Total-Scattering Measurements and Comparisons for Collisions of Electrons and Positrons with N_2O

Ch. K. Kwan, Y.-F. Hsieh, W. E. Kauppila, Steven J. Smith, T. S. Stein, and M. N. Uddin
Department of Physics and Astronomy, Wayne State University, Detroit, Michigan 48202

and

M. S. Dababneh
Department of Physics, Yarmouk University, Irbid, Jordan
(Received 12 December 1983)

Total cross sections (Q_T) for 1–500-eV positron and electron scattering by N_2O are measured by a beam-transmission method. Comparisons of these results with prior electron and positron measurements of Q_T for CO_2, N_2, and CO, made by our group, reveal several remarkable similarities in the shapes and magnitudes of the Q_T curves for the triatomic and also for the diatomic molecules. Small differences in the absolute Q_T values for N_2O and CO_2, and for N_2 and CO, may be due to the weak permanent dipole moments of N_2O and CO.

PACS numbers: 34.80.-i

It has been known for some time that certain molecules, because of their similar structure and geometry, scatter electrons in intriguingly similar ways. An example is the isoelectronic pair N_2 and CO. A number of authors have commented on a variety of processes in which N_2 and CO give remarkably similar results for electron scattering: Hake and Phelps[1] have observed that the transport properties of electrons in CO resemble those in N_2; Schulz[2] has commented on their similarities for resonance formation and vibrational excitation; Onda and Truhlar[3] have discussed their similar behavior in rotational excitation; and Bromberg[4] and Dubois and Rudd[5] have recognized similarities in their elastic differential cross sections at higher energies. Recent theoretical calculations for electron scattering from these molecules by Jain[6] and Tayal *et al.*[7] have found interesting similarities in the elastic differential, integral, and momentum transfer cross sections in the 40–800 eV energy range. Measurements of Q_T for these gases performed in our laboratory[8,9] have not only confirmed the findings of Jain regarding electron Q_T's but also have shown that many of the conclusions concerning the Q_T's for electrons can be extended to those of positron Q_T's on these gases as well (see Ref. 9 for a detailed discussion). In order to investigate further the possibility that other molecules may have similar characteristics, we choose for comparison the following pair of molecules in the N-O-C family: N_2O and CO_2. They are isoelectronic, linear in their ground states, and formed by adding an oxygen atom to N_2 and CO, respectively.

In this paper we present measurements of the total cross sections for electron and positron scattering by N_2O in the energy range of 1–500 eV. This is the first time that total cross sections have been reported for positron impact on nitrous oxide. In addition, no Q_T data have been available for the e^--N_2O system at energies beyond 50 eV.

This work constitutes an extension of the experimental studies being pursued in this laboratory on electron and positron total-scattering cross sections by gases using a beam-transmission method; detailed descriptions of the apparatus, experimental procedure, and error analysis have previously been reported.[10,11] The primary difference in the electron and positron measurements of Q_T is that the positron beam originates from an ^{11}C positron source (produced by bombardment of a polycrystalline ^{11}B target with a 4.75-MeV proton beam from a Van de Graaff accelerator), while the electron beam is produced by a thermionic electron source. The energy widths for both the e^+ and the e^- beams are about 0.1 eV. Using the method of Kauppila *et al.*,[11] we estimate that the experimental errors for our present absolute electron Q_T results range from 5% at 1.2 eV to 3% at 500 eV and for the e^+-N_2O Q_T results, range from 6% to 4%, respectively. The errors for comparisons of our electron and positron data are smaller than the absolute Q_T errors because of the fact that several of the error components affect the electron and positron measurements in the same way. For the same reason, this is also true when comparing our results for different gases. We estimate that the total errors in the comparisons of our electron and positron measurements (and in our comparisons for different gases) is 3%

for electrons and 4% for positrons. However, the above estimates do not include the potential source of error associated with incomplete discrimination against projectiles scattered at small angles in the forward direction. Depending on the extent that forward-angle scattering occurs, our measured results may be lower than the actual total cross sections. Following the procedure elaborated by Kauppila *et al.*,[11] the discrimination angle ranges from 20° at 2 eV to 8° at 500 eV for the present e^+ measurements, and ranges from 11° at 2 eV to 5° at 500 eV for the e^- work. In order to estimate the extent that small-angle scattering could affect our Q_T results, detailed information on the differential scattering cross section would be needed. We note also that with the use of a retarding element after the scattering region, there is complete discrimination against projectiles scattered with an energy loss of more than a few tenths of an electronvolt.

