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RECENT DEVELOPMENTS IN SUB-DOPPLER SPECTROSCOPY IN A THIN CELL

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Abstract : We report on the special sub-Doppler features of high-resolution spectroscopy in a thin cell, in conditions when the atomic free path is anisotropic as due to the special cell geometry. The most recent developments include linear spectroscopy under normal incidence, an extension to transition between excited states, and the observation of atoms flying under grazing incidence in a pump-probe scheme with spatially separated beams

1. INTRODUCTION

For a dilute gas, the special geometry of the container can affect the spectral lineshapes, notably when the transient effects, that are velocity-dependent, have to be included in the analysis. It was early shown by Dicke [1] that a lineshape narrowing could be observed, in the microwave domain, as a result of the relatively enhanced contribution of the slow atoms. In the optical domain, we had recently observed sub-Doppler features in the transmission, under normal incidence, of a *single* resonant beam through an alkali vapor cell whose thickness is 10-1000 μm [2]. In these experiments, performed on the D₂ line of Cs, the absorption was reduced at line center, as due to an hyperfine optical pumping transfer efficient only for those rare atoms [3] flying nearly parallel to the wall, that are insensitive to the Doppler shift, while experiencing a long interaction time. We report here on the last spectroscopic developments with thin cells.

2. LINEAR REGIME AND COHERENT INTERACTION

Although the hyperfine pumping of alkali metal vapors is an elementary observation in laser spectroscopy, it is nevertheless a nonlinear process : when the light power is low enough, its buildup time can largely exceed the interaction time, even for the slowest atoms. In the *linear* regime, the optical absorption exhibits a relatively fast transient build-up, as it is simply related to the atomic coherence, and it is susceptible to lead to an interferometric dependence with the cell length [4]. In a real cell, this partial interferometric dependence is actually washed out. Moreover, thanks to the enhanced sensitivity of a FM technique, we succeeded in observing sub-Doppler features in the transmission through a thin cell (up to 50 μm thickness) under an ultra-low power irradiation (1-100nW/cm²), ensuring a linear behavior.

3. TRANSITION BETWEEN EXCITED STATES

The above-demonstrated rare combination of sub-Doppler features and linear behavior, reminiscent of atomic beam spectroscopy, may offer various advantages, notably when saturation of the transition turns to be difficult or ineffective, or for transitions between excited states when a fine tuning of the intermediate

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steps of excitation is unwanted. In order to test such a possibility, we have investigated on the $6P_{1/2}$ - $6D_{3/2}$ transition of Cs (876 nm) the transmission of thin vapor cells irradiated by a *broadband* pumping on the D_1 line (894 nm). As shown on the spectrum of fig .1, a sub-Doppler signal appears centered on the atoms with null (longitudinal) velocity, superimposed to the Doppler-broadened absorption. Note that the recording is here obtained in a *linear regime* (optical pumping efficiency is indeed limited by the short lifetime of the excited states). More specifically, the analysis of the present sub-Doppler signal shows that it may actually originate in a (transit-time) velocity-selective pumping into the $6P_{1/2}$ level (which is particularly efficient on the D_1 line), rather than in the coherent linear excitation at 876 nm

4. SATURATION SPECTROSCOPY IN SEPARATED FIELDS

Usual saturated absorption spectroscopy with counterpropagating beams, and its specific features in the context of a thin cell, were already analyzed [3]. Here, we consider the situation (fig.2) when a spatial separation between the pump and the probe beams restricts the signal contribution to those atoms having traveled under grazing incidence. An interesting point is that the experimental set-up itself imposes the accuracy of the "grazing incidence", simply given by T/D , with T the cell thickness and D the distance between the pump and probe beam axes (assumed to be normal to the cell). This should provide an easy access to the tail of the atomic velocity distribution (i.e. those atoms with arbitrary small normal velocity, that are generally out-of-reach with the common detection techniques used for desorption measurement). Also, it eliminates the statistical difficulties related with velocity selection through low-power optical pumping in a thin cell (see discussion in [3]). In very preliminary experiments on a $20\ \mu\text{m}$ cell, we could observe on the Cs D_2 line the response of atoms pumped in a central spot (diameter $\sim 1\text{mm}$), and probed by a ring shape beam (as generated by diffractive optics) 4mm away from the pump. This corresponds to an effective 2 m/s velocity selection, already sharper than the 5m/s currently obtained on the D_2 line.

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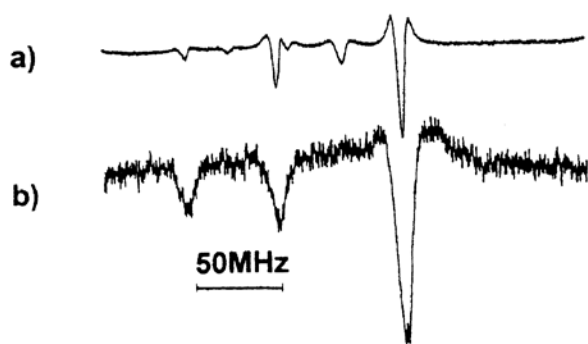


Figure 1 : Comparison between : (a) a saturated absorption spectrum on a transition between excited states (Cs 876 nm, $6P_{1/2}$ - $6D_{3/2}$) showing the Doppler-free resonance and the associated crossover resonances ; and : (b) linear absorption spectrum in a $10\ \mu\text{m}$ cell irradiated with a single low-power beam (here $10\ \mu\text{W}$, results are linear in the 50nW - $100\ \mu\text{W}$ range). The Doppler-free peaks are associated with a velocity selection of the slowest atoms. In both experiments, the the 894 nm ($6S_{1/2}$ - $6P_{3/2}$) pump beam is broadband, and does not carry velocity selective. An FM modulation is applied to the probe beam, and the signal is recorded after demodulation at twice this frequency.

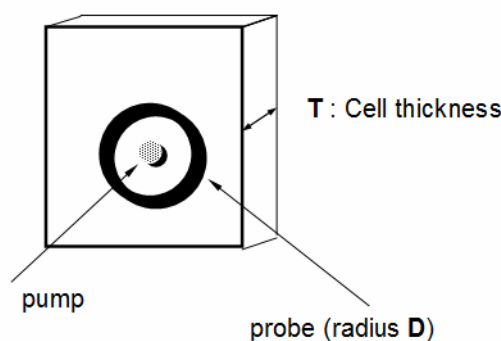


Figure 2 : Principle scheme of the experiment with spatially separated pump and probe beams.