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Resonance Features and Fine-Structure Effect in the Asymmetry of Polarized Electrons Scattered Inelastically from Mercury Atoms

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(Received 6 May 1981)

The energy dependence of the asymmetry in inelastic scattering of polarized electrons by Hg atoms (excitation of the 6^3P_1, 6^3P_2, and 6^1P_1 states) has been studied for a scattering angle of 90° and collision energies between the threshold energies and 22 eV. Structures in the measured asymmetry have been found which are due to formation of negative-ion states. Evidence has been found that interference between exchange and fine-structure interaction also causes a scattering asymmetry.

PACS numbers: 34.80.Dp

Spin-polarization effects in elastic scattering of low-energy electrons from atoms and surfaces have been studied with increasing effort in the past fifteen years. The work on electron polarization in inelastic scattering is, however, very limited; indeed,[1-3] one of the reasons being the greater difficulties of such experiments. This situation has recently been alleviated by the advent of techniques which yield rather high currents of polarized electrons with a small energy spread.[4]

Such sources of polarized electrons allow the spin-dependent interaction to be studied in an alternative way. Instead of using an unpolarized primary beam and measuring the spin polarization of the scattered electrons one can use a polarized primary beam with polarization P and observe the left-right asymmetry A of the scattered intensity.[5]

Measurements of the polarization of inelastically scattered electrons have been made earlier for the two channels of the Hg atom with energy losses 6.7 and 11.0 eV at primary energies between 30 and 180 eV.[1,2] The results may give the impression that there is a tendency of the polarization effects to decrease as the primary energy is diminished. On the other hand it has been pointed out that in the energy range where exchange effects play a role, polarization effects caused by fine-structure interaction within the target may occur[6] which have not been observed so far. Contrary to "pure" exchange scattering which will not give rise to spin-polarization effects unless electrons or atoms are initially polarized,[5b] the combined effect of fine-structure interaction and exchange gives rise to spin polarization of the continuum electron. This is because atomic fine-structure levels can be excited coherently via ("direct") collision without spin transfer and via exchange collision with spin transfer ("spin flip").[6] This "coherence" will vanish if the fine-structure states are not resolved, which is the description used most.[5b] In addition, strong polarization effects in inelastic scattering may be expected at collision energies where negative-ion states Hg^- are temporarily formed. This can be concluded from earlier observations of resonances in e-Hg scattering[7] and from studies of the polarization of elastically scattered electrons in the vicinity of such resonances.[8]

In order to check these ideas, measurements of the asymmetry A for excitation of the 6^3P_1, 6^3P_2, and 6^1P_1 states of mercury (energy losses 4.89, 5.46, and 6.7 eV) have been made between the threshold energies and about 22 eV. They became feasible since a GaAs source of polarized electrons[4] has been constructed (polarization P) so that A/P could be determined through an asymmetry measurement in a single scattering experiment, whereas the earlier polarization measurements were double scattering experiments.[1,2]

Figure 1 shows a schematic diagram of the apparatus. Longitudinally polarized electrons are photoemitted in ultrahigh vacuum from a GaAs crystal which is irradiated with circularly polarized light. After deflection of the electrons by 90° their polarization is rotated by a magnetic lens through 90° to be perpendicular to the plane of the drawing. The (transversely polarized) electrons then pass through a differential pumping stage and, after another deflection by 90°, are focused onto the mercury target. A pair of energy analyzers positioned at the angle of 90° select the inelastic scattering channel to be studied. The energy analyzers, like the deflectors, are of the Jost type (simulated spherical).[9] The overall energy resolution of the experiment was about 200 meV. The energy scale has been calibrated by observing the optical excitation function of the mercury 6^3P_1 level.[10] The left-right asymmetry of the polarized electrons which have excited the energy state selected by the spectrometers and have been scattered through 90° is detected by a pair of Channeltrons. Instrumental asymmetries could easily be corrected by reversal of the electron polarization (rotation of the quarter-wave plate through 90°); additional checks were made by use of linearly polarized light which yields unpolarized electrons. We used primary currents at the target between 3 and 10 nA. The electron polarization has been determined by elastic scattering from Hg for which the Sherman function is well known.[11] A typical value of the electron polarization is 27% at the wavelength 676 nm of the light.

