COUPLED ELECTRON-PHONON EXCITATIONS IN CRYSTALS

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The electron-phonon interaction is of a fundamental importance in solid state physics. It is responsible for such phenomena as classical superconductivity, different kinds of the Jahn-Teller effect, temperature shift and broadening of zero-phonon lines in crystals, crystal-field levels' relaxation, and so on.

If a phonon and an electronic excitation of a crystal are in resonance, interaction between them leads to formation of coupled electron-phonon modes. This phenomenon is typical of a very broad class of stoichiometric *f* and *d* materials and is accompanied by an energy renormalization and redistribution of intensities in the low-frequency part of the spectra. As just this part of the energy spectrum governs thermodynamic and magnetic properties of the compound, it is important to understand physics of coupled electron-phonon modes and of their behavior in external magnetic fields.

In my lecture, I'll briefly review a history of studying coupled electron-phonon excitations in crystals and, then, present the results on investigating coupled electron-phonon modes in the multiferroic praseodymium iron borate.

Terahertz spectroscopy was used to investigate the interaction between the lattice phonons and the electronic excitations associated with 4*f* crystal-field transitions in $PrFe_3(BO_3)_4$ and $SmFe_3(BO_3)_4$ single crystals [1]. A temperature-dependent interference between two types of excitations was observed in $PrFe_3(BO_3)_4$ in which the frequency of 4*f* crystal-field electronic excitation of Pr^{3+} falls into the TO – LO frequency interval of the optical phonon mode near 50 cm^{-1} (1.5 THz). Experimental data were explained on the basis of a theoretical model of coupled electron-phonon modes. The fitting procedure revealed the value 14.8 cm^{-1} for the electron-phonon coupling constant. This rather large value points to an essential role played by the electron-phonon interaction in physics of multiferroics [1].

The coupled modes of $PrFe_3(BO_3)_4$ demonstrate an interesting bifurcation behavior in an external magnetic field [2]. The field behavior of the spectrum of excitations differs qualitatively from the behavior in the absence of electron-phonon coupling. In particular, in the antiferromagnetic phase, a nonzero gap appears in the spectrum of coupled electron-phonon modes in an arbitrarily small external magnetic field. This effect, as well as the behavior of coupled modes in paramagnetic and antiferromagnetic spin-flop phases in magnetic fields up to 30 T, parallel to the *c* axis were successfully explained and modeled using the same theory as in the case of a zero magnetic field and the same set of parameters. In the case of the easy-axis AFM phase, there are two electronic branches and a phonon, the quadratic equation converts into a cubic one and bifurcations corresponding to an abrupt appearance of the third root are observed [2].

It is worth noting that to detect this effect, a unique experiment has been carried out, namely, low-temperature reflection measurements in the far-infrared (terahertz) spectral region and in the Voight geometry (i.e., with radiation incident onto the sample at the direction perpendicular to that of an applied external magnetic field). Strong magnetic fields up to 30T were used.

The measurements were performed in the Institute of Spectroscopy, the Brookhaven National Laboratory (USA), and High Field Magnet Laboratory (Netherlands). The crystals were grown in the Kirenskiy Institute of Physics (Krasnoyarsk). I am grateful to my coauthors of [1,2].

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