# Polarization of Slow Electrons by Hg and Range of Applicability of the Relativistic Hartree Potential

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New measurements on the angular and energy dependence of the polarization of slow electrons scattered by mercury atoms are reported. Special attention is paid to electron energies below 500 eV where, according to a recent paper of Schonfelder, deviations from the present theories should be expected, since at small energies the use of the static Hartree potential for treating the scattering process should no longer be a good approximation. Since the measurements were made with an angular resolution of $\pm 1°$, a direct comparison with the theoretical results was feasible. Absence of plural scattering was carefully checked. The discrepancies between theory and experiment reported by Schonfelder did not appear, and the theoretical results proved reliable down to 100 eV, the lowest energy for which numerical evaluations of the present theories were available. A survey of the work which has been done so far on electron polarization by scattering from mercury atoms indicates sound knowledge of the polarization effect for energies between 100 and 2000 eV and scattering angles from 30° to 150°.

## I. INTRODUCTION

RECENT theoretical and experimental investigations have shown that one can get highly polarized electron beams by scattering low-energy electrons from mercury atoms. The degree of polarization,

$$P(E,\vartheta)=(N_\uparrow-N_\downarrow)/(N_\uparrow+N_\downarrow),$$

where $N_\uparrow$ and $N_\downarrow$ are the numbers of electrons with spins parallel and antiparallel, respectively, to the normal of the scattering plane, is a rapidly oscillating function of electron energy $E$ and scattering angle $\vartheta$ and takes on very high values.

The correspondence between the experimental results obtained by different authors[1–5] indicates that the theoretical results for $P(E,\vartheta)$ are very reliable for electron energies above 500 eV. Polarizations up to 0.85 have been measured so far.[5]

Below 500 eV, however, knowledge of the polarization effect was fragmentary and contradictory: At those small energies the degree of polarization $P$ changes very rapidly with changing energy $E$, so that measurements must be made in small energy steps in order to get a complete picture. Moreover, below 500 eV discrepancies exist among the experimental results of different authors,[2,4,5] and the first measurements at these lower energies[2] showed "significant deviations"[6] from theory.

The theoretical approximations which had to be made in the calculation of the electron-scattering data seemed to be an obvious reason for the differences between the experimental and theoretical results,[6] since the present theories[7,8] treat the elastic scattering by the relativistic Hartree potential of the mercury atom without taking into account the electrical polarizability of the atom, as well as exchange and other effects[6] which are known to be important when low-energy electrons are scattered by atoms.

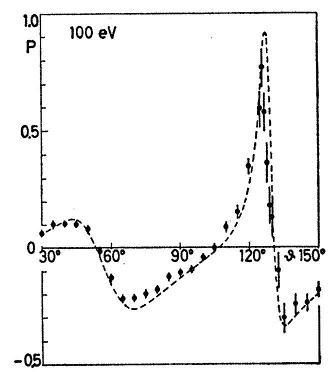


FIG. 1. Angular dependence of the polarization $P$ for 100 eV. Solid circles, experimental values with statistical errors, dashed line, theory.

However, some of the discrepancies which had been said to exist between theory and experiment could not be confirmed by our earlier measurements.[4,5] Since the measurements had been made only at a few energies below 500 eV, they might be regarded as not sufficiently comprehensive for assuring agreement between theory and experiment. Furthermore, it would be interesting to know when the above-mentioned theoretical approximation breaks down, because our present knowledge on this point is only qualitative. Therefore, further polarization measurements have been made which allow a conclusive comparison of experimental and theoretical values for $P(E,\vartheta)$ in the energy range between 500 and 100 eV and in the angular range $30°\leq\vartheta\leq150°$.

