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Technical Notes

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Collision Integrals for Ion–Neutral Interactions of Air and Argon

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Introduction

ACCURATE modeling of the transport properties of weakly ionized air is important in several fields, including the aerothermodyamics of reentering spacecraft and the study of laboratory plasmas. According to Chapman–Enskog theory (see Ref. 1), the transport properties of a gas mixture can be computed to second-order accuracy with the knowledge of just four binary interaction parameters: the diffusion collision integral $\Omega^{1,1}$, the viscosity collision integral $\Omega^{2,2}$, and the dimensionless collision integral ratios $B^* = (5\Omega^{1,2} - 4\Omega^{1,3})/\Omega^{1,1}$ and $C^* = \Omega^{1,2}/\Omega^{1,1}$. In a recent paper,[2] a new methodology was presented for the approximate calculation of collision integrals for ion–neutral interactions, and tabular data were presented for all such interactions in 11-species (N_2, N_2^+, O_2, O_2^+, NO, NO^+, N, N^+, O, O^+, and e) weakly ionized air. The purpose of the present Note is to extend this analysis to air–argon mixtures, which requires data for an additional 11 ion–neutral interactions. Air–argon interactions are of interest for reentry applications, as well as for laboratory plasmas and arc jet simulations, where argon is frequently added as a diluent.

Results

The collision integrals presented in this Note are computed using the Tang–Toennies[3] effective one-dimensional potential approach. Details of the methodology as extended to ion–neutral interactions are given in Ref. 2. The resulting collision integrals are expected to be accurate to within 25% over the temperature range from 300 to 15,000 K, which is sufficient for engineering applications such as mixture transport properties, but may not be adequate for certain analyses (ion transport in plasma sheaths, for example). For each binary interaction, the method requires just five input parameters: the dipole polarizability α and dispersion coefficient C_6 of each species and the quadrupole polarizability α_q of the neutral. Additional required parameters, including the higher-order dispersion coefficients C_{2n} and octopole polarizability, are computed using the recursive relationships outlines in Ref. 2. Recommended values of these constants for 11-species air were compiled in Ref. 4. These values were used to compute the collision integrals presented in Ref. 2. The addition of argon adds two additional species (Ar and Ar^+) to the mixture. Table 1 lists the relevant input parameters and associated references for these species (Refs. 4–8).

Tables 2 and 3 show the computed diffusion $\Omega^{1,1}$ and viscosity $\Omega^{2,2}$ collision integrals for the 11 ion–neutral interactions between argon and air species. All of the data were generated using the method presented in Ref. 2, with the exception of $\Omega^{1,1}$ for Ar–Ar^+ interactions, which was directly integrated from momentum transfer cross sections[9] to account for resonant charge-exchange effects[10]

Table 1 Polarizabilities and dispersion coefficients for Ar and Ar^+

Species	α, Å^3	α_q, Å^5	C_6/e^2, Å^5
Ar	1.640[a]	2.002[b]	2.652[c]
Ar^+	1.067[d]	——	1.115[e]

[a]Reference 5.
[b]Reference 6.
[c]Reference 7.
[d]Reference 8.
[e]Reference 4, Eq. (41).

Table 2 Diffusion collision integral $\Omega^{1,1}$ (Å^2) as a function of temperature for ion-neutral interactions

