AUTLER–TOWNES EFFECT IN DOUBLE OPTICAL RESONANCE

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Received 16 February 1978

Two frequency stabilized dye lasers and a sodium atomic beam are used to study the Autler-Townes effect in the aligned $3S_{1/2}, F = 2, M_F = 2 \rightarrow 3P_{3/2}, F = 3, M_F = 3, \rightarrow 4D_{5/2}, F = 4, M_F = 4$ states. This system is to a very good approximation an isolated three-level atom. The Autler–Townes doublet splittings are measured as a function of the intensities of the two lasers and their detunings from resonance. The experimental results are in good agreement with theory.

When a monochromatic laser of even modest power is tuned to a two-level atomic resonance the levels are strongly mixed. This causes the levels to be split by the linear ac Stark effect. This splitting leads to the three peaked resonance fluorescence spectrum which has received a great deal of attention recently [1–4]. If a second laser is scanned in frequency between the split intermediate level and another higher lying level, the splitting shows up in the fluorescent intensity from the highest level. This effect is just the double optical resonance analog of the microwave-optical Autler–Townes effect [5].

The double optical resonance effect has been observed several times in recent years [6–10], but in each case complications in the atomic level structure or in the experimental setup has made a detailed comparison with theory impossible. We are able to overcome these difficulties by using an atomic beam and optically pumping the atoms into an aligned state. In this state the atoms are to a quite good approximation describable as three-level atoms. The three-levels are the $F = 2, M_F = 2$ component of the $3S_{1/2}$ ground state of sodium, the $F = 3, M_F = 3$ component of the $3P_{3/2}$ level, and the $F = 4, M_F = 4$ component of the $4D_{5/2}$ level.

The experimental apparatus consists of a thermal sodium atomic beam collimated to 0.8 mrad and illuminated at right angles by two colinear but oppositely directed laser beams. The laser beams are parallel to each other, and orthogonal to the atomic beam within 1 mrad. Laser A operating at resonance to the sodium D_2 line produces a beam with a gaussian profile 3 mm in diameter. It is quite accurately circularly polarized by a Glan–Thomson polarizer and a Soleil–Babinet compensator. The laser is frequency stabilized to within ±1 MHz by locking it to a transmission maximum of a Fabry–Perot cavity. The gaussian tail of this laser beam optically pumps the atoms into the aligned state. Laser B operating at 5688 Å produces a beam with a gaussian profile 1 mm in diameter and is positioned at the center of the first laser beam. This laser beam is circularly polarized with a Glan–Thomson polarizer and a quarter wave plate, and is frequency locked to a transmission maximum of a piezoelectrically scanned spherical Fabry–Perot. The Fabry–Perot is scanned through the 5688 Å transition and the laser follows with its short term frequency jitter limited to ± 0.5 MHz.

The interaction region where the two laser beams and the atomic beam intersect is imaged through a beam splitter and interference filters onto two pinholes. The beam splitter and the filters allow the fluorescence from the two transitions to be monitored separately. The pinholes allow the photomultipliers to collect light from only the central 1/2 mm of the interaction region where the laser intensities are constant.

The experiment consists of illuminating the atomic beam with two lasers. Laser A is held fixed in frequency at particular detunings, δ_A, from resonance with the 5890 Å transition. Laser B is scanned in frequency through the 5688 Å resonance, and the fluorescence from the two excited states is measured. Each experiment is repeated five to ten times and the results averaged to eliminate short noise and mechanical vibrations.

Initially, laser A is tuned to exact resonance with the first transition. The fluorescence from the top level is measured as laser B is tuned through resonance for various intensities of laser A. The results are shown in fig. 1. At low intensity, fig. 1a, the resonance is a simple lorentzian with fwhm of 12 MHz. In the figs. 1b and c we see how the line splits out at higher power levels.

The theory has been worked out in detail [11]. It predicts that the splitting should increase as the square root of the intensity of laser A. The comparison of theory and experiment with no free parameters is shown in fig. 2. The error bars represent the uncertainty in the measured laser intensity.

