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Transport coefficients and cross sections for electrons in N_2O and N_2O/N_2 mixtures

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Abstract
A standard swarm analysis of electron scattering cross sections in nitrous oxide (N_2O) is presented. The experimental results for drift velocities and effective ionization coefficients (differences between the ionization and attachment coefficients), obtained over an extended range of E/N (electric field normalized to the gas number density) by the pulsed-Townsend technique, are compared with the numerical solution of the Boltzmann equation. Our analysis shows that commonly used sets of cross sections have to be modified in order to fit the new experimental data, in particular the dissociative cross sections for attachment and electronic excitation (with a threshold energy of around 4.0 eV). Using a single set of cross sections it was possible to fit both the data for pure N_2O and those for the N_2O/N_2 mixtures with 20%, 40%, 60% and 80% N_2O.

S Online supplementary data available from stacks.iop.org/PSST/19/025005/mmedia

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Because of its involvement in the nitrogen cycle, nitrous oxide (N_2O) is produced by both natural and human-related sources (fossil fuels and solid waste combustion, fertilizers, industrial processes). N_2O has been used in medicine as an anesthetic, in laser technology, for N-doping of oxide materials [1], deposition of diamond-like carbon films [2] and even suggested as a possible replacement for some gases which are being used in the electrical industry as gaseous insulators. Renewed interest in this molecule is due to its role in the greenhouse effect [3–5], with approximately 120 years of lifetime in the stratosphere and a high global warming potential (GWP) of 310 (as a reference, the GWP of $CO_2 = 1$). N_2O is also an ozone depleting substance [6]. Although the concentration of N_2O in the atmosphere is much lower (319 ppb) than that of carbon dioxide and methane, many efforts are being made in order to decompose this gas in exhaust gases (together with other nitrogen oxides, NO_x) by means of electrical discharges, and thereby reduce the damage and pollution it causes. Despite the fact that N_2O has been the subject of many scientific and applied studies since the first half of the past century [7, 8] to date, it appears that rather significant discrepancies between the existing cross section data sets still exist [9]. Recently, electron collisions in nitrous oxide have been discussed by Zecca *et al* [10] and Mechlińska-Drewko *et al* [11]. The need for more detailed and reliable cross sections has been stressed by the Landolt–Börnstein compilation [12] and by the work of Malone and co-workers [13] on dissociative excitation of nitrous oxide, but a need for a revision of a swarm normalization of the available data persists.

In the case where major gaps and large uncertainties in the cross section database exist, measurements of transport coefficients, which are the necessary experimental data in any swarm procedure, could be of great help. This is in particular the case for the low electron energies, where this procedure for the determination of cross sections proved to be exceptionally accurate [14, 15]. For moderate and high mean energies, the swarm procedure can also be useful since both ionization cross sections and rate coefficients are usually

determined accurately. In other words, the high energy tail of the electron energy distribution function (EEDF) is extremely sensitive to the overall energy losses below the ionization threshold [16]. Consequently, if experimental results for ionization coefficients exist, then the assumed excitation cross sections can be normalized.

For a detailed description of the swarm procedure, see [17, 18]. Basically, the method consists of numerous trials of adjusted cross section sets until agreement is obtained between calculated and measured transport data with satisfactory accuracy. The knowledge of the sensitivity of the transport data to a certain process, and the extent to which the realistic limitations of the cross section modifications that are being introduced affect other processes (whether they require additional modification of other cross sections in the same or even the opposite direction) is a matter of experience, skill and patience. The non-uniqueness of the cross section sets obtained by this procedure can be considered as a serious problem when reaction rates for specific channels are sought for. On the other hand, the completeness of the results, in the sense of correct EEDF and balances of the number, momentum and energy of particles is the undeniable advantage of the technique, as well as the fact that its results are directly applicable in plasma modeling.

In addition to the accuracy and availability of the experimental data, another critical aspect of the swarm analysis is the accuracy in the calculation of transport coefficients. Current status in the field of swarm experiments, determination of cross section sets and in the development of the theory and phenomenology of the transport phenomena is discussed in a review paper by Petrović *et al* [19].

In spite of the lack of a complete set of reliable data, only very few swarm experiments on N_2O have been performed, and most of these many years ago [9]. A recent exception is the measurements of the ratio of the transverse and longitudinal diffusion to mobility by Mechlińska-Drewko *et al* [11].

The purpose of this paper is to present new results, measured as well as calculated, for drift velocities and effective ionization/multiplication coefficients for electrons in N_2O, in order to evaluate some of the commonly used cross section sets and to propose possible improvements to the existing data. An additional test of the newly derived cross sections is made by comparing the calculated and measured drift velocities and effective ionization coefficients for N_2O/N_2 mixtures with different abundances of N_2O.

From the point of view of the application of non-equilibrium plasmas, the mixtures of certain gases can play a very important role [20–22]. Usually, one component of the mixture can be used in order to control the electron energy [23] or momentum transfer collisions, while the other is being analyzed in order to improve the uniqueness of the cross section sets which are obtained by swarm analysis [24]. On the other hand, it has been a common practice that attaching gases are mixed with well-established non-attaching gases in order to evaluate the attachment rates [25]. We have decided to measure drift velocities and effective ionization coefficients in N_2O/N_2 mixtures because of the reliability of the cross sections for nitrogen [26]. Nitrogen is a non-attaching gas, thereby providing the possibility of improving the attachment cross section of N_2O from the data in mixtures dominated by nitrogen. In addition, transport coefficients in such a mixture could be a good basis to develop sets for atmospheric discharges for removal of pollution or for potential gaseous dielectrics.

