Role of "Scars" in the Suppression of Ionization in Intense, High-Frequency Fields

In a numerical study of a one-dimensional model of an atom with potential $-1/(1+x^2)^{1/2}$ in a high-frequency field $F\cos(\omega t)$, Su, Eberly, and Javanainen[1] found that the ionization decreases when F becomes large and that the electron probability exhibits a double-peak structure which they associated with the "dichotomous" wave function in the time-averaged atomic potential studied by Pont *et al.*[2] However, the peaks of the dichotomous wave functions were predicted[2] to be separated by a distance $2F/\omega^2$ while Su's peaks are only $F/\omega^2 \equiv \alpha_0$ apart.

Our analysis indicates that these multiply peaked wave functions result from the *diabatic* excitation of wave functions that are localized to the vicinity of unstable and weakly stable periodic orbits embedded in the chaotic classical phase space. These "scarred" wave functions provide a new mechanism for the high-field stabilization that accounts for the reduced spacing of the peaks and relates this problem to other strongly perturbed quantum systems[3] where scars play an important role.

In the high-field, high-frequency limit, the classical motion of a free electron in the oscillating field is perturbed during the short times when the electron is moving slowly in the vicinity of the atomic potential. Consequently, the classical equations of motion in the oscillating Kramers-Henneberger frame can be well approximated by a nonlinear, area-preserving map,

$$x_{n+1} = x_n + Tp_{n+1}, \tag{1}$$

$$p_{n+1} = p_n + kf(x_n), \tag{2}$$

where x_n and p_n are the relative positions and momenta of the electron evaluated once every period, $T=2\pi/\omega$, of the field. The "kick" function is

$$f(x) = -g(r_+)/(1+x^2)^{3/4} + g(r_-)/[1+(x+2\alpha_0)^2]^{3/4}, \tag{3}$$

where $g(r_\pm) = E(r_\pm) - 0.5K(r_\pm)$ is expressed in terms of complete elliptic integrals with arguments $2r_+^2 = 1 - x/(1+x^2)^{1/2}$ and $2r_-^2 = 1 + (x+2\alpha_0)/[1+(x+2\alpha_0)^2]^{1/2}$, and $k = 2\sqrt{2}/\sqrt{F}$. The points plotted in Fig. 1, for 100 iterations of the map for a number of different initial conditions, show that for Su's field parameters[1] the classical dynamics is mostly chaotic in the vicinity of the double-well kicking potential $V(x) = -k\int G(x)dx$.

The quantum dynamics is determined by a quantum map[4] defined by the unitary time evolution operator for one period of the oscillating field, $U(T) = \exp(-iTp^2/2)\exp[-iV(x)]$. In analogy with our previous studies of the microwave ionization of Rydberg atoms,[3] we find that some of the quasienergy (QE) states of U remain localized to the vicinity of the two weakly stable fixed points in the double-well kicking potential at $x \approx 0$ and $\approx -2F/\omega^2 = -37$ and also near the unstable fixed point on the saddle between the wells as shown in Fig. 1.

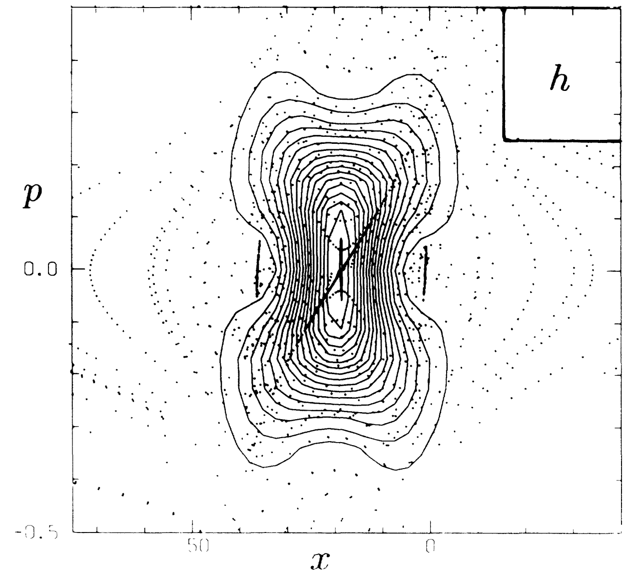

FIG. 1. The level contours of the Husimi distribution (Refs. 3 and 4) for the QE state that scars the unstable fixed point at $x = F/\omega^2 = -18.5$, superimposed on the classical x-p Poincaré section for the map with $F=5.0$ and $\omega = 0.52$ a.u.

If a superposition of these scarred QE states are diabatically excited by the applied field, then part of the electron distribution will remain in the vicinity of the atom with peaks spaced F/ω^2 apart. Moreover, this dynamical localization is determined by the size of the classical "stochasticity" parameter $K = kT \propto 1/\sqrt{F}\omega$ which *decreases* with both increasing field F and frequency ω.

R. V. Jensen
Applied Physics
Yale University
New Haven, Connecticut 06520

B. Sundaram
Los Alamos National Laboratory, MS B-268
Los Alamos, New Mexico 87545

Received 23 July 1990
PACS numbers: 32.80.Rm, 05.45.+b, 42.50.Hz

[1] Q. Su, J. H. Eberly, and J. Javanainen, Phys. Rev. Lett. **64**, 862 (1990).

[2] M. Pont, N. R. Walet, M. Gavrila, and C. W. McCurdy, Phys. Rev. Lett. **61**, 939 (1988).

[3] R. V. Jensen *et al.*, Phys. Rev. Lett. **63**, 2771 (1989).

[4] S.-J. Chang and K.-J. Shi, Phys. Rev. A **34**, 7 (1986).