If we keep laser A at resonance and at constant power but gradually increase the power of laser B there is power broadening, and the doublets eventually merge into one lorentzian with a width which is the square root of the sum of the squares of the two Rabi frequencies. This is illustrated in fig. 3.

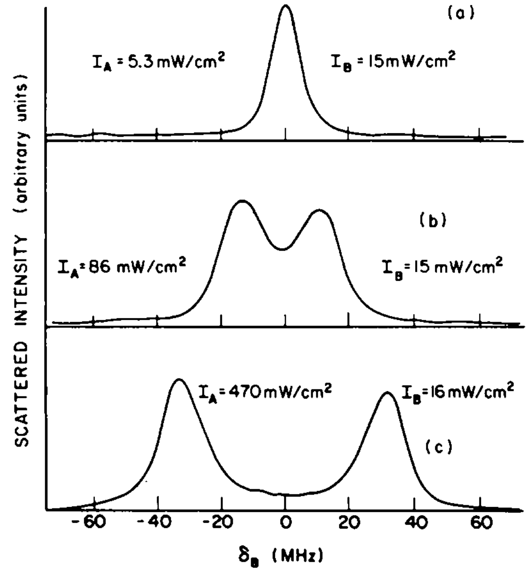

Fig. 1. Autler–Townes doublet. Laser A is exactly at resonance. The splitting increases as the intensity of laser A increases. δ_B is the detuning of laser B from resonance.

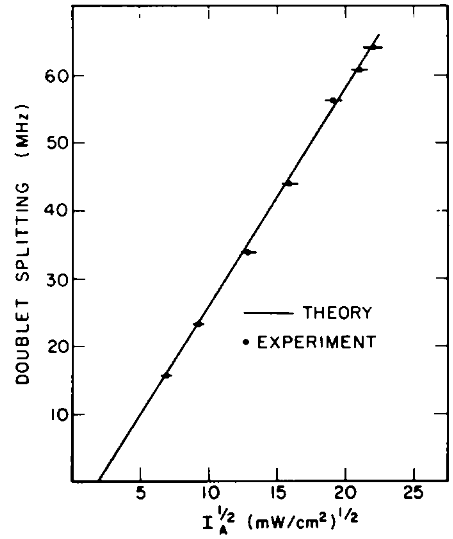

Fig. 2. Comparison of theory and experiment. There are no free parameters. The error bars represent the uncertainty in the laser intensity.

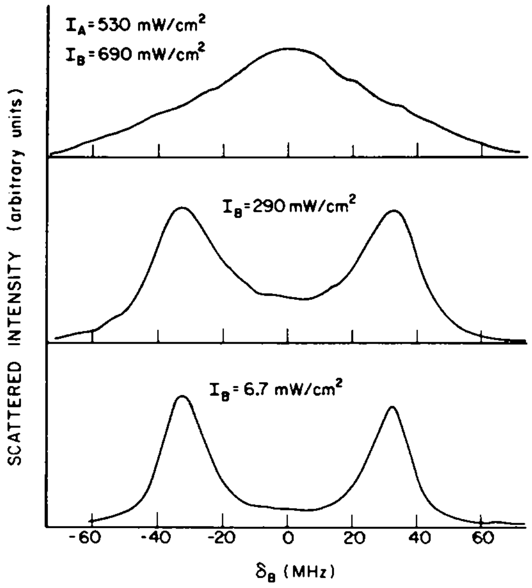

Fig. 3. Power broadening of doublet. As the intensity of laser B is increased the doublet fills in and becomes a single power-broadened lorentzian.

