Measurement of total cross sections for the scattering of positrons by argon and xenon atoms

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Experimentally determined values for total scattering cross sections for e^+-Ar and e^+-Xe collisions in the 2–50 eV range are presented and compared with earlier sets of measurements, between which major discrepancies exist, and with recent theoretical calculations.

Recent advances in the theoretical treatment of the scattering of positrons by atoms other than H and He[1–5] have drawn attention to discrepancies existing in the experimentally determined values of positron total scattering cross sections.[6–8] For example, the positron-argon cross sections measured by Canter *et al.*[7] are approximately 25% higher than those of Kauppila *et al.*[6] over most of the energy range observed, and the preliminary results of Stein *et al.*[8] for xenon show a rapidly rising cross section at positron energies below 4 eV, a feature not present in the results of Canter *et al.*

In view of these discrepancies, the recent measurements of Coleman *et al.*[9] in helium and neon have been extended to include the determination of total cross sections for the scattering of positrons of energies between 2–50 eV by argon and xenon atoms. The time-of-flight (TOF) spectrometer used for the measurements was developed from the original design of Coleman *et al.*[10] and is described by Burciaga *et al.*[11] and, in greater detail, by Coleman *et al.*[9]

Positrons from a ^{22}Na source pass through a thin disk of plastic scintillator into an evacuated flight tube and immediately impinge upon an MgO-coated grid. Approximately 1 in 10^5 of the incident positrons leave the grid with energies in a spectrum of width 1.5 eV, peaked at 1.6 eV, and are accelerated to the desired mean energy by the application of a potential to the coated grid. The positrons move through a 32-cm-long cylindrical flight tube under the influence of an axial magnetic field and, if unscattered, are annihilated on an aluminum target.

Electrical pulses, derived from the detection of (a) light flashes in the source scintillator disk and (b) annihilation radiation from the target, are fed into a standard nanosecond timing spectrometer. The time of flight of each unscattered positron is thereby recorded. The flight tube is curved to enable the insertion of lead shielding between the detector at the target end and the source. By comparing the counts in the peaked time spectra accumulated with and without gas in the flight tube, the attenuation of the beam resulting from positron scattering is measured. From this and from knowledge of the path length in the scattering region and the number density of the target atoms, the total scattering cross section is obtained.

Periodic checks on the exponential dependence of the transmitted beam intensity upon target atom density were performed, with positive results. These checks were not, however, deemed to provide conclusive evidence that little or no forward-scattering errors were present, as the expected deviation from exponentiality ensuing from the detection of forward-scattered positrons would be masked by the statistical deviations on the data points. A more satisfactory treatment of the forward-scattering problem is discussed below.

As a consequence of the extension of the positron energy spectrum over more than 2 eV, cross sections for a range of positron energies are extracted from a single pair of time spectra. The analysis procedure, in which signal spectra are divided into 0.5-eV-wide sections, is described fully by Coleman *et al.*[9] In principle, there should be agreement between cross sections at the same positron energy obtained from different peak pairs. However, argon and xenon cross sections obtained from the long-time (low-energy) sides of the peaks were found to be consistently lower than those at the same energies derived from the short-time (high-energy) sides of peaks centered at lower energies. This effect, which increases in severity as the long-time peak limits are approached, is symptomatic of the detection of positrons scattered through small forward angles and their inclusion with unscattered positrons in the "gas spectra." The time of flight of a positron is increased if it is scattered; consequently, there are more timed scattered positrons in the long-time peak sections, their numbers tending to zero as the short-time limit is approached. Cross sections deduced from sections on the short-time edges are, therefore, closer to the true values. In practice, the numbers of timed scattered positrons were minimized by reducing the strength of the axial magnetic field to its lowest experimentally practical level (transporting about 80% of the positrons to the target *in vacuo*) and the cross section measured at a given positron energy is independent of the position of the corresponding energy section in the short-time halves of different peak pairs, a result which is illustrated in Fig. 1.

A reasonable interpretation of the results represented in Fig. 1 is that scattered positrons are effectively absent from the short-time sides of the peaks; by comparing cross sections at the same energy obtained from the long- and short-time sides of different peak pairs it is estimated that scattered positrons which are unavoidably detected and whose times of flight remain within the time limits of the long-time halves of signal peaks centered at 2, 4, 6, 8, and 10 eV constitute 6, 4, 3, 1, and 0.5% and 5, 6, 5, 5, and 3% of peaks attenuated by argon and xenon, respectively. Reduction of these percentages to 1% or less can be achieved by further reduction of the magnetic field strength to a level which allows transmission of only about 30% of the slow positrons *in vacuo*; however, the loss of statistical precision currently renders this action impractical for cross-section measurement.

