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Interaction of Dirac fermions with surface lattice excitations and electron-phonon coupling on topological insulator surfaces

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Surface Dirac fermions are robust against backscattering, but other scattering events can affect their anticipated ballistic behavior. Technical improvements may minimize or eventually eliminate surface defects, but phonons are always present. Consequently, coupling to phonons should be the dominant scattering mechanism for Dirac fermions on these surfaces at finite temperatures. Recent measurements of phonon dispersion curves on the (001) surfaces of several binary and ternary topological insulators were carried out using coherent inelastic helium beam surface scattering techniques. The dispersion curves reveal similar features among these materials: first, the absence of long-wavelength Rayleigh waves. Second, the appearance of a low-lying optical phonon branch with isotropic convex dispersive character in the vicinity of the Γ-point. Lattice dynamics calculations based on the pseudo-charge model show that the optical phonon branch appears with a concave shape when Dirac fermions are absent, but its dispersion changes to a convex shape when Dirac fermions are present. Theoretical analysis attributes this dispersive profile to the renormalization of the surface phonon excitations by the surface Dirac fermions. The contribution of the Dirac fermions to this renormalization is derived in terms of a Coulomb-type perturbation model. Moreover, this optical branch displays a V-shaped minimum at approximately $2\mathbf{k_F}$ that defines a Kohn anomaly. Using a Hilbert transform, we are able to obtain the imaginary part of the phonon self-energy from the real part fitted to the dispersion curve of the surface optical phonon branch. From this imaginary part of the self-energy we obtain a branch-specific electron-phonon coupling constant as a function of wave-vector. The average electron phonon coupling associated with this branch is found to be strong, especially for Bi_2Se_3, reflecting the pronounced renormalization described above.