# Positron Differential Elastic-Scattering Cross-Section Measurements for Argon

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Relative elastic differential cross sections are measured for 100- to 300-eV positrons and electrons scattering at 30° to 135° angles from argon atoms in the first crossed-beam experiment to be performed with a positron beam. Good agreement is found with prior electron work and the few available calculations for positrons. The shapes of the positron and electron differential cross-section curves at 100 eV are quite different, but appear to become more similar at 300 eV.

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It is well known that the measurement of differential cross sections (DCS's) for a specific scattering channel will provide a more stringent test of a scattering theory than the measurement of the corresponding total cross section for that specific process. In the rapidly developing field of positron-atom (molecule) scattering where there have been significant recent improvements in slow-positron-beam technology and experimental methods, the focus of experiments during the last few years[1] has been expanding well beyond the measurement of total-scattering cross sections by room-temperature gases to the measurement of total-scattering cross sections for alkali-metal atoms, inelastic cross sections for positronium formation and for atomic excitation and ionization, and some initial measurements of DCS's for elastic scattering. In general, one of the main limitations on doing a wide variety of positron scattering experiments, as have been performed for electron scattering, is the production of sufficiently intense slow positron beams.

In this Letter we report the first application of a crossed-beam experiment for positron-gas scattering, which in this case is employed to measure DCS's for elastic scattering of 100–300-eV positrons by argon at angles from 30° to 135°. All prior positron scattering experiments have employed a relatively static gas target with a considerably larger product of the target-gas number density and the positron-beam path length through the target gas than can be obtained in a crossed-beam experiment. It is also to be noted that the present measurements represent the first positron DCS measurements where the elastically scattered positrons are detected directly at the various angles of scattering. The only prior DCS measurements for positron scattering were made by Coleman and McNutt[2] using a time-of-flight technique where they observed the proportional increase in flight time for magnetically confined 2–9-eV positrons that had been elastically scattered through angles of between 20° and 60° from the incident beam direction as they passed through a target gas cell.

A comparison of the scattering of positrons and electrons by the same atoms (molecules) can be interesting because of the projectile similarities (same magnitude for the mass, charge, and spin) and differences (sign of charge and absence of the exchange interaction for positrons). This comparison was dramatically illustrated for helium where it was found[3] that the positron and electron total-scattering cross sections merge to within 2% for projectile energies above 200 eV, while at 2 eV the electron total cross section is more than 2 orders of magnitude larger.[4] In the case of argon, chosen as the target gas for the present elastic DCS measurements because of its appreciably larger scattering cross sections than those for helium, the measured[3] total-scattering cross sections for positrons at 100 and 300 eV are 18% and 13% lower, respectively, than for electrons. At sufficiently high energies it is expected that the scattering of positrons and electrons will become the same, and it would seem that the comparison of elastic DCS measurements should provide a good test of where this merging does occur.

The experimental setup for the present DCS measurements is shown in Fig. 1 where the projectile positron or electron beam is crossed with an atom beam with the scattered projectiles detected for various angles of scattering with respect to their incident direction. The atom beam effuses from a multichannel capillary array (oriented perpendicular to the projectile beam) with an effusing area that is 2.5 $mm^2$ and an aspect ratio (length:diameter) of 25:1. An MKS Baratron capacitance manometer with an automatic pressure-controlling system is used to maintain a constant head pressure of 9 Torr on the capillary array throughout all of the reported DCS measurements. A 50-mCi sodium-22 radioactive source along with an annealed tungsten moderator[5] (of the backscattering type) is used to produce the primary positron beam having a beam intensity of $> 10^5$/sec at 200 eV and an energy width of about 2 eV, while the more intense electron beam with an energy width of about 3 eV consists of secondary electrons coming from the moderator and source assembly. The projectile energy is established by the bias voltage applied to the moderator. Channeltron electron multipliers (CEM's) are used to detect both the primary (CEM No. 1) and

