Nondispersing Bohr wave packets using circularly polarized microwave fields

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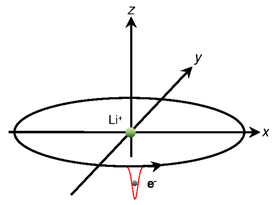
Introduction

It is possible to make nondispersing Bohr wave packets in a straightforward way starting from Li Rydberg atoms in an np eigenstate[2]. These atoms are first exposed to a linearly polarized microwave field at the orbital frequency, 17.6 GHz at $n = 72$. The linearly polarized field phase locks the electron wave packet to the microwave phase, making a nondispersing wave packet in which the electron oscillates in a highly eccentric, approximately linear orbit. We detect the phase locked motion of the electron with a 1/2 ps half-cycle pulse synchronized with the microwave field. Slowly changing the microwave polarization from linear to circular polarization creates a nondispersing Bohr wave packet that survives for thousands of orbits.



Experimental Setup

A thermal beam of Li atoms pass through a 17.564 GHz Fabry-Pérot microwave cavity. The atoms are excited at the center of the cavity by three 5 ns laser pulses to np states of $70 \leq n \leq 75$ via the route $2s \rightarrow 2p \rightarrow 3s \rightarrow np$. Subsequent to the laser excitation the atoms are exposed to a combination of x- and y-polarized microwave pulses, as shown in Fig. 2.

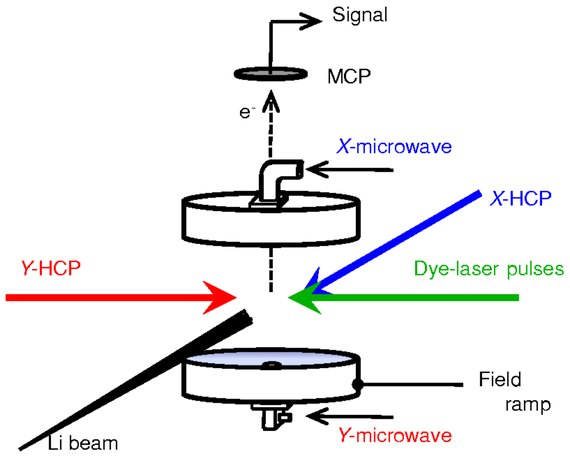


FIGURE 2: Schematic diagram of the experimental setup.

If the Kepler frequency of the atom is within 500 MHz of the microwave frequency, a 1 V/cm microwave field converts the atoms in the np state to a nondispersing wave packet in which the electron's motion is approximately one dimensional and phase-locked to the oscillating field. Then a second microwave pulse is injected into the cavity through the lower mirror to produce a field polarized in the x direction, the phase of which is shifted by 90° from the y-polarized field. As the amplitude of the x-polarized field rises to match that of the y-polarized field the microwave field slowly changes from linear to circular polarization. The electron's motion is locked to the field and evolves from a linear to a circular orbit.

To detect that the Rydberg atom has been converted from an np eigenstate to a linearly oscillating wave packet and then to a circular wave packet we observe the time variation of the x or y momentum of the electron with a 1/2 ps half cycle pulse (HCP), which is short compared to the 56 ps period of the Kepler orbit and the microwave field. The HCP can be polarized in either the x or y direction. Typically the amplitude of, for example, an x-polarized HCP is set to ionize those atoms in which the electron has x momentum $p_x > 0$.

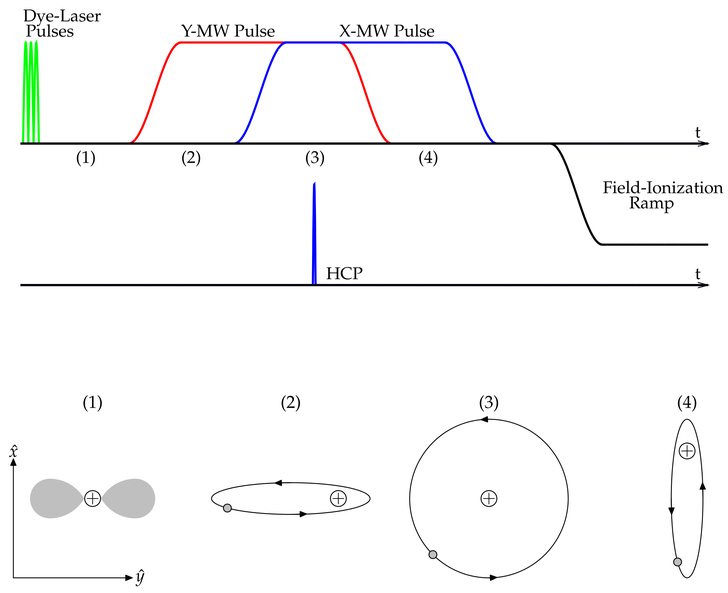
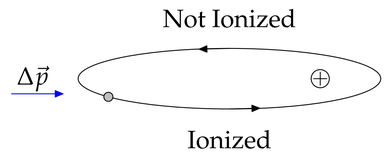


FIGURE 4: Timing diagram and Rydberg electron orbits at times (1) - (4).

