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## ELASTIC DIFFERENTIAL SPIN-EXCHANGE CROSS SECTIONS FOR SCATTERING OF SLOW ELECTRONS BY POTASSIUM*

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We have measured the differential spin-exchange cross section $\sigma_{ex}(\theta)$ relative to the differential cross section $\sigma(\theta)$ for the scattering of 0.5-eV electrons by potassium, for angles between 10° and 180° in the electron polar scattering angle. The ratio $\sigma_{ex}(\theta)/\sigma(\theta)$ increases monotonically from approximately 0 at 10° to 0.7 ± 0.1 at 180°.

This Letter reports preliminary measurements of the ratio of the differential spin-exchange cross section $\sigma_{ex}(\theta)$ to the differential cross section $\sigma(\theta)$ for the elastic scattering of 0.5-eV electrons by potassium. The range of electron scattering angles studied was from 10° to 180° in the electron polar scattering angle. The atomic-beam recoil technique was used.[1,2] Previously, a similar technique was used to obtain bounds on the total spin-exchange cross section $\sigma_{ex}$ for the scattering of electrons by potassium.[1] More recently, optical pumping experiments have been used to determine $\sigma_{ex}$ in the thermal energy range for electrons scattered by the alkali elements.[3] The present work, however, represents the first electron-atom differential exchange measurements reported to date.[4,5]

The observed ratios can be expressed in terms of the direct and exchange scattering amplitudes $f(\theta)$, $g(\theta)$ by

$$\frac{\sigma_{ex}(\theta)}{\sigma(\theta)} = \frac{|g|^2}{\frac{3}{4}|f-g|^2 + \frac{1}{4}|f+g|^2},\quad (1)$$

or equivalently, in terms of the singlet (S) and triplet (T) scattering amplitudes, as

$$\frac{\sigma_{ex}(\theta)}{\sigma(\theta)} = \frac{|S-T|^2}{3|T|^2 + |S|^2}.\quad (2)$$

A schematic diagram of the experimental arrangement is shown in Fig. 1. The atom beam is spin-polarized and velocity selected by a Stern-Gerlach dipole magnet, and is spin-analyzed after scattering by an E-H gradient-balance magnet.[6] The entire analyzer and detector assembly can be rotated about the interaction region, so that differential scattering-in measurements can be made, as a function of atomic recoil scattering angle. A suitable transformation is then used to calculate the corresponding electron polar scattering angle $\theta$. The oven is displaced in such a direction that the analyzer reflects atoms which do not undergo a spin charge during scattering.[7]

Measurements are made of the ratio of the scattering signal with analyzer on to that with the analyzer off. Corrections are made for the residual depolarization initially present in the beam (~1%) and for the transmission factor for balanced atoms in the analyzer (~75%).
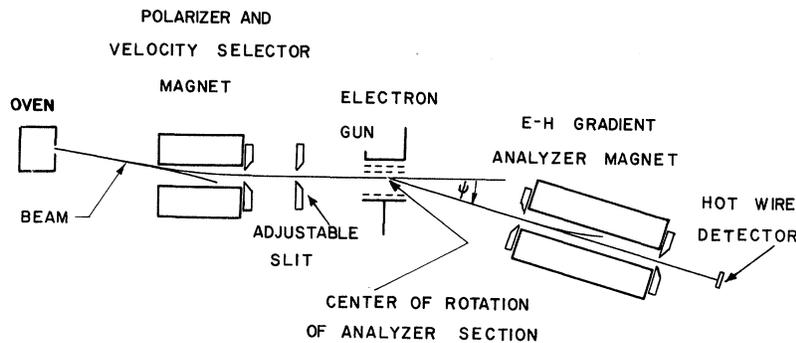
FIG. 1. Schematic diagram of the apparatus. Scattering takes place in a magnetic field of 500 G in the direction of the incident electrons. The magnetic field of polarizer, gun, and detector are all in the same direction and fringing fields throughout the apparatus prevent depolarization of atoms when passing from one region to another.

Neglecting magnetic interactions, the spin of the atom can only change by an exchange event, below the threshold for excitation (1.6 eV for potassium). Thus the experiment measures $\sigma_{ex}(\theta)/2\sigma(\theta)$, the factor 2 arising because only half of the exchange events (those with antiparallel spins) are observable. The ratio $\sigma_{ex}(\theta)/\sigma(\theta)$ can vary between 0 and $\frac{4}{3}$, the maximum value occurring when $|S| = 3|T|$ with a phase difference of $\pi$ between $S$ and $T$. Experimental values of this ratio are shown in Fig. 2, for an electron energy of 0.50 eV. At small angles ($<30°$) the uncertainty in $\theta$ arises from the finite width of the atom beam. At larger angles it is due to the width of the atom velocity distribution and of the electron energy distribution. The latter has a half-width of about 0.35 eV.