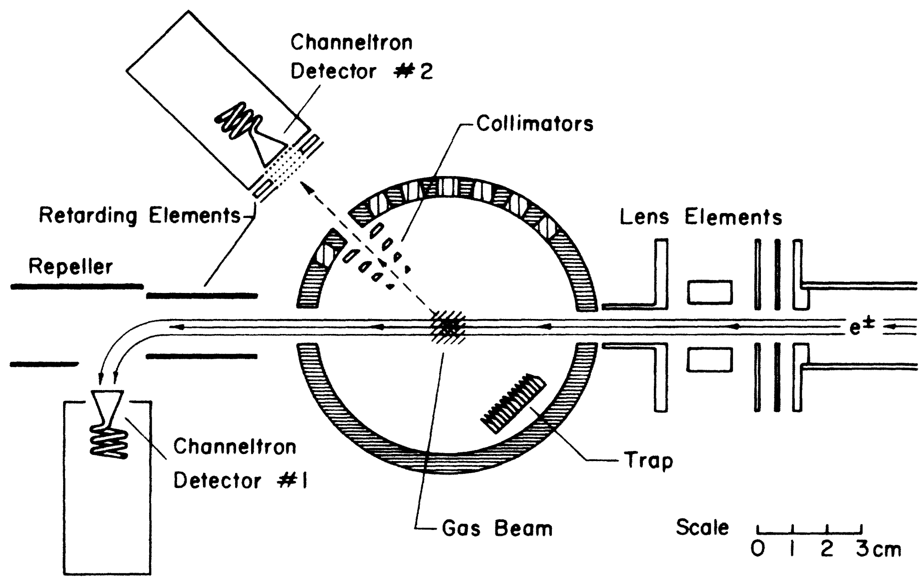


FIG. 1. Schematic diagram of the crossed-beam apparatus for measurement of elastic differential scattering cross sections.

scattered (CEM No. 2) projectiles with CEM No. 1 offset to reduce noise (higher-energy positrons, gamma rays, etc.) coming directly from the sodium-22 source. The vacuum system for this experiment provides differential pumping between the scattering and detector regions. This experiment is performed in a relatively magnetic-field–free region (< 10 mG) with electrostatic fields used to transport, focus, and analyze the projectile beams. The angular acceptance of CEM No. 2 for scattered projectiles is defined by the collimators and estimated from the geometry to be about $\pm 8°$. In order to reduce noise for CEM No. 2 a "nonreflective" trap composed of a stack of knife-edged plates is located diametrically opposite to CEM No. 2. A considerable amount of lead shielding (not shown in Fig. 1) is also used between the sodium-22 source and the CEM detectors to reduce noise.

A retarding element preceding CEM No. 2 is used for separation of the elastic differential scattering signal from other noise counts that are detected. In Fig. 2 are shown retarding-potential curves of the difference signal (with and without the gas beam on) detected with CEM No. 2 at an angular positron of 30° when +100 or −100 V is applied to the source moderator for positrons and electrons, respectively. It is seen that within a few volts of the applied voltage the scattered projectile signal drops rapidly, which corresponds to the elastically scattered projectiles. Since the smallest inelastic energy loss that can occur for a positron or electron scattering from argon, such that the projectile is still detected, is 11.5 eV (associated with excitation of argon), we determined the desired relative elastic-scattering signal $S$ at a given scattering angle and energy by using the expression

$$S = [S_{<g} - S_{<0}] - [S_{>g} - S_{>0}],$$

where $S_{<g}$ and $S_{<0}$ are the signals detected by CEM No. 2 for a retarding potential a few volts below (<) the rapid drop of the retarding curve with ($g$) and without (0) the gas beam present, while $S_{>g}$ and $S_{>0}$ are the signals detected by CEM No. 2 for a retarding potential several volts above (>) the rapid drop with and without the gas beam present. The relative DCS's for each projectile and energy are obtained from the ratio of the signal $S$ to the primary beam signal (detected by CEM No. 1). This ratio ranged from about $10^{-5}$ to $10^{-7}$, while the overall signal-to-noise ratio for CEM No. 2 for positrons varied from typically $10^{-1}$ to $10^{-2}$ for angles greater than 45°. These basic limitations on this experiment required that long counting times (in many cases exceeding several days at a single angle) be used to acquire positron

