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Low Temperature and Neutron Physics Studies

Final Progress Report for Terminal Period
March 1, 1986 to May 31, 1987
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Department of Physics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

C. G. Shull, Principal Investigator

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Terminal Progress Report for Contract DE-AC02-76ER03342.A017, "Low Temperature and Neutron Physics Studies" in Department of Physics, Massachusetts Institute of Technology, covering Period March 1, 1986 to May 31, 1987.

I. Summary

A search for a novel coupling interaction between the Pendellösung periodicity which is formed in a diffracting crystal and the Larmor precession of neutrons in a magnetic field has been carried out. This interaction is expected to exhibit a resonant behavior when the two spatial periodicities become matched upon scanning the magnetic field being applied to the crystal. Observations on a diffracting, perfect crystal of silicon with neutrons of wavelength 1 Angstrom show the expected resonant action but some discrepancy between the observed magnitude of the resonance effects remains for interpretation.

II. Neutron Spin-Pendellösung Resonance

Most effort was expended by the staff during this period in completing the theoretical and experimental demonstration of the coupling effects that arise between the spatial Pendellösung periodicity and the Larmor precession periodicity occurring when neutrons are passed through a diffracting crystal. The Bragg diffraction process in a perfect crystal arranged in transmission Laue geometry results in a periodic change of neutron momentum direction as passage through the crystal occurs. If the crystal is subjected to an externally applied magnetic field at the same time, the neutron spin will experience Larmor precession about the field direction and theoretical analysis suggests that a resonance phenomena will occur when the two spatial periodicities become matched by experimental control. One type of coupling mechanism between the separate phenomena arises from the already studied spin-orbit phenomena which is sensitive to the local direction of incident momentum and neutron polarization. Other unrecognized types of interaction between neutrons and scattering atoms may also exist which can contribute to this resonant effect. We have performed a concentrated experimental search during the last contract period for (a) the existence of this resonant action and (b) the quantitative accounting for the measured effects by theoretical analysis of the expected spin-orbit mechanism.

A single crystal of pure, perfect silicon (minimal dislocation density) was used in symmetrical transmission Laue geometry diffracting neutrons of wavelength about 1 Angstrom. A homogeneous magnetic field ranging to about 1 Tesla was applied to the crystal by an iron core electromagnet and this developed the Larmor precession whose periodicity could be adjusted according to the field strength. Careful control of the incident neutron beam characteristics (divergence and wavelength spread) were necessary in order to produce a well-developed spatial Pendellösung structure in the crystal. This was first studied by itself without a magnetic field by observations of the Bragg reflection intensity as a function of incident neutron wavelength. With suitable experimental configuration, a well-developed Pendellösung oscillation in the released intensity (high contrast) was realized. Following this, the incident wave-length was then set at selected positions in the Pendellösung pattern and the magnetic field was applied and scanned in small increments around the expected resonance value. Pronounced resonant effects were measured in the Bragg intensity with field scanning which showed up as either resonance peak, resonance minima, or double sided resonance perturbations depending upon the initial Pendellösung structure selection.

The observations have shown without question that the expected resonance effects are present. It should be mentioned that numerous experimental problems were encountered and overcome in these studies. Principal among these were temperature uniformity over the crystal and magnetic field homogeneity both in front of and over the crystal. In order to minimize temperature gradients in the crystal (thickness 0.55524 (8) cm so that 25 Pendellösung periods were developed) the crystal and magnet assembly were contained in a thermally isolated box with feedback temperature control on the electromagnet cooling water. Thus changes in temperature associated with magnet power in the field scanning were compensated by appropriate changes in cooling water from a refrigerator unit. Homogeneity in the field was measured to be within 0.04% over the crystal region. A stabilized current supply for the electromagnet permitted field scanning in steps of 30 gauss at the resonant field value of 6000 gauss. Fine slits of width 0.15 mm were used on the entrance and exit faces of the crystal so as to develop the spatial Pendellösung structure.

Two features of the observed resonance features are of significance in the comparison with the theoretically expected effects: these are (1) the width of the resonant features (peak, minimum, or side perturbations) in magnetic field units and (2) the fractional magnitude of the resonant features. Our analysis to date shows that the measured width effects are in good agreement with that expected but that a discrepancy outside of experiment uncertainty exists in the resonant magnitude. The observations suggest that the strength of the spin-orbit interaction is about 18% larger than that calculated from a first principles evaluation for the case of the electronic charge distribution in silicon atoms as established by x-ray form factor analysis. The existence of possible extraneous experimental effects or possible additional spin-orbit effects is being explored.

III. Research Personnel

Professor C. G. Shull, Principal Investigator

Professor A. Zeilinger, Co-Investigator

Professor M. A. Horne, Co-Investigator

Professor D. M. Greenberger, Co-Investigator

Professor H. J. Bernstein, Co-Investigator

Mr. K. D. Finkelstein, Graduate Student, Research Assistant

IV. Publications during Period

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