Each experimental point has been measured with the four circularly polarizing positions of the $\lambda/4$ plate, two of them yielding σ^+ light, and two, σ^- light. In each position about 10^4 electrons were counted by each Channeltron within 10 to 80 s, depending on energy. The four values for A/P obtained at one energy were averaged to yield the value shown in Fig. 2. The signal-to-background ratio (Hg beam on and off) has been determined for each energy of measurement; at the higher energies it was above 10:1, and at the low energy end, clearly above 4:1. The measuring cycles have been performed automatically under the control of an Apple-II microcomputer which also evaluated the data. The reproducibility of the results was very good even after a reassembly of the apparatus.

Figure 2 shows the energy dependence of A/P for the excitation of the 6^3P_1, 6^3P_2, and 6^1P_1 states of Hg between the threshold energies and 22 eV. The vertical error bars include the statistical error and the reproducibility; the horizontal bars give the energy resolution and are not plotted for each point.

It is obvious from Fig. 2 that one should not conclude from the earlier measurements mentioned above that the polarization effects in inelastic scattering decrease as the energy is diminished. Particularly within a few eV above threshold pronounced structures with large values of A/P are

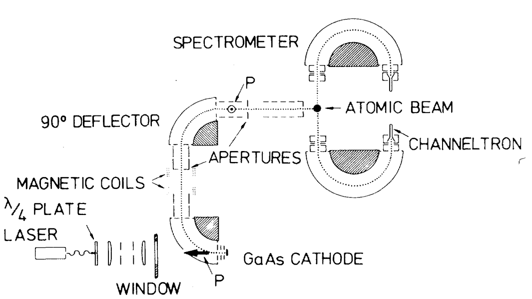

FIG. 1. Schematic diagram of the experimental arrangement (not to scale).

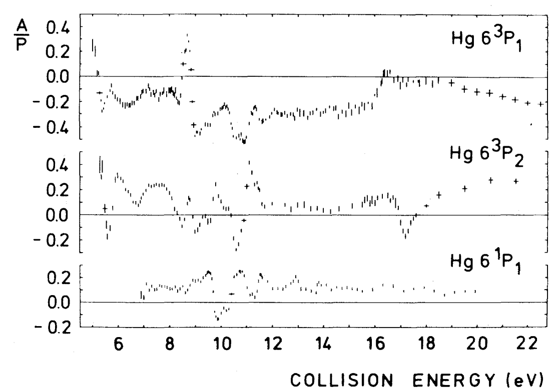

FIG. 2. Measured A/P vs collision energy for excitation of 6^3P_1, 6^3P_2, and 6^1P_1 levels in Hg by polarized electrons. (A denotes asymmetry; P denotes polarization of incident electrons.)

observed. This is the energy range where resonance structures in the cross sections due to formation of negative-ion states have been found by other authors[7] and in the present experiment. The traditional resonance structure in the intensity recently found by Kazakov, Korotkov, and Shpenik[7] can be directly compared with our asymmetry measurement since the scattering angle and energy range of their work coincide with ours. At somewhat higher primary energies where the resonance features disappear, Fig. 2 still shows significant asymmetry. The asymmetry measurement for excitation of 6^3P_2 shows that at these somewhat higher primary energies the asymmetry has the opposite sign than for 6^3P_1. This indicates that the mechanism anticipated by one of us[6] which produces additional polarization effects by interference of fine-structure interaction and exchange is effective and may even dominate the effects caused by spin-orbit interaction of the continuum electron. A more detailed analysis and further results will be given elsewhere. The present work has been stimulated by measurements of K. Franz, who has observed excitation of the 6^3P_2 state at collision energies up to 30 eV and larger scattering angles and who is presently performing polarization measurements at different angles in our laboratory.

We gratefully acknowledge the assistance of Dr. K. Jost in the construction of electron optical parts and of Dr. K. Kollath, Dipl.-Phys. R. Möllenkamp, and D. Möller in making the GaAs source operational. The project is supported by the Deutsche Forschungsgemeinschaft.

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