Hyperfine Paschen-Back regime realized in Rb nanocell

Armen Sargsyan, Grant Hakhumyan, Claude Leroy, Yevgenya Pashayan-Leroy, Aram V. Papoyan, David Sarkisyan

To cite this version:

Armen Sargsyan, Grant Hakhumyan, Claude Leroy, Yevgenya Pashayan-Leroy, Aram V. Papoyan, et al.. Hyperfine Paschen-Back regime realized in Rb nanocell. Optics Letters, Optical Society of America, 2012, 37 (8), pp.1379 - 1381. <hal-00687006>
Rubidium atoms are widely used in atomic cooling, information storage, spectroscopy, magnetometry etc [1, 2]. Miniaturization of alkali vapor cells is important for many applications [3–6]. Atom located in magnetic field undergoes shift of the energy levels and change in transition probabilities, therefore precise knowledge of the behavior of atomic transitions is very important [7]. In case of alkali atomic vapor use a sub-Doppler resolution is needed to study separately each individual atomic transition between hyperfine (hf) Zeeman sub-levels of the ground and excited states (in case of a natural mixture of $^{85}$Rb and $^{87}$Rb the number of closely spaced atomic transitions can reach several tens). Recently it was shown that a one-dimensional nanometric-thin cell (NTC) with the thickness of Rb atomic vapor column $L = \lambda$, where $\lambda = 794$ nm is the wavelength of laser radiation resonant with $D_1$ line of Rb, is a good tool to obtain sub-Doppler spectral resolution. Spectrally narrow velocity-selective optical pumping (VSOP) resonances located exactly at the position of atomic transitions appear in the transmission spectrum of NTC at laser intensities $\approx 10$ mW/cm$^2$ [4, 6, 8]. When NTC is placed in a weak magnetic field, the VSOPs are split into several components depending on total angular momentum quantum numbers $F = I + J$, with amplitudes and frequency positions depending on $B$-field, which makes it convenient to study separately each individual atomic transition.

In this Letter we describe a simple and robust system based on NTC and permanent magnets, which allows of achieving magnetic field up to 0.7 T sufficient to observe a hyperfine Paschen-Back regime [9]. The magnetic field required to decouple the nuclear and electronic sub-states of the ground-state hyperfine splitting of $^{85}$Rb and $^{87}$Rb is the Bohr magneton $\mu_B$. For such a large magnetic field the eigenstates of the Hamiltonian are described in uncoupled basis of $J$ and $I$ projections ($m_J, m_I$). In Fig. 1 six transitions of $^{85}$Rb labeled 4 - 9, and four transitions of $^{87}$Rb labeled 1 - 3 and 10 are shown in the case of $\sigma^+$ polarized laser excitation for the HPB regime. The selection rules: $m_J = +1; m_I = 0$.

The sketch of the experimental setup is shown in Fig. 2. The circularly ($\sigma^+$) polarized beam of extended cavity diode laser (ECDL, $\lambda = 794$ nm, $P_L = 30$ mW, $\gamma_L < 1$ MHz) resonant with $^{85}$Rb $D_1$ line, was directed at normal incidence onto the Rb NTC (2) with the vapor column thickness $L = 794$ nm (a typical example of a recent version of the NTC is described in [6]). The NTC was placed in a special oven with two openings. The transmission signal was detected by a photodiode and was recorded by a four-channel digital storage oscilloscope. A polarizing beam splitter (PBS) was used to purify initial linear radiation polarization of the laser radiation followed by a $\lambda/4$ plate (1) to produce a circular polarization. The magnetic field was directed along the laser radiation propagation direction $k$.

A simple and efficient scheme based on one-dimensional nanometric thin cell filled with Rb and strong permanent ring magnets allowed direct observation of hyperfine Paschen-Back regime on $D_1$ line in 0.5 – 0.7 T magnetic field. Experimental results are perfectly consistent with the theory. In particular, with $\sigma^+$ laser excitation, the slopes of $B$-field dependence of frequency shift for all the 10 individual transitions of $^{85}$ and $^{87}$Rb are the same and equal to 18.6 MHz/mT. Possible applications for magnetometry with submicron spatial resolution and tunable atomic frequency references are discussed.

