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Book Reviews

Inelastic Scattering of Neutrons in Solids and Liquids. Proc. Symposium, Chalk River, 10-14 September, 1962. International Atomic Energy Agency, Vienna, (1963). Vol. I, 469 pages, paper bound, $9.00. Vol. II, 341 pages, paper bound, $7.00.

The papers in these Proceedings have been arranged into five groups: "Liquids and Molecules," "Solids," "Experimental Technique," "Magnetic Scattering" and "General Problems." The first four titles are self-explanatory; the substances studied range from gaseous methane to liquid tin, from potassium dihydrogen phosphate to nickel-palladium alloys, and include such exotic fauna as *n*-amyl alcohol, and Dowtherm-A. Several of the 'techniques' papers deal with the production and filtering of cold neutrons, while the collection called "General Problems" is a potpourri of theoretical papers. Two of these (Kokkeedee and Hahn) consider the very complicated mathematics that describes the influence of phonon-phonon (i.e. anharmonic) and electron-phonon interactions upon neutron scattering. Another discusses Debye-Waller factors (Barron, *et al.*), and another, dielectric constants (Cochran and Cowley). Then, there is a pleasant (and unexpected!) discussion of the Mössbauer effect (Singwi) and, finally, a discussion of the analysis of scattering data into self and interference terms (Egelstaff) which brings us to the heart of the matter.

Though knowledge of the inelastic scattering is important in the design of thermal reactors, the designer need not concern himself with the fine details of the scattering law. His computer codes require only certain moments of the differential inelastic cross sections, and these may be obtained with sufficient accuracy from mathematical 'models' which might be considered naïve by the solid-state physicist. Since direct integration of the scattering data is not yet practical, the 'model' approach must prevail.

The key word in the model-analysis of the scattering law is 'Gaussian.' The self-correlation function introduced by Van Hove, is assumed to be Gaussian in its dependence upon r^2. The width function, which characterizes a particular system, is described by a spectral function, $p(\beta)$, that has a fairly direct physical interpretation. In an harmonic solid, $p(\beta)$ is proportional to the distribution function for lattice vibrations; more generally it is the spectral function for the velocity autocorrelation function for a typical atom in the medium. Then, $p(0)$ is proportional to the self-diffusion coefficient.

The Gaussian approximation, combined with the incoherent approximation, which connects *all* of the scattering with the self-correlation function, should satisfy the needs of the reactor physicist. (We have come a long way from the heavy gas model!). A technique for extracting $p(\beta)$ from the scattering data has been devised by the Harwell group (Egelstaff and Schofield). In these Proceedings, it is applied to light and heavy water, liquid bromine, glycerol, ammonia, polyethylene, graphite, beryllium, beryllium oxide, . . . and more. As the transcript of the discussion shows, the $p(\beta)$ analysis is by no means easy, since the experimental data contain coherent and non-Gaussian components that are unknown a priori and are eliminated through inspired iteration. In fact, recent calculations of $p(\beta)$ for beryllium and graphite, based upon the solution of the equations of motion, do not agree closely with the experimental $p(\beta)$. One should note, too, that not all of the experiments were analyzed in terms of Gaussian correlations. The Chalk River group (Brockhouse, *et al.*) presented its data through 'pictures' of the scattering law itself. In the case of scattering by water, Fourier transform methods produced curves of the self-correlation function and of the mean square distance of travel of a proton, as a function of time.

From the point of view of the solid-state physicist, the spectral function presents only part of the picture of crystal dynamics. The dispersion relations for phonons, which may be extracted from the coherent scattering, yield considerably more information. From them, one infers the nature of the binding forces and parameters for fitting particular potentials. (One can then regain $p(\beta)$ by solving the equations of motion!) Most of the session on "Solids" was devoted to the discussion of dispersion relations for common materials (aluminum, magnesium, copper, graphite, . . .). Here, as throughout the book, the number of ex-

perimental papers greatly exceeds the number of theoretical papers.

We have limited ourselves, in this review, to the aspect of the conference that should be most important to readers of *Nuclear Science and Engineering*. Much has been omitted. The reader will find discussions of the (small!) modification of resonance-capture cross sections by chemical binding effects, of precise calculations of scattering by molecular gases and of several magnetic effects. The Proceedings contain 67 papers (for $16.00, paper-bound), which may be compared with the eleven papers presented at the first meeting of this type in Stockholm, 1957. A fourth conference will have taken place in Bombay before this review is published. It will be most interesting to chart the rate at which this young subject continues to grow.

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Introduction to Neutron Distribution Theory. By L. C. Woods. Methuen and Company, Ltd., London, (1964). 132 pp. $5.50.

Neutron distributions are usually described only in terms of the neutron-phase space density that satisfies the linear Boltzmann equation (the transport equation); and it is in this conventional sense that this monograph presents an introduction to neutron-distribution theory. It is in fact, an introduction to steady-state neutron-transport theory with emphasis on the transport equation itself and on the deduction of several approximating equations to be used in the treatment of special problems. As such, it provides a useful and concise summary of much of the material presented in Davisson's *Neutron Transport Theory*.

In this reviewer's opinion the breadth of coverage and the attention to physical principles achieved in approximately 130 pages is truly remarkable. Furthermore, though the exposition is terse, it is lucid and largely self-contained. It should be comprehensible to anyone with the motivation, adequate mathematical background, and some appreciation of classical physics. Matters pertaining to nuclear dynamics are barely mentioned explicitly, but sufficient attention is devoted to the meaning and analytical representations of cross-sections and the scattering and fission frequencies to provide considerable insight into the problems of neutron moderation, thermalization and space-energy diffusion.

The book is divided into three chapters of roughly equal length. The first, entitled "Basic Equations," is primarily concerned with the development and discussion of the integro-differential and integral equations of neutron-transport theory. A derivation of the equations for the zeroth- and first-harmonic (velocity angular) moments of the phase space density is then sketched and the P_1 approximation introduced. A concept of the slowing-down density is described and the way in which it enters into the equation for the zeroth-harmonic moment is indicated. (Considering the generality of most of the presentation in this book, it was mildly disappointing that the author chose to restrict the notion of the slowing-down density to that of downward flow in energy only, instead of employing the slightly more useful and distinctly more general notion of net downward flow.) The equations of the P_N approximation are deduced and boundary conditions appropriate to the phase space density and its various harmonic moments are discussed.

Chapters two and three present a sampling of special applications of these equations rather carefully chosen to illustrate either fairly general ideas or widely used and/or generalizable mathematical techniques. To a certain extent, chapter two deals mainly with the former and chapter three with the latter. The second chapter is devoted to a discussion of neutron moderation in homogeneous, infinite and finite systems. Consequently many of the fundamental concepts important to reactor theory are brought out and clarified. The equations for the zeroth- and first-harmonic moments (the consistent-P_1 equations) are used here. Approximations are introduced when needed to keep the analytical treatment going—usually without much comment but with considerable operational precision.

Finally, in chapter three, some of the mathematical techniques of reactor analysis are summarized under the heading of "Multi-Group Theory." Considering the diversity and subtlety of the mathematical methods that have been brought to bear on the problem of calculating neutron densities in special instances, it is not unexpected that this chapter is the least coherent and self-contained of the three. Nevertheless a large amount of information about mathematical technique is described—interesting in itself to the casual reader and useful as an introductory survey