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Attosecond-Scale Probing of the Electron Motion in the H-Atom Groundstate

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ABSTRACT

Based on recent advances in attosecond strong-field spectroscopy and the current feasibility for trapping individual groundstate H-atoms from a neon-gas matrix, an experiment to probe the groundstate motion of the electron in the H-atom is proposed here.

Keywords: H-Atom Groundstate; Electron Motion

1. Introduction

Both the quasi-quantum-theoretic Bohr model for the H-atom, with integer-quantized classical orbits for the electron, and the Schrödinger wavefunction formulation, with the pointlike electron residing in stationary-state probability distributions around the proton, accurately yield Rydberg's spectra for the Lyman, the Balmer and the higher-order series. Why both Bohr and Schrödinger produce the experimental Rydberg physics stems from the characteristic-caustic mathematical theory for linear partial and associated ordinary differential equations [1]. However, the physical pictures of Bohr and Schrödinger are strikingly different: the Bohr picture features integer-quantized classical paths, while the Schrödinger formulation has the pointlike electron simply filling stationary-state probability distributions, with observable electron motion precluded by the axioms of quantum theory.

Now in the Bohr model 1s groundstate, the electron moves on a circular orbit of radius $r_B = 0.529\times10^{-8}\,\text{cm}$ at a velocity

$$v = \left[2(13.6\,\text{eV})/0.511\,\text{MeV}\right]^{1/2} c = 2.189\times10^{8}\ \text{cm/sec},$$

with the virial theorem implying that the kinetic energy of the electron is the negative of the total groundstate binding energy, –13.6 eV. Hence the transit time for a complete orbit is $\Delta t = 2\pi r_B/v = 1.52\times10^{-16}\ \text{sec} \equiv 152$ attosec, a magnitude in the range of recent attosecond strong-field spectroscopy experiments [2-6]. Also recently, it has been shown feasible to trap individual groundstate H-atoms from a neon-gas matrix [7]. These two remarkable recent technological advances suggest an experiment to probe the groundstate motion of the electron in an isolated cold H-atom.

2. Proposed Experiment

A proposed scheme for trapping individual cold H-atoms from a solid neon matrix has been suggested recently, along with quantitative *ab initio* quantum calculations that demonstrate theoretical feasibility if the heating-rate to the H-atoms can be properly limited [7]. The solid neon matrix with magnetically captured paramagnetic low-energy H-atoms is grown in a cell structured with a cold sapphire substrate. The trapping technique depends essentially on the energy transfer rate from the thermal bath to the H-atoms, given in theory by the classical linear Boltzmann equation. While manifest assumptions are involved in the proposed scheme, current experiments in progress will determine if this trapping scheme for cold H-atoms can be effected [8].

Let us assume that the trapping scheme for individual cold H-atoms can indeed be effected. Then, if such isolated H-atoms are subjected to strong $\left(\sim10^{13}\ \text{W/cm}^3\right)$ attosecond pulses at the Bohr groundstate frequency

$\nu_B = (\Delta t)^{-1}$ and wavelength

$\lambda_B = c/\nu_B = c(\Delta t) = 45.6\ \text{nm}$, a sharply peaked resonance ionization may be evident. The key thing here is that $\lambda_B = 45.6\ \text{nm}$ from the Bohr model is precisely one-half the wavelength 91.2 nm, the ionization wavelength for groundstate H. Thus, since the concentration of isolated H-atoms is anticipated to be greater than $\sim10^{14}/\text{cm}^3$ in the neon-gas matrix-trap, a sharply peaked resonance associated with two ionizations of H-atoms may appear as the ultraviolet laser is tuned through $\lambda_B = 45.6\ \text{nm}$. On the other hand, the H-atom 1s groundstate in the Schrödinger formulation does not feature any motion-related significance to $\lambda_B = 45.6\ \text{nm}$, and the attosecond pulses should ionize H-atoms with a monotone increase in number of ionizations as the laser wavelength decreases through $\lambda_B = 45.6\ \text{nm}$, without a sharply peaked resonance. Hence, the observational result of the experiment would be of fundamental theoretical interest.

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