Beyond Planck-Einstein quanta: Crossover from frequency driven to amplitude driven excitation in a nonequilibrium many-body system

James Freericks[1], Wen Shen[1], and Tom Devereaux[2]

[1] *Department of Physics, Georgetown University, 37th and O Sts. NW, Washington, USA*

[2] *Stanford Institute for Materials and Energy Science, SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*

In 1901, Planck introduced the idea of light quanta to calculate the spectrum for black body radiation, which was employed by Einstein in 1905 to explain the mysterious quantum properties of the photoelectric effect. Later in the 1950s, Kubo and Greenwood independently derived the linear response of a quantum system to an applied external field, and found that the energy available for excitation was determined by the frequency of the driving field as given by the Planck-Einstein relation. As the magnitude of the driving field is further increased into the nonlinear regime, one expects that there will be a crossover from frequency-driven excitation of the quantum system to amplitude-driven excitation. The first hint of such a quantum effect comes from the solution of the Landau-Zener tunneling problem in the 1930s, where a tunneling excitation is determined by the speed at which the minimal excitation gap is approached, which is proportional to the amplitude of an effective driving field. Here we use the exact quantum solution of a charge-density-wave system driven by an electric field to show generically how such a crossover occurs in solid state systems. We find that the behavior is quite complex due to excitation and de-excitation processes, so that it is no longer true that tunneling is optimized when the field amplitude is the highest. When the field amplitude becomes very large, there is a novel quantum oscillatory behavior in the excitation spectroscopy that appears to describe a new regime for quantum phenomena in strong fields.

This work was supported by the National Science Foundation for the development of the algorithms and by the Department of Energy for the application to the quantum excitation problem. JKF was also supported by the McDevitt bequest at Georgetown University.