was connected to one of two terminals. The connection was either regular or random depending on the type of the pattern control. However, it was arranged so that the electric field was applied on a half of all gaps while the other half were field free. The electric potential between the two terminals was adjusted so that the atom that passed through the gap with the electric field underwent a pi phase shift. The pattern of the binary hologram was imprinted on the pattern of holes in the gap. By switching the electric potential between the terminals we showed the shifting, and erasing of the atomic pattern as well as the switching of two patterns.

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QThB2 **8:15 am**

Recovery of classically chaotic behavior with noise in the quantum kicked rotor

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Quantum effects can suppress chaotic motion in systems with chaotic classical limits. This suppression relies on quantum interferences, and thus decoherence due to noise and dissipation should restore classical behavior. Decoherence is especially important in reconciling the classical and quantum descriptions of chaotic systems, where simple estimates predict that nonclassical effects appear after only a short time, even for macroscopic systems.[1]

We use the tools of atom optics to study the effects of noise in a quantum system that is classically chaotic. We prepare cold cesium atoms in a magneto-optic trap, and after the trap is extinguished, they are "kicked" by a pulsed standing wave of far-detuned light. The Hamiltonian for the atomic center-of-mass motion in the experiment is

$$H = \frac{p^2}{2m} + V_0\cos(2k_L x)\sum_n F(t - nT), \quad (1)$$

where $F(t)$ represents the temporal envelope of the pulses. In the regime of short pulses, this system is a realization of the kicked rotor, a paradigm system for the study of classical and quantum chaos. The classical dynamics of this system are characterized by approximately diffusive growth in momentum. However, the quantum dynamics are strikingly different: the diffusion that one expects classically only occurs for a finite time, after which quantum effects inhibit the diffusion, and the momentum distribution settles into a stationary exponential form. This effect is known as dynamical localization, and is a signature of the quantum suppression of classical chaos.

To study the effects of noise on localization, we introduce several types of noise, including amplitude noise, timing noise, and noise in the phase of the standing wave. In general, the addition of noise results in loss of localization, and hence restored diffusion. We observed this delocalization with amplitude noise and with spontaneous emission in previous work, but at the time it was not clear whether or not the behavior had returned to the classical limit. To address this issue, we have performed extensive measurements on the effects of noise in the experiment. We have also constructed a detailed classical model of the experiment, which accounts for aspects of the experiment that are not included by the ideal model in Eq. (1). For sufficiently large levels of noise, the experimentally measured momentum distributions are well described by the classical model with noise, providing compelling evidence of a return to classical behavior. We have also studied the dynamics in the transition regime, when the quantum localization is broken but the dynamics are still nonclassical. In this regime the short-time correlations significantly affect the dynamics, and the effects can be different in the quantum and classical cases.[2] We observe that for our experimental parameters (far away from the semiclassical limit), the noise must be strong enough to destroy these correlations in order to obtain good correspondence.

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QThB3 **8:30 am**

Chaotic dynamics and tunneling of an atom in a magneto-optical double-potential well

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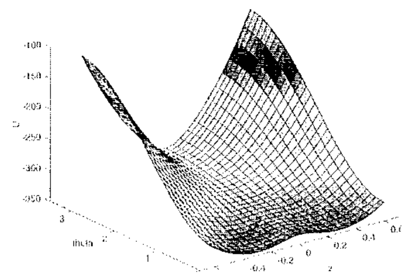
Dynamics associated with a particle in a double-potential well play a key role in numerous areas of pure and applied sciences, and is an important paradigm for quantum coherent evolution. Most fundamental is the decay or oscillation of a meta-stable state via quantum tunneling. We consider the dynamics of laser cooled atoms in a magneto-optical lattice of such double wells.[1] Through a combination of polarization gradients and Zeeman interaction, the potential for a spin 1/2 atom near a given lattice site has the form

$$U(z) = \frac{1}{2} m\omega z^2 + (m\omega\Delta z) z\sigma_z - \left(\gamma \frac{\hbar}{2} B_x\right)\sigma_x$$

where $\sigma_{x,z}$ are the Pauli spin-operators, B_x is the applied transverse magnetic field, and γ is the gyromagnetic ratio. In the absence of B_x, spin up and down atoms see independent harmonic potentials separated by Δz. The coupling field allows Larmor precession between the two internal states, but because the internal and external states are correlated, this is accompanied by motion of the atomic wave packet. For certain conditions, this motion represents tunneling through a classically forbidden barrier. Because the potential energy depends not only the atomic position, but also on the internal state, the potential barrier is not uniquely defined by the total energy.



QThB3 **Fig. 1.** Potential energy as a function of z and θ

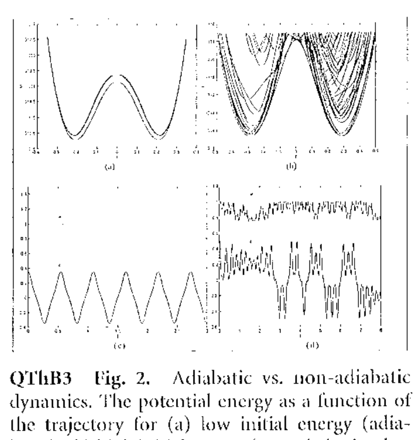
In order to better define the condition for quantum tunneling we consider the classical dynamics associated with our Hamiltonian. Our model thus consists of a magnetic moment moving in a combination of a scalar potential plus a spatially inhomogeneous effective-magnetic field:

$$H = \frac{p^2}{2m} + U_0(z) - \vec{\mu} \cdot \vec{B}_{eff}(z),$$

$$U_0 = \frac{1}{2} m\omega^2 z^2,$$

$$\vec{B}_{eff}(z) = -\left(\frac{2m\omega\Delta z}{\gamma\hbar} z\right)\mathbf{e}_z + B_x\mathbf{e}_x.$$

Connection with the quantum problem is made through the substitution, $\vec{\mu} \rightarrow \gamma\hbar\vec{\sigma}/2$. In general, for non-adiabatic motion, the external motion is coupled to the internal state dynamics producing nonlinear equations of motion. The magnetic moment moves on a potential surface which is a function of position as well as the angle between the directions of the magnetic field and the magnetic moment, θ (Fig. 1). The adiabatic potentials form the edges of this potential surface. For initial energy close



QThB3 **Fig. 2.** Adiabatic vs. non-adiabatic dynamics. The potential energy as a function of the trajectory for (a) low initial energy (adiabatic), (b) high initial energy (non-abalabatic, chaotic). The cosine of the angle between the magnetic moment and the magnetic field direction, w, measures the degree of adiabaticity. The position z as a function of time shows periodic adiabatic motion (c) versus chaotic non-adiabatic motion (d).