Circularly Polarized He Radiation for Electron Polarimetry

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Because of the large systematic uncertainties of Mott scattering, alternative methods for more accurate absolute electron polarimetry are presently being discussed. One of them is the measurement of the circular polarization of impact radiation produced by polarized electrons. The present paper shows that the transition $3^3P \rightarrow 2^3S_1$ (388.9 nm) from the unresolved 3^3P_J multiplet of helium is very appropriate for the absolute calibration of electron polarization. This can be utilized to increase the accuracy of polarization analysis with a Mott detector.

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The rapid growth of the number of electron-polarization experiments has created an increasing need for precise electron polarimeters. Despite the occasional use of other polarimeters, Mott scattering is still the standard technique for electron polarimetry.[1] The systematic uncertainties of Mott-scattering polarimetry, which are mainly caused by multiple and plural scattering, are rather large. The absolute uncertainty is certainly not smaller than $\pm 5\%$.[2] Unfortunately, one can frequently find uncritical papers in the literature which give overly optimistic uncertainty limits of their polarization measurements—sometimes as low as 1%.

One of the alternative methods of electron-polarization analysis is the measurement of the circular polarization of impact radiation produced by polarized electrons. Though the idea was suggested two decades ago,[3] some drawbacks of the suggested transitions[3,4] have prevented it from being widely used in polarized-electron studies.

One of the weaknesses is seen by inspection of Fig. 1. It shows the circular polarization versus incident electron energy E of the $7^3S_1 \rightarrow 6^3P_0$ (404.7 nm) radiation produced by polarized electrons in mercury. It is a remeasurement of earlier results obtained in our laboratory.[5] Apart from better statistical accuracy, the curve is identical with the previous one, which demonstrates the good reproducibility of the results—a feature of importance for the aspect considered in the present paper. Although, for reasons discussed by Wykes,[4] this nonresonant transition is particularly suitable for electron-polarization analysis, the irregular structure of the curve is a serious drawback for this purpose. The structure, which is caused by resonances (short-lived states of Hg^-), implies that the circular light polarization drops from 88% to 15% within an energy range of 1 eV above threshold. This strong energy dependence continues as the electron energy increases.

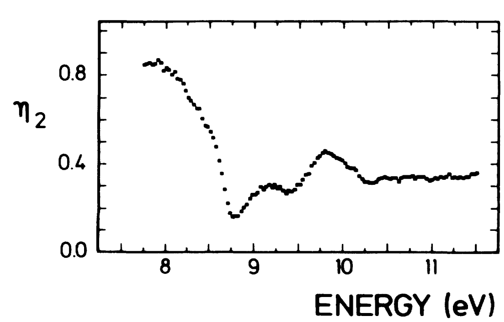

FIG. 1. Circular light polarization η_2 normalized to the electron polarization by which it is caused. Transition Hg 7^3S_1-6^3P_0 (404.7 nm).

For the optical detection of electron polarization, such a sensitive dependence of the light polarization (i.e., of the analyzing power) on the electron energy is damaging. It means that the electron energy has to be very well defined if the electron polarization is to be determined from the light polarization. Besides, it is impossible to rely on the theoretical value of the light polarization which has been calculated by Wykes to be 88.7%: Even for electron energies slightly above threshold, the light polarization is clearly lower and has to be calibrated before it can be utilized for an absolute measurement of electron polarization. Consequently, the hope for "a simple relationship" between electron and light polarization "that holds at all incident electron energies for which cascade contributions to the relevant line radiation are negligible"[6] is not fulfilled, so that the Hg transition is inappropriate to serve as an absolute standard for electron-polarization analysis.

It is the purpose of the present paper to demonstrate that among the other transitions that have been discussed for optical detection of electron polarization the transition $3^3P \rightarrow 2^3S_1$ (388.9 nm) from the unresolved

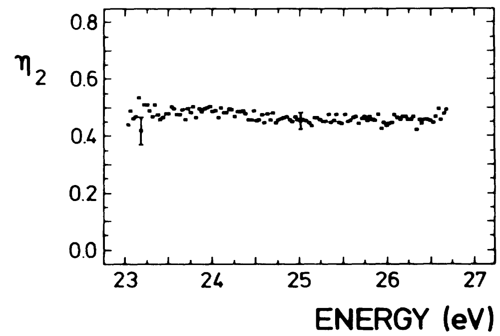

FIG. 2. Circular light polarization η_2 normalized to the electron polarization by which it is caused. Transition He 3^3P-2^3S (388.9 nm).

3^3P_J multiplet of helium is a very good candidate. The use of transition has been suggested by Gay,[6] whose arguments are confirmed by the present experiment.

Figure 2 shows our experimental result, which has been obtained in the following way. Helium atoms in their ground state $1s^2\,{}^1S_0$ were excited by an electron beam with a transverse polarization P_y. The polarization of the light emitted along the y direction in the transition $3^3P_J \rightarrow 2^3S_1$ (388.9 nm) was analyzed. We used an experimental setup (Fig. 3) similar to that described by Wolcke *et al.*[7] The main changes were the installation of a new source of polarized electrons[8] and the use of two targets.