The cross sections shown in Figs. 2 and 3 are the means of values obtained from the short-time peak sides only and are compared with recent experimental and theoretical values. The argon results are in good agreement with those of Kauppila *et al.*[6] and are in excellent agreement with the recent semiempirical calculation of the

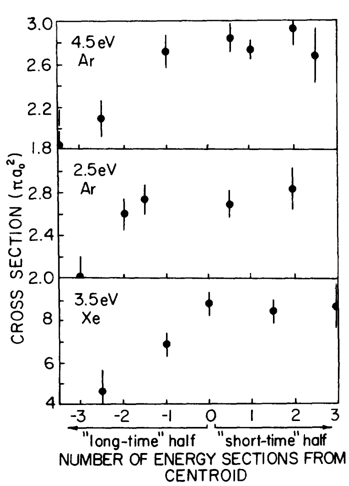

FIG. 1. Total cross sections for positrons of energies 2.5 and 4.5 eV in argon and 3.5 eV in xenon, as a function of the position of the appropriate 0.5-eV-wide energy sections in the peaked signal spectra.

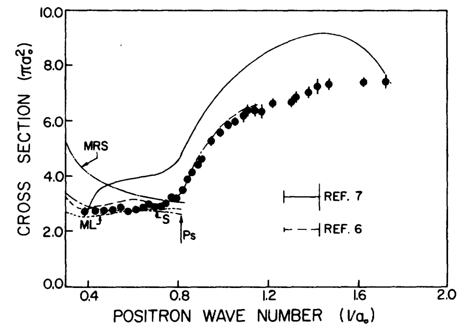

FIG. 2. Total positron-argon scattering cross sections. Deviations lie within the size of the points unless shown. For clarity, the experimental data of Kauppila *et al.* (Ref. 6) and Canter *et al.* (Ref. 7) are represented by the broken and solid lines, with typical error bars at each end of the momentum range shown on the inset. ML: Montgomery and LaBahn (Ref. 12) 3*P-D* (Norm); S: Schrader (Ref. 3); MRS: McEachran *et al.* (Ref. 4).

elastic scattering cross section by Schrader[3] and an earlier polarized orbital calculation of Montgomery and LaBahn.[12]

For xenon the results resemble those of Canter *et al.*[7] between 3–17 eV (ka_0 = 0.47–1.1) and the sharp increase at low positron energies reported by Stein *et al.*[8] is not present. Above 17 eV the cross sections of Canter *et al.* decrease because no allowances were made for forward scattering. The discrepancies between the present xenon measurements and those of Stein *et al.* might be thought to result from the different abilities of the experimental systems to differentiate clearly between unscattered positrons and those scattered through small forward angles. However, in order to account for the 1:1.7 ratio between the present results and those of Stein *et al.* at 2 eV (ka_0 = 0.38), for example, the TOF of over 30% of the positrons

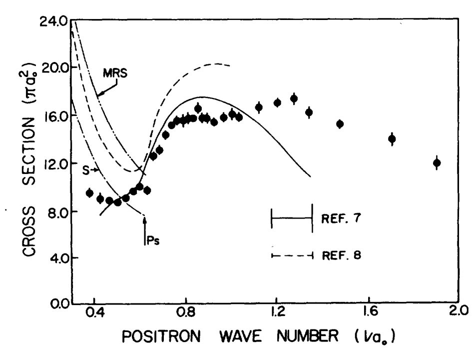

FIG. 3. Total positron-xenon scattering cross sections. Presentation of data follows the conventions of Fig. 2. The measurements of Canter *et al.* (Ref. 7) are not corrected for forward-scattering effects. MRS: McEachran *et al.* (Ref. 5).

scattered from the short-time half of the peaked time distribution must remain within the time limits of that half. The implication of this high percentage figure would be that the angular distribution of positrons scattered by xenon atoms is peaked more strongly and at smaller forward angles than the distribution for argon. However, the calculations of Schrader[3] show that the angular distribution of 2-eV positrons scattered by xenon is very similar to that for argon. For example, 30% of positrons scattered by xenon are deflected through angles of less than 18° and by argon through less than 20°. An explanation of the large divergence of the experimental results for xenon at low energies founded on forward-scattering errors is not, therefore, supported by the good agreement between the present results in argon and those of Kauppila *et al.*[6] in the same energy range.

An estimate of the upper limit of the angular discrimination, or resolution, of the present apparatus may be gained by calculating the scattering angle which produces an increase in the measured TOF large enough to move positrons scattered at the midpoint of the flight tube from the short-time limit to beyond the center of the short-time half of a time spectrum. This angle, which varies slightly with energy, is about 20°, and would apply if all forward-scattered positrons were constrained to reach the target. The saturation behavior of the cross sections on the short-time sides of the plots shown in Fig. 1 suggests that, in practice, the use of a weak axial magnetic field substantially reduces the numbers of scattered positrons reaching the end of the flight path and whose TOF remains in the short-time halves of the time spectra. This would tend to make the angular discrimination somewhat better than indicated above.

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