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Observation of the Autler-Townes effect on infrared laser transitions of xenon

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The use of an active cell located outside the laser cavity has allowed us to observe the Autler-Townes effect under well-defined conditions. The splitting is proportional to the square root of the density of energy flux. An experimental value of the transition probability for the line at $\lambda = 3.51$ μm is proposed.

It has been shown recently[1] that it is possible to observe the Autler-Townes effect in the optical range, that is, the splitting of a single line when an intense electromagnetic field couples one of the two levels involved in the transition with a third one.[2] In particular, optical densities of energy flux in the vicinity of 1 W/cm^2, easily provided by gas lasers, are enough to observe the splitting. Experimentally, the effect was first observed by Schabert, Keil, and Toschek[3,4] on the coupled transitions of neon, at $\lambda = 633$ nm and $\lambda = 1.15$ μm. In that case, a high power is required for the saturating beam and the active cell was located inside the laser cavity. Recently, in our laboratory, the effect has been observed with other techniques involving an atomic-beam experiment with dye-laser sources.[5]

For the experiments reported here, we chose two infrared transitions of xenon at $\lambda = 3.51$ μm and $\lambda = 4.54$ μm, for which the required power is much smaller, allowing the use of an external active cell. Under these conditions, all parameters are well defined, and characteristic profiles have been recorded with high contrast and good signal-to-noise ratio. Furthermore, the splitting has been measured as a function of the saturating power.

PRINCIPLE OF THE EXPERIMENT

We study a three-level system, as shown in Fig. 1. In the active medium, a dc discharge, the transition at $\lambda = 3.51$ μm is saturated by an intense electromagnetic field at a given frequency; the resulting perturbation is analyzed by a frequency scanning of the amplification (or absorption) profile on the other transition at $\lambda = 4.54$ μm. Then, the characteristic splitting may appear in such a three-level system when the two beams propagate in the same direction.

The setup used in this experiment (Fig. 2) is similar to that described in a previous Letter.[6] The first electromagnetic field is provided by a powerful single-mode laser, stabilized in the Lamb dip, and the second one is provided by a short single-mode laser, tunable over a narrow spectral range. The two laser beams copropagate in the active cell; they are mixed before crossing the cell and separated by use of two identical beam splitters, S_1 and S_2, reflective at 3.51 μm and transparent at 4.54 μm. The saturating beam is modulated at 750 Hz; a lock-in detection of the probe beam is then used to record the signal resulting from the non-linear interaction.

The two lenses L_1 and L_2 allow the concentration of the beams inside the cell, so that the weak field probes the central region of the saturating field; therefore, in spite of a radial Gaussian distribution of the laser energy, the volume of interaction corresponds to a nearly constant density, a fundamental condition for observation of the Autler-Townes doublet. For the same purpose, we have used a very short active cell (length 5 cm) so that the longitudinal distribution of energy is also near-

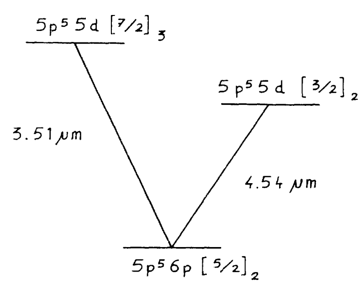

FIG. 1. Three-level system in Xe I.

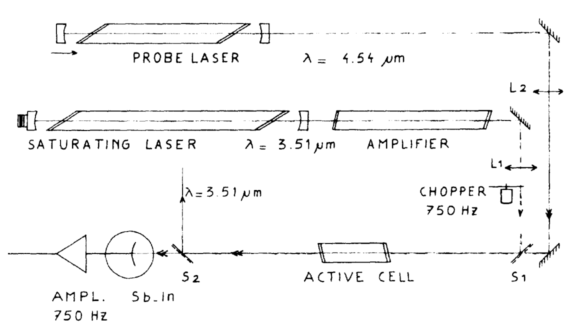

FIG. 2. Schematic diagram of the setup.

ly constant along the discharge.

A high power on the transition at $\lambda = 3.51$ μm is generally obtained by adding helium to the discharge of xenon[7]; this procedure leads to an important pressure shift, and the frequency of oscillation therefore differs noticeably from the frequency of absorption. To avoid this, we have used a pure-xenon laser followed by an amplifier tube; under these conditions, the saturating laser and the active cell can be filled with pure xenon (here, 99% ^{136}Xe) at similar pressures.

