Evaporation and Field Ionization of Helium for Use in Dark Matter Detection

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Primary physics goals: Demonstrate an energy sensitivity of 1 meV for nuclear recoils using a detection scheme based on quantum evaporation of helium atoms followed by field ionization.

Experimental approach and setup: Less than of 1 meV of energy is required to evaporate a helium atom from superfluid helium or to desorb an atom from certain surfaces. The ability to detect single helium atoms in the gas by field ionization opens up the possibility to search for WIMP scattering from nuclei with comparable recoil energy. A helium atom becomes field-ionized when one of its electrons tunnels into a positively charged metal tip through a field-distorted barrier. The helium ion then accelerates from a high potential, typically several keV, to a cathode which can be a calorimeter, a channeltron, or a microchannel plate. The impact of a single ion is easy to detect.

Summary of existing and future physics results: The application of the well-established technology of field ionization is a new approach to low-mass dark matter detection. Its threshold energy sensitivity of 1 meV is unrivaled for nuclear recoils. Its usefulness in dark matter searches depends primarily on achieving a high quantum efficiency. It is well known that the ionization probability is essentially unity when a helium atom enters the vicinity of a charged metal tip where electric field reaches about 5 V/Å. It is also known that the probability of atomic helium reaching the tip grows with increasing tip voltage due to the polarization forces that draw in the helium; the effective collection area around a single tip can be as wide as a micrometer. Furthermore, the collection efficiency increases significantly with decreasing temperature down to at least 4.2 K, as helium evidently migrates along neighboring surfaces toward the tip. These and other processes must be investigated within the context to detecting individual atoms in vacuum at very low temperature.

Timescale of future plans: Field ionization is an active, developing field of research motivated by a variety of different technical applications and is presently abetted by the advancing technology of nanoscience. Large area arrays of ionization tips of different types are routinely fabricated for a number of purposes. Given the large number of approaches that have the potential of meeting the technical requirements of a field ionizer for dark matter searches, a dedicated research effort extending over several years is required. We would develop a scalable fabrication process, experimentally establish the quantum detection efficiency, and investigate the possibility of dark counts.

Rough budget estimate: Dilution refrigerator ($350k), postdoc for 3 years ($300k), fabrication and consumables ($75k). Estimated $725k budget for 3 years.