Letters to the Editor

"Brute Force" Polarization of In^{115} Nuclei; Angular Momentum of 1.458-ev Neutron Resonance

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GORTER[1] and Kürti and Simon[2] have suggested the possibility of polarizing nuclei by the direct application of a large external magnetic field to the nuclear spin system at a very low temperature. The magnitude of the polarization f_N has been given by Simon[3] and Rose[4] as

$$f_N = \frac{1}{3}\frac{I+1}{I}\frac{\mu H}{kT} \tag{1}$$

for the case $\mu H \ll kT$, where I is the nuclear spin quantum number, μ is the nuclear magnetic moment, k is the Boltzmann constant, H is the applied magnetic field, and T is the absolute temperature. Even in the most favorable cases, values of $H/T \sim 10^5$ gauss/deg are necessary to obtain polarizations of ~ 1 percent. Thus, to achieve useful polarizations by this method, it is necessary to use the method of adiabatic demagnetization to obtain sufficiently large H/T values. Rose[4] has also pointed out that the absorption of polarized s neutrons by polarized nuclei forms a basis for determining the angular momentum J of levels of the compound nucleus. When the absorption is due to a single level (as near a resonance), the value of J for this level is obtained from the *direction* of the change in absorption cross section with changes in relative spin orientation. The expressions for the neutron cross section σ are

$$\sigma = \sigma_0[1 + f_n f_N I/(I+1)] \quad \text{if} \quad J = I + \tfrac{1}{2}, \tag{2a}$$

and

$$\sigma = \sigma_0(1 - f_n f_N) \quad \text{if} \quad J = I - \tfrac{1}{2}. \tag{2b}$$

Here σ_0 is the cross section in the absence of polarization, and f_n is the neutron polarization. In such an experiment the fractional change in the transmitted neutron intensity, $\Delta C/\bar{C}$, is given by

$$\Delta C/\bar{C} = 2 \tanh(Nt\sigma_0 f_n f_N f_I) \tag{3}$$

for reversal of the relative spin orientations. In (3), $Nt\sigma_0$ is the macroscopic absorption cross section of the sample, and f_I is $I/(I+1)$ if $J = I + \frac{1}{2}$ and unity if $J = I - \frac{1}{2}$. For small polarizations, $\Delta C/\bar{C}$ is proportional to $Nt\sigma_0$ as well as to the product of the two polarizations $f_n f_N$. It is therefore advantageous to make the nuclear sample as thick as possible consistent with intensity requirements.

Experiments have been carried out on the polarization of In^{115} nuclei. Indium was selected because of its large nuclear magnetic moment, and because the thermal neutron cross section is almost entirely due to the 1.458-ev resonance.[5] The metal was used to obtain a short nuclear spin-lattice relaxation time[6] and a high thermal conductivity.[7] The metal, in the form of 20 thin plates $0.025 \times 1.5 \times 3.5$ cm, was thermally connected to a cooling salt some 12 cm away by means of silver wires. Each indium plate was soldered to the upper end of a wire and the coolant salt was crystallized around the lower ends of the wires to provide thermal contact to the salt. This unit was in turn mounted on rigid insulators in a silver cage which was cooled by another demagnetized salt and suspended on nylon strings. Both salt samples were $Fe(NH_4)(SO_4)_2 \cdot 12H_2O$. This assembly was mounted in a cryostat described previously.[8] The design of the sample assembly was based on minimization of eddy current heating and reduction of the possibility of heating due to vibration. The salts were cooled by adiabatic demagnetization from 0.99°K and 16 400 gauss to a final temperature near 0.035°K.[9] The sample assembly was then slowly lowered[8] to place the cooling salts within a magnetic shield and to bring the In plates into the gap of the Weiss magnet in such a manner that the plane of the plates was parallel to the field direction. The magnet was then turned on slowly to 11 150 gauss. These operations were performed slowly to reduce heating; in particular the field was raised very slowly near the In superconducting threshold value.

The source of neutrons was a beam from the ORNL graphite reactor. The nuclear sample was bombarded with polarized thermal neutrons obtained by reflecting this beam from the 220 planes of a magnetized Fe_3O_4 crystal.[10] The energy selected was 0.075 ev in first order, and a subsequent reflection from the 111 planes of a Cu crystal served to reduce the second-order content of the beam to ~ 1.6 percent.

