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"Low Temperature and Neutron Physics Studies"

Progress Report for Period

October 1, 1971 to August 1, 1972

Department of Physics

Massachusetts Institute of Technology

Cambridge, Massachusetts

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Project Research Activities

(A) Diamagnetic Scattering by Bismuth

We have continued to study the diamagnetic scattering of bismuth all through the past period. A single crystal of very pure bismuth, whose extinction characteristics had been previously explored, has been magnetized in our 60 kilogauss superconducting magnet and the polarization ratio (ratio of Bragg reflected intensity upon neutron polarization inversion) has been determined for five reflections, namely (111), (110), (112), (222) and (220). These have been studied with the crystal held at room temperature and additionally some temperature dependent measurements have been carried out on the (111) reflection. In all cases, the field application direction has been perpendicular to the trigonal axis of the bismuth crystal.

The magnetic field induces a diamagnetic moment at the bismuth atom sites and the resultant coherent magnetic scattering amplitude (proportional to the field strength) is sensed in polarized neutron scattering. In spite of the high field strength, the intensity effects are still very small with the largest change of intensity (for the (111) reflection) being only about 100 parts per hundred thousand. Nevertheless this intensity effect can be measured to a few parts per hundred thousand with our equipment if sufficient counting time is used. The counting interval depends, of course, on the Bragg reflection intensity and on the average it requires about a six week period to collect data to a precision of 8 or 10 parts per hundred thousand for a given reflection.

Data collected to date show a significant directional effect as shown in the following figure.

Additional Bragg reflections are available in the region about $(\sin \theta)/\lambda = 0.280$ and these will be studied. On the figure is shown the effect that is expected for the 78 core electrons, the 5 outer 6s and 6p electrons and the total atom as calculated from diamagnetic theory assuming normal electron mass. These have been calculated from non-relativistic, Hartree-Fock, self consistent field wave functions of Mann. The forward magnetic scattering effect (at $(\sin \theta)/\lambda = 0$) is expected to be 432 parts per 100,000 and the innermost (111) reflection data shows evidence for the tail-end of this anomalous forward form factor.

The interpretation of these anomalous effects, both directional and absolute level, must await the results of further data collection. They imply that the induced atomic diamagnetization is either strongly directional in azimuth angle about the field axis or that a diamagnetic structure is being induced in the crystal with non-equivalent bismuth atom diamagnetization. If the latter turns out to be supported by the experimental results, then there exists a new diamagnetic crystallography analagous to the usually studied ferromagnetic and anti-ferromagnetic crystallography. No hint of this has been available in the extensive diamagnetic literature.

(B) Design and Construction of Sample Low-Temperature Facility in Superconducting Magnet

Our present superconducting magnet has permitted sample temperatures to be controlled at and above liquid nitrogen temperature (78°K) with the magnet coils of course having been held at liquid helium temperature (4.2°K). During the past period we have made laboratory tests on a liquid helium flow system which permits sample temperatures as low as 2.0°K somewhat below the helium lambda transition. Such a system will work satisfactorily but we are currently constructing a different insert version which is simpler and which should permit temperatures to about 1.4°K. This will be installed and tested during the next period once we have completed our room temperature bismuth studies.

(C) Ferromagnetic Domain Topography in Co-Fe Alloy

The magnetization characteristics of face-centered cubic Co-5% Fe are such that a thin sheet with (211) faces is expected to show uniaxial domain magnetization along the $[1\bar{1}1]$ axis. Such a sheet crystal of thickness 12 mils has been prepared and carefully annealed and polished. Polarized light reflection has been used to display the resultant domain band structure. The sheet crystal has been placed on a polarized neutron spectrometer and a very small beam has been used to produce Bragg reflection. A translational scan of the crystal shows very pronounced polarized neutron intensity effects as a domain wall is traversed because of the reversed magnetization relative to the neutron polarization on the two sides of the wall. The domain topography is also being studied by neutron photographic techniques again with an incident polarized neutron beam.

(D) Pendellosung Fringe Structure in Silicon

Final analysis has been completed on our full spectrum neutron fringe patterns for silicon that have been discussed in past reports. These have shown that the propagating neutron wave field in the crystal must be considered as spherically coherent, that the specimen crystals exhibit a weak curvature, and that the fringe study leads to a precision determination of $+0.41491(10) \times 10^{-12}$ cm as the silicon atom scattering amplitude characteristic of the nuclear force interaction.

Laboratory Staff

Professor C. G. Shull, Department of Physics
 Dr. W. M. Shaw, Post-doctoral Research Associate until August 1, 1972
 Professor M. Schlenker, Visiting Scientist from University of Grenoble, Grenoble, France
 Mr. D. Frank, Graduate Research Assistant
 Mr. D. Moncton, Graduate Research Assistant
 Mr. A. Piecka, Undergraduate Thesis Student
 Mr. P. Briggs, Undergraduate Thesis Student

Publications

- (1) "Neutron Diffraction Study of the Kondo Effect in Cu-Fe", C. Stassis and C. G. Shull, Phys. Rev. B₅, 1040-1046 (1972).
- (2) "Spherical Wave Neutron Propagation and Pendellösung Fringe Structure in Silicon", C. G. Shull and J. A. Oberteuffer, Physical Review Letters, September 1972.