2. Experiment

The pulsed-Townsend apparatus used for measuring the electron drift velocity and the effective ionization coefficients in N_2O and N_2O–N_2 has been described in detail previously [27]. The discharge apparatus consists of a parallel-plate capacitor (12 cm in diameter) to which an external voltage is applied. The initial photoelectrons are released from an aluminum cathode by the action of a UV laser pulse (Nd : YAG, 355 nm), passing through a highly planar, central copper mesh aligned with the surface of the anode. The displacement current produced by the electrons and its ionic progeny flows through a transimpedance amplifier (40 MHz, $10^5\,\mathrm{V\,A^{-1}}$), the output of which is applied to the input of a digital oscilloscope. Base pressures of 1 μTorr were readily achieved. The gas pressure was monitored by a Baratron gauge with an accuracy of 0.025%. A fixed gap distance of 3.1 cm was used throughout. Room temperature varied over the range 293–300 K. The N_2O and N_2 gas samples were supplied by Praxair and Matheson with quoted purities of 99.5% and 99.999%, respectively. No further purification procedures were carried out.

The electron drift velocity and the effective ionization coefficients were derived from the analysis of the fast electron component [27]. Briefly, the electron drift velocity is calculated as the time elapsed between the half-height of the leading and trailing edges, as shown in figure 1. It is well known that electron attachment in N_2O proceeds dissociatively, leaving O^- as the main negative ion product [28]. It is also known that this ion detaches readily, and such an effect was seen in some of the electron avalanches as an *excess* current left behind the first electron transit. This effect is shown in figure 1 for two different pressures, where one readily notes that the excess current becomes small as the pressure is reduced, and hence it allows the application of the standard analysis referred to below. The electron avalanches displaying substantial amounts of electron detachment were discarded during this work. However, these will be reconsidered for further analysis when a simulation code that considers electron detachment becomes available.

Even though the influence of electron detachment on the waveforms that we regarded as suitable for analysis was small, this was nevertheless present to a small extent, and therefore, precluded us from evaluating the longitudinal diffusion coefficient. Thus, after subtraction of the 'excess' current, the falling portion of the electron transient is fitted according to the equation [27]

$$I_e(t) = \frac{n_0 q_0}{T_e} \exp[(\alpha - \eta) W t], \qquad (1)$$

where n_0 is the initial number of photoelectrons, q_0 is the electron charge, T_e is the electron transit time, $W = d/T_e$ is

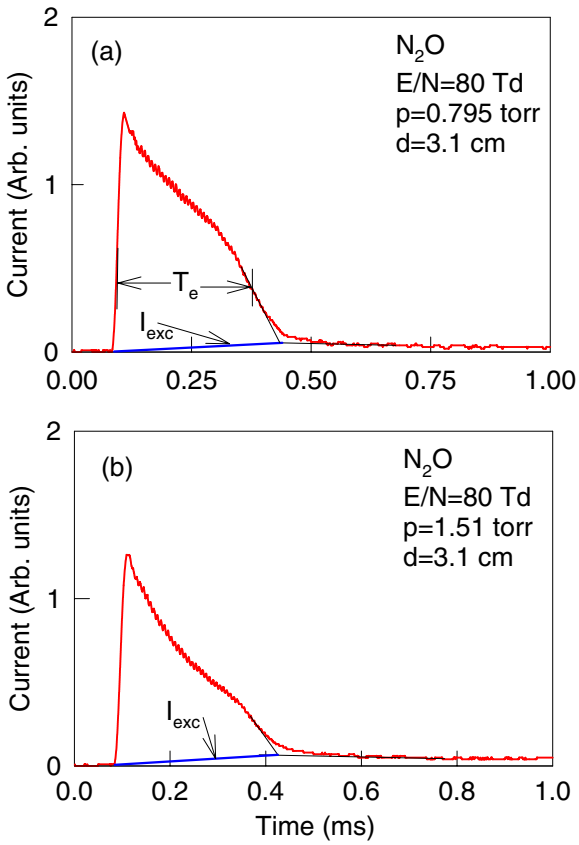

Figure 1. Two examples of electron avalanches in N_2O at low pressures. The 'excess current', I_{exc}, consisting of positive and negative ions and electrons detached from the latter is shown. This excess current is subtracted from the total, measured current, thereby leaving the electron current, from which $(\alpha - \eta)$ is obtained.

the electron drift velocity, with d as the gap spacing, and α and η are the electron impact ionization and attachment (spatial) coefficients, respectively.

The experimental uncertainties were 1–2% for the electron drift velocity and 5–8% for the effective ionization coefficient. Even though we could obtain values for $(\alpha - \eta)/N$ simultaneously with those of the drift velocity W, when the effective ionization coefficient becomes small (below 10^{-20} cm^2), the slope from which one derives this value is almost flat, and then a precise assessment of this coefficient is uncertain. This is the reason why we have limited the presentation in this paper of this parameter for $E/N > 10$ Td.

3. Numerical techniques and procedures

The calculations of transport coefficients were performed by using two different techniques as represented by two computer codes. The first one [29] (ELENDIF) solves the Boltzmann equation in the two-term approximation (TTA). The second is a Monte Carlo (MC) code that we have developed and tested on numerous occasions [30–32].

