Quantum Control in a Finite Anharmonic Ladder of States

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We present theoretical and experimental studies that explore the degree to which it is possible to prepare and detect an arbitrary quantum superposition state of the nine $|F{=}4, M_F = -4, ..., +4\rangle$ Zeeman sublevels of the ground state Cs atom. This system is quite attractive experimentally because it can be manipulated on the slow time scale set by the Larmor frequency. Also, spin systems such as this may prove useful in quantum computing or in precision measurement applications. In our experiment, simultaneous application of a uniform magnetic field B_0, a time dependent transverse magnetic field $B(t)$, and a uniform optical field results in a Hamiltonian $\mathrm{H} = -\vec{\mu} \cdot \vec{B}(t) + M_F^2 \hbar\omega_E |M_F\rangle\langle M_F|$, where $\vec{B}(t) = B_0\hat{z} + B(t)\hat{x}$, and $\vec{\mu}$ is the atomic magnetic dipole operator. The last term in the Hamiltonian represents the light shift induced by the optical field. With $B(t)$ set to zero, it yields a finite anharmonic ladder of nine quantum states. Because of the anharmonicity, $B(t)$ induces motions of the spin that are not simply rotations of the initial state. Rather, it is possible by judicious choice of $B(t)$ to produce an arbitrary spin state. We have theoretically modelled this system and identified particular pulse shapes for $B(t)$ that can produce desired nontrivial target states, starting from a pure $|M_F = 0\rangle$ state that is easily prepared by optical pumping. Further, we have proven experimentally that we can coherently manipulate this state using the B_0 and $B(t)$ terms. Very novel resonance lineshapes are observed, which show multiple interference minima and maxima due to the fact that all nine sublevels are excited. We have also recently constructed a laser to generate the light shift term, and experiments are in progress to demonstrate the full quantum control of this system. Finally, we discuss tomographic methods to measure the quantum state that we have prepared. We acknowledge the support of this work by the N.S.F and the NASA microgravity research division.