We detect the remaining Rydberg atoms with a field ionization pulse applied to the lower cavity mirror. The resulting electrons are driven through a hole in the upper cavity mirror to a microchannel-plate (MCP) detector and the integrated signal is recorded as the fine time delay of the HCP is scanned. If the atom is in an energy eigenstate and the electron's motion is not phase-locked to the microwave field there is no variation in the signal, but if the atom has become a nondispersing wave packet there is a variation with the 56 ps period of the microwave field[1].

Preferential Ionization with Half-Cycle Pulses



The linearly polarized HCP gives the electron an impulsive momentum kick $\Delta\vec{p}$. If the initial momentum of the electron is $\vec{p}_0$ the energy transferred to the electron by the HCP is

$$\Delta W = \vec{p}_0 \cdot \Delta\vec{p} + \Delta p^2/2. \quad (1)$$

If ΔW exceeds the binding energy of the initial state, ionization of the atom occurs. We typically set the amplitude of the HCP so that 50% of the atoms in an eigenstate of the same energy are ionized. Equivalently, all atoms in which the electron is moving in the direction of the momentum kick from the HCP are ionized.

Results

In Fig. 3 we show the transformation of Li atoms in the $72p$ eigenstate into a wave packet oscillating linearly in the y direction, then to a circularly polarized Bohr wave packet, and finally to a wave packet oscillating linearly in the x direction. The microwave field amplitudes of the x- and y-polarized fields are ~ 1 V/cm, far smaller than the typical atomic field, $\propto 1/n^4$, felt by the Rydberg electron, 191 V/cm for $n = 72$. Specifically, we show the result of exposing atoms initially excited to the $72p$ state in zero field to the microwave pulse shown in Fig. 2, a microwave field initially polarized in the y direction, then circularly polarized, and finally polarized in the x direction.

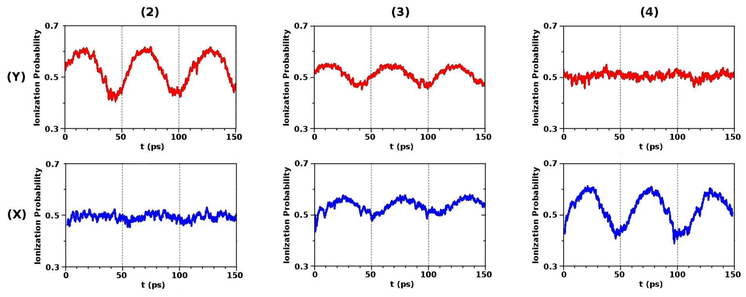


FIGURE 6: Signals observed when atoms are exposed to y- and x-polarized HCPs and the time delay is scanned at the times of (2), (3), and (4).

A circularly polarized wave packet can have left or right circular polarization, and in Fig. 4 we show the result of turning on the x-polarized field of Fig. 2 with phase shifts of $\pm 90°$. As shown, when the atoms are exposed to an x-polarized HCP at time (3) of Fig. 2 the modulation exhibits a 180°-phase shift, while the modulation from the y-polarized HCP is unchanged, as expected for left- and right-hand circularly polarized wave packets.

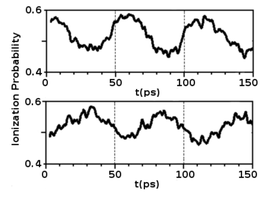


FIGURE 7: Signals observed in right- and left-circularly polarized fields at time (3), when scanning the time delay of the x-polarized HCP.

In conclusion, we report the first observation of nondispersing Bohr wave packets. The technique we have used is relatively simple and robust, and it is possible to make long-lived wave packets which can be used in other experiments. For example, one can imagine using the synchronized electron motion as the basis of phase sensitive detection. More generally, this work shows that it is straightforward to take advantage of the fact that a nondispersing wave packet is phase-locked to the microwave field to manipulate the wave packet using the polarization, amplitude, and frequency of the microwave field.

References

[1] H. Maeda and T. F. Gallagher. Nondispersing wave packets. *Phys. Rev. Lett.*, 92(13):133004, Apr 2004.

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