In Fig. 1 we compare our present low-energy e^--N_2O Q_T measurements with earlier measurements by Bruche,[12] Ramsauer and Kollath,[13] and Zecca *et al.*[14] Our measurements agree quite well with the measurements of Bruche, except at the peak (2.3 eV) of the shape resonance where our Q_T values are about 25% higher. The results of Zecca *et al.* (which were normalized to those of Bruche at 4 eV) show a much less pronounced shape resonance than the present measurements and those of Bruche.

The complete set of present Q_T measurements for e^+ and e^- scattering by N_2O are shown in Fig. 2 along with prior (e^+,e^-)-CO_2 Q_T measurements.[8,9] It is seen that above 5 eV the shape and magnitude of the Q_T results for both N_2O and CO_2 are very similar for each respective projectile. In fact, the electron Q_T curves are particularly close to each other (within a few percent) above 5 eV. Meanwhile, the e^+-N_2O Q_T results tend to be slightly, but noticeably, higher than those for the e^+-CO_2 system with the discrepancy ranging from 8% in the vicinity of 30 eV to 1% at 500 eV. At the lowest energies (< 5 eV) the internal structure of the target molecule plays a more prominent role in the collision process, and it would be expected that for different gases the differences in the Q_T's will be more pronounced there. Nevertheless, the comparison in Fig. 2 of the present results with those of Hoffmann *et al.*[8] for (e^+,e^-)-CO_2 scattering at these low energies show that all the features discussed there are also present for N_2O scattering. For electron scattering there are prominent shape

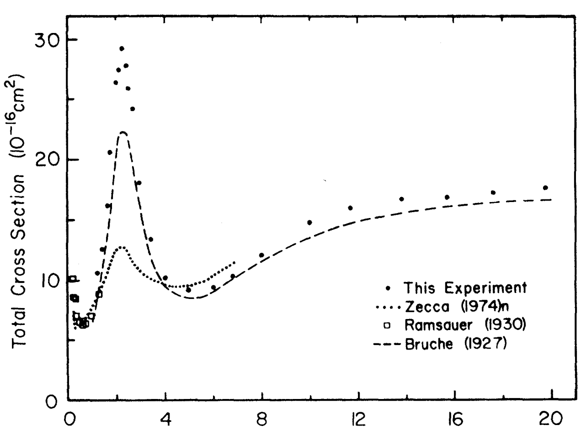

FIG. 1. Low energy e^--N_2O total–cross-section measurements. The present results are shown with the measurements of Bruche (Ref. 12), Ramsauer and Kollath (Ref. 13), and Zecca *et al.* (Ref. 14). The "*n*" refers to normalized measurements.

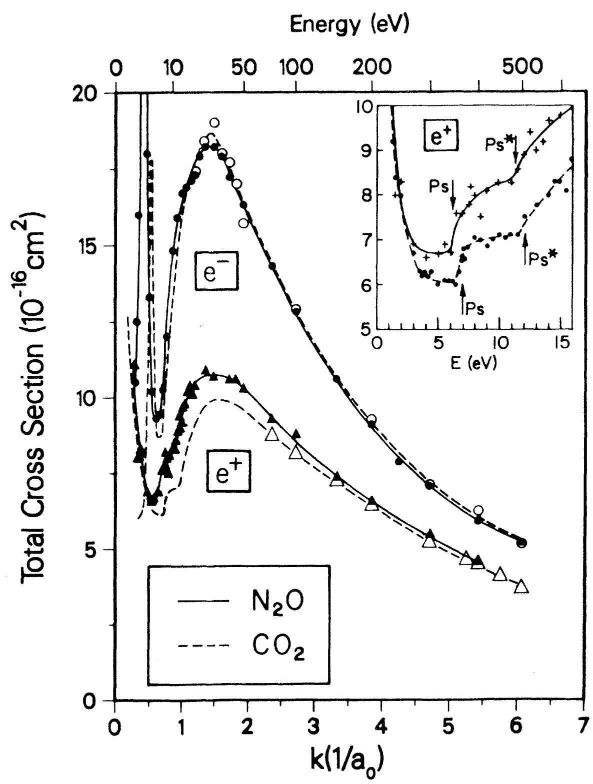

FIG. 2. Comparison of (e^+,e^-)-N_2O and (e^+,e^-)-CO_2 total cross sections up to intermediate energies. The present measurements of (e^+,e^-)-N_2O total cross sections are compared with the CO_2 results of Hoffman *et al.* (Ref. 8) and Kwan *et al.* (Ref. 9). The threshold energies for formation of positronium in the ground and first excited states are indicated by the arrows labeled Ps and Ps*, respectively (inset).

