which approaches a constant value d_0 for large values of n. For $p=0.8413=1-0.1587$ (Table I) they approach the normal limits computed from the standard deviation. The asymptotic values d_0 can be computed explicitly; for the lower limit one obtains $d_0=(x_p^2-1)/3$ and for the upper limit $d_0=(x_p^2+2)/3$, where x_p depends on the choice of p and is defined by the appropriate expression for the gaussian normal limits $n\pm x_p\sqrt{n}$.

The author is indebted to Roy Thomas for valuable discussions.

[1] R. A. Fisher, Proc. Cambridge Phil. Soc. **26**, 528 (1930).
[2] If a constant *a priori* distribution were accepted as legitimate, it would discredit the established custom of quoting, for the most likely average number of counts, the observed number n which is located where the probability density function $W_n(a)$ has its maximum. Instead, the median or the average value of $W_n(a)$ should be used (Fisher, reference 1); the most likely value for a would then have to be given as approximately $n+2/3$ if the median were chosen (2/3 is exact for large values of n), or as $n+1$ if the average were chosen. However, the argument should be confined to the statement that the probability for the occurrence of just n counts is highest for that average count which is numerically equal to n; this supports the customary method for choosing the most likely value of a.
[3] R. A. Fisher, Econometrica **3**, 353 (1935).
[4] It can be seen that this means, in the case of the upper limit, a return to the integration over $W_n(a)$ which was rejected above when it was to have seved the original purpose of evaluating conventional precision limits. On the other hand, the evaluation of the lower limit now consists of an integration over $W_{n-1}(a)$.
[5] K. Pearson, *Tables of the Incomplete Gamma-Function* (Cambridge University Press, London, 1934).

Resonance in the Neutron Cross Section of Lithium*

P. H. Stelson and W. M. Preston
Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received August 6, 1951)

THE total neutron cross section of lithium from 20 to 1400 kev has been measured by Adair using a neutron energy spread of about 20 kev.[1] A large resonance was found at 270 kev, which was interpreted as an excited state in Li^8 with total angular momentum $J=2$, formed by $l=1$ neutrons. In connection with measurements of the total cross section of nitrogen, using the compound LiN_3, we have recently remeasured the total cross section of lithium. We find a higher value for the maximum cross section of this resonance, which agrees well with a $J=3$ assignment.

The total cross section of lithium was measured using neutrons produced by the Li(p, n) reaction, which are monoenergetic in this energy range. The first run was made with 10-kev resolution using a metallic lithium scatterer, one inch in diameter and 0.472×10^{24} nuclei/cm^2 thick, encased in a thin-walled (5 mil) steel cylinder. The scatterer was placed a mean distance of 12 cm from the target in the forward direction and the detector, a one-inch diameter, propane gas counter was placed a mean distance of 28 cm from the target. The data are shown in Fig. 1 as circles. The second run, indicated by the solid dots, was done with 5-kev resolution under the same geometrical conditions but with a scatterer of 0.118×10^{24} nuclei/cm^2 thickness. Corrections for target thickness were applied to the neutron energies. The incident proton energies are based on the $Li^6(p, n)$ threshold calibration point of 1.882 Mev. A scattering-in correction was applied which increased the cross-section values by 2 percent in the case of the long scatterer and was negligible for the short scatterer. The resulting data are shown in Fig. 1.

Since the first excited state of the Li^7 nucleus is 479 kev above the ground state, one can assume that elastic scattering is the only process contributing to the cross section. The neutron energies are low enough so that only $l=0$ neutrons will contribute to the potential scattering, and, in fact, the value given by theory using the nuclear radius $R=1.5A^{\frac{1}{3}}\times10^{-13}$ cm agrees well with the value indicated by experiment. Since a dip due to interference is not observed near the resonance, one deduces that the resonance is not excited by $l=0$ neutrons. Therefore the cross section in the neighborhood of the resonance is given by:

$$\sigma_{n,n}=\pi\lambda^2(2l+1)G_{Jl}\frac{\Gamma_n^2}{(E-E_r)^2+\Gamma_n^2/4}+\sigma_{\text{potential}}, \qquad (1)$$

using the conventional notation.[2] The maximum cross-section value of the resonance depends on the magnitude and orientation of the angular momentum vectors s, l, and $\mathbf{I}$. For a given configuration of the vectors s, $\mathbf{I}$, and l to form the compound state of angular momentum J, the statistical weight factor is

$$(2J+1)/[(2I+1)(2l+1)(2s+1)]. \qquad (2)$$

There are cases where two different configurations of the vectors s, I, and l can form the same resultant J vector. One then has to decide whether the correct value is given by expression (2) or by twice that value, i.e., whether the states are degenerate. The question of the proper statistical weight factor or the strength of the spin-orbit coupling makes the large resonance in lithium especially interesting.

