The Slow Neutron Resonant Scattering of Gold*

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ALTHOUGH much information has been accumulated concerning slow neutron resonances, relatively little experimental evidence is available concerning the detailed energy dependence of the scattering cross section near a resonance.

Using the apparatus described previously,[1] in conjunction with the Columbia slow neutron velocity spectrometer,[2] the 4.87-ev Au resonance[3] has been investigated with results in excellent agreement with theory, and the level parameters have been evaluated.

TABLE I. Level widths and neutron cross sections in gold.

	Γ_{NO}	Γ	σ_{P2}	σ_{P1}
$J_1=1$	(0.0211 ± 0.002)	(0.172 ± 0.010)	(10.6 ± 0.6)	(13.3 ± 1.3)
$J_1=2$	(0.0163 ± 0.0015)	(0.133 ± 0.010)	(17.6 ± 0.9)	(8.0 ± 1.4)

If a sample is thick enough to give very small transmission and if the ratio of the scattering to total cross sections, (σ_s/σ_t), is less than about 0.5, in which case the diffusion length is less than the sample thickness, then the ratio of the sample counting rate to that of a reference thick graphite sample, (N_x/N_C), is independent of sample thickness and depends only on the ratio (σ_s/σ_t). A calibration curve for (N_x/N_C) *vs.* (σ_s/σ_t) was obtained, for our geometry, using thick B_2O_3 and Ni_2B standards. The scattering and $1/v$ terms for the standards were determined by transmission measurements to give $(\sigma_s/\sigma_t)B_2O_3=(1+10.4E^{-\frac{1}{2}})^{-1}$ and $(\sigma_s/\sigma_t)Ni_2B=(1+3.31E^{-\frac{1}{2}})^{-1}$.

Using this calibration, the ratio (σ_s/σ_t) was measured for a thick gold sample in the vicinity of the resonance, and compared with theoretical curves based on the Breit-Wigner one-level formulas of the form[4]

$$[\sigma_c=\sigma_{co}\Gamma^2(E_0/E)^{\frac{1}{2}}]/[4(E-E_0)^2+\Gamma^2] \quad (1)$$

$$\sigma_s=(G_2\sigma_{P2})+4\pi G_1\{R_1^2+[\lambda\!\!\!^-{}_0^2\Gamma_{NO}^2+4\lambda\!\!\!^-{}_0\Gamma_{NO}R_1(E-E_0)]/[4(E-E_0)^2+\Gamma^2]\} \quad (2)$$

$$\sigma_{co}=4\pi\lambda\!\!\!^-{}_0^2G_1\Gamma_{NO}\Gamma_Y/\Gamma^2. \quad (3)$$

Gold has one stable isotope of spin $\frac{3}{2}$, so $J_1=1$ or 2 and $G_1=\frac{3}{8}$ or $\frac{5}{8}$ for the "resonant spin state," and $G_2=\frac{5}{8}$ or $\frac{3}{8}$ for the "non-resonant spin state." The first term on the right in Eq. (2) is the constant (potential) scattering of the "non-resonant spin state." The second term gives the potential, resonance, and interference terms in the scattering for the "resonant spin state." The symbols have their usual significance.

The value $\sigma_{co}\Gamma^2=(638\pm17)$ barn-ev^2 in Eq. (1) was determined by a least squares fit to σ_t (from transmission measurements) in the thermal energy region. With $\sigma_{co}\Gamma^2$ fixed, only Γ_{NO}/Γ, $(G_2\sigma_{P2})$, R_1, and J_1 remain as undetermined parameters. Near 2 to 3 ev the scattering is nearly zero for the resonant spin state, so (σ_s/σ_t) determines $(G_2\sigma_{P2})=(6.6\pm0.33)$ barns. For a given choice of $\sigma_{co}\Gamma^2$ and the *total potential* scattering, almost identical curves for (σ_s/σ_t) result for $J_1=1$ and $J_1=2$, when suitable related choices are made for (Γ_{NO}/Γ) in the two cases, so further evidence is needed to determine J_1. When J_1, $\sigma_{co}\Gamma^2$, and $G_2\sigma_{P2}$ are given, (σ_s/σ_t) is mainly sensitive to (Γ_{NO}/Γ) near resonance, and to R_1 far from resonance on either side. Thus, both of these parameters can be evaluated by comparison with experiment to give Table I.

The values of σ_{P2} and other results[5] indicate strongly that $J_1=1$. A detailed report of this work will be published shortly.

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Screening of Electronic Interactions in a Metal

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IN recent publications,[1,2] Landsberg and Wohlfarth have shown that the assumption of a screened Coulomb interaction between electrons in a metal eliminates certain difficulties arising from the treatment of the effects of the exchange energy according to the free particle approximation. With the free particle approximation, the exchange contribution to the Coulomb interaction energy of two electrons of wave vectors $\mathbf{k}_1$ and $\mathbf{k}_2$ is $W_{1,2}=-2\pi e^2/L^3|\mathbf{k}_1-\mathbf{k}_2|^2$, where $\mathbf{k}=\mathbf{p}/\hbar$ and $\mathbf{p}$ is the electronic momentum. For a given electron, the total energy of interaction with all the other electrons is

$$W_i=\sum_{j\neq i}W_{i,j}=-\frac{e^2k_0}{2\pi}\left(2+\frac{k_0^2-k^2}{k_0k}\ln\left|\frac{k+k_0}{k-k_0}\right|\right),$$

where k_0 is the absolute value of the wave vector of an electron at the top of the Fermi distribution, and all of the levels are assumed to be occupied up to k_0. Since the E *versus* k curve for a given electron becomes very steep as k approaches k_0, at low temperatures the density-in-energy of electron levels is correspondingly reduced. Bardeen[3] has shown that for this reason the specific heat of the electron gas should vary as $-\ln T/T$, in contrast to the linear dependence on T obtained when the exchange energy is ignored. Experiments indicate that a linear dependence is correct and therefore that calculations based on perturbation theory overestimate the effects of exchange energy. This overestimate is found also to lead to incorrect predictions at low temperatures for conductivity and diamagnetism, and for the soft x-ray spectrum. In fact, Landsberg proposed the screened Coulomb interaction on a purely empirical basis in order to obtain agreement with experiment for the width of the tail of the soft x-ray emission spectrum of sodium.

Simple mathematical analysis makes clear the fact that the increased steepness of the E *versus* k curve originates in the long range of the Coulomb interaction, which, as we have seen, leads to a very large exchange energy for electrons of nearly equal momenta. If, with Landsberg, one assumes the Coulomb force to be screened, then one will no longer obtain so large a modification of the E *versus* k curve. Wohlfarth showed that a linear dependence of the specific heat on temperature is regained, and that agreement with experiment is obtained with a potential $V=(e^2/r_{ij})\times\exp(-r_{ij}/\lambda)$ when the screening radius λ is chosen to be of the order of 10^{-8} cm, the value introduced by Landsberg.

We have been led independently to the concept of an effective screened Coulomb force as a result of a systematic classical and quantum-mechanical investigation of the interaction of charges in an electron gas of high density. We have treated this problem with the aid of certain canonical transformations, which make possible a solution which is much more accurate than the perturbation theory solutions on which previous calculations have been based.[4] Our results show that the Hamiltonian for a system containing a high density of electrons can be split into two parts