The accuracy of the two-term technique and its applicability in deriving cross sections has been frequently questioned [19, 33–35]. This has been well studied for N_2 by Haddad [36], Pitchford and Phelps [37] and Phelps and Pitchford [38]. In general, the accuracy of the two-term versus multi-term code has been analyzed on many different examples and the implications for accurate comparisons with cross sections have been addressed recently by White *et al* [39], while Petrović *et al* [19] have focused more on the application of the swarm-normalized cross section data for plasma modeling. We cannot recommend without special provisions the use of a two-term code to determine the transport data for modeling, although it is a common practice and often sufficiently accurate. However, in our studies the two-term method results are used to facilitate repeated cross section modifications, to guide the eye in the plots through MC data that have a limited number of points and to show the possible users how large the differences may be. Over a wide range of E/N, the differences between the two-term and the more accurate codes are negligible. In general, the differences are within the limits that may be acceptable for plasma modeling but not for a very accurate determination of the cross sections from the transport data as performed by Haddad [36] (see also [40]). Such an analysis, however, is possible only over a limited, low range of mean energies and becomes much more complex at higher E/N, where numerous processes control the energy transfer of electrons.

Following the analysis of the accuracy of the two-term code, one should perhaps perform an analysis of the uncertainty of the derived cross sections that would be very difficult and too complex. A simpler yet still quite complex example is the analysis of the uncertainty in the cross sections by Petrović [41] and Petrović *et al* [19]. However, it is impossible to implement it under realistic conditions for N_2O. Nevertheless, having in mind the numerous processes that affect the results at the same time, each with its own uncertainty, and the goal to provide the plasma modeling community with a set of data, the discrepancies between experimental and predicted transport data are satisfactory.

On the basis of the above, we believe that the two-term code can be used for numerous and repetitive runs of calculations that are required in the process of adjusting cross sections to fit the experimental results. Also, generally available TTA codes, like the one that we have used, are easy to work with, with no special requirements concerning computational recourses and with reasonable duration of each calculation, which facilitates obtaining data for a large number of points and thereby to smooth the graphs. However, for final runs some exact technique has to be employed. MC simulation is such a technique, as it is limited only by the accuracy of the cross section models and by the statistics of sampling during MC averaging.

Thus, in most cases our final conclusions on the cross sections in this paper are based on the results of our MC code [31, 32]. The code is based on numerical integration of the equation for collision probability and it is well tested for the case of both model and real gases. The code also provides a technique to establish the difference between the so-called flux and bulk transport coefficients that are different due to the non-conservative nature of collisions [42]. The definitions and formulae for electron transport coefficients can be seen in Petrović *et al* [31]. In this paper we shall present mainly the bulk properties since these are measured in the experiments.

In our simulations we followed the evolution of each of 5×10^5 initial electrons through a large number of collisions in time and infinite space under the action of a constant electric field. The density-normalized dc field was varied over a wide range from 1 to 800 Td (1 Td $= 10^{-21}$ V m^2). The initial electron energy distribution was Maxwellian with a mean energy of 1 eV. The gas density was 3.54×10^{22} m^{-3} which corresponded to a pressure of 1 Torr (133.3 Pa) at the gas temperature of 273 K. All electron scattering was assumed to be isotropic regardless of the nature of collisions, and swarm conditions were fulfilled, namely that mutual electron interactions were negligible as compared with electron–molecule interactions.

4. Results and discussion

All the calculated cross section and the measured swarm data reported in this paper can be found at the website http://mail.ipb.ac.rs/~cep/ipb-cnp/ionsweb/index.htm

4.1. Cross section and transport data on nitrous oxide (N_2O)

The cross section set for electrons in N_2O that we have used as the initial input for the calculation of electron drift velocities, effective ionization coefficients and other transport and reaction rate data, represents the compilation of the most reliable and frequently used cross sections so far, whether they are the results of theory, crossed beam experiments or swarm analysis. For future reference, we shall refer to it as 'the initial set'. It contains the semi-empirical elastic momentum transfer, which is taken from Hayashi [43], as well as the electronic excitations (with the threshold energies of 4, 8.5 and 9.6 eV). The vibrational excitations for (1 0 0), (01 0) and (0 0 1) modes are taken from Zecca *et al* [10], the dissociative attachment from Rapp and Briglia [44] and dissociative excitations are from Malone *et al* [13]. Finally, sparse results for the ionization cross section of Märk and co-workers [45] were extrapolated towards higher energies by using the Born approximation. Both stable and metastable ions detected by Märk *et al* are included.

Using momentum transfer cross sections in our MC simulation is equivalent to assuming isotropic scattering. While this approximation may seem crude from the point of view of binary collision physics, averaging of numerous processes over a large number of different directions makes this a very good approximation for the energy range covered here. Problems occur when we either have a very low elastic and a large inelastic cross section, or at very high E/N under non-hydrodynamic conditions (runaway electrons, etc) where directed motion is favored both by scattering and kinetics of the discharge. In such situations, a more detailed representation of collisions may be necessary. Further improvement of the present set may follow those lines, but for plasma modeling this refinement is not required except for the representation of transport in high voltage sheaths.

