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Absolute total cross section measurement for electron scattering on N_2O in the energy range 600–4250 eV

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Abstract. Absolute total cross sections for electron scattering on nitrous oxide (N_2O) molecules have been measured between 600 and 4250 eV. It has been noticed that N_2O and carbon dioxide exhibit similarities in the energy dependence of their total cross sections. The results have been compared with available theoretical and experimental results. No previous data for impact energies above 500 eV have been found in the literature.

1. Introduction

The knowledge of the total cross sections for electron scattering (TCSES) from atoms and molecules is very important for testing various models of electric and magnetic interactions. The data of TCSES are also important to developing subjects such as astrophysics, atmospheric physics, plasma physics and chemical physics. Up to now in the intermediate, and especially in the high, energy range, most theoretical results for TCSES obtained using the Born approximation (Inokuti and McDowell 1974) and the Born–Bethe theory (Inokuti 1971) are in good agreement with experimental data. It is therefore of interest to use experimental absolute TCSES and their fitted parameters to check the suitability of these theories (Jain and Baluja 1992, Zecca *et al* 1995, Garcia *et al* 1996). In recent years, nitrous oxide (N_2O) has attracted increasing interest due to its role in a number of important processes. For example, N_2O has been found to be important in the chemistry of the upper atmosphere where it may play roles in the destruction of the ozone layer (Wang and Sze 1980). Moreover, N_2O has been used in lasers, and in medicine as an anaesthetic.

In the past a number of measured TCSES from N_2O were reported by Brüche (1927a), Ramsauer and Kollath (1930b), Zecca *et al* (1974), Kauppila *et al* (1983) and Szmytkowski *et al* (1984). In the theoretical calculations for TCSES from N_2O, Joshipura and Patel (1994) first presented results followed by Liu (1997). We have measured the TCSES from N_2O in the energy range 600–4250 eV. No previous experimental TCSES from N_2O for impact energies above 500 eV can be found in the literature.

2. Experiment

2.1. Experimental set-up

The experimental set-up is similar to that described in previous work (Xing *et al* 1995, 1997) and will only briefly be mentioned here. The 202 mm long collision chamber (CC)

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and 70 mm long drift distance between the CC and the analyser allowed measurements with an angular resolution of 6.3×10^{-5} sr. We renewed the power system and the gas adjustor, and improved the differential pumping to enable measurements at high energy. The analyser, with a retarding field, avoids the contribution of inelastic scattering to TCSES. The gas pressure in the CC was measured with an absolute capacitance manometer (MKS Baratron 127A). The pressure in the region of the gun and analyser was maintained at less than 2.5×10^{-5} Pa during the measurements.

2.2. Procedure

The principle of the measurement of TCSES (σ_t) using a transmission technique is based on the following law:

$$\sigma_t = (NL)^{-1} \ln(I_0/I_c) \tag{1}$$

where N is the atomic density obtained from the temperature inside the CC and the gas pressure in the CC, L is the interaction-region length when a beam passes through gas, and (I_0/I_c) is the ratio of the beam intensity in front of and behind the CC. Equation (1) is not strictly valid for making the actual measurement because of small-angle scattering. By extrapolating the experimental elastic differential cross sections (Johnstone and Newell 1993, Marinkovic *et al* 1986) and comparison with the elastic differential cross sections from N_2O and CO_2, we estimated the maximum relative contributions of the elastic small-angle scattering to TCSES to be less than 0.3% for N_2O for our experimental conditions. In order to minimize experimental error, the measurements of (I_0/I_c) were performed in alternatively vacuum and gas-feed CC conditions. Then equation (1) is replaced by equation (2):

$$\sigma_t = -(NL)^{-1} \ln[(I_c/I_0)_g/(I_c/I_0)_v] \tag{2}$$

where $(I_c/I_0)_g$ and $(I_c/I_0)_v$ are the ratios between the transmission- and primary-beam intensity with and without gas feed in the CC. The temperature inside the CC was estimated from the outside. Eight pressures were measured in one run. Final values given in this work were weighted means of two or three runs for most energies. The pressure value was chosen according to $(I_c/I_0)_g$ and was in the pressure range 0.04–1.4 Pa. The temperature range outside the CC was between 290 and 301 K and the MKS sensor head was maintained at 318 K. The pressure correction for the thermal transpiration was made by the semiempirical formula of Takaishi and Sensui (1963). Detailed descriptions of our other experimental procedures have been reported (Xing *et al* 1995).

2.3. Error evaluation

Both I_c and I_0 currents were measured by the same instrument (model D-88 microgalvanometer). The error introduced was limited to the nonlinearity error. It was evaluated to be less than 0.5%.

The accuracy of the pressure measurements was assumed to be better than 1%, as stated by the manufacturer of the manometer. The errors made in pressure correction for the thermal transpiration effect were estimated to be less than 0.5%. The errors caused by the instability of gas feed and power supply were all less than 0.5%, and that by the instability of beam intensity produced by the pressure disequilibrium on the beam line was less than 1%.

The uncertainty in the interaction-region length was estimated to be less than ± 2.5 mm and this results in an error in the cross section of less than 1.5%. Its maximum uncertainty occurred when the pressure in the CC was at its maximum.