The observed increase of the ratio with scattering angle is to be expected, since larger angles correspond to scattering with smaller
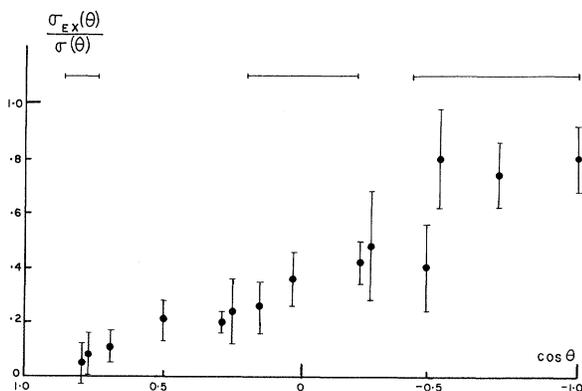


FIG. 2. Experimental values of $\sigma_{ex}(\theta)/\sigma(\theta)$ for an electron energy of 0.5 eV. Horizontal error bars indicate uncertainty in $\cos\theta$ at three different angles.

impact parameters on the average. Preliminary data indicate that at higher energies the ratio at large angles is even greater ($1.0 \pm 0.30$ at 1.0 eV). A quantitative comparison with calculated singlet and triplet phase shifts is now in progress.[8] Further measurements at other energies below threshold are being made, and we are also attempting to obtain data with a reduced electron energy distribution (~0.20 eV).

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## OSMOTIC PRESSURE OF DILUTE SOLUTIONS OF He³ IN He⁴ †

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The osmotic pressure of dilute solutions of He³ in liquid He⁴ has been measured at 0.320, 0.650, and 1.16°K for He³ concentrations up to 2%. The results do not agree well with the calculations of Ebner based on the effective potential of Bardeen, Baym, and Pines.

The Landau-Pomeranchuk model of a dilute solution of He³ in He II has recently been extended to finite He³ concentrations and low temperatures by Bardeen, Baym, and Pines (BBP)[1,2] and by Emery.[3] According to BBP the He³ quasiparticles postulated by Landau interact weakly via a spin- and velocity-independent effective potential $V(r) = \int V(k)e^{i\mathbf{k}\cdot\mathbf{r}}d\mathbf{k}/(2\pi)^3$ for which the Fourier transform $V(k)$ has been fitted to experiment. The value of $V(k)$ at $k = 0$, $V_0$, which is equal to $\int V(r)d\mathbf{r}$, has been shown by Baym[4,2] to be given by

$$V_0 = -\alpha_0^2 m_4 s^2 / n_4, \qquad (1)$$

where $m_4$ is the mass of a He⁴ atom and $s$ and $n_4$ are the velocity of sound and the number density of pure He⁴. The "BBP parameter" $\alpha_0$ is defined so that the volume occupied by a He³ atom in solution at 0°K is $1 + \alpha_0$ times the volume occupied by a He⁴ atom; experimentally[5] $\alpha_0 = 0.284 \pm 0.005$. Using experimental data[6] at temperatures low compared with the Fermi temperature, BBP guessed $V(k)$ to be of the form $V(k) = V_0 \cos\beta k$. With a value of $V_0$ in agreement with (1) and $\beta = 3.16$ Å they obtained a good fit to the spin-diffusion coefficient $D$, the spin susceptibility $\chi$, and the specific heat, all measured at low temperatures for two He³ concentrations, $X = 0.013$ and $X = 0.0506$. Since low-temperature properties only depend on particles at the Fermi surface, $V(k)$ was determined for $k \leq 2k_F$ ($X = 0.0506$) corresponding to $\beta k \lesssim 2$. A more recent calculation by Baym and Ebner[7] based on the BBP potential gives good agreement with ultrasonic attenuation measurements by Abraham et al.[8] but does not agree well with the low-temperature thermal conductivity $\kappa$ measured by

Abel et al.[9] The disagreement with the thermal conductivity may be due, at least in part, to an uncertainty in the theoretical expressions for $D$ and $\kappa$ introduced by the use of approximate solutions of the Boltzmann equation.[10]

Ebner has extended the empirical $V(k)$ of BBP to higher values of $k$ by fitting the spin-diffusion data at temperatures which are high compared with the Fermi temperature; he has also developed expressions for the spin susceptibility[11] and chemical potentials[12] $\mu_3$ and $\mu_4$ in the same temperature range. The object of this Letter is to present data on the osmotic pressure which can be compared with Ebner's calculations for $\mu_4$ so as to check his determination of $V(k)$ and that of BBP.

The osmotic pressure was measured between an upper and a lower chamber which were machined in one copper block (to keep them at the same temperature $T$) and which were connected to each other by a Vycor glass superleak[13] which was the only opening into the lower chamber. The two chambers were filled with measured amounts of helium through a capillary tube opening into the upper chamber. The upper chamber contained some liquid of He³ atomic concentration $X$ and some vapor so that the pressure was always the saturated vapor pressure $p(X, T)$. The lower chamber was kept completely filled with pure He⁴ and was at a pressure $p - \pi$ determined by the equality of the He⁴ chemical potential across the superleak[14]:

$$\mu_4(X, p, T) = \mu_4(0, p-\pi, T).$$

Expanding the right-hand side in powers of $\pi$ gives

$$\mu_4(X, p, T) - \mu_4(0, p, T) = \pi(X, p, T)v_4(p, T), \qquad (2)$$