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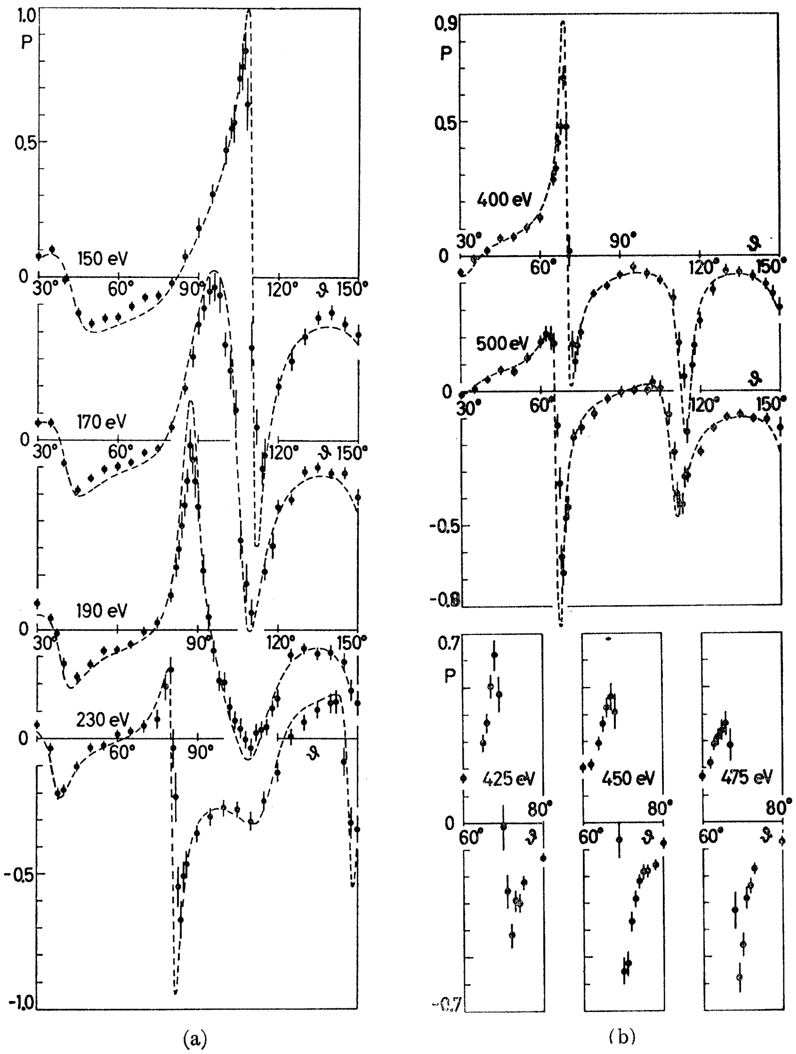


FIG. 2. Angular dependence of the polarization $P$ for electron energies of (a) 150–230 eV, (b) 400–500 eV. Solid circles, experimental values with statistical errors, dashed line, theory.

## II. EXPERIMENTAL TECHNIQUE

A previous publication[5] included a detailed description of the apparatus. Therefore we will just give an outline of the experiment: A beam of monoenergetic electrons crosses a mercury vapor jet by which some of the electrons are scattered. The scattered electrons first pass through an energy-filter lens which removes inelastically scattered electrons. They are then post-accelerated to 120 keV, and finally enter a Mott detector in which their polarization is analyzed.

Special attention was paid to the following points: The density of the mercury atomic beam was made low enough to avoid plural scattering (measurements on the influence of plural and multiple scattering[9] showed that at the lower energies investigated here, one has to use very low target densities in order to avoid misleading results). The angular resolution $\Delta\vartheta$ was about $\pm 1°$ (at 100 eV it was about $\pm 1.5°$) and thus sufficiently high to make possible a direct comparison with the theoretical results for an ideal angular resolution.

## III. RESULTS AND DISCUSSION

The angular dependence of the polarization was measured down to 100 eV, because, to our knowledge, this is the lowest energy for which the present theories have been numerically evaluated. At smaller energies we measured only a few polarization values for $\vartheta = 90°$. Figure 1 gives a comparison of the experimental and theoretical results for 100 eV. There are no significant differences between theory and experiment and the agreement must be called good. It must not be regarded as a failure of the theory when here and in some of the following figures the theoretical maximum at the very narrow polarization peak is slightly higher than the experimental result. The reason is that the width of that peak is comparable to the angular resolution.

Similar results on the agreement between theory and

[9] Z. Physik (to be published).

experiment were presented earlier[5] at 180 and 300 eV[10] and have now been confirmed at several other energies below 300 eV, as Fig. 2(a) demonstrates. Figure 2(b) shows that the earlier reported[6] discrepancies between theory and experiment at 500 and 400 eV do not exist. In order to avoid any misunderstanding, we should point out that the apparent disagreement between the theoretical curves shown by Steidl *et al.*[2] and those plotted here is only fictitious: The former authors corrected the theoretical values for their angular resolution. Any discrepancies between theory and experiment should be even more pronounced in the present, uncorrected presentation.