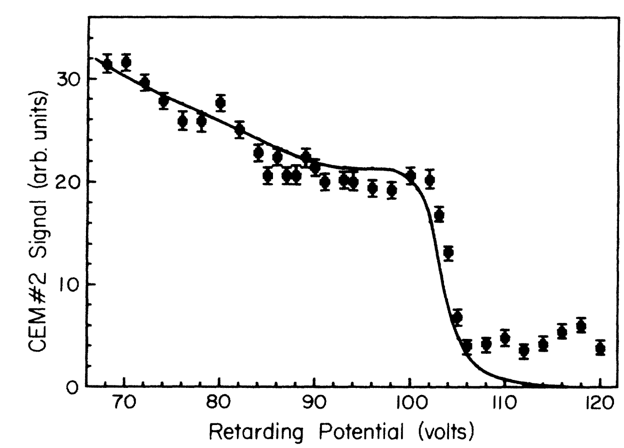


FIG. 2. Retarding-potential curves for positrons (circles) and electrons (line) scattered at 30° and detected by CEM No. 2 for an applied voltage of 100 V to the source moderator.

data with the aid of computer control. Many of the measurements were repeated several different times to check that the results were reproducible. The small signal $S$ was the main reason that a rather large acceptance angle for CEM No. 2 was designed into the apparatus and also the reason that a high head pressure (9 Torr) is used for the capillary-array atom-beam source, even though this could lead to a less than ideal atom beam. As a result, the electron DCS measurements made with this apparatus with the same approach (by mere reversal of the electrostatic potentials on the various beam-controlling elements) provide a very important test of the overall experiment since they can be compared with prior experiments and calculations which have been found to be quite reliable. For comparison purposes the present relative DCS's (for each projectile and energy) are normalized at 90° to prior theoretical or experimental work. A more detailed description of the apparatus and approach will be provided elsewhere.

The present normalized elastic DCS measurements are shown in Figs. 3 and 4 along with some prior measurements (for electrons)[6,7] and some theoretical calculations.[8-10] It is to be noted that in the case of electron scattering only one piece of prior work[6,7,10] at each energy was chosen for comparison in these figures because in each case the work chosen is in very good agreement with other prior work and considered to be reliable. It can be seen that the present electron measurements (which have been normalized at each energy to the prior work at 90°) are in good shape agreement with the prior work over a range of angles at these different energies which exhibits considerable structure and considerable variation in the magnitude of the DCS's. The only noticeable discrepancies are at our smaller angles where our measurements become about a factor of 2 higher at 30° than the prior comparison work. The origin of this discrepancy could be due to the present experiment's nonideal electron beam characteristics (e.g., energy width and source size), rather large angular acceptance of CEM No. 2 (compared with prior electron experiments), or large head pressure that is required on the capillary array to obtain a measurable signal for the positron measurements, or a combination of these effects. The large head pressure could produce a more diffuse gas beam than the effusing area of the array with a resulting angle-dependent effective-path-length error, as investigated for electron-helium differential elastic scattering by Register, Trajmar, and Srivastava,[11] that could give values that are too large for the measured DCS's at angles significantly different from 90°. In general, it is concluded on the basis of the electron measurements that this experiment (designed for positron elastic DCS measurements) is working well with