	T, K											
Interaction	300	500	1000	2000	3000	4000	5000	6000	8000	10,000	12,000	15,000
Ar–N_2^+	29.26	21.77	14.82	11.16	9.92	9.29	8.88	8.60	8.19	7.91	7.70	7.45
Ar–O_2^+	28.95	21.24	13.17	8.35	6.74	5.94	5.46	5.14	4.71	4.43	4.22	3.99
Ar–NO^+	28.92	21.16	13.63	9.51	8.13	7.44	7.00	6.70	6.28	5.99	5.78	5.53
Ar–N^+	28.70	21.01	13.27	8.90	7.46	6.74	6.29	5.99	5.58	5.30	5.09	4.85
Ar–O^+	28.78	21.07	13.13	8.52	6.99	6.22	5.76	5.45	5.03	4.75	4.54	4.30
Ar–Ar^+	49.00	45.52	41.51	38.23	36.55	35.43	34.61	33.95	32.95	32.20	31.60	30.89
N_2–Ar^+	30.17	22.02	14.08	9.71	8.26	7.52	7.06	6.74	6.30	6.00	5.77	5.51
O_2–Ar^+	28.69	20.92	13.38	9.32	7.97	7.29	6.86	6.56	6.14	5.85	5.63	5.37
NO–Ar^+	29.56	21.63	13.92	9.67	8.25	7.54	7.09	6.77	6.35	6.05	5.83	5.57
N–Ar^+	23.05	16.76	11.18	8.31	7.35	6.84	6.51	6.28	5.95	5.71	5.53	5.32
O–Ar^+	19.22	13.92	9.51	7.30	6.53	6.11	5.83	5.62	5.32	5.10	4.93	4.73

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Table 3 Viscosity collision integral $\Omega^{2,2}$(Å^2) as a function of temperature for ion-neutral interactions

	T, K											
Interaction	300	500	1000	2000	3000	4000	5000	6000	8000	10,000	12,000	15,000
$Ar–N_2^+$	31.16	23.83	16.21	12.07	10.75	10.08	9.69	9.41	8.99	8.69	8.52	8.26
$Ar–O_2^+$	29.22	22.68	14.74	9.33	7.51	6.63	6.13	5.79	5.34	5.06	4.85	4.62
$Ar–NO^+$	30.02	23.03	15.11	10.46	8.97	8.22	7.78	7.48	7.04	6.76	6.55	6.29
$Ar–N^+$	29.63	22.73	14.77	9.84	8.25	7.46	7.01	6.70	6.27	5.99	5.79	5.55
$Ar–O^+$	29.32	22.68	14.69	9.48	7.77	6.92	6.45	6.13	5.69	5.40	5.20	4.96
$Ar–Ar^+$	29.99	22.99	15.17	10.58	9.10	8.37	7.94	7.64	7.22	6.93	6.73	6.48
$N_2–Ar^+$	31.20	23.93	15.65	10.72	9.13	8.33	7.87	7.55	7.09	6.79	6.57	6.30
$O_2–Ar^+$	29.43	22.55	14.81	10.27	8.82	8.08	7.65	7.35	6.92	6.63	6.41	6.16
$NO–Ar^+$	30.51	23.55	15.45	10.65	9.11	8.33	7.88	7.57	7.13	6.83	6.61	6.35
$N–Ar^+$	24.69	18.47	12.30	9.09	8.06	7.53	7.21	6.99	6.64	6.38	6.23	6.01
$O–Ar^+$	21.03	15.44	10.46	8.03	7.23	6.79	6.52	6.32	6.00	5.78	5.62	5.41

properly. The collision integrals for $Ar–Ar^+$ calculated in this work were compared to those computed[11] using the potential parameters of Aubreton et al.[12] for six of the molecular states of the $Ar–Ar^+$ system and were found to agree to within 25% at 300 K and 5% at 15000 K.

The dimensionless collision integral ratio B^* was found to be approximately constant at a value of 1.1 for temperatures above 1000 K and varied between 1.2 and 1.3 at lower temperatures for all ion–neutral pairs (a value consistent with polarizability expressions). The dimensionless ratio C^* was found to range from approximately 0.75 at low temperatures (below 1000 K) to a high-temperature limit of 0.95. To the accuracy warranted by the current analysis, using a constant value of $B^* = 1.2$ and $C^* = 0.85$ over the temperature range from 300 to 15,000 K would be an appropriate approximation.

Summary

Collision integrals are computed for all eleven ion-neutral interactions between air species and argon. The estimated accuracy is 25% over the temperature range from 300 to 15,000 K. The resulting data can be used to compute transport properties of ionized air-argon mixtures.

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