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LOW TEMPERATURE AND NEUTRON PHYSICS STUDIES

Progress Report
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"Low Temperature and Neutron Physics Studies"Abstract

Experimental research work with the neutron diffraction spectrometers at the MIT Research Reactor has concentrated during the past year on (a) dynamical diffraction effects in perfect crystals, (b) exploitation of a neutron interferometer system in studying various fundamental physics problems and (c) studies of the Fresnel diffraction patterns produced by simple slit systems. It has been found that neutrons in the process of being diffracted in an extended crystal travel with an anomalous drift velocity smaller than the normal group velocity. Moreover the transmission of these drift neutrons through the crystal has been established as being anomalously high analogously to the anomalous Borrmann transmission of X-rays. A two-crystal interferometer system has been used to search for the existence of a Shimony phase effect that would arise from the presence of additional nonlinear energy terms in the Schrodinger equation. No phase effects were found and an upper limit of $3 \cdot 10^{-13}$ ev has been set for the magnitude of such terms. The interferometer has also been used to search for a possible coupling of the neutron magnetic structure with a vector magnetic potential and again no phase effect was measurable. Preliminary experiments on the effect of interferometer rotation while the neutrons are in transit have shown that the normal effects caused by terrestrial rotation can be modified or suppressed. Additional research has been carried out at Institut Laue-Langevin (Grenoble) in which single (and multiple) slit Fresnel diffraction patterns are being studied in a search for nonlinear optical effects.

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Introduction

During the past contract period ranging from September 1, 1979 to the present, we have continued an active program of research using neutron diffraction facilities available at the MIT Research Reactor. This program has included problems in the area of solid state physics and in areas of neutron dynamical diffraction wherein anomalous transmission effects have been studied with large perfect crystals and in neutron interferometry where fundamental neutron physics aspects have been investigated. Our professional staff during the period has included three graduate thesis students, Mr. Don Atwood, Mr. John Arthur, and Mr. B. Takala, the part time association of Professor M.A. Horne (Stonehill College) and Professor D.M. Greenberger (City College of New York) as well as the principal investigator Professor C.G. Shull (MIT). Professor Shull has been on sabbatical leave during the period January to June, 1980 and he has, with two return consultation visits to MIT, been occupied with research investigations at Hahn-Meitner Institut in West Berlin, Germany and at Institut Laue-Langevin in Grenoble, France.

Project Research Activities

(A) Diamagnetic Scattering of Neutrons by Bismuth

Experimental activity on this research problem had been completed in the last period and further data analysis and preparation of the findings for publication has continued during the present period. The experiment had included polarized beam scattering from single crystals in a high magnetic field environment with establishment of the diamagnetic component in the Bragg reflections about three orthogonal crystallographic axes. With Fourier transformation of the data, we obtained diamagnetization maps portraying the atomic and lattice electron response to the applied field and these maps display very interesting inter-atom magnetization distribution. This problem represented the doctoral thesis activity of Dr. Stephen Collins (now at Raytheon Co.) and the results will be shortly in publication.

(B) Anomalous Flight Time of Neutrons in Diffracting Crystals (co-sponsored with National Science Foundation)

Our last progress report has discussed the results of neutron flight time measurements through a large (20 cm) diffracting crystal of silicon. These studies show the existence of an anomalous *drift velocity* of the diffraction neutrons along the lattice planes of the crystal which is related to the normal group velocity through the cosine of the Bragg angle. Accordingly the transit time through the crystal can be made in principle as long as wanted and this may serve as a novel technique for storing neutrons for exploitation in fundamental physics applications. Further analysis of the experimental data has been carried out during the present period which show that the anomalous drift neutrons are also transmitted through the crystal with an *anomalously low absorption coefficient*. This is analogous to the anomalous Borrmann transmission

of X-rays through diffracting crystals and it arises because nodal positions of the travelling neutron wave are located at atom (or nuclear) sites. Thus the normal nuclear absorptive process is not effective and the crystal becomes very transparent to the neutron radiation. In one particular configuration that was studied the effective path length of the neutrons was equivalent to that in passage through a crystal nearly 2 meters long and yet only minimal absorption was indicated. The results of these studies have been submitted for publication in Physical Review Letters and should appear shortly.

(C) Search for a Non-Linear Variant of the Schrödinger Equation by Neutron Interferometry (co-sponsored with National Science Foundation)

It has been pointed out by Shimony (Phys. Rev. A20, 394 (1979)) that the presence of additional non-linear terms in the Schrödinger equation describing the propagation of a neutron in free space would imply phase effects which could be studied in a neutron interferometer system. During the past period we had completed the reconstruction of our neutron interferometer system and after studying its performance we decided to search for the possible existence of the Shimony phase effects.

In the Schrödinger wave packet description of a moving particle, one is faced with the feature that the packet expands in space and time. To avoid this unphysical characteristic, quantum theorists have postulated the existence of additional non-linear terms in the Schrödinger equation which would stabilize the packet against expansion, somewhat in analogy to soliton solutions in solid state physics. From the known successes of linear quantum mechanics in describing physical phenomena, a useful upper limit to the magnitude of possible non-linear energy terms of $4 \cdot 10^{-10}$ ev can be set. In the above reference, Shimony has shown that a neutron interferometer experiment with use of attenuating plates is capable of sensing lower levels of these terms. The existence of such terms, as Shimony has pointed out, would imply that a mere repositioning of an attenuating plate from upstream to downstream in a neutron beam, would result in a phase change, and this could be sensed after recombining two coherent beams in an interferometer.