Table 1. Absolute total cross section for electron scattering on N_2O (in 10^{-20} m^2). Total errors are given in per cent.

Energy (eV)	Cross section	Error	Energy (eV)	Cross section	Error
600	4.44	5.0	2000	1.77	5.0
650	4.19	4.3	2200	1.62	5.3
700	3.99	4.6	2400	1.52	4.5
800	3.65	4.4	2600	1.40	4.3
900	3.32	4.0	2800	1.36	4.8
1000	3.05	4.0	3000	1.27	4.5
1100	2.80	4.3	3250	1.19	4.5
1200	2.71	4.5	3500	1.12	5.4
1300	2.54	5.0	3750	1.11	5.2
1400	2.35	5.0	4000	1.05	5.5
1600	2.12	4.8	4250	1.01	5.5
1800	1.91	5.2			

The error produced by observational errors was less than 1% and its maximum occurred when the I_c was at a minimum.

The errors resulting from the uncertainty of the electron energy definition was less than 0.3%. That estimated for the relative contributions of the elastic small-angle scattering together with the multiple scattering to TCSES was less than 0.5%. The gas purity for N_2O was 99.9%.

From the above the overall systematic error of the measurements is less than 2.5% and the typical statistical error is lower than 3%.

3. Results and discussion

Results of the present measurements are given in table 1 and are compared with the theoretical results and available experimental cross sections above 100 eV in figure 1. As seen from figure 1, the trend of the experimental results of Kauppila *et al* (1983) at intermediate energy agrees with ours. The theoretical results of Joshipura and Patel (1994) above 400 eV are in agreement with the results of Kauppila *et al* (1983) (within 5%) and with our results in the energy range 600–1000 eV (within 3%). The calculated values of Liu (1997) are higher than our results by 19% at 600 or 1000 eV, 15% at 2000 eV, 11% at 3000 eV and 3% at 4000 eV.

4. Comparison between N_2O and CO_2 TCSES

Some time ago Brüche (1927) and Ramsauer and Kollath (1930) pointed out qualitative similarities in the energy dependence of total cross sections for pairs of isoelectronic molecules like CO–N_2 and CO_2–N_2O. Kwan *et al* (1984) compared their own total cross section measurements for N_2O with the CO_2 total cross sections of Hoffman *et al* (1982) and Kwan *et al* (1983), and found good agreement between the σ_t measurements of the two molecules in the energy range 15–500 eV. In the energy range 600–4250 eV comparison of our e^-–N_2O σ_t with the e^-–CO_2 σ_t of Garcia *et al* (1996), Szmytkowski *et al* (1987) and Xing (1997) is provided in figure 2. From this figure it is seen that in the energy range 600–4250 eV the e^-–CO_2 σ_t are larger than the e^-–N_2O σ_t at lower energies; in the intermediate-energy range the e^-–N_2O σ_t are slightly larger than the e^-–CO_2 σ_t, and in the

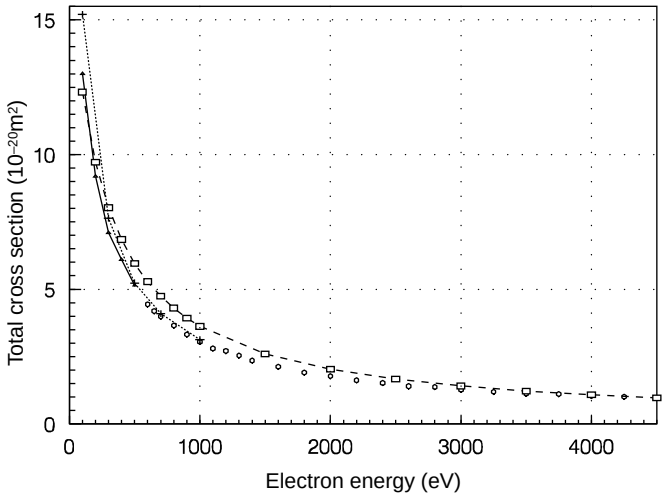

Figure 1. Comparison of calculated e^-–N_2O total cross section with the experimental data. ○ present work, —▲— Kauppila *et al* (1983), – –□– – Liu (1997), · · · + · · · Joshipura and Patel (1994).

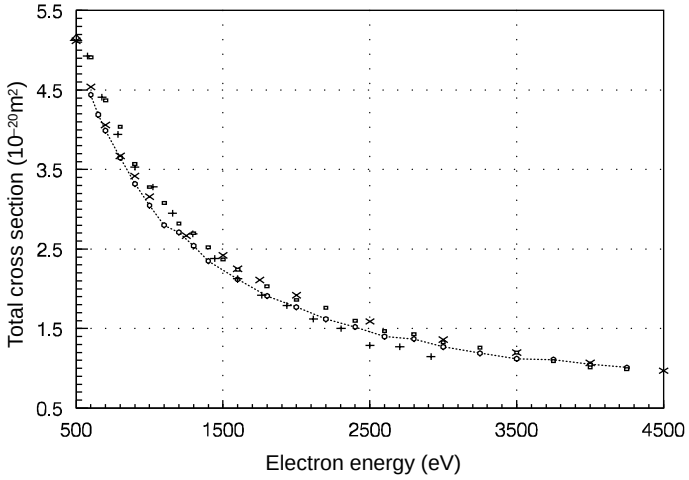

Figure 2. Comparison of the experimental total cross sections for electron scattering on N_2O and CO_2. · · ·○· · · present work, N_2O; △ Kauppila *et al* (1983), N_2O; □ Xing *et al* (1997), CO_2; × Garcia *et al* (1996), CO_2; + Szmytkowski *et al* (1987), CO_2.

