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Unusual Dielectric Behavior at Low Temperatures: Neutrality Induction and Excited Dipole States in Germanium Detectors for MeV-Scale Dark Matter Detection

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This work explores a fascinating oddity in semiconductor dielectric behavior at very low temperatures, with a particular focus on germanium detectors operating at helium temperatures. The relative capacitance rapidly decreases below 11 K and stabilizes at 6.5 K, which is similar to the fully depleted state that was measured at 77.8 K under ambient circumstances. Interestingly, this neutralization process happens without reference to bias voltage, suggesting that it is an inherent feature. This trend is confirmed by consistent observations, which show that neutrality is induced below 6.5 K. The neutralization of the intrinsic charge of the semiconductor is mostly attributed to excited dipole states. This unusual finding casts doubt on long-held beliefs and offers new information about the physics of semiconductors at extremely low temperatures.
Furthermore, by taking advantage of the low binding energy of these dipole states, this work not only advances theoretical understanding but also presents a novel idea of using germanium detectors at helium temperatures for MeV-scale dark matter detection. A detailed examination clarifies the fundamental processes behind this unique dielectric behavior and the ensuing induction of neutrality. In addition to its theoretical importance, this study opens up new possibilities for the development of low-temperature semiconductor device design and optimization.

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