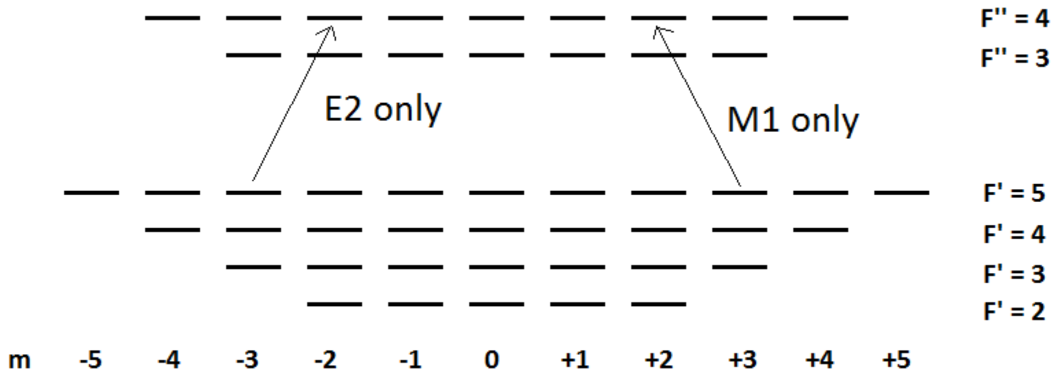

Figure 3: Hyperfine Transitions that exhibit either only E2 or M1 transition in $6p_{3/2} \rightarrow 8p_{1/2}$.

In another experiment by Antypas and Elliott, two-photon excitation was used to observe interference of weak interactions [3]. $6s_{1/2} \rightarrow 7s_{1/2}$ is a dipole forbidden transition but in the presence of DC electric field, the mixing of P and S orbitals allows the transition to take place (DC Stark effect). In this configuration, the two photon excitation is a strong interaction, and the Stark-induced transition is a weak one.

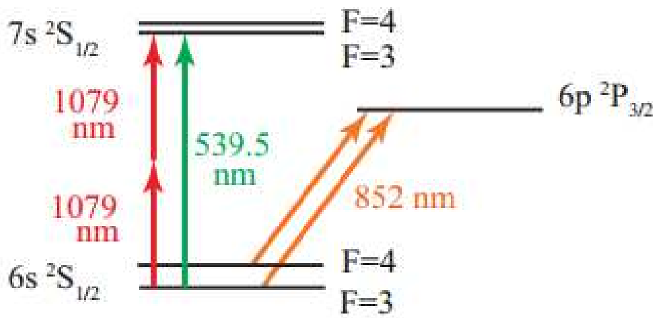

Figure 4: $6s_{1/2} \rightarrow 7s_{1/2}$ transition is excited with a two-photon laser (1079 nm) and a single photon laser (539.5 nm). Optical pumping (852 nm) prepares Cesium atoms at the desired level.

The measured strength of $6s_{1/2} \rightarrow 7s_{1/2}$ is a combination of the two-photon transition, Stark-induced transition (β), and magnetic dipole transition (M1). By varying the DC electric field, the authors measured the ratio of the weak interaction strengths, $\frac{M1}{\beta} \sim -29.55$.

Lastly, an experimental setup for hyperfine ground states transition in Francium has been proposed [4]. Transitions from one ground state level to another usually involves a microwave transition and therefore are electric dipole forbidden. Such microwave transition has a strong dipole moment so the authors suggest the measurement of electric anapole transition using a

microwave cavity to suppress the magnetic dipole transition. Raman lasers will cause strong interaction in this transition. Then, the interference between the Raman transition and the electric anapole transition will lead to the transition strength ratio.

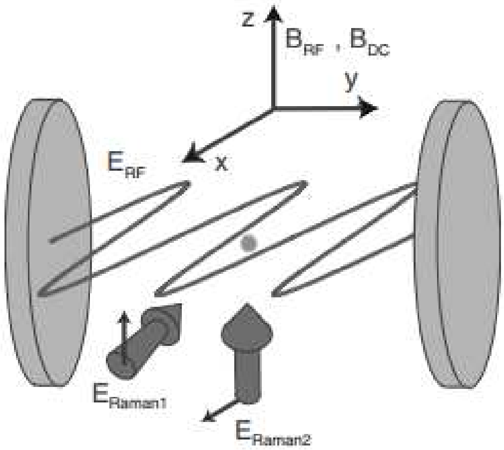

Figure 5: The proposed schematic for the experimental setup inside the MOT. The microwave field inside the cavity is set up such that the node of the magnetic field happens at the location of Fr sample. The Raman lasers propagate perpendicular to one another.

References:

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[4] E. Gomez, S. Aubin, G. C. Sprouse, L. A. Orozco, and D. P. DeMille, Phys. Rev. A. 75, 033418 (2007)