It is not necessary to provide here a thorough survey of the available sets of cross sections, cross section data and transport data, as well as of the analyses of the cross section sets. This purpose is well served by the reviews of Gallagher *et al* [46] and Karwasz *et al* [9]. The set has been constructed mainly starting from the set of Mechlińska-Drewko *et al* [11] with some extensions which led to improved fits with the new and old transport data. Using this set enabled us to fulfill the need to reproduce the existing experimental values of drift velocities as accurately as possible, and to reach at least a similar energy (E/N) dependence of the calculated effective ionization coefficients to the measured ones.

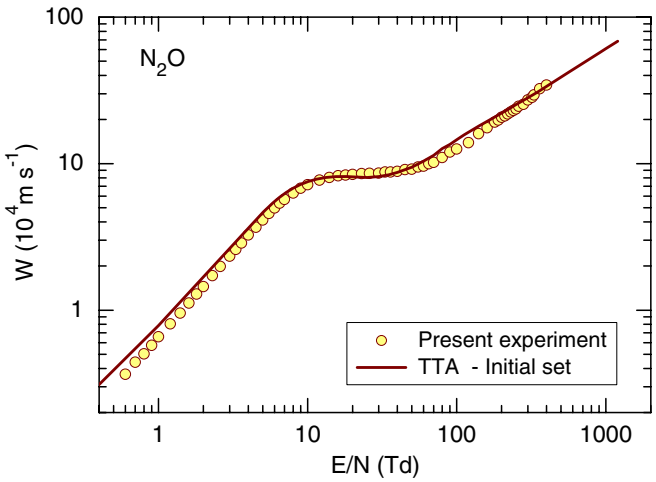

Figure 2. Drift velocities for electrons in N_2O, derived from the initial set of cross sections.

4.2. Pure nitrous oxide (N_2O)

One can see that the above-mentioned goals have been achieved at least to some extent from figures 2 and 3, which present the newly measured and calculated data based on the initial cross section set. As seen from figure 2, the calculated drift velocities are consistent with the experimental ones over almost the entire range of E/N. Small discrepancies over the lower portion of the E/N range ($E/N < 2$ Td and around 100 Td) indicate that the elastic momentum transfer cross section proposed by Hayashi needs some—albeit minor—adjustments to achieve a good fit to the measured drift velocity. The fact that for the low energy range the TTA is inadequate due to the large vibrational excitations must also be taken into account [39].

Figure 3 shows the effective ionization coefficient $(\alpha - \eta)/N$ as a function of E/N. For $E/N \sim 3$ Td, $(\alpha - \eta)/N$ is negative, although its value is relatively small. This is because the electronic excitations and ionization are almost negligible at these electron mean energies, and the dissociative attachment cross section is small in magnitude as compared with vibrational excitations and elastic scattering. When dissociative attachment increases, then $(\alpha - \eta)/N$ becomes more negative, but it eventually decreases when ionization becomes considerable. Finally, the effective ionization becomes positive, both due to the increasing ionization cross section and the fact that the cross section for electron attachment becomes negligible at higher energies. A very narrow range of E/N where the effective ionization coefficient is in the vicinity of a zero value (losses due to attachment are compensated with ionization) is of special interest, since it corresponds to the typical working conditions

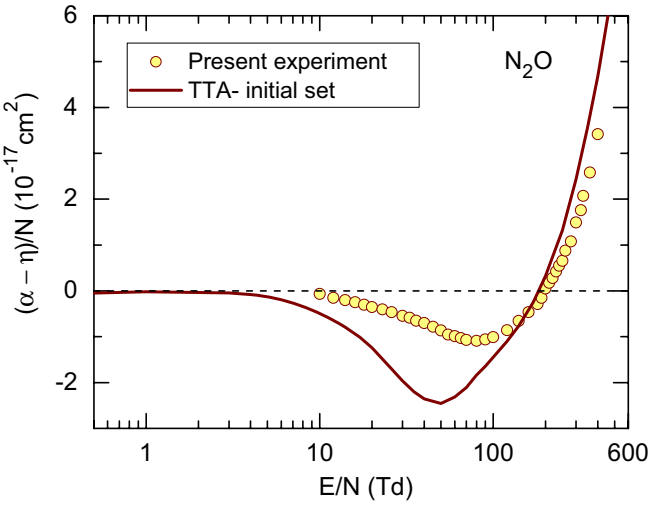

Figure 3. Calculated effective ionization coefficient for N_2O with the initial set of cross sections and its comparison with the present measurements.

for gas discharges and collision plasmas. This is also the region where the non-conservative nature of electron transport does not affect transport coefficients, and hence the bulk and flux coefficients do not differ significantly (see figure 8).

However, for $(\alpha - \eta)/N$ there is a serious discrepancy between the newly measured data and the values calculated on the basis of the initial set (figure 3). Therefore, some adjustments in the corresponding inelastic processes had to be made. Not only the electronegative character of N_2O, represented here in the form of negative values of $(\alpha - \eta)/N$, is overrated in our calculations, but it seems that the negative branch of the energy (E/N) dependence is shifted towards lower energies. The calculated $(\alpha - \eta)/N$ reaches the peak value at a lower E/N than the measured one, which means that the corresponding peak in the cross section (at 2.3 eV) should be shifted towards slightly higher energies or at least that the cross section at higher energies should be increased. Having this in mind, and the fact that the dissociative attachment cross section employed in the initial set had a rather complex energy dependence, one could not expect to fit the calculated data to the experimental ones with just one scaling factor. It should be noted that even for very low energies, the two sets of data disagree, even though this cannot be clearly seen from the graph. Nevertheless, at these energies, a swarm analysis based on only two sets of transport data cannot produce unique results, since there are other inelastic channels (vibrational excitation); thus, we tried as much as possible to maintain the shape of the attachment and other cross sections.