high-energy range the e^-–N_2O σ_t and e^-–CO_2 σ_t are close to each other. The calculated TCSES data of Liu (1996, 1997) for CO_2 and N_2O exist in the analogous case. Using our measurements, the TCSES for CO_2 are larger than those for N_2O (Xing 1997) by 10.6% at 600 eV, 7.5% at 1000 eV, 5.1% at 2000 eV and 4.7% at 3000 eV, and the TCSES for CO_2 are lower than for N_2O by 1.8% at 3750 eV, 3.8% at 4000 eV and 2% at 4250 eV.

A few parameters of both molecules are listed in table 2 (Lide 1990) and, as can be seen, the differences in these physical parameters between CO_2 and N_2O are very small except for the dipole moment. In order to further understand the dependence of the TCSES on incident electron energy and the relation between the TCSES and the physical parameters

Table 2. Some physical parameters of the studied molecules.

	Number of electrons	Bond length (Å)	Bond angle (deg)	Dipole moment (Debye)	Polarizability ($Å^3$)
CO_2	22	1.162	180	0	2.911
N_2O	22	1.126[a]/1.186[b]	134	0.167	3.03

[a] For N–N.
[b] For N–O.

including the potential, more experimental data and further theoretical calculations for the TCSES in the intermediate- and high-energy ranges are necessary.

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References

Brüche E 1927a *Ann. Phys.* **83** 1065
——1927b *Ann. Phys.* **83** 70
Garcia G and Manero F 1996 *Phys. Rev.* A **53** 250
Hoffman K R, Dababneh M S, Hsieh Y-F, Kauppila W E, Pol V, Smart J H and Stein T S 1982 *Phys. Rev.* A **25** 1393
Inokuti M 1971 *Rev. Mod. Phys.* **43** 297
Inokuti M and McDowell M R C 1974 *J. Phys. B: At. Mol. Phys.* **7** 2382
Jain A and Baluja K L 1992 *Phys. Rev.* A **45** 202
Johnstone W M and Newell W R 1993 *J. Phys. B: At. Mol. Opt. Phys.* **26** 129
Joshipura K N and Patel P M 1994 *Z. Phys.* D **29** 269
Kauppila W E, Dababneh M S, Hsieh Y-F, Kwan Ch K, Smith S J, Stein T S and Uddin M N 1983 *Proc. 13th Int. Conf.on the Physics of Electronic and Atomic Collisions (Berlin)* ed J Eichler *et al* (Amsterdam: North-Holland) Abstracts p 303
Kwan Ch K, Hsien Y-F, Kauppila W E, Smith S J, Stein T S, Uddin M N and Dababneh M S 1983 *Phys. Rev.* A **27** 1328
——1984 *Phys. Rev. Lett.* **52** 1417
Lide D R 1990 *CRC Handbook of Chemistry and Physics* 71st edn (Boca Raton, FL: Chemical Rubber Company)
Liu Yufang 1996 Private communication
——1997 Private communication
Marinkovic B, Szmytkowski Cz, Pejcev V, Filipovic D and Vuskkovic I 1986 *J. Phys. B: At. Mol. Phys.* **19** 2365
Ramsauer C and Kollath R 1930a *Ann. Phys.* **4** 91
——1930b *Ann. Phys.* **7** 176
Szmytkowski Cz, Karwasz G and Maciag K 1984 *Chem. Phys. Lett.* **107** 481
Szmytkowski Cz, Zecca A, Karwasz G, Oss S, Maciag K, Marinkovic B, Brusa R S and Grisenti R 1987 *J. Phys. B: At. Mol. Phys.* **20** 5817
Takaishi T and Sensui Y 1963 *Trans. Faraday Soc.* **59** 2503
Wang W and Sze N D 1980 *Nature* **286** 589
Xing S L, Shi Q C, Chen X J, Xu K Z, Yang B X, Wu S L and Feng R F 1995 *Phys. Rev.* A **51** 414
Xing S L, Yu C Q, Shi Q C, Zhang F, Yao L Q, Ma T Q and Xu K Z 1997 *Chin. J. At. Mol. Phys.* **14** 294
Zecca A, Karwasz G P and Brusa R S 1992 *Phys. Rev.* A **45** 2777
Zecca A, Lazzizzera I, Krauss M and Kuyatt C E 1974 *J. Chem. Phys.* **61** 4560
Zecca A, Nogueira J C, Karwasz G P and Brusa R S 1995 *J. Phys. B: At. Mol. Opt. Phys.* **28** 477