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A Solid ^{3}He Polarized Target*

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We discuss the feasibility of brute force polarization of solid ^{3}He by the application of high magnetic field at low temperature. ^{3}He is a few nucleon system which has been previously polarized and studied extensively by the condensed matter community.[1,2] Ignoring exchange effects, the nuclear polarization is $f_1 = \tanh(\mu B/kT)$, where μ is the ^{3}He nuclear magnetic moment. This produces f_1 = 26.5% at 20 millikelvin in a 7 Tesla external magnetic field, and greater than 45% at 10 millikelvin. Solid ^{3}He is thus an attractive candidate for nucleon - neutron spin-spin total cross-section measurements such as are being carried out on aluminum[3] at the Triangle Universities Nuclear Laboratory. It also offers possibilities for polarized neutron capture experiments which could test alternative explanations of the charge symmetry breaking effects observed in the $(\gamma,p)/(\gamma,n)$ cross section ratio for ^{4}He.

An experimental complication of an ^{3}He target is that the solid must be grown from the gas before each experiment, requiring a gas handling system capable of at least 30 bars pressure.[4] The sample must be grown in a container capable of withstanding the pressure and connected through a thin filling tube to the room temperature gas storage. To minimize background corrections the walls of the container should be thin and made from a non-magnetic material, e.g. epoxy or a silver alloy.

The parameters of importance in polarizing a solid by the brute force technique are its specific heat, thermal conductivity, and spin-lattice relaxation time, i.e. the time it takes for the nuclear spins to reach the temperature of the crystal lattice. At the lowest melting pressures the molar volume of the bcc solid is about 24 cm^3/mole.[4] The solid is highly compressible so that a 17 cm^3/mole sample can be grown at about 250 bars. The specific heat includes a phonon term with a Debye temperature of about 20 Kelvin[4] and a nuclear magnetic term:

$$C_{\text{magnetic}} = \lambda B^2/\mu_0 T^2 \sim (5.0 \times 10^{-6}\ \text{J-K/mole-T}^2)\ B^2/T^2$$

where T is the temperature, B is the externally applied magnetic field in Tesla, μ_0 is the permittivity constant and λ is the molar nuclear Curie constant.[5] The thermal conductivity scales as T^3, characteristic of an insulator, and is about 10^{-2} Watts/K-m T^3 at 20 millikelvin.[5] The thermal interface resistance R_K between the solid ^{3}He and the walls of a copper container scales as T^{-3} and $R_K T^3$ is about 0.005 K^4-m^2/Watt at 60 millikelvin.[5] The spin-lattice relaxation time in the low density solid is of the order of minutes[6], allowing a polarized sample to be produced by an overnight cooldown.[2] At higher densities the relaxation time increases to the order of a few days.[7]

Although it has been proposed to use the method of Pomeranchuk cooling for producing polarized solid ^{3}He[8], there are inherent problems in controlling the growth of the solid - liquid interface and the placement of the solid phase in the Pomeranchuk cell.[5] In such a cell the ^{3}He is used as its own refrigerant to reduce the cooldown time but the solid density is limited to its value at the melting curve. We propose to simply use the dilution refrigerator to cool and polarize the ^{3}He at 10 to 20 millikelvin. The solid target will be grown from the liquid in a cylindrical chamber constructed of epoxy, having large surface area sintered silver sponges located at the upper and lower inner surfaces for thermal contact. The cell will be mounted in the bore of our 7 Tesla split coil superconducting magnet and thermally connected to the mixing chamber of the dilution refrigerator through a 30 cm. long copper wire bundle. The growth of the crystal will be monitored by a capacitive pressure gauge[9] and the polarization measured directly by a nuclear magnetic resonance coil, both located away from the reaction volume. The temperature will be determined by nuclear orientation thermometry. In this geometry a nominal size of the polarized target would be about 0.50 moles of solid contained in a 2.54 cm. right circular cylinder. A cell having sintered silver at each end is also suitable for carrying off the heat produced by nuclear reactions in the solid ^3He. At 20 millikelvin the temperature gradient produced by 100 nanowatts of heat deposited by the neutron beam into the center of the solid ^3He would be less than 1 millikelvin. With a flux of about 10^4 neutrons/second, the heat deposited by a 12 MeV neutron beam is in fact much lower, of the order of a few nanowatts.

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