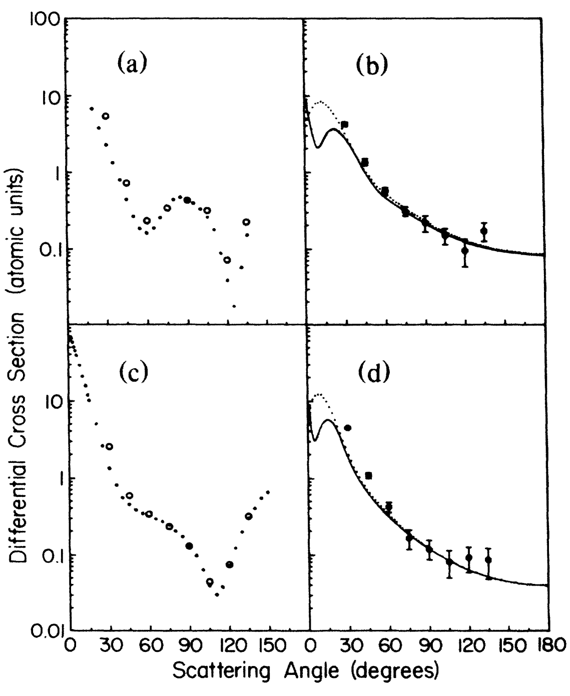


FIG. 3. Present elastic DCS measurements with statistical uncertainties (a) for electrons (open circles) at 100 eV compared with Ref. 6 (dots); (b) for positrons (circles) at 100 eV compared with Ref. 8 (solid line) and Ref. 9 (dotted line); (c) for electrons (open circles) at 200 eV compared with Ref. 7 (dots); and (d) for positrons (circles) at 200 eV compared with Ref. 8 (solid line) and Ref. 9 (dotted line). In each case the present measurements are normalized to the comparison work at 90°.

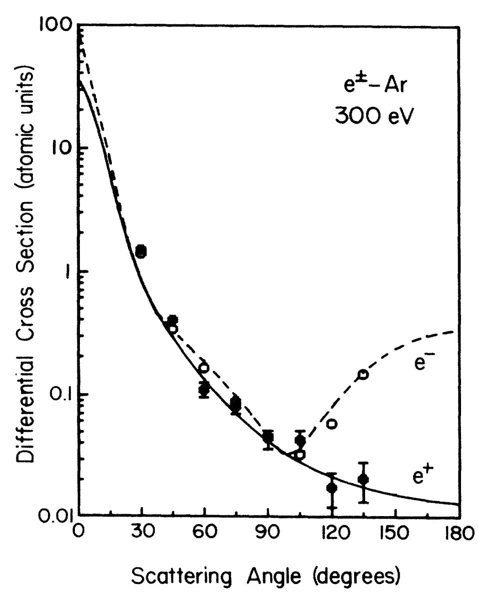


FIG. 4. Present elastic DCS measurements with statistical uncertainties for positrons (filled circles) and electrons (open circles) compared with (and normalized at 90° to) the results from Ref. 10 for positrons (solid line) and electrons (dashed line).

only a possible minor correction being necessary at the smaller angles. Additional investigations are in progress to evaluate the origin of the small discrepancy.

For the case of positron elastic differential scattering from argon at these intermediate energies the only prior work that has been done are calculations by McEachran and Stauffer[8] (using a polarized orbital method), Nahar and Wadehra[9] (using a model potential calculation with one adjustable parameter), and Joachain *et al.*[10] (using an optical-model theory). It is found that the present positron DCS measurements, which are normalized to the calculations at 90°, are in agreement (within the statistical uncertainties of the measurements) with these calculations except at the smallest angles of scattering, where the present measurements may be slightly high for the same unknown reason(s) as is the case for electrons.

In view of the rather close values for the total-scattering cross sections for positrons and electrons by argon from 100 to 300 eV, it is interesting to compare the observed shapes of the respective elastic DCS curves. It is seen that at 100 eV there is very little similarity between the positron and electron DCS curve shapes. Meanwhile, at 300 eV the shapes (and absolute mangitudes as indicated by the theory) of the observed DCS curves are quite similar in the angular range from 30° to 105° with the electron curve than rising at larger angles while the positron curve continues decreasing. For positron scattering at angles less than 30°, inaccessible with the present experimental setup, there are some interesting questions to be resolved in regard to the predicted shapes of the DCS curves in that the calculation of the McEachran and Stauffer[8] indicates a maximum and minimum, the calculation of Nahar and Wadehra[9] suggests only a maximum, and the calculation of Joachain *et al.* has no maximum. An approach that we plan to use to try to resolve at least partially the nature of the positron DCS curve at small angles is to extend our measurements to lower energies where the structure(s) predicted by McEachran and Stauffer[8] and by Nahar and Wadehra[9] shift to larger scattering angles.

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