Stochastic Ionization of Electrically Polarized Hydrogen Rydberg Atoms

Experiments on the excitation and ionization of Rydberg atoms in strong microwave fields[1,2] have been proposed for the investigation of "quantum chaos" since these systems can exhibit chaotic behavior in the classical limit. In a recent Letter, Bayfield and Pinnaduwage[3] presented the first experimental measurements of the microwave excitation and ionization of hydrogen Rydberg atoms prepared in highly eccentric, nearly one-dimensional states. The purpose of this Comment is to compare these results with a classical analysis of this perturbed nonlinear oscillator.

The experiments were performed with electrically polarized atoms in their lowest $n=60$ Stark state in a spatially uniform microwave field, polarized along the static field direction, with frequencies between 6 and 8 GHz and oscillating electric field amplitudes ranging up to 22 V/cm. When the field was increased above ~ 5 V/cm, transitions to the $n=57$–64 levels and then ionization were observed; for most perturbation frequencies the beam was fully ionized for field strengths $\geqslant 20$ V/cm. However, classical calculations[4] of the electron trajectories for quasistatic perturbations predict that for this range of frequencies a critical field strength of 28 to 36 V/cm must be exceeded before ionization can occur. These are approximately a *factor of 2 larger than* the threshold fields observed experimentally.

These theoretical results are confirmed by a detailed simulation of the classical electron orbits for the one-dimensional hydrogen atom in the $n=60$ state in a combined static field of 5.5 V/cm and a 6.9-GHz microwave field of 16 V/cm. Figure 1 shows a Poincaré section for several electron trajectories, plotted once every period of the perturbation in the action-angle variables for the one-dimensional Coulomb potential.[5] The actions corresponding to the lowest Stark levels for principal quantum numbers ranging from $n=57$ to 70 are labeled on the right-hand side. For $n\leqslant 63$ the classical orbits lie on smooth curves which indicate the persistance of Kolmogorov-Arnold-Moser (KAM) surfaces. Since these KAM surfaces confine the dynamics in the two-dimensional phase space, the classical orbits corresponding to these energy levels can never ionize. In contrast, the experimental results displayed in Fig. 3 of Ref. 3 show significant ionization for these microwave parameters. A possible explanation for this discrepancy between the classical theory and the experiment is that resonant multiphoton excitations to higher levels[6] enable the excited electron to access the chaotic domain of phase space for $n\geqslant 64$.

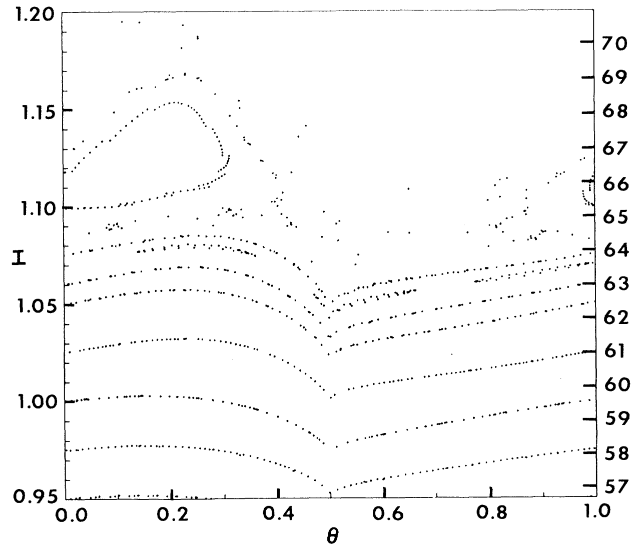

FIG. 1. Regular and chaotic electron trajectories in action-angle space for a one-dimensional hydrogen atom in a microwave field. The prominent island for $n=64$–69 corresponds to a classical resonance with the third harmonic of the perturbation frequency.

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