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Giant Kerr effect in degenerate closed transitions

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Abstract: Giant Kerr nonlinearities about twelve orders of magnitudes greater than in glass were measured under negligible absorption conditions within two different closed transitions of the cesium D_2 line characterized by electromagnetically induced transparency or absorption.

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Electromagnetically induced transparency (EIT) and electromagnetically induced absorption (EIA) are accompanied by extremely steep dispersive patterns. Among other systems both can be observed in degenerate two-level systems under different conditions regarding the degeneracy of the upper and lower levels. In this experiment we used a phase-locked three-beam heterodyne interferometer to simultaneously couple and probe the two closed transitions present in the ^{133}Cs D_2 line: 6s $^2S_{1/2}$ F=4 $\rightarrow$ 6p $^2P_{3/2}$ F=5 and 6s $^2S_{1/2}$ F=3 $\rightarrow$ 6p $^2P_{3/2}$ F=2. The first was characterized by EIA, the second by EIT. During a measurement the coupling-laser frequency was kept fixed to the one of the desired transition. The probe laser was at first detuned from the corresponding resonance frequency and subsequently run through it, while remaining phase locked to the coupling laser. The employment of an atomic beam propagating orthogonally to the direction of propagation of the lasers contributed to the reduction of the Doppler broadening and enabled the experimentalists to measure dark or bright resonances with widths below 20 kHz [1]. The accompanied dispersion signals were measured with the aid of an auxiliary off-resonant laser (called reference laser): further details on the experimental apparatus used in this experiment can be found in a recent publication [2].

It is well known that the probe dispersion in a medium and the refractive index of such a medium can be easily related, because the dispersion is the derivative of the refractive index with respect to the probe detuning. From the measured dispersion spectra it was then possible to extract information on the probe refraction within the cesium beam. Thus it could be measured that cesium, once driven on one of the above mentioned transitions, showed not only a huge linear refractive coefficient, as it could be expected from the steepness of the dispersive patterns, but also Kerr nonlinearities of higher orders which varied as a function of the applied coupling-laser intensity.

Indeed it is possible to expand the probe refractive index at various, fixed probe detunings from the two-photon resonance frequency as a function of the coupling laser in accordance to the formula:

$$n(I_c) - 1 = n_0 + n_2 I_c + n_4 I_c^2 + \ldots$$

On this basis it was possible to extract the nonlinear Kerr coefficients associated with the bright and the dark state. In this experiment we were able to obtain nonlinear Kerr coefficients n_2 of the order of 10^{-5} cm^2/mW for the dark state and of -10^{-7} cm^2/mW for the bright state, which were respectively accompanied by absorption coefficients of the order of 0.01 cm^{-1} and 0.1 cm^{-1}. Such nonlinearities were several orders of magnitudes greater than those measured in usual Kerr media and were obtained in the presence of a much lower medium absorption.

It is noteworthy that the absorption in the case of a dark resonance was only a factor 5 greater than that within glass. Therefore, in the case of the dark resonance we calculated a figure of merit which related the dispersion at a chosen detuning with the induced transparency at the same detuning. Using this figure of merit it was possible to identify the optimal working point (optimal detuning) at which the system had to be driven - as a function of the applied coupling-laser intensity - to maximize the Kerr nonlinearity and simultaneously minimize the medium absorption. In the case of a coupling power of about 3.18 mW and a laser beam radius of about 2.2 mm the figure of merit was peaked at a probe detuning δ of about 160 kHz (see Fig.1). The value of this peak was at least a factor 10^5 greater than that measured in the absence of the coupling laser, i.e. in the presence of a simple one-photon transition for the probe laser, thus showing desired improvement.

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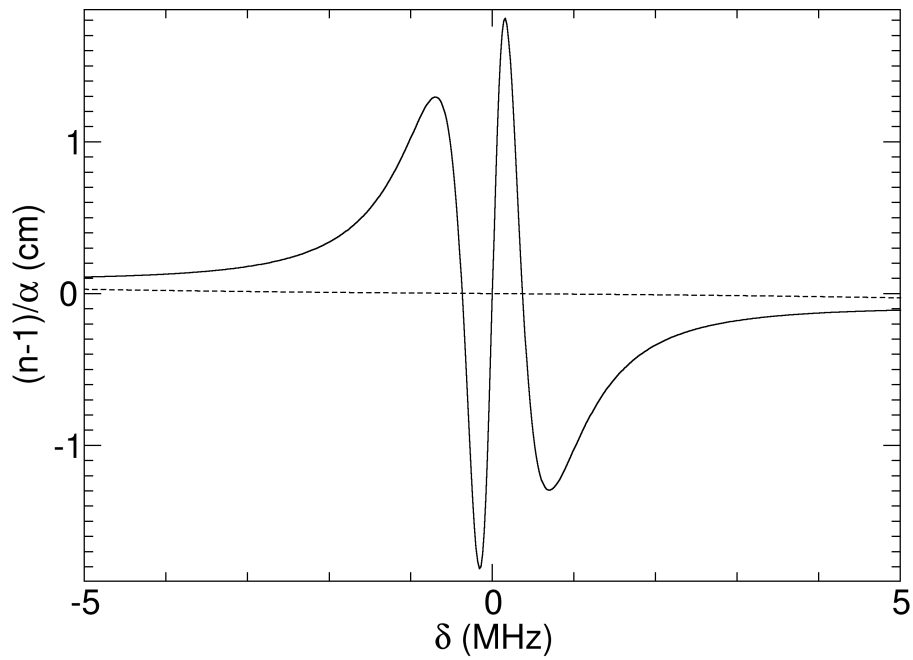

Fig.1: Figure of merit showing the ratio between the non-unitary part of the refractive index and the absorption coefficient for a probe laser probing a degenerate two-level system in the presence (continuous line) or in the absence (non-continuous line) of an applied coupling field.

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