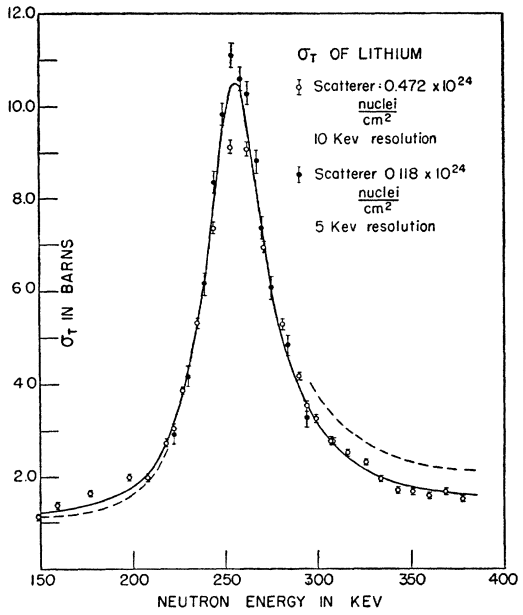

FIG. 1. The total cross section of lithium. The solid curve is calculated from theory for a $J=3$, $l=1$ assignment. The dashed curve is calculated for a $J=3$, $l=2$ assignment. Neutron energies are corrected for target thickness.

Adair pointed out that the resonance probably has too large a width to be attributed to $l=2$ neutrons. In addition we find that the shape (asymmetry) of the resonance does not fit an $l=2$ assignment (see below). Therefore, taking the resonance as excited by $l=1$ neutrons, the possible values of J are 0, 1, 2, or 3 since $s=\frac{1}{2}$ and $I=\frac{3}{2}$. Using the statistical weight factor (2) the $\sigma_{\max}-\sigma_{\text{potential}}$ values for these different J values are calculated as 1.3, 4.0, 6.7, and 9.4 barns, respectively, where $(E_r)_{\text{lab}}$ is taken as 256 kev and a correction is applied for the 92.5 percent Li^7 isotopic abundance. The states with $J=1$ or 2 can be formed by two different relative orientations of the vectors s, l, and I and if these are degenerate the $\sigma_{\max}-\sigma_{\text{potential}}$ values are 8.0 and 13.4 barns. From Adair's curve one obtains the value of 6.8 barns, which would indicate $J=2$ and no degeneracy. However, considering the resolution employed, one would expect the true value to be somewhat larger, thus perhaps supporting the assignment $J=1$ and degeneracy.

The best curve drawn through our experimental points taken with the 5-kev resolution gives a value for $\sigma_{\max}-\sigma_{\text{potential}}$ of 10.0 barns, which agrees reasonably well with the calculated value of 9.4 barns for $J=3$. Unfortunately, this compound state is formed

by only one configuration of the vectors s, l, and I and therefore cannot yield information on the strength of spin-orbit coupling. The solid curve drawn in Fig. 1 is calculated from formula (1) taking $\sigma_{\text{potential}}=1.1$ barns, $(E_r)_{\text{lab}}=256$ kev, $J=3$, $l=1$, and $(\Gamma_n)_{\text{lab}}=40$ kev. In computing the curve, the variation of λ and Γ_n with energy was taken into account. It is seen that the asymmetry of the resonance is nicely accounted for by the variation with energy of these two quantities. The dashed curve shows the behavior of the calculated curve away from resonance (fitted at resonance) for the assignment $J=3$ but $l=2$.

An almost coincident resonance ($E_n=270$ kev) has been reported for the $Li^6(n, \alpha)$ reaction.[3] If, by chance, there were a large coincident resonance in the σ_T of Li^6, calculations indicate that its maximum value could not exceed $\sim$10 barns. When multiplied by the relative abundance of Li^6 (7.5 percent) it would contribute, at most, 0.75 barn to the σ_T of lithium at the peak of the resonance. The presence of such a resonance would, therefore, tend to improve the agreement of the calculated and experimental curves.

* This work was jointly supported by the ONR and the Bureau of Ships.
[1] R. K. Adair, Phys. Rev. **79**, 1018 (1950).
[2] R. K. Adair, Revs. Modern Phys. **22**, 249 (1950).
[3] J. M. Blair *et al.*, quoted by Goldsmith *et al.*, Revs. Modern Phys. **19**, 259 (1947).

On the Nature of the Superconducting State*

LASZLO TISZA
Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received August 6, 1951)

IN a recent paper[1] the author advanced the view that the discussion of superconductivity requires the use of many-electron wave functions. The superconducting transition was considered to be somewhat similar to an order-disorder transformation, with a characteristic difference. Instead of being frozen in a definite position in the crystal, the superlattice describing the ordered state is supposed to resonate, say, among ω-positions equivalent under the translation group of the crystal. An external electric or magnetic field would induce a supercurrent provided $\omega \geqq 3$. The case $\omega=2$ corresponds to an insulating state.