OCIS codes: 020.1335, 010.3640
does not exceed 2%). The similar dependence for lines: HPB theory; symbols: experiment, inaccuracy for components 1 - 10 (six transitions, 4 - 9 belonging to 85Rb, and four transitions, 1,2,3 and 10 belonging to 87Rb). Change in probe transmission is ΔT = 4%. The lower gray curve is the fluorescence spectrum of the reference NTC with L = λ/2, showing the positions of 87Rb, Fg = 1 → Fe = 1,2 transitions for B = 0, labeled as 1 - 1’ and 1 - 2’ (all frequency shifts are measured from Fg = 1 → Fe = 2).

Rb NTC could be implemented for mapping strongly inhomogeneous magnetic fields by local submicron spatial resolution. Particularly, for 0.1 T/mm gradient, the displacement of NTC by 5 μm results in 10 MHz frequency shift of VSOP resonance, which is easy to detect. Also development of a frequency reference based on NTC and PRM, which is B-field-tunable in over 10 GHz range, is of high interest. The above studies and techniques can be successfully implemented also for HPB studies of D lines of Na, K, Cs, and other atoms.

The research leading to these results has received funding from the FP7/2007-2013 under grant agreement n°205025 - IPERA. Research conducted in the scope of the International Associated Laboratory IRMAS (CNRS-France & SCS-Armenia).

Fig. 2. Sketch of the experimental setup. ECDL - diode laser, FL - Faraday isolator, 1 - λ/4 plate, 2 - NTC in the oven, PBS - polarizing beam splitter, 3 - permanent ring magnets, 4 - photodetectors, 5 - stainless steel II-shape holder (shown in the inset).

Fig. 3. Transmission spectrum of Rb NTC with L = λ for B = 0.605 T and σ+ laser excitation. Well resolved VSOP resonances located at atomic transitions are labeled 1 - 10 (six transitions, 4 - 9 belonging to 85Rb, and four transitions, 1,2,3 and 10 belonging to 87Rb). Change in probe transmission is ΔT = 4%. The lower gray curve is the fluorescence spectrum of the reference NTC with L = λ/2, showing the positions of 87Rb, Fg = 1 → Fe = 1,2 transitions for B = 0, labeled as 1 - 1’ and 1 - 2’ (all frequency shifts are measured from Fg = 1 → Fe = 2).

(components 1 - 3 and 10) are shown in the inset of Fig. 4. The HPB regime condition is fulfilled better for B > 0.6 T. As it is seen from Eq. (1), and also confirmed experimentally, the dependence slope is the same for all the transition components of both 85Rb and 87Rb: [gJ(5S1/2)mJ + gJ(5P1/2)mJ] μB B = 18.6 MHz/mT (as gJ ≪ gI we ignore its contribution). Onset of this value is indicative of Rb D1 line HPB regime. Note that in our previous study for B ~ 20mT [12] and under the same conditions we observed 32 transitions, as opposed to 10 remaining in HPB regime.

The values for nuclear (gI) and fine structure (gJ) Landé factors, and hyperfine constants A_hfs are given in [11]. The magnetic field dependence of frequency shift for components 4 - 9 (88Rb) is shown in Fig. 4 (solid lines: HPB theory; symbols: experiment, inaccuracy does not exceed 2%). The similar dependence for 87Rb...
Fig. 4. Magnetic field dependence of frequency shift for transition components labeled $4 - 9$ ($^{85}$Rb) and $1 - 3, 10$ ($^{87}$Rb, in the inset). Solid lines: theory; symbols: experiment. The inaccuracy is $\leq 2\%$ for components $4 - 9, 1$ and $10$, and $\leq 5\%$ for components $2$ and $3$. Larger error for $3$ and $2$ is caused by closely located strong transition $7$ and location on the transmission spectrum wing, respectively.

References