aromatic organic crystals under our experimental conditions is presumably associated with exciton motion in these systems. It is not understood at present why fluorene should be an exception.

C. J. GORTER: Does not the study of the (forbidden) double jumps also have advantages in the investigation of hyperfine structures in some substances?

C. A. HUTCHISON, JR.: The van der Waals technique of studying $\Delta M_s = \pm 2$ transitions in randomly oriented systems does not resolve hyperfine structure because of the anisotropy broadening which arises from the relatively large values of D and E.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN VOL. 17, SUPPLEMENT B-I, 1962 PROCEEDINGS OF INTERNATIONAL CONFERENCE ON MAGNETISM AND CRYSTALLOGRAPHY, 1961, VOL. I

Paramagnetic Susceptibility of Conduction Electrons in Sodium Metal^{*†}

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The paramagnetic susceptibility of conduction electrons in sodium metal has been remeasured by the technique of magnetic resonance absorption. The new value is $\chi_p^e = (1.13 \pm .05) \times 10^{-6}$ c.g.s. volume units. The result is temperature independent within experimental error from 4.2° K to 77° K.

Some consequences of this new value of the susceptibility are: (1) Reasonable agreement between the calculated diamagnetism of the conduction electrons and the value which may be deduced from experiment. (2) Fair agreement between the experimental χ_p^e -electronic specific heat ratio and theoretical estimates of this ratio which include electron-electron interactions.

The paramagnetic susceptibility, χ_p^e , of the conduction electrons in a metal is one of those properties of the metal which is sensitive to the Coulomb repulsive forces between the electrons. The calculation of Bohm and Pines¹⁾ of the properties of an interacting electron gas stimulated the measurement²⁾ a number of years ago of the paramagnetic susceptibility of lithium and sodium. The results of (2) for sodium seemed in substantial agreement with Pines' calculation, but the contribution of the conduction electrons to the diamagnetism of the metal, a result which was inferred from the paramagnetism meas-

* Supported by the National Science Foundation.

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urements and total susceptibility measurements, was in complete disagreement with calculations by Kohn and Kjeldaas³⁾. We undertook the remeasurement of χ_p^e for sodium in order to clarify the situation with respect to the diamagnetism.

The theory of the measurement of χ_{p}^{e} is elucidated in detail in reference (2). Briefly, the method involves comparing the area under the electron spin resonance absorption line to the area under the nuclear resonance in the same sample with the same apparatus. Only the external field in which the resonance is observed is changed during the measurement. The basic equation relating the area to the susceptibility is

$$\chi_p = \frac{2\gamma}{\pi\omega} \int_0^\infty \chi''(H_0) dH_0 \,. \tag{1}$$

 γ is the gyromagnetic ratio of electron or

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Taken in part from a thesis submitted by W. E. Vehse in partial fulfillment of requirements for a Ph. D. degree. A more extensive account of this work will appear in a later publication.

nuclear spin, and ω the angular frequency of the applied r.f. field. One may obtain the working relation by taking the ratio of (1) applied to the electron resonance to (1) applied to the nuclear resonance, and obtain

$$\chi_p^e = \chi_p^n \frac{\gamma_e A_e}{\gamma_n A_n} \,. \tag{2}$$

 A_e and A_n are the areas under the electron and nuclear resonances respectively, γ_e and γ_n their respective gyromagnetic ratios, and $\chi_p^n =$ $N\gamma_n^2 h^2 I(I+1)/3kT$ is the familiar Langevin-Debye formula. Since N is the number of sodium atoms per unit volume, (2) gives χ_p^e in c.g.s. volume units.

The samples were prepared by dispersing the sodium in either paraffin oil or paraffin wax. Small particles were obtained by agitating the mixture with power from a commercial ultrasonic "soldering-gun". Particle sizes of about one micron in diameter were obtained.

The measurements were performed by the technique used for the first measurement of γ_p^e in lithium metal: "Q-meter" detection was used, and $\chi''(H_0)$ of both resonances was displayed on the oscilloscope. For all measurements the angular frequency ω was about $2\pi \times 10$ mcps. The abscissa was obtained by applying to the x-axis of the oscilloscope the integrated output of a pickup coil attached to the outside of the glass dewar at the position of the sample.

Data was taken between 4.2°K and 77°K. The best signal-to-noise for the ratio A_e/A_n in equation (2) occurred at 20°K. Most measurements were made at that temperature, with rather extensive measurements also made at 77°K.

We have obtained the following results: at 77°K, $\chi_p^e = (1.12 \pm .05) \times 10^{-6}$; at 20°K, $\chi_p^e =$ $(1.13\pm.05)\times10^{-6}$; and at 4.2°K, $\chi_p^e = (1.09\pm.08)$ $\times 10^{-6}$, all in c.g.s. volume units. These are averages for 10, 30 and 3 runs respectively. For purposes of comparison with theory, we use $m^*/m=1.25^{4}$. The Kohn and Kjeldaas diamagnetic susceptibility with this effective mass is $\chi_{D}^{e} = -.21 \times 10^{-6}$. Using $\chi_{total} = .65$ $\times 10^{-6}$, we infer from $\chi_{\text{total}} = \chi_D^e + \chi_p^e + \chi_D^{\text{ion}}$ that $\chi_{D}^{e} = (.65 - 1.13 + .18) \times 10^{-6} = -.30 \times 10^{-6} \text{ c. g. s.}$ vol. units. The value of the ion core susceptibility $\chi_D^{\text{ion}} = -.18 \times 10^{-6}$ is subject to considerable uncertainty and may be as high as $-.30 \times 10^{-6}$ ⁵⁾. There is now substantial agreement between the calculation of Kjeldaas and Kohn and experiments.

We may also combine our results with recent measurements of the electronic specific heat to compare with theory. Following Falicov and Heine⁶⁾, the ratio of the susceptibility to the specific heat, γ , may be written as $\chi_p^e/\gamma = 3\mu_B^2/\pi^2 k^2(1-\nu)$ where ν is an integral which depends upon the electronelectron interaction. We obtain for the factor $(1-\nu)^{-1}$ the value 1.41 using γ from Gaumer and Heer⁷⁾, and 1.29, using the γ of Lien and Phillips⁸⁾. Pines' theory gives $(1-\nu)^{-1}$ =1.48, whereas Falicov and Heine believe $(1-\gamma)^{-1}=1.24$ to be a more realistic theoretical estimate.

Within the precision of the measurements we detect no change in χ_p^e with temperature. While our data does not definitely rule out the 3% decrease in the susceptibility between 20°K and 77°K implied by the observed Knight shift⁹⁾, we feel that the 8% decrease of the total susceptibility over the same temperature range observed by Hedgecock¹⁰⁾ cannot be ascribed to χ_p^e .

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