The superlattice itself was attributed to the electronic distribution alone; in other words the vibrations of the ions around the ideal lattice positions were ignored. However, recent experimental[2] and theoretical work[3] has provided convincing evidence that the interaction of the electrons with the lattice vibrations constitutes an essential aspect of superconductivity. Therefore, the study of the many-electron eigenfunctions has been reopened from a more systematic point of view. A detailed paper is now completed for publication, the results of which may be summed up as follows.

Fundamentally a crystal is a collection of electrons and nuclei. The usual separation of the electronic and vibrational wave functions is based on the adiabatic approximation.[4] One solves the electronic eigenvalue problem for fixed nuclear positions, and the electronic energy provides the potential for the nuclear vibrations. The validity of this method depends on the assumption that the electronic level is nondegenerate and its separation from the next one is large compared to the spacing of the nuclear states. This condition is not satisfied for the case of metals; hence a rigorous quantitative theory will have to overcome unusual difficulties.

We have applied symmetry considerations to obtain a qualitative insight into the possible coupling cases. The usual method of considering the metal as a mixture of an electron gas and a phonon gas appears only as one limiting case. This state may become unstable, resulting in a phase transition into a state exhibiting a resonating superstructure. This has the same symmetry properties as the superstructure postulated in reference 1 and could be used in a similar fashion to explain superconductivity and the well-known increase of the resistivity of certain metals at low temperatures. On the other hand, the dynamic properties of the superstructure are essentially different from those considered earlier. The superstructure is produced by the interlocking of the electronic and nuclear fluctuations; the coupling is so strong that it is no longer possible to consider the nuclear vibration as occurring in a fixed potential.

The present ideas are compatible with the Fröhlich-Bardeen conception[3] of the nature of the interaction responsible for superconductivity. However, the latter theories lead only to a short-range order, whereas we were able to define a parameter of long-range order marking the emergence of the above-mentioned superstructure.

The correspondence between the experimental facts and the theoretical possibilities provided by the symmetry consideration is suggestive. The conclusions obtained can be submitted also to a severe experimental test. Our postulated superlattice should give rise to x-ray superstructure lines. Existing x-ray investigations[5] are scanty and were carried out in view of finding variations in the lattice constant. Hence an x-ray study of the superconducting transition would be of considerable interest.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and the ONR.
[1] L. Tisza, Phys. Rev. **80**, 717 (1950).
[2] E. Maxwell, Phys. Rev. **78**, 477 (1950); Reynolds, Serin, Wright, and Nesbitt, Phys. Rev. **78**, 487 (1950).
[3] H. Fröhlich, Phys. Rev. **79**, 845 (1950); Proc. Phys. Soc. (London) **A64**, 129 (1951); J. Bardeen, Phys. Rev. **80**, 567 (1950), **81**, 469, 829 (1951).
[4] M. Born and R. Oppenheimer, Ann. Physik **84**, 457 (1927).
[5] W. H. Keesom and H. Kamerlingh Onnes, Leiden Comm. **174b** (1924).

A Search for Charge-Exchange Scattering of π^+ Mesons*

RICHARD WILSON† AND JOHN P. PERRY
University of Rochester, Rochester, New York
(Received August 8, 1951)

EXPERIMENTS with photographic plates[1,2] showed meson tracks which stopped without any apparent nuclear interaction. These could be attributed to charge-exchange scattering events or to stars where only fast neutrons were emitted. Moreover, charge-exchange scattering need not always lead to events of this type, for some of the scatterings might be inelastic and give rise to proton recoils.

We have made a direct search for charge-exchange scattering of 44-Mev π^+ mesons on Be and D_2O. The experimental arrangement is shown in Fig. 1. The scintillation crystals 1, 2, and 3 count

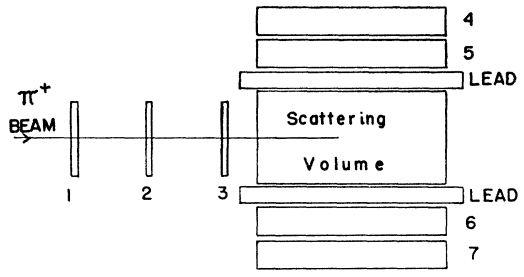

FIG. 1. Experimental arrangement.

the incident 50-Mev π^+ mesons defined as previously described.[3] After passing through the telescope, the mesons have a residual energy of 44 Mev and impinge upon targets of Be or D_2O. The Be target stops the mesons; that of D_2O slows them to 20 Mev. We look for pairs of γ-rays from π^0 decay by two scintillation counter telescopes 4, 5 and 6, 7, each with a Pb radiator of two radiation lengths thickness. The fraction of the total solid angle subtended is 0.06. We assume the scattering is isotropic.

Random counts are assessed by means of a channel which records the coincidence of a pulse from a coincidence in crystals 4, 5, 6, and 7 with a delayed meson pulse. This should indicate