RESULTS

Typical profiles, recorded for strongly different densities of energy, are shown in Fig. 3. The first one [trace (a)] shows the non-Lorentzian profile observed at low density, here 0.013 W/cm^2. To the sharp resonant signal in emission is superposed a broad background in absorption which was already predicted and observed by Toschek and co-workers.[3,8] The slight asymmetry is due to a very weak detuning of the laser oscillation at 3.51 μm, compared to the central frequency of the absorption transition.

When the level of power is increased, the signal becomes broader and more intense; when a sufficient level is reached, the line splits into two components, symmetrical with respect to the central frequency of the sharp low-power profile, and the intensity remains constant. In addition, one observes a broadening of the components essentially due to degeneracy of the levels.[9] Trace (b) of Fig. 3 shows such a typical profile; here, the separation of the doublet is $\delta\nu = 25 \pm 2$ MHz; the density of energy flux is $\rho = 0.26 \pm 0.05$ W/cm^2, corresponding to a saturating power of 1 mW and a beam diameter of 0.7 mm.

We have studied the separation $\delta\nu$ vs the saturating power; it can be written $\delta\nu = 2k\Omega_R$ where k is a numerical factor depending on the relative frequencies of the two transitions and Ω_R is the Rabi frequency.[3] When the detuning between the laser oscillator and the central frequency of the absorption line can be neglected, Ω_R is proportional to the electric dipole moment P and to the square root of the density of energy flux of the saturating transition: $\Omega_R = (P/\hbar)(8\pi\rho/c)^{1/2}$. Our measurements, illustrated in Fig. 4, clearly confirm this dependence of $\delta\nu$ on the square root of ρ.

From the two previous expressions and experimental values of $\delta\nu$ and ρ, and taking degeneracy into account, one deduces a value for the absolute transition probability of the line of xenon at $\lambda = 3.51$ μm: $A = (0.7 \pm 0.4) \times 10^6$ sec^{-1}. This first measured value is in good agreement with previous theoretical calculations by Aymar.[10]

CONCLUSION

We have observed the separation of the Autler-Townes doublet under very good conditions, in particular with high signal-to-noise ratios; our

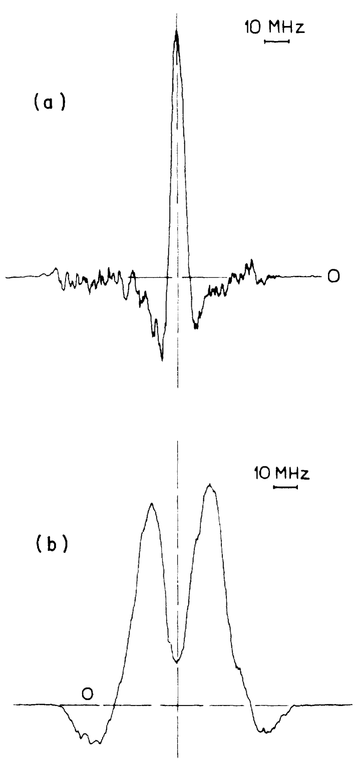

FIG. 3. Trace (a): low-power signal; trace (b): high-power signal.

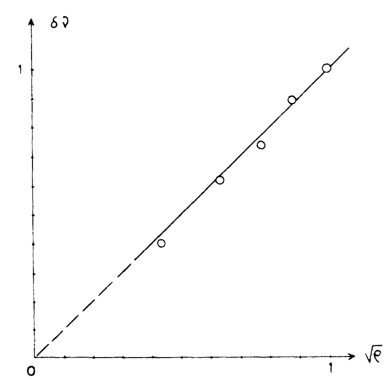

FIG. 4. Autler-Townes splitting vs the square root of the density of energy flux ρ. Scales are in units of the maximum separation: $\delta\nu = 25 \pm 2$ MHz, $\rho = 0.26 \pm 0.05$ W/cm^2.

measurements clearly confirm the predicted linear dependence of the separation on the square root of the density of energy flux. Additionally, a first value for the transition probability at 3.51 μm is proposed. This has been made possible because we have used very stable gas lasers (in intensity and in frequency) and also because, in the mean infrared, these light sources are powerful enough to observe such nonlinear effects.

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