The relative spin orientation of the neutrons and nuclei could be made either parallel or antiparallel as follows: By adding small magnetic fields produced by Helmholtz type coils to the stray fields already present from the Fe_3O_4 magnet and the low-temperature Weiss magnet, (1) a smooth rotation of a relatively strong field (~ 30 gauss) or (2) an abrupt reversal of a weak field was produced.[11] In the first case the neutron spins were polarized 87 percent antiparallel to the nuclear spins, and in the second case the polarization was 79 percent in the parallel direction. The intensity of the beam transmitted by the nuclear sample was measured with a $B^{10}F_3$ counter. With the nuclei polarized as previously discussed, alternate 5 minute counts were taken with the two spin configurations. The counting rate was ~1000 counts/min, the background ~100 counts/min. The transmitted intensity change in percent, corrected for background, between the two relative orientations of neutron and nuclear spins is plotted in Fig. 1 as a function of time. This represents the average of 4 runs which were nearly the same in initial conditions and warmup rate. The consistency of the data taken in these 4 runs is demonstrated by a comparison among the runs of the average transmission change calculated from all data of a given run, disregarding the time variation. These were 5.44±0.6, 5.33±0.7, 5.76 ±0.7, and 5.45±0.7 percent. To prove that the transmission change of Fig. 1 was indeed due to the nuclear polarization, additional experiments were interspersed with the above runs which were duplicates of these in every respect except that the temperature of the indium sample was 4.2°K. In accordance with the above equations the expected change of transmission would then be 0.07 percent. The average change actually observed in all such counts was 0.035±0.52 percent. In addition, it was established that the intensity of the beam incident on the indium was independent of neutron spin direction within 0.3 percent.

At the low temperature, the transmission of the sample was found to be greater when the relative spin orientation was antiparallel. This establishes that the angular momentum of the compound state corresponding to the 1.458-ev resonance in In is $J=I+\frac{1}{2}=5$. This result disagrees with that of Brockhouse.[12] The

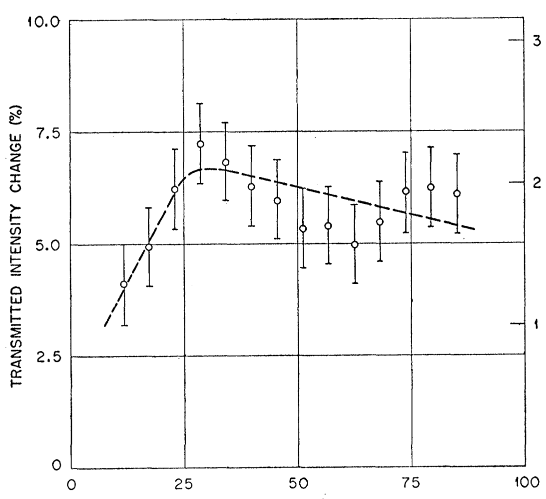

FIG. 1. Observed change in transmitted neutron intensity with reversal of relative spin orientation, corrected for background, as a function of time. Average of four runs; other runs give similar results. Zero of time taken shortly before end of application of nuclear polarizing field. The scale on the right gives the corresponding nuclear polarization.

lowest temperature attained by the indium sample may be calculated from the maximum $\Delta C/\bar{C}$ observed, and was 0.043±0.005°K, corresponding to a nuclear polarization of 2.1 percent.

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Differential *p-p* Scattering Cross Sections at 419 Mev*

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PREVIOUSLY, we published differential cross sections for *p-p* scattering at 419-Mev incident energy as a function of angle.[1] We used a proton beam produced by scattering the cyclotron circulating beam to the right at 14° from an internal beryllium target. The *p-p* cross sections were measured by scattering this proton beam to the left from a liquid hydrogen target, and are designated here as $(d\sigma/d\omega)_L$.

This proton beam was tested for spin polarization with a negative result, but the test method involving inelastic *p-p* scattering was later found inadequate owing to the small polarization of the inelastic scattering itself. Indeed the incident beam was subsequently found to be about 50 percent polarized.[2] In addition, the polarization of hydrogen was measured at 439 Mev,[3] and found to be positive at angles of less than 45° laboratory angle. It follows that at small angles, the reported *p-p* cross sections[1] are somewhat lower than for unpolarized protons and may be corrected for the polarization[2] of hydrogen $P(\theta)$ by use of the relationship

$$\left(\frac{d\sigma}{d\omega}\right)_{\text{unpolarized}}=\left(\frac{d\sigma}{d\omega}\right)_L\Big/[1-0.5P(\theta)].$$

The *p-p* differential cross sections for unpolarized protons of 417-Mev average energy (2-Mev average energy loss in liquid hydrogen) consequently have been evaluated from these data[1] and are given in Table I.