In the preceding spectra we have shown the fluorescence at 5688 Å from the $4D_{5/2} \rightarrow 3P_{3/2}$ transition as we tune laser B. We have also monitored the fluorescence at 5890 Å from the intermediate level, $3P_{3/2}$, to the ground state, $3S_{1/2}$ as we tune laser B. Those results are compared in fig. 4. The curves are

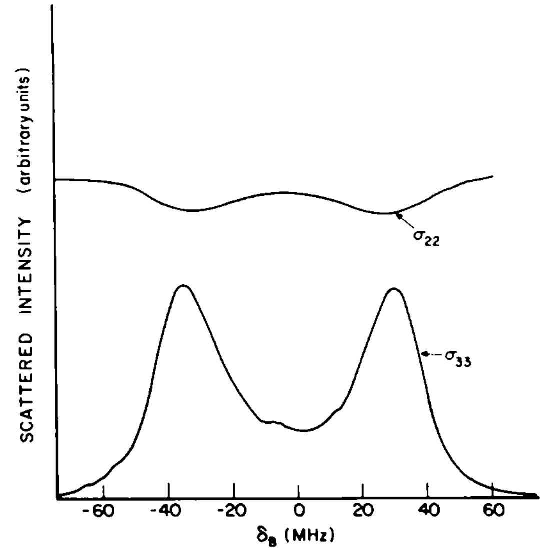

Fig. 4. Depletion of the intermediate level. The experimentally determined populations of the top-level, σ_{33}, and the intermediate level σ_{22} change in the opposite directions at resonance. Steady-state population inversions result.

labeled σ_{22} and σ_{33} to indicate that the fluorescent intensities are directly proportional to the respective populations of the second and third levels. The population of level 2 is seen to decrease at just the point at which the population of level 3 is a maximum. This can actually lead to a steady-state inversion between the two levels. A more detailed discussion of this point will be presented in a longer paper in the near future.

If we detune laser A from resonance the symmetry is destroyed. The effect of this detuning is shown in a composite drawing in fig. 5. The symmetric spectra at resonance become asymmetric quickly as we detune from resonance. The splitting between the peaks should increase along a hyperbola as a function of δ_A, the detuning of laser A from resonance. Theory and experiment are compared in fig. 6. Again the theory and experiment agree to quite good accuracy with no free parameters.

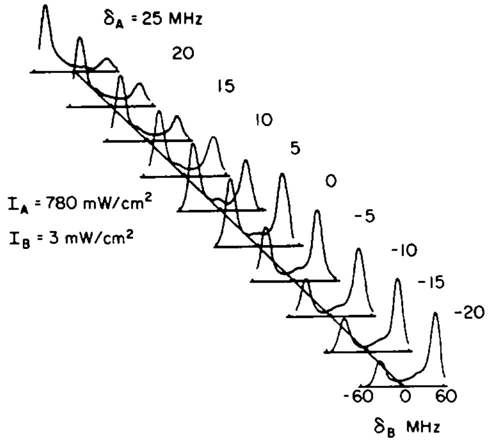

Fig. 5. Off-resonance spectra. As δ_a, the detuning of laser A from resonance changes, the spectra become asymmetric and eventually approach two-photon singlets.

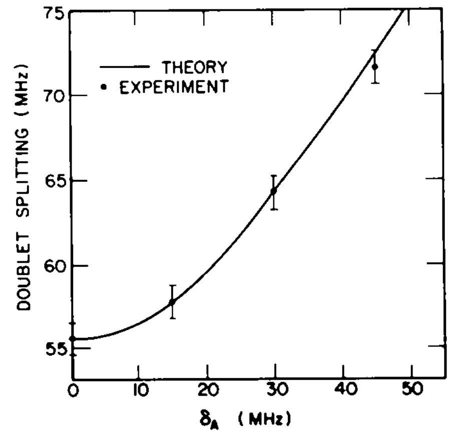

Fig. 6. Comparison of theory and experiment. The measured doublet splittings as a function of δ_A are compared with the theoretically predicted hyperbola.

Conclusion. Theory and experiment are shown to be in good agreement in the Autler–Townes effect if a good 3-level atom is used, and if the lasers are sufficiently stable. Further analysis of the results describing the atomic inversions achieved, determining the shifts as well as the splitting of the lines, etc. will be published in a longer paper.

We wish to acknowledge W.A. Molander who assisted in the data reduction. Professor C.W. Gabel aided in the development of the lasers used in this experiment. This research was supported in part by O.N.R. under Contract N0014-68-A-0091 and by the National Science Foundation.

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