resonances at 2.3 and 3.8 eV for N_2O (of $^2\Sigma^+$ symmetry) and CO_2 (of $^2\Pi_u$ symmetry), respectively—a feature which is absent for positron scattering from these gases. Beyond these shape resonances, the e^- total cross sections increase and reveal a broad maximum around 25 eV for N_2O and 30 eV for CO_2. It is interesting that broad shape resonances at intermediate energies (10–40 eV) caused by higher excited states of the negative molecular ion are not uncommon for electron-molecule scattering, as has been discussed by Lynch *et al.*[15] for CO_2, OCS, and CS_2. They suggest a possible enhancement of vibrational excitation at these resonances. Total-cross-section measurements, however, may be too insensitive to detect these effects.

In the case of positrons the Q_T curves for N_2O and CO_2 also reveal similar qualitative features. The Q_T's increase rapidly below 2 eV. Both curves show an abrupt rise ("bump") at the positronium formation thresholds of 6.25 eV for N_2O and 7.0 eV for CO_2 suggesting a significant increase of inelastic scattering (due to positronium formation) at these energies, which is consistent with our earlier measurements for other gases.[8–10] It is curious that the overall increases of the Q_T's from the positronium formation thresholds for N_2O and CO_2 are not as large as for most of the other gases that have been studied up to the present time. There appears to be a second statistically significant increase in the Q_T curves for N_2O and CO_2 at an energy of about 5 eV above each positronium formation threshold (see inset of Fig. 2). Since the first excited state of positronium is 5.1 eV above the ground state, these latter increases in the Q_T curves may be due to the formation of positronium in the first excited state.

It is relevant to the present discussion that comparisons between prior electron and positron measurements of Q_T for N_2 and CO by our group,[8,9] which are shown together in Fig. 3, indicate a very similar situation as we have observed for N_2O and CO_2, in that there are striking similarities and some small differences in the shapes and magnitudes of the respective Q_T curves. For electron scattering both the N_2 and CO Q_T curves exhibit shape resonances at low energies and agree to within a few percent of each other for electron energies above 10 eV. For positron scattering both of the Q_T curves are increasing at the lowest energies and exhibit appreciable increases after the positronium formation threshold.

In comparing the electron and positron Q_T magnitudes for the diatomic and triatomic molecules in Figs. 2 and 3, it is intriguing that both of the polar molecules, CO and N_2O (with dipole moments of

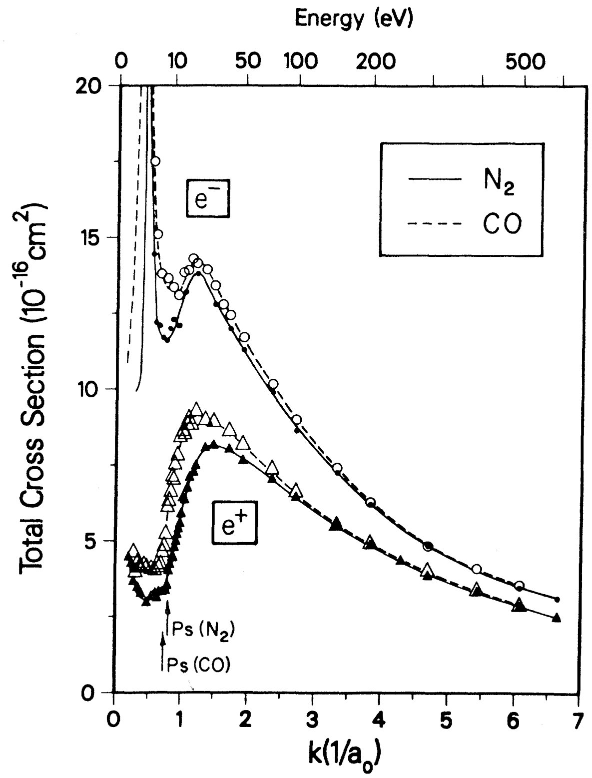

FIG. 3. Comparison of (e^+,e^-)-N_2 and (e^+,e^-)-CO total cross sections up to intermediate energies. The (e^+,e^-)-N_2 results are from Hoffman *et al.* (Ref. 8) and the (e^+,e^-)-CO results from Kwan *et al.* (Ref. 9). The threshold energies for formation of positronium in the ground state are indicated by the labeled arrows.

