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ATOMIC COHERENCE CREATED BY A PULSED DYE LASER

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ATOMIC COHERENCE CREATED BY A PULSED DYE LASER

by

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We have measured level population as a function of laser pulse envelope area for an atom which could be approximated as a two level system.

An ideal two-level system under the action of an oscillating force is one of a few quantum mechanical systems for which the time dependent Schroedinger equation can be solved exactly. The solution predicts that the population of the upper state, for a system which was entirely in the lower state at $t=0$, varies as $\sin^2 A$, where

$$A = \int_0^t \Omega(t) dt, \text{ and}$$

$$\Omega = \frac{e \varepsilon_0(t) x_{12}}{\hbar}.$$

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Here ϵ_0 is the envelope of the laser electric field, and x_{12} is the atomic matrix element. This oscillation of the population in time has previously been seen using fluorescence from the upper state as a measure of state population for an atom excited by generally non-tunable lasers.

We have observed Rabi flopping in a $j=3$ to $j=2$ transition in a uranium atomic beam using a tunable single mode pulsed dye laser. The upper level population was monitored by ionizing upper state atoms with a second laser and detecting ions. The length of the first step laser pulse was fixed; the pulse area was varied by varying the intensity of the laser. The upper state population was measured as a function of intensity and therefore pulse area.

One of the purposes of the experiment was to understand the way in which the atomic levels and laser used in the experiment differed from an ideal two level system with monochromatic excitation. Three identified experimental effects could cause departures from an ideal system: beam spatial nonuniformity, laser frequency spread and drift, and degenerate atomic levels with different matrix elements.

The experiment was designed to minimize departures from an ideal two-level system. The beam was made spatially uniform to within 30% in intensity (15% in electric field) by lenses and apertures. The laser frequency spread and drift were minimized by using a stable single mode laser and adjusting the cavity length to maintain the laser center frequency at the center of the atomic line. Most of the departure of the system from an ideal monochromatically illuminated system came from laser drift and frequency spread.

The $j=3$ and $j=2$ energy levels had many degenerate sublevels each with different values of azimuthal quantum number. In order to avoid the large spread in Rabi frequencies caused by all possible transitions between these levels, linearly polarized light was used to generate only the five $\Delta m=0$ transitions, leading to only three different Rabi frequencies, differing by, at most, 25%. The combination of these three frequencies would give rise to several easily observable cycles of $\sin^2(A)$ before destructive interference took place.

An approximation to the expected ion signal as a function of laser pulse area was obtained from a Lawrence Livermore Laboratory computer program, SHUX, which solves the Schrodinger equation for an N level system and calculates populations as a function of time. This code predicts, for a spatially uniform, temporally Fourier transform limited beam, illuminating atoms with a Doppler width narrower than the beam frequency spread, that the population of the upper state should oscillate between 90% and 10% as A is increased, leading to a large and easily measurable effect. This result is independent of the shape of the laser pulse in time.

Uranium 238 atoms from a depleted uranium source held at 1500°C were formed into a beam with about 0.15 GHz transverse Doppler spread. At 1500°C about 3% of the atoms in the beam were thermally excited into the $j=3$ state 3868 cm^{-1} above the ground state. A single mode Rushford-Hackel dye laser tuned to 441 nm with a pulse length of 5 ns and frequency spread of 0.18 GHz excited atoms to the $j=2$ state at $26,558\text{ cm}^{-1}$. 15 ns later a multimode pulsed laser tuned to 426 nm ionized the population of

the $j=2$ level. The ion current was measured as a function of the intensity of the first (441 nm) laser.

Ions were collected by a channeltron electron multiplier and the resulting current signal was recorded with a boxcar averager and signal averaging computer.

In the beam of the 441 nm laser a rotating neutral density filter swept through an intensity range of 100:1 every three seconds (300 laser pulses). The number of ions was recorded as a function of time and hence of laser intensity. After several hundred cycles of the rotating attenuator, the ion signal representing the upper state population of the $j=3$ to $j=2$ system showed one or two Rabi flopping cycles before saturation set in.

The peak to valley ratio of the ion signal was about 30% of the initial peak, probably because the laser and Doppler frequency spreads were reducing the Rabi flopping coherence from its single frequency value of approximately 90%. These results show that coherent phenomena can be observed in uranium beams with single mode pulsed lasers.

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