Charge transfer of C^+, N^+, and O^+ in N_2 and H_2

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(Received 13 February 1978)

We report absolute measurements of the total cross section, σ_{10}, for charge transfer of C^+, N^+, and O^+ in N_2 and H_2 in the energy range of 5–100 keV. Maxima in all six cross sections occur in this energy range.

I. INTRODUCTION

Total cross sections for charge transfer when energetic C, N, and O ions are incident on N_2 and H_2 are of interest because these ions are present as impurities in ion sources. These ion-source impurities may sometimes be removed by magnetic analysis of the accelerated beam. This is not practical, however, for the intense beams that will produce neutral particles for injection into devices used for controlled-thermonuclear-reactor research. Since these neutral particles will be obtained by passing ions through a neutralizing gas of H_2 or N_2, charge-transfer cross sections are needed to assess the rate at which impurity atoms from the ion source enter the plasma-confinement region.

The experimental method used in the present study detected those fast neutral particles formed in single charge-transfer collisions and scattered less than 1°. Angular-distribution measurements made during the experiment indicated that this method detected more than 95% of all scattered neutral particles.

Section II describes the apparatus and procedures used to obtain the data. These are presented, discussed, and compared with other data in Sec. III.

II. APPARATUS AND PROCEDURE

The ion beam was produced by a 100-kV positive-ion accelerator using an rf ion source containing N_2, O_2, or CO gas. The accelerator delivered a beam of magnetically analyzed ions having an energy spread of approximately ±50 eV to the experimental chamber. The beam energy was determined to ±2% by measuring the terminal potential with a voltage divider and correcting for ion-source potentials.

The experimental apparatus, shown in Fig. 1, is basically the same as that described in earlier papers.[1-4] The incident ion beam was collimated by apertures A and B. The chamber and deflection plates between A and B are normally used only when a neutral incoming beam is desired. However, during this set of measurements the deflection plates served a different function which will be discussed later in this paragraph. The collision region, located between B and C (gas cell), was 1.64-cm long. In the determination of the cross section the geometrical length was used, since previous calculations[1] had indicated that end effects resulted in a correction of no more than 1%. The pressure of the target gas was measured with a capacitance manometer. Apertures C and D collimated the scattered beam so that all particles scattered from the collision region into a cone of half-angle 1° reached the detector. First, with the gas cell evacuated, the electrostatic analyzer plates (between the gas cell and detector) were grounded and the incident ion-beam current I_i was measured with the secondary-electron multiplier. Then, with gas in the collision region, a voltage sufficient to remove all charged particles was applied to the analyzer plates, and the total neutral component I_0 was measured with the secondary-electron multiplier. Since this is a differentially pumped system, the background pressure in the accelerator varies with target-gas pressure. Although this pressure is low, $\sim 2\times10^{-6}$ torr, the flight path between the analyzing magnet and experimental chamber is long enough that the incoming beam contains a small pressure-dependent fraction of neutral particles. To correct for this fraction, the incident ion beam was removed by the previously mentioned deflection plates (between apertures A and B), and the resulting signal to the secondary-electron multiplier, which was due to the neutrals in the incoming beam, was subtracted from the total neutral signal I_0. The corrections which resulted from this procedure were usually

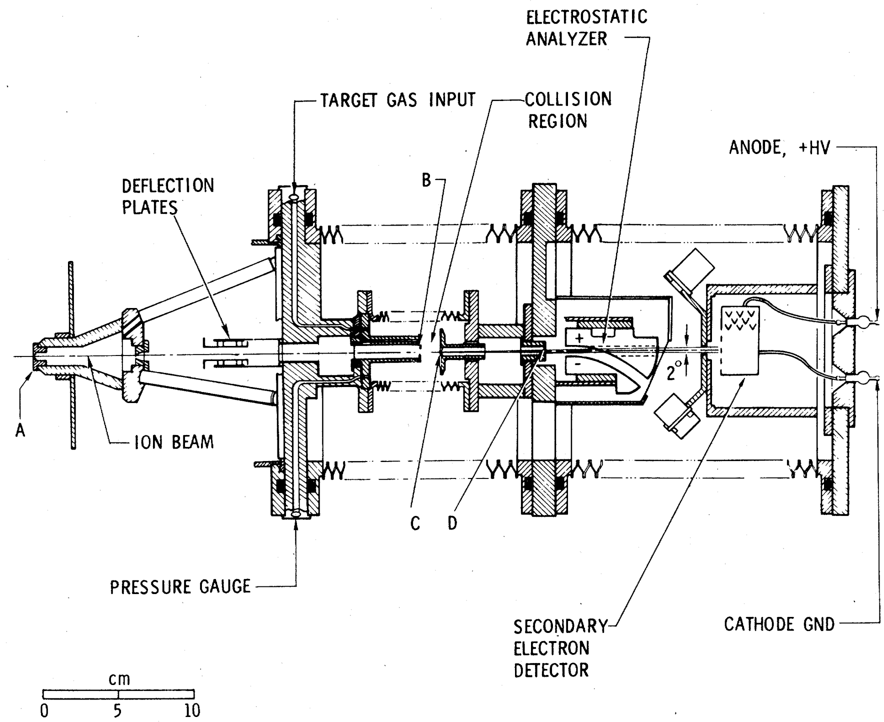

FIG. 1. Experimental apparatus.

no more than 3%. For each energy of the incident beam the ratio of the corrected neutral signal to the ion-beam signal was obtained for at least ten different collision-chamber pressures in the range of 0–1.2 mtorr. For this to represent the true ratio of neutrals to ions in the beam, γ (the secondary-electron-emission ratio) must be the same for ions and neutrals. This has been shown to be