As for the positive branch of the calculated $(\alpha - \eta)/N$ curve, this seems to be steeper, with a departure of about 40%, from the experimental one. In order to fit the experimental data, we decided to control the high energy tail of the EEDF and to reduce the ionization by increasing the excitation cross section with the lowest threshold energy (4 eV).

We have decided to adjust the total momentum transfer cross section first, with the aim of reproducing W within the experimental uncertainties. After adjusting particular inelastic cross sections, we have obtained the elastic momentum transfer

Table 1. Scaling factors for cross section renormalization.

Cross section	Energy (eV)	Scaling factor
Electronic excitation ($\varepsilon_{th} = 4$ eV)	4.0–422	1.55
Dissociative attachment	0.21–2.5	0.25
	2.6	0.92
	2.7	1.37
	2.8–3.1	2.5
	3.2–4.3	3.75
	4.5	3.33
	5.0	1.24
	5.1	0.24
	6.0–55	0.15
Total momentum transfer	0.25–0.9	1.15
	3.0–4.5	1.15
	5.0	1.32
	6.0	1.32
	7.0–4000	1.15

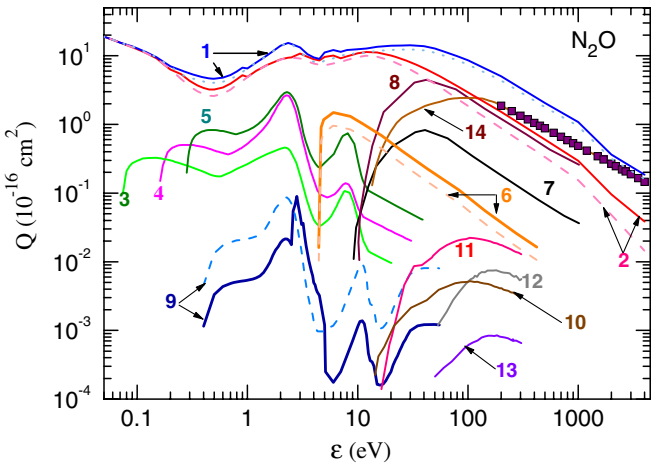

Figure 4. Recommended set of cross sections for electrons in nitrous oxide (N_2O): total momentum transfer (1), elastic momentum transfer (2), vibrational excitation (3, 4, 5), electronic excitation (6, 7, 8), dissociative attachment (9), dissociative electronic excitation (10–13), ionization (14). Symbols denote our extrapolation to measurements. Dashed lines represent the initial cross sections before scaling. See the supplementary material (stacks.iop.org/PSST/19/025005/mmedia) for values of recommended cross sections.

cross section as a difference between that total and the sum of all inelastic processes. After a number of iterative calculations we concluded that the best fit to experimental ionization and attachment data could be achieved when the cross sections were normalized with the scaling factors as listed in table 1.

A summary of the recommended cross sections for electron interactions with N_2O is given in figure 4. The dashed lines represent the initial cross sections before scaling. The values of the recommended cross sections are given in the supplementary material (stacks.iop.org/PSST/19/025005/mmedia). Additionally, all the cross sections and the measured transport coefficients, including those for the N_2O–N_2 mixtures, as well as the cross sections may be found at the website http://mail.ipb.ac.rs/~cep/ipb-cnp/ionsweb/index.htm

Figures 5 and 6 show the comparison with data from the literature of calculated and measured electron drift velocities

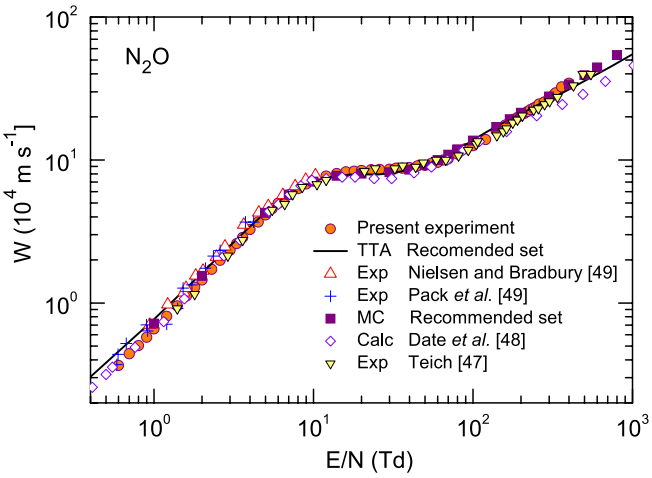

Figure 5. Drift velocity for electrons in N_2O as a function of E/N: comparison of present results (experiment—solid circles, MC calculations—solid squares, TTA calculations—solid line) with previously published data [47–49]. See the supplementary material (stacks.iop.org/PSST/19/025005/mmedia) for the recommended values of electron drift velocities in N_2O.

