Phase-dependent quantum interferometry of degenerate Rydberg states

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Direct control of atomic coherences is necessary for a number of fundamental studies based on quantum interference and entanglement of atomic states. Some tests of these phenomena could be performed with the microwave transitions in Rydberg atoms which have the advantages of long radiative lifetimes and opportunity to analyze their populations by a selective field ionization (SFI) technique with a single atom sensitivity.

In the present work we have developed and realized experimentally a novel techique for quantum interferometry of *degenerate* Rydberg states [1]. It is based on the fact that the probabilities of transitions between degenerate states depend not only on the populations of sublevels of the initial state but also on the phase relations between their wave functions. The relations are usually set up in a process of coherent laser excitation of atomic states. If we could change the phases after the laser excitation, then we could control the probabilities.

The technique consists of four subsequent and separated in time steps [Figs. 1(a)-1(d)]. After the laser excitation [step(a)] of a Rydberg state with the degenerate sublevels 1 and 2 we can apply a short pulse of weak electric field [step(b)]. The pulse causes a temporary energy splitting of the sublevels, and consequently changes the phase relations between their wave functions due to the time dependent $\exp(-\imath W_{1,2}t/\hbar)$ phase factors, where $W_{1,2}$ are the energies. Then a pulse of a resonant microwave field with a proper linear polarization induces both transitions from the sublevels 1, 2 to some adjacent nondegenerate state 3 in zero electric field [step (c)]. After the pulse a population of the state 3 is monitored by the SFI in adiabatically rising electric field [step(d)].

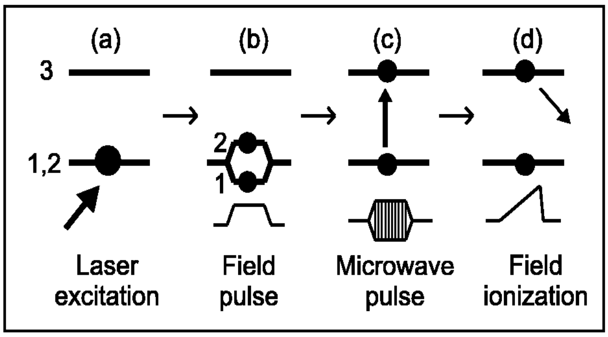

Figure 1: Scheme for quantum interferometry of degenerate Rydberg states.

In fact, the proposed method represents an "intra-atomic interferometer" which is sensitive to the phase relations between degenerate Rydberg sublevels. One may analyze the phases by measuring the probability of the transition as a dependence on the amplitude of the electric field pulse. On the other hand, the effect may be considered as a Raman-type process in which a phase-controlled coherent population trapping takes place in a degenerate Λ-system.

We have used a microwave transition $37P_{3/2}\rightarrow 37S_{1/2}$ at 70.166 GHz in sodium Rydberg atoms for the experiments. The $37P_{3/2}$ state was excited by a three-step laser scheme by a pulsed laser emission with a variable linear polarization. Measuring the population of the 37S state N_{37S} we could record the interference signal as a dependence of N_{37S} on the amplitude of the electric field pulse E_{max} having a 0.35 μs duration.

The observed interference signals are shown in Fig. 2 for two polarizations of the exciting laser emission (indicated by the arrows). Frequency of the oscillations is growing due to the quadratic Stark effect on the S and P states. Remarkable features of Figs. 2(a) and 2(b) are inverse (shifted by π) phases of the interference signals.

The obtained results are important for the experiments on microwave spectroscopy of degenerate Rydberg states, when an atomic density is extremely low, and the atoms have long radiative lifetimes.

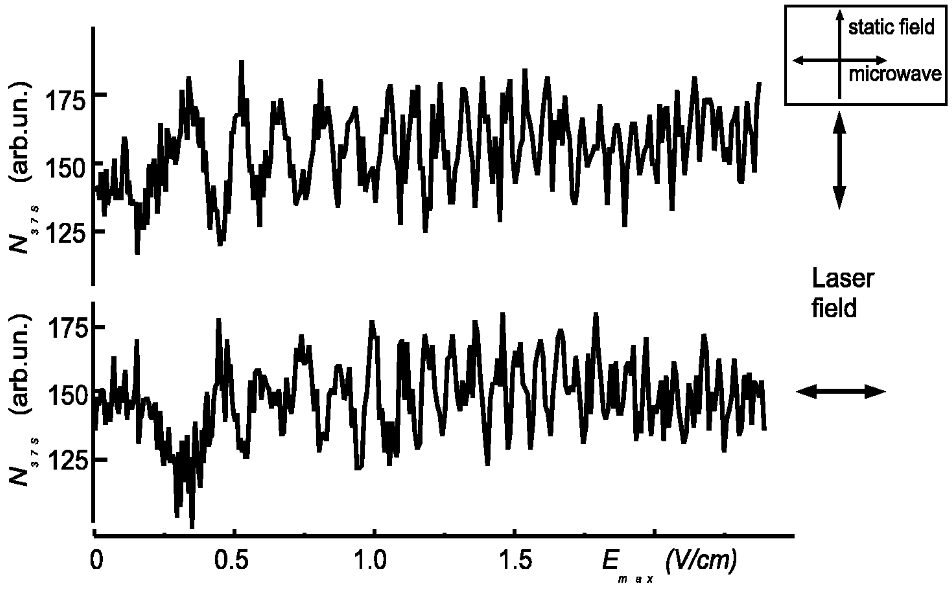

Figure 2: Interference signals recorded at different laser polarizations (indicated by the arrows), and fixed directions of the static electric field and polarization of the microwave field (shown in the inset).

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[1] I. I. Ryabtsev and I. M. Beterov, to be published in *Phys. Rev. A.* May 01 (2000).