We have searched for this phase change in our two-crystal interferometer system in two experiments using both LiF and Cd attenuating plates. The experiment was performed with two matched plates of either material, one upstream in beam A and the other downstream in beam B, and intensity change on the steep side of a fringe was looked for upon inversion of the configuration. The use of two plates serves to double the sensitivity of the experiment. The combined result of the experiments showed the Shimony phase effect to be $-0.07(\pm 0.20)$ degrees or the equivalent of a interference fringe shift less than $1/1800$ of a fringe. This can be interpreted in terms of an upper limit on the magnitude of non-linear energy terms corresponding to $3 \cdot 10^{-13}$ ev. Thus the experiment has shown no measurable effect but a new upper limit, three orders of magnitude below that previously known, has been set for the existence of non-linear energy terms in the Schrödinger equation. A description of the experiment has been recently published.

(D) Single and Double Slit Diffraction of Neutrons

During Professor Shull's sabbatical leave period at Hahn-Meitner Institut in West Berlin, he and Dr. W. Treimer have been preparing to perform a careful study of single and double slit diffraction of neutrons. The interest in such patterns arises from the question as to whether there is evidence that a non-linear form of optics is called for in accounting for the experimental patterns. In this respect, the objective is similar to that discussed in section (C) in that the existence of non-linear terms in the Hamiltonian would imply the existence of Shimony phase effects in the production of the diffraction pattern from this simple configuration. The interferometer experiment described in (C) and the slit pattern experiment differ in that the former looks for phase change upon longitudinal change of the wave function (before and after an attenuating plate) whereas the latter explores phase changes resulting from the transverse variation of the wave function. It can be shown that non-linear terms would modify the *intensity gradients* in the diffraction patterns and this would be observable in the measured half-widths of diffraction peaks.

The experiments planned at Berlin have been delayed because of reactor operational changes and in the meantime the prospect of performing similar experimentation at Institut Laue-Langevin in Grenoble arose. Accordingly Professor Shull has spent most of the last month at Laue-Langevin collaborating with Dr. R. Gähler on experiments of this type.

The ILL experiments utilize a low energy neutron beam from a cold-source guide tube, beam port D18. A monochromatic beam of long wavelength neutrons, typically 20 Å, is prepared by prism refraction, and this beam is passed through a fine entrance slit of width 20 µm. The test slit system is placed 5 m beyond the entrance slit and the Fresnel diffraction pattern produced by the test slit is scanned with an observing slit (also very fine 20 µm) at a distance of 5 m beyond the test slit. This optical assembly is unique among reactor facilities anywhere and the combination of long wavelength radiation and long path length offer more sensitivity to the detection of non-linear terms than the interferometer technique with its shorter wavelength and path length. These experiments are being actively pursued at the time of writing.

(E) Terrestrial Rotation Effects on Intrinsic Phase Gradient in a Neutron Interferometer

It has been clearly demonstrated in neutron interferometer experiments at Missouri by Werner and colleagues that the earth's rotation produces an intrinsic phase effect in a normal 3-crystal interferometer system. We have observed in our 2-crystal interferometer a sizeable intrinsic phase gradient which is however larger in magnitude and of reversed sign from that calculated on the basis of terrestrial rotation. In attempting to explain this observation, we have been led to suspect that enhanced effects may be present in the relatively thick crystals of our interferometer system as compared to the normal thin 3-crystal system. Theoretical analysis, although incomplete, has indeed suggested this possibility and we have started an experimental program directed to clarification of the concept.

Our interferometer system is of such design that we can provide controlled rotational motion of the interferometer while the neutron beam is in transit. Thus we have the possibility of suppressing terrestrial rotation or reversing or modifying the effects in a controlled manner. Preliminary experiments have indeed shown that this can be done and we are actively engaged in quantifying the effects.

(F) Search for Neutron-Magnetic Vector Potential Coupling

. It has been suggested by one of our group (Greenberger) that it would be useful to explore the possibility of a coupling of the neutron dipole moment with the magnetic vector potential with a neutron interferometer system. This would represent a zero-charge analog to the famed Bohm-Aharonov effect in which the electronic charge is found to couple with the magnetic vector potential to produce a phase effect in electron interferometric systems.

Since the technique and equipment for observing such an effect is similar to that used in searching for the Shimony phase effect of Section (C), it was decided to perform such an experiment. For this purpose a small picture-frame crystal of Fe was obtained from Professor M. Schlenker (Grenoble) and this was activated magnetically with a small coil so that circulating magnetic flux flowed continuously through the iron loop with no leakage outside the loop. The loop was then placed in the interferometer with one of the coherent beams passing through the open central section of the loop where no magnetic field existed. This was then shuttled from left coherent beam to right coherent beam and phase changes were searched for. After a period of data collection, the phase effect was established as $-0.56(\pm 0.67)$ degrees. Thus no effect was measurable with the circulating magnetic flux of 175 gauss-cm^2 available in the magnetic loop.

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Laboratory Publications

"Search for a Nonlinear Variant of the Schrödinger Equation by Neutron
Interferometry"
C.G. Shull, D.K. Atwood, J. Arthur, and M.A. Horne
Phys. Rev. Letters 44, 765 (1980)

"Anomalous Flight Time of Neutrons through Diffracting Crystals"
C.G. Shull, A. Zeilinger, G.L. Squires, M.A. Horne, D.K. Atwood,
and J. Arthur
Phys. Rev. Letters, June (1980)

"Study of Diamagnetic Structure of Bismuth by Polarized Neutron Diffraction"
S. Collins, C.G. Shull, and R.M. Moon
(to be submitted)

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