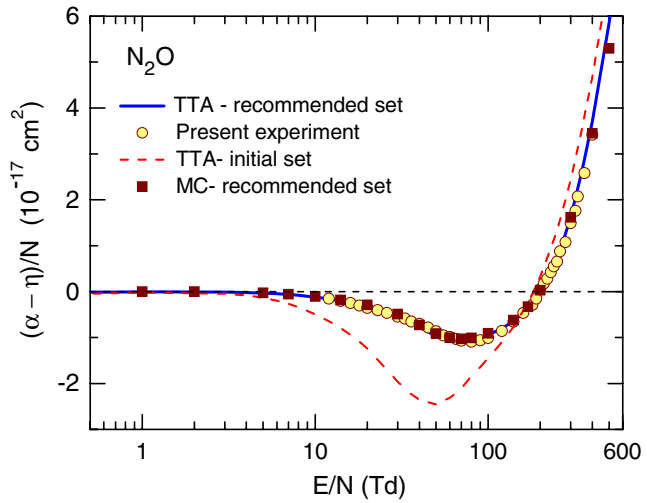

Figure 6. Comparison between calculated and measured effective ionization coefficients in N_2O. See the supplementary material (stacks.iop.org/PSST/19/025005/mmedia) for the recommended values of this coefficient.

and effective ionization coefficients, respectively. Calculations are based on our final modification of the cross sections. We performed the calculation by using both TTA and MC codes.

The recommended values of electron drift velocities and effective ionization coefficients are given in the supplementary material (stacks.iop.org/PSST/19/025005/mmedia), and also may be found at the website http://mail.ipb.ac.rs/~cep/ipb-cnp/ionsweb/index.htm

It is worthwhile noting that drift velocities measured by Teich [47], with a similar pulsed-Townsend apparatus, agree very well over most of the covered E/N range (figure 5). The calculation of Date *et al* [48] shows agreement within the expected combined error bars with our MC calculations as well as with our experimental results over the lower portion of the E/N range. With the increase in E/N, these results are systematically smaller than ours. Drift velocities of

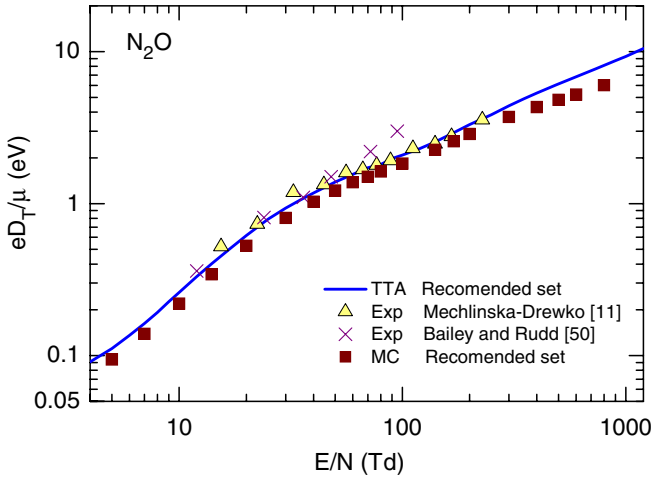

Figure 7. Comparison between present calculated characteristic energies and previously measured ones [11, 50].

Nielsen and Bradbury and Pack *et al*, all compiled by Dutton [49], fit our TTA calculations better at the lowest E/N and show some scatter at higher E/N. As expected, TTA values differ from both experimental and MC results in the region where a minimum in the elastic momentum transfer exists and low energy inelastic processes reach their peak values. An agreement well below our stated experimental uncertainty has also been reached with the measured effective ionization coefficients over the whole range of reduced electric field that was employed in our study.

As the diffusion coefficient is extremely sensitive to the presence of inelastic processes, and therefore also to their changes, we have decided to calculate the characteristic energies, eD_T/μ. Figure 7 shows the comparison between present calculations and measured characteristic energies [11, 50]. Calculations agree well with the measurements of Bailey and Rudd [50] up to $E/N = 50$ Td. For $E/N > 50$ Td, these experimental results depart significantly not only from our calculations, but also from recent measurements of Mechlińska-Drewko *et al* [11], with which our predictions agree well.

On the basis of what has been presented, we can conclude that the cross section modifications ensure the consistency of the cross section set with the best available experimental results, and that the renormalized set of cross sections can be recommended for further use.

As an illustrative example of the previous discussion about the effect of non-conservative collisions, we show the difference between bulk and flux drift velocities and characteristic energies as a function of the reduced electric field (figure 8). In particular, for the drift velocity we note that for $E/N > 100$ Td, the bulk values are higher, while for $E/N < 100$ Td the flux values are higher. The opposite is true for characteristic energies.

In addition, we have applied the presently recommended set of cross sections as the input parameters for calculations of other transport coefficients (electron mean energies, individual ionization and attachment coefficients) and rates for individual processes.

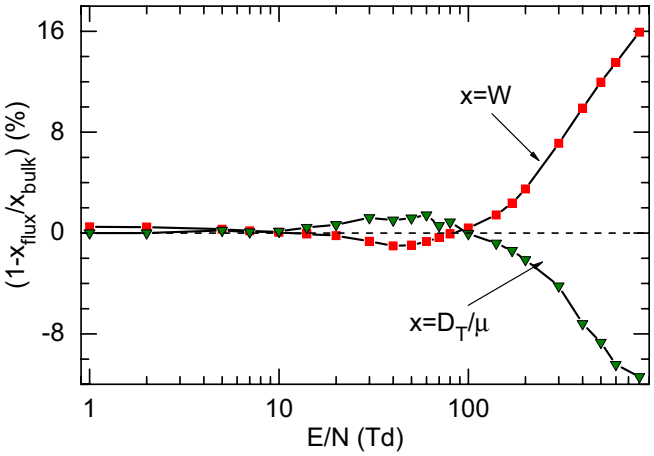

Figure 8. Difference between bulk and flux transport properties (drift velocities—solid squares and characteristic energies—solid triangles) for electrons in N_2O.