0.112 and 0.167 D,[16] respectively), have noticeably larger Q_T's for positron scattering than the corresponding nonpolar molecules, N_2 and CO_2. Meanwhile, the Q_T's for electron scattering by these two pairs of molecules are much closer to each other than for positrons. These observations raise some interesting questions as to what role the permanent dipole moment plays in positron and electron scattering by these molecules and why there is a more pronounced effect for positrons. The Q_T differences for positrons may be related to the positronium channel (which is open only to positrons), although the Q_T differences also are seen to exist below the positronium formation thresholds. In electron differential elastic scattering cross section measurements for N_2 and CO, Bromberg[4] has found that in the energy range 300–500 eV there are no significant differences in the differential cross sections at a particular energy for scattering angles greater than 12°, while at smaller angles the CO cross sections rise at a slightly faster rate than for N_2. This observation led Bromberg to suggest that these small differences may be attributable to the permanent dipole moment of CO, which has been supported in the recent theoretical work by Tayal *et al.*[11] In view of this information, it is likely that the e^--CO Q_T results may be slightly larger than the e^--N_2 results because of the additional small-angle elastic scattering for CO. As a result of the lack of theoretical work and any more detailed experimental work (than Q_T measurements) on positron scattering by CO, N_2 CO_2, and N_2O, it can only be speculated that the larger differences in the Q_T measurements for positron scattering than for electron scattering by N_2O and CO_2, and by N_2 and CO, may result from the permanent dipole moments of N_2O and CO having a greater effect on positron scattering. It would seem that these latter comparisons and the possible evidence for formation of postronium in the first excited state for positron scattering by N_2O and CO_2 should provide a stimulus for future experimental and theoretical work.

We are grateful to D. Jerius for his untiring help in various aspects of this project and to Dr. J. M. Wadehra for useful discussions concerning this work. This work was supported by the National Science Foundation under Grant No. PHY80-07984.

[1]R. D. Hake, Jr., and A. V. Phelps, Phys. Rev. **158**, 70 (1967).

[2]G. J. Schulz, in *Principles of Laser Plasmas,* edited by George Bekefi (Wiley, New York, 1976), Chap. 2.

[3]K. Onda and D. G. Truhlar, J. Chem. Phys. **73**, 2688 (1980).

[4]J. P. Bromberg, J. Chem. Phys. **52**, 1243 (1970).

[5]R. D. Dubois and M. E. Rudd, J. Phys. B **9**, 2657 (1976).

[6]Ashok Jain, J. Phys. B **15**, 1533 (1982).

[7]S. S. Tayal, Ashok Jain, A. N. Tripathi, and M. K. Srivastava, J. Chem. Phys. **78**, 3021 (1983).

[8]K. R. Hoffman, M. S. Dababneh, Y. F. Hsieh, W. E. Kauppila, V. Pol, J. H. Smart, and T. S. Stein, Phys. Rev. A **25**, 1393 (1982).

[9]Ch. K. Kwan, Y. F. Hsieh, W. E. Kauppila, S. J. Smith, T. S. Stein, M. N. Uddin, and M. S. Dababneh, Phys. Rev. A **27**, 1328 (1983).

[10]T. S. Stein, W. E. Kauppila, V. Pol, J. H. Smart, and G. Jesion, Phys. Rev. A **17**, 1600 (1978).

[11]W. E. Kauppila, T. S. Stein, J. H. Smart, M. S. Dababneh, Y. K. Ho, J. P. Downing, and V. Pol, Phys. Rev. A **24**, 725 (1981).

[12]E. Bruche, Ann. Phys. (Leipzig) **83**, 1065 (1927).

[13]C. Ramsauer and R. Kollath, Ann. Physik (Leipzig) **7**, 176 (1930).

[14]A. Zecca, I. Lazzizzera, M. Krauss, and C. E. Kuyatt, J. Chem. Phys. **61**, 4560 (1974).

[15]M. G. Lynch, D. Dill, J. Siegel, and J. L. Dehmer, J. Chem. Phys. **71**, 4249 (1979).

[16]R. D. Nelson, Jr., D. R. Lide, Jr., and A. A. Maryott, *Selected Values of Electric Dipole Moments for Molecules in the Gas Phase,* U. S. National Bureau of Standards, National Standard Reference Data Series—10 (U. S. GPO, Washington, D. C., 1967).