For calibration of the electron polarization, a heated stainless-steel pipe which was mounted 1 mm below the electron beam effused a mercury beam in the y direction. An electron spectrometer could be rotated around the scattering center. The asymmetry of elastic electron-Hg scattering was measured between angles of 60° and 120° at an energy of 12 eV. A previous measurement of this asymmetry[9] served as a rough calibration, giving a mean electron polarization of $P_y = (29 \pm 2.5)\%$ in the present measurement.

The helium beam was produced by effusion from high pressure (a few hundred pascals) through a copper cylinder with a diameter of 1 mm mounted in the x direction. The background pressure with the gas valve closed was about 2×10^{-5} Pa. With the helium beam running, a pressure of about 1×10^{-3} Pa was maintained in the scattering chamber.

The light detection system consisted of a lens system ($f = 22.5$ mm) which also served as a vacuum window. It accepted a cone with a half angle of 21° and formed a nearly parallel light beam. The light beam passed through a $\lambda/4$ plate and then through a rotatable pile-of-plates analyzer with an analyzing power of 0.97 ± 0.005. The data shown in Fig. 2 were corrected for the acceptance angle of $\pm 21°$ by about 3.3%. For the separation of the 388.9-nm wavelength, an interference filter (Schott UV-IL, $\lambda = 387.8$ nm, $\Delta\lambda = 8.0$ nm) was used with which the neighboring wavelengths could be suppressed.

The sharp increase of the 3^3P_J excitation function at threshold was calibrated by comparison with the energy of the resonances in the optical excitation function of the transition 6^3P_1-6^1S_0 (253.7 nm) in mercury. The electron beam current at the target was 30 nA with an energy spread of about 250 meV.

From the threshold (23.0 eV) to the first cascade process (from the 4^3S_1 level at 23.59 eV) the theoretical result of Gay, who had predicted a circular polarization η_2 of 49% for the observed line, is confirmed within the uncertainty of 8% of the absolute calibration of our electron polarization. The variations of the data points shown in Fig. 2 are purely statistical errors—two typical error bars are shown—and no significant deviation from

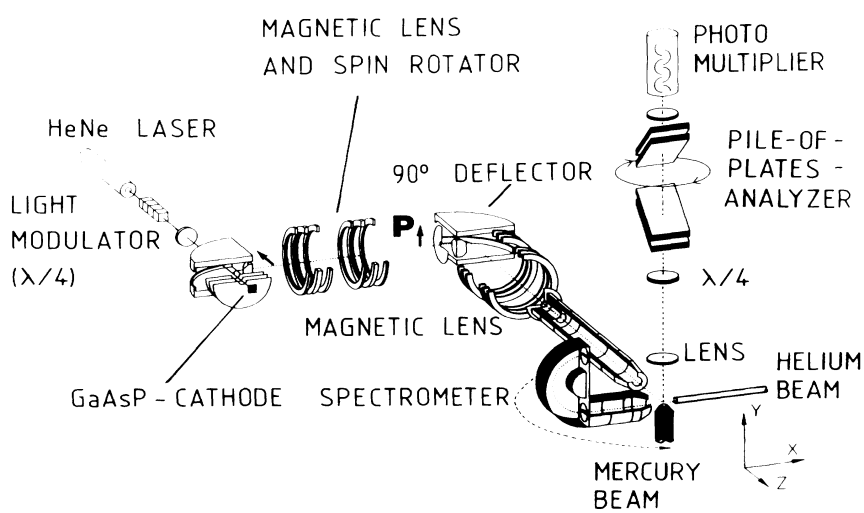

FIG. 3. Schematic diagram of the apparatus.

a constant value of η_2 was observed below 23.59 eV. We also measured a single point at 23.35 ± 0.08 eV—where the counting rate was typically 40 s^{-1}—with much better accuracy (error bar $\pm 0.6\%$). The value of this single point agrees very well with the value $\bar{\eta}_2$ which we obtained by averaging the data from Fig. 2 between 23.0 and 23.59 eV. Above 23.59 eV the analyzing function decreases slightly with increasing electron energy as a result of cascading processes which reduce the value from 49% to 46%. Resonances in the excitation function (He^- states) could not be resolved with the energy spread of our electron beam of 250 meV. Other authors have observed some resonance features, which they identified as doublet states.[10] Spin-orbit effects during the excitation process which might be caused by resonances are not to be expected: The natural widths (> 20 meV) of the observed doublet He^- states are much broader than any fine-structure splitting ($\ll 1$ meV) that they are likely to have, and quartet states cannot be seen in an electron-scattering experiment with He.[10]

In summary, He 3^3P-2^3S_1 radiation is suitable for electron polarimetry mainly for two reasons: (i) There is no significant dependence of the circular light polarization on the incident electron energy. At energy widths of 250 meV (as used here) or larger, no disturbing resonance features have been observed. (ii) There is not much risk in relying on the calculated value of 0.49 for the circular light polarization, as is necessary for an absolute calibration of electron polarization. The theoretical approximations,[6] such as the validity of *LS* coupling, that underlie the numerical value should clearly hold for the light He atom within the 1% uncertainty limit which we eventually anticipate for a calibration of the electron polarimeter.

Finally, we want to point out that it is not the efficiency of this technique which makes it interesting for electron polarimetry. In this respect the Mott detector is superior.[1,11] However, for purposes of calibration, either of a Mott detector or a source of polarized electrons, it seems very promising to follow the course described here.

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