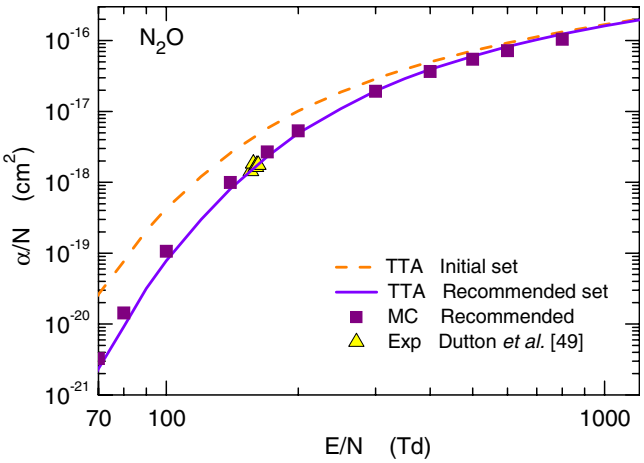

Figure 9. Ionization coefficient for electrons in N_2O.

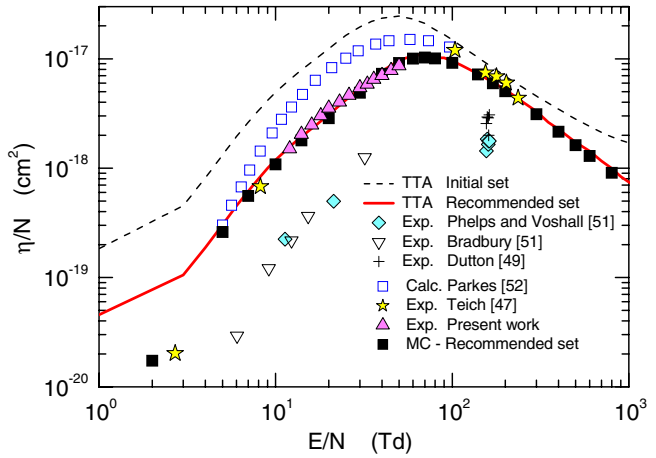

Figure 10. Dissociative attachment coefficient for electrons in N_2O.

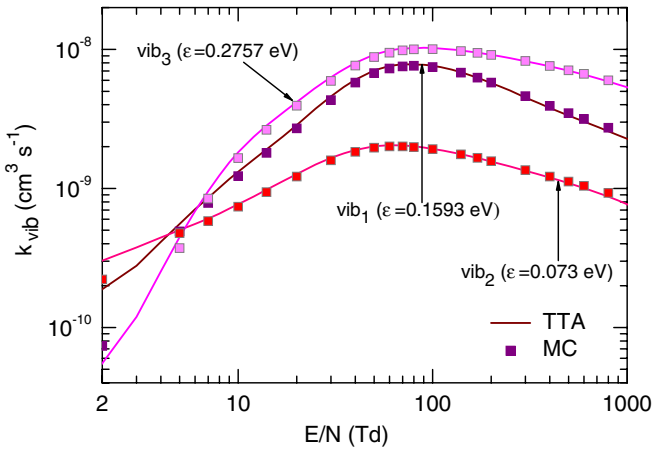

Figure 11. Rate coefficients for vibrational excitation in N_2O calculated with the recommended set of cross sections.

Figure 9 shows the comparison between the calculated ionization coefficients (obtained both with the initial and recommended sets of cross sections) and the data given over the very narrow energy region in the compilation of Dutton [49]. The fact that exceptionally good agreement is reached between the compiled data and those calculated with the newly recommended set of cross sections confirms the strategy of rescaling the excitation cross section. Figure 10 shows the calculated attachment coefficients in N_2O, together with the previously published data. We note that the experimental data of Phelps and Voshall [51] agree with those of Bradbury (as reported by Phelps and Voshall in [51]) and Dutton [49] but disagree with the present data within 40%, except at the lowest E/N values, where the situation is better for the MC calculations, while the TTA, as expected, suffers from serious inadequacy. Provided that the ionization coefficient α/N is negligible below $E/N = 50$ Td (see figure 9), our present experimental data of $(\alpha\eta)/N$ can be regarded as the values for η/N. We have plotted these values in figure 10, showing good agreement with the presently calculated MC and TTA data for $12 < E/N < 50$ Td. The η/N values due to Teich [47] over the E/N range 85–230 Td agree well with our calculations, except for the η/N value at E/N 100 Td. It is to be noted that Teich also used the time-resolved pulsed-Townsend technique. Discrepancies between the present data and those calculated by Parkes [52] are within the same uncertainty. Further improvements on the low energy cross sections would require new measurements.

From a number of reaction rates that we have obtained in our study, we choose to show only the vibrational excitation rates (figure 11) calculated with the recommended set as an input parameter. One can note that the rate coefficients show resemblance to the energy dependences of the corresponding cross sections.