A comparison of the 400- and 500-eV curves shows a strong energy dependence of the polarization between 60° and 80°. To consolidate our results, this angular range was examined in 25-eV steps. These experimental results [Fig. 2(b)] cannot be compared with theoretical ones so far. Theoretical calculations at these energies would give a further check of our statement of agreement between the present theories and experiments.

Instead of presenting more of our measurements on the angular dependence, we want to give an example of the energy dependence of the polarization. In Fig. 3, $P(E, 90°)$ is given for the full energy range covered by our measurements (50–2500 eV). Comparison with the theoretical values which are plotted as far as they exist, shows excellent agreement.

The agreement of theory with experiment between 500 and 1700 eV has never been questioned, since all the measurements existing[1,2,5] confirmed the theory. Moreover, the energies for which theoretical values have been calculated are sufficiently close to each other in that range[11] so that further measurements there seemed unnecessary.

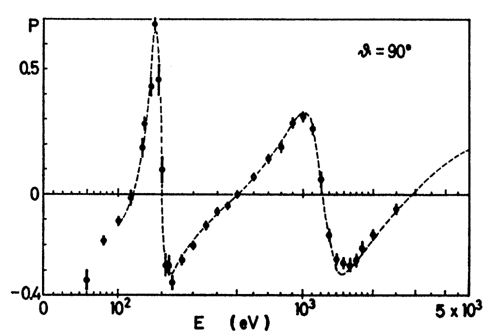


FIG. 3. Energy dependence of the polarization $P$ from 50 to 2500 eV for $\vartheta = 90°$. Solid circles, experimental values with statistical errors; dashed line, theory. To get a clear survey of the energy range in question a pseudologarithmic scale given by log $(1+E/100 \text{ eV})$ ($E$ in eV) was used on the abscissa which is linear for small $E$ and logarithmic for large $E$.

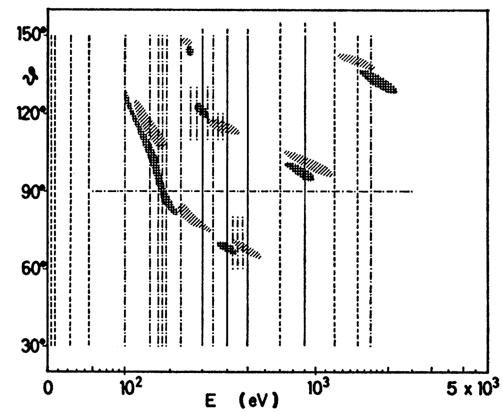


FIG. 4. Regions of $|P| > 0.5$ according to theory, and the ranges covered by measurements. Checkered areas: $P > 0.5$, hatched areas: $P < -0.5$. Dashed line, measurements of the Mainz group (Refs. 1–3), dash-and-dot line, measurements of our group (Refs. 4 and 5). Solid line represents overlapping measurements of both groups. The abscissa scale is the same as in Fig. 3.

Since the polarization of slow electrons scattered by mercury atoms has been investigated very intensely during recent years, it is difficult to maintain an over-all picture of the work which has been done so far. For this purpose Fig. 4 may be useful. In this energy-angle diagram those areas are given where $|P| > 0.5$ is to be expected according to theory. Furthermore, those ranges are indicated where measurements have been made so far. The measurements cover the whole region thoroughly enough to provide consistent information on the polarization effect and on the validity of the theory between 100 and 2000 eV from $\vartheta = 30°$ to 150°. As the present paper shows, it is sufficient in this region to treat the scattering problem by using the static relativistic Hartree potential. It is not yet necessary to take the above mentioned effects of atomic polarizibility, exchange, etc., into account.

## ACKNOWLEDGMENTS

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[10] For lack of theoretical data, comparison with theory could not be made at the time we published our polarization measurements taken around 300 eV in 20-eV steps (Ref. 5). Meanwhile, M. A. Coulthard made calculations for the energies and angles required which show that comparison between theory and experiment at 260, 280, 320, and 340 eV gives results very similar to those found for 300 eV (Ref. 5): There is good agreement between the theoretical and experimental results apart from a slight angular shift by about 2°.

[11] In addition to the theoretical values published as tables or graphs (Refs. 7 and 8), tabulated polarization values for 100, 150, 170, 180, 190, 210, 230, 250, 260, 280, 320, 340, 700, 900, 1400, 1600, 2000, 3500, 4000, and 5000 eV were at our disposal. We are indebted to Dr. H. J. Meister and Dr. M. A. Coulthard for kindly sending us their unpublished results.