Beyond the Tunneling Model: Quantum Phenomena in Ultracold Glasses

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When perfect crystals are cooled to low temperatures their elastic constants will not change noticeably below 1 K as the number of elementary excitations is very small. In contrast, glasses or, more generally, disordered solids exhibit significant changes of their elastic properties even at temperatures in the Millikelvin range. The remarkable temperature dependence is caused by tunneling states — localized low-energy excitations present in virtually all disordered solids. Their microscopic nature is still only vaguely known; in a simplifying picture they can be thought of as particles — atoms or small clusters of atoms — being able to move between two neighboring equilibrium positions in the disordered environment.The theoretical baseline for the description of the elastic and also of the thermal and dielectric properties of glasses was marked by the phenomenological tunneling model. In this model the existence of double well potentials with a broad distribution of their characteristic parameters is assumed, because of the large variety of local configurations in a glass. Moreover, it is supposed that tunneling states can interact with phonons via resonant and relaxation processes whereas a mutual interaction between tunneling states is neglected.

While early measurements of the low temperature properties of glasses indicated good overall agreement with the predictions of the tunneling model more recent studies showed significant deviations below about 100 mK. In particular, we mention the temperature dependence of the elastic and dielectric susceptibility, the decay of coherent echoes, the occurrence of memory effects and the appearance of an unexpected magnetic field dependence. These experimental observations show that our understanding of the low temperature properties of glasses is incomplete. Most likely, the reason for the short coming of the tunneling model at very low temperatures lies in the assumption of non-interacting tunneling systems. We will discuss the experimental evidence for the importance of interaction between tunneling centers in glasses and the related theoretical background.