Up-down asymmetry of the electrons ejected from barium 6p\textsubscript{1/2}nk autoionizing states

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Introduction

Electric dipole photoionization of atoms by light linearly polarized in the z direction usually leads to angular distributions of electrons which are symmetric in the z (up) and -z (down) directions. The up-down symmetry has its origin in the fact that the atoms are usually in a state of good parity, and electric dipole photoionization simply reverses the parity if an odd number of photons are absorbed and leaves it unchanged if an even number of photons are absorbed.

The symmetry can be broken if the electrons are ejected from atomic states which do not have good parity, such as the Rydberg Stark states formed in the presence of an electric field. In a static field in the z direction, the Rydberg electron in a Stark state can be localized primarily on the +z or -z side of the atom [1]. Photoionization or autoionization of Stark states can be expected to result in superpositions of even- and odd-parity continua, with the result that the up-down symmetry of the electron ejection is broken.

As a simple example, we show in Fig. 3 the classical trajectory of an electron initially in an l = 3 orbit aligned along the -z axis which autoionizes as it passes near the core and leaves the atom in the +z direction. In a zero-field (i.e., Stark) state, electron orbits along the +z and -z axes are equally likely, resulting in no up-down asymmetry of the ejected electrons. However, if the electron’s orbit is on the -z side of the atom, as in Fig. 3 or in a Stark state, the electron is ejected preferentially in the +z direction.

While the existence of the up-down asymmetry in the photoionization and autoionization of atomic states which do not have a well-defined parity, such as the Stark states, seems obvious, it has not, to our knowledge, been observed. The impetus to its observation is that to form the Stark states generally requires such strong fields that it is impossible to determine the direction in which the electrons have been ejected from the atom.

Experimental Approach

Laser excitation scheme is shown in Fig. 4. (a) All the laser pulses are 5-ns long and are fired in static field as shown in Fig. 5. In Fig. 5, the first 3 µs of the field ramp, a microwave field resonant with the 6s(n + 3)d to 6n'k state transitions at the field E\textsubscript{a} = E\textsubscript{b} is present, and as the field ramp passes through E\textsubscript{a}, the atoms undergo adiabatic rapid passage from the 6s(n + 3)d state to the 6n'k state.

At a chosen time, and therefore field, after the microwave pulse, atoms in the 6n'k state are excited to the autoionizing 6p\textsubscript{1/2}nk state by a third laser pulse at a wavelength of \(\sim 493\) nm. This excitation, the isolated core excitation (ICE), is one in which the ion core is excited while the outer nk electron remains a spectator [2]. The 6p\textsubscript{1/2}nk atoms autoionize rapidly, during the third laser pulse, and the electrons resulting from autoionization are forced through a 1.8-cm diameter hole in the top plate and fly to the 1.8-cm diameter microchannel plate (MCP) detector 3.2 cm above the top plate as shown in Fig. 6.

Experimental Results and Discussion

We have observed the ejected electrons from Ba 6p\textsubscript{1/2}nk states of n = 28 and 29, 54 k on - 1 in electric fields. For both n, k = 15 and 16 are in the middle of the Stark manifold as shown in Fig. 8. These states have small Stark shifts, and the wave function of the Rydberg electron is up-down symmetric. States of k < 15 are red states, and the wave functions are localized on the upward side of the atom, while states of k > 16 are blue states, and the wave functions are localized on the downward side of the atom.

Fig. 9a k = 5 more electrons ejected in the upward direction are detected. Fig. 9b k = 16 the earlier electron signal is only slightly larger than the later one. Fig. 9c k = 21 the earlier and later signals are comparable in amplitude, but the time-integrated later signal is larger.

In Figs. 10, the observed up-down asymmetry is not large. In higher r states, the electron does not come as near the core due to the centrifugal potential, and the electron is no longer ejected with as strong a preference for the +z or -z direction. In our experiment, we have studied the Stark states which are composed of states of \(k > 5\) for which there is less asymmetry in the direction of the ejected electron than the lower r states.

From a quantum-mechanical point of view, the asymmetry arises from the interference between partial waves of even and odd. Autoionization rates of the Ba 6p\textsubscript{1/2}nk states fall quickly with k, so the interference terms cannot be too large. Calculating the probability of ejection in a specific direction, P(\theta,\phi), poses a theoretical challenge, and we hope these data will inspire a theorist to undertake it.

Conclusion

We have observed the up-down asymmetry in electrons ejected from an asymmetric atomic state, specifically from Ba 6p\textsubscript{1/2}nk autoionizing Stark states. The red autoionization states are more likely to eject the electrons in the upfield direction, while the blue autoionizing states are more likely to eject the electrons in the downfield direction.

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References