4.3. Data for mixtures of nitrous oxide with nitrogen (N_2O/N_2)

We have measured the electron drift velocities and effective ionization coefficients for 20%, 40%, 60% and 80% of N_2O in mixtures with N_2. Calculations have been performed only by using the TTA code, with the recommended set of cross sections for N_2O as an input parameter. Having in mind all the remarks concerning the applicability of the TTA, we believe that this is good enough for our aim in this investigation. The cross section set for nitrogen is adopted

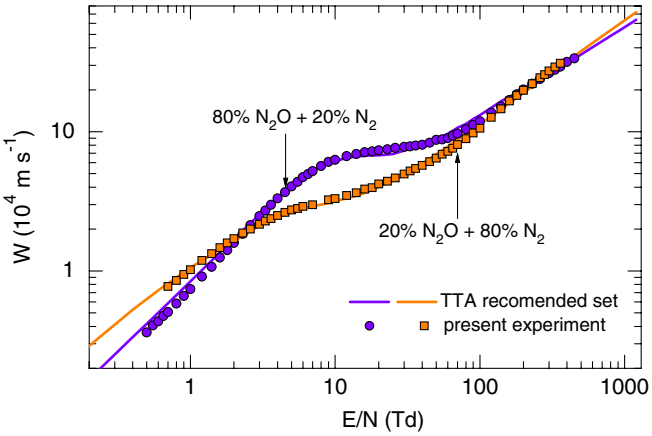

Figure 12. The comparison of experimental and calculated values of drift velocities in 80% and 20% N_2O/N_2 mixtures.

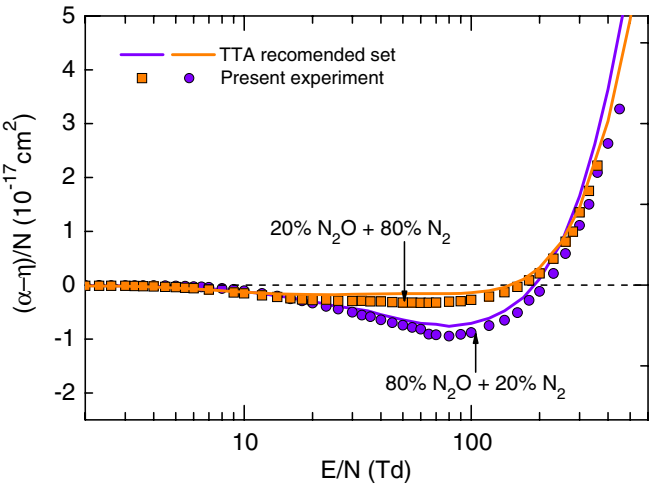

Figure 13. The comparison of calculated and measured effective ionization coefficients for 20% and 80% N_2O/N_2 mixture.

from the *Sigmalib* database of the ELENDIF code [29] and represents the compilation of the most reliable data produced by Haddad [53], Phelps [54] and Phelps and Pitchford [38]. In spite of some existing discrepancies we may assume that the cross sections for pure nitrogen are very well known and that mixture data may be used for the determination of the cross sections for N_2O.

Figures 12 and 13 show the comparison between the calculated and measured electron drift velocities and effective ionization coefficients, respectively, for two different abundances of N_2O/N_2 mixtures. As seen, the rescaled set of cross sections reproduces the experimental results well enough to uphold the statement that the set may be recommended for modeling electron transport in N_2O containing collisional plasmas. Even though it is not shown for the sake of space, the analysis for the case of 40% and 60% mixtures is similar, and it also confirms the proposed set.

Most importantly, the ability of the cross section set to model effective electron multiplication coefficients gives support to our claim that our measurements are not affected considerably by electron detachment.

5. Conclusion

In this paper we have presented two groups of two experimental transport data (drift velocity and effective ionization coefficient) obtained by an accurate pulsed-Townsend technique in pure nitrous oxide and in a number of mixtures with nitrogen. The experiment was performed for four abundances, namely 20%, 40%, 60% and 80%. We have used all those sets of data to evaluate commonly used cross section data for N_2O. In our evaluation, performed with two-term and MC codes, we have shown that some modifications in the cross sections are necessary in order to reproduce the experimental data. The swarm analysis that we have performed shows that the best fit to experimental data can be achieved when modifications to the electronic excitation cross section and elastic momentum transfer cross section of Hayashi [43], and the attachment cross section [11, 44] are made according to table 1.

The analysis of the transport data for four different mixtures has justified the cross section modifications that we have made. It is important to note that the present set satisfies several independent sets of data: present drift velocities (confirmed by some additional sources in the literature), present data for $(\alpha - \eta)/N$, all for pure N_2O and for four of its mixtures with nitrogen, and also the characteristic energy data of Mechlinska-Drewko *et al* [11].

Using nitrogen as a buffer gas in mixtures does not give an exceptional sensitivity to the vibrational excitation cross sections as may be achieved in mixtures with Ar. Nevertheless, as an electropositive gas, nitrogen is particularly good for normalizing the attachment cross sections of the electronegative component. Thus, the fit of effective ionization rates by the cross section that was obtained from the pure N_2O data is important support for the validity of the attachment cross section.

While one could claim that the present set should be used for plasma modeling since it satisfies all the requirements for number, momentum and energy balances [16, 19], one still cannot be satisfied with substantial changes in some cross sections, and particularly that for attachment. This would make repeated measurements of attachment cross sections, as well as the measurements of more transport data, worthwhile.

The effect of non-conservative collisions on transport data has also been discussed by showing a considerable effect both in the region where attachment and ionization dominate. In a similar fashion, the TTA method has been shown to give results with errors too large for cross section analysis, albeit acceptable for plasma modeling.

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