The opening of the symposium. From left to right: The Honourable Gordon Churchill, Bronislaw Buras (IAEA), and J. L. Gray and W. B. Lewis (Atomic Energy of Canada, Ltd.).

INELASTIC SCATTERING of NEUTRONS in SOLIDS and LIQUIDS

By H. Palevsky

THE IAEA-UNESCO Symposium on Inelastic Scattering of Neutrons in Solids and Liquids held September 10–14, 1962, at Chalk River, Ont., was the third international symposium since 1957 in this rapidly developing field. At the first meeting held in September 1957 in Stockholm, 11 papers from 6 countries were presented, whereas at the meeting just concluded, the program was limited to 65 papers from 13 countries. This growth reflects both the greater recognition by the physics community of this powerful experimental technique and the greater availability of nuclear machines to provide the neutron sources needed for measurements.

It is perhaps appropriate to explain briefly why there is so much interest in this new measuring tool. In the past, the most widely used probe for investigating the structure of solids was the x-ray photon. When x rays are incident on condensed matter they are scattered elastically with momentum transfers characteristic of the spacings of the atoms in the sample. The practical requirement that the scattering angles be large enough to allow accurate measurements is met by using x rays of wave length comparable to the spacings of the atoms (Bragg's scattering law). For the same reason, neutrons having de Broglie wave length of 1–10 Å units are used for solid- and liquid-state measurements. However, neutrons and x rays of the same wave length have many different physical properties. In particular, it is the property of the neutron's sizeable mass that underlies the novel measurements in this field. When the neutron is scattered by a sample of condensed matter, it changes energy in amounts comparable to its initial energy, as well as changing its momentum. These energy changes are characteristic of the motions of atoms or molecules in matter. Thus, for example, in the case of solid samples, the energy and momentum changes of the scattered neutrons are characteristic of the normal modes of vibration, and one has a very simple and direct means for measuring the phonon energy as a function of its wave vector.

The neutron couples to the interatomic motions through its nuclear interaction. Because the extension of the nucleus is about 10^4 times smaller than the neutron wave length, the nucleus can be considered as a point scatterer. The interaction is therefore particularly simple (characterized by an isotropic scattering amplitude), with the result that the neutron can "see" all the microscopic atomic motions and is not restricted by selection rules. One further characteristic of the neutron, which makes it a unique probe, is its magnetic moment. Through the interaction of the neutron moment with unpaired electrons in para- and ferroelectric materials, neutron measurements yield direct information concerning magnetic properties of materials. In particular, the inelastic measurements yield very direct information about dynamical magnetic properties such as spin waves.

In the peaceful, late-summer atmosphere of Chalk

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River, some 60 active workers in this field gathered to present 65 communications of their recent efforts using this neutron technique. The conference was welcomed to Canada by the Honorable Gordon Churchill, chairman of the Committee of the Privy Council of Canada on Scientific and Industrial Research, who greeted the participants in the name of the government of Canada and the Prime Minister. Bronislaw Buras of the IAEA opened the symposium and expressed warm appreciation to the government of Canada and Atomic Energy of Canada Limited for their generous invitation to hold this meeting in their country. The meeting consisted of seven half-day sessions covering the broad topics of experimental techniques, solids, liquids and molecules, magnetic scattering, and general problems. The chairman of the opening session was our host, W. B. Lewis, director of the Chalk River Laboratory.

To get the participants, who were for the most part experimenters, into a proper frame of mind, the IAEA scientific secretaries for the meeting, B. Buras of Poland and A. W. McReynolds of the United States, scheduled as the first speaker of the opening session J. J. J. Kokkedee of the Netherlands. He presented a field-theoretical paper on the influence of phonon-phonon and electron-phonon interactions on the one-phonon peaks observed in neutron scattering from solids. H. Hahn, of the Federal Republic of Germany, spoke on the same subject from a perturbation theory point of view. Line broadening and line shifts are observed experimentally only near the melting points of aluminum (measured by Larsson) and lead (Brockhouse), because of the present low resolution of the experimental apparatus. Therefore, the calculations presented, based on rather simple models, do not give very good agreement with experiment. However, with the early advent of a new generation of high-flux reactors, such problems will be amenable to detailed experimental investigations, and the development of a proper theoretical framework is of great importance.

The most interesting paper in the session on experimental techniques was the one contributed from the USSR. J. Janik of Poland, who is collaborating with Professor Shapiro's group at the Joint Institute for Nuclear Research at Dubna, discussed the use of the pulsed reactor for cold-neutron research. This machine gives a burst of unmoderated neutrons of ~ 30 μsec duration, with a peak intensity of $\sim 2 \times 10^{17}$ neutrons/sec. The neutrons are moderated to boost the low-energy end of the spectrum, with the result that the burst is lengthened to about 100 μsec. The maximum repetition rate, limited by the generation of heat, is 8.3 pulses per second. Flight paths of 10 and 45 meters are utilized and the longer path gives a resolution of $\sim 0.5\%$ in energy at 5×10^{-3} eV. This resolution is about a factor of five better than equipment designed for the same measurements in the West. The apparatus has been used to obtain accurate measurements of the short-time diffusive motions of molecules in H_2O. However, there remain some problems with the high background rate in the thermal region, which, at present, somewhat limit the general usefulness of the instrument.

Whereas the earlier meetings in the field were mostly concerned with experimental equipment and general methods of data analysis, this meeting was mainly concerned with the results of the application of the low-energy neutron scattering technique to a variety of problems concerned with different aspects of the nature of solids and liquids. A most interesting piece of work was carried out by Mozer and Otnes of Brookhaven, who presented data on a localized mode of vibration generated by small concentrations of nickel in palladium. In a related field, Tchernoplekov, Zemlyanov, Brovman and Tchetserin of the Kurchatov Institute studied the frequency spectrum of a disordered Ti-Zr alloy.

Cochran and Cowley of the Cavendish Laboratory presented some very beautiful data on the temperature dependence of the lowest energy transverse optical mode in strontium titanate. The reststrahlen frequency for this mode can be correlated with the temperature dependence of the static dielectric constant.

Jacrot presented some interesting results of work done by the Saclay group, which would indicate that spin waves exist in iron some 30° below the Curie point.

K. Mikke from Poland and P. K. Iyengar from India presented similar measurements on the ammonium halides. Changes in line width and energy of the torsional oscillations of the NH_4 ion were measured above and below the order-disorder transition.

W. Kley of Ispra reported on some very recent work done by his group at the Euratom Laboratory, where they have observed the effect of the electrons on the frequency spectrum of the phonons (Kohn effect) in vanadium.

The papers quoted above were chosen to illustrate the broad fields of investigation now underway with the cold-neutron technique. There were also a number of papers presented on the study of the microscopic motions of molecules in liquids, and phonon and spin-wave spectrum in solids. These were continuations of the types of studies presented at the meeting two years ago in Vienna.

Any report of this meeting would be incomplete without some comment concerning the superb organizational work carried out by the AECL and IAEA staff. As is typical of such meetings, there were receptions in the evenings. Also planned were numerous tours of the Atomic Energy Installations and a trip on the Ottawa river one afternoon. That these functions came off smoothly and were obviously enjoyed by all participants is not accidental. The diligent planning and staff work was clear to those present who had any experience in the administration of a large meeting.

I presume to speak for all the delegates in this expression of appreciation to the International Atomic Energy Agency for having assumed the responsibility for the continuing sponsorship of international meetings in this field.