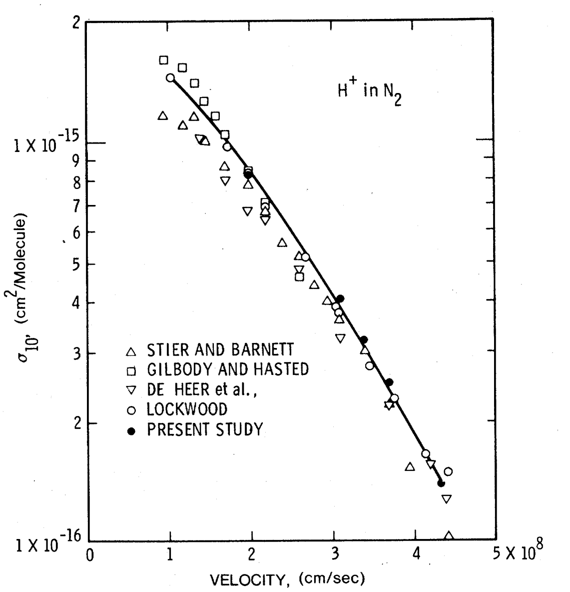

FIG. 2. Total cross section for charge transfer, σ_{10}, of H^+ in N_2 vs velocity of the incident H^+.

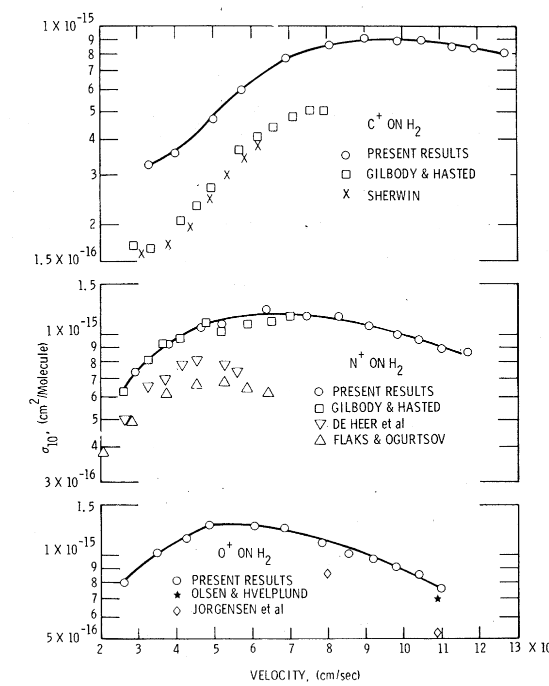

FIG. 3. Total cross section for charge transfer, σ_{10}, of C^+, N^+, and O^+ in H_2 vs velocity of the incident ion.

true to a good approximation.[5,6]

A computer collected the data and calculated a linear least-squares fit of the corrected ratio versus pressure. The slope obtained from this fit was then used to determine the cross section. The linearity of the pressure dependence affirmed that single-collision pressure conditions existed in the collision region.

III. DATA AND DISCUSSION

There are few other measurements of these cross sections in the open literature. As a check

TABLE I. Cross section for charge transfer, σ_{10}, of C^+, N^+, and O^+ in H_2 and N_2.

Kinetic energy (keV)	Velocity (10^7 cm/sec)	σ_{10} (10^{-16} cm^2/molecule)	Kinetic energy (keV)	Velocity (10^7 cm/sec)	σ_{10} (10^{-16} cm^2/molecule)
	C^+ in H_2			C^+ in N_2	
6.7	3.27	3.27	5.7	3.02	4.11
10.0	3.99	3.58	9.9	3.97	4.34
15.4	4.96	4.69	20.0	5.65	6.60
20.6	5.73	5.95	29.3	6.84	8.43
29.8	6.90	7.68	39.7	7.96	9.30
40.6	8.05	8.55	50.2	8.95	10.1
50.5	8.98	9.04	60.6	9.83	10.4
60.5	9.83	8.80	69.6	10.5	10.6
69.1	10.5	8.87	79.5	11.3	10.7
80.4	11.3	8.40	88.4	11.9	10.0
89.1	11.9	8.33	99.4	12.6	10.0
101.0	12.7	8.02			
	N^+ in H_2			N^+ in N_2	
6.1	2.89	7.27	5.5	2.74	8.28
10.6	3.81	9.16	9.7	3.64	10.0
15.9	4.66	10.5	19.5	5.16	11.6
19.8	5.20	10.7	29.5	6.35	12.7
29.8	6.38	12.1	39.4	7.34	13.6
40.3	7.42	11.4	49.7	8.25	12.3
50.3	8.29	11.5	60.2	9.07	13.1
60.0	9.06	10.6	70.8	9.84	11.8
70.7	9.83	9.90	79.9	10.5	11.5
79.1	10.4	9.49	89.1	11.0	11.0
89.1	11.0	8.84	99.5	11.7	10.6
99.3	11.7	8.61			
	O^+ in H_2			O^+ in N_2	
6.00	2.68	7.98	5.9	2.66	12.0
9.9	3.44	10.1	9.9	3.44	13.1
15.3	4.28	11.3	19.3	4.81	15.4
19.7	4.86	12.9	28.9	5.88	15.3
30.4	6.03	12.7	39.3	6.86	14.5
39.2	6.85	12.5	49.2	7.67	13.4
51.0	7.81	11.0	60.7	8.52	12.9
60.7	8.52	10.1	68.8	9.07	11.7
70.3	9.17	9.60	78.7	9.71	11.5
79.9	9.78	9.04	89.6	10.4	10.3
90.3	10.4	8.44	99.6	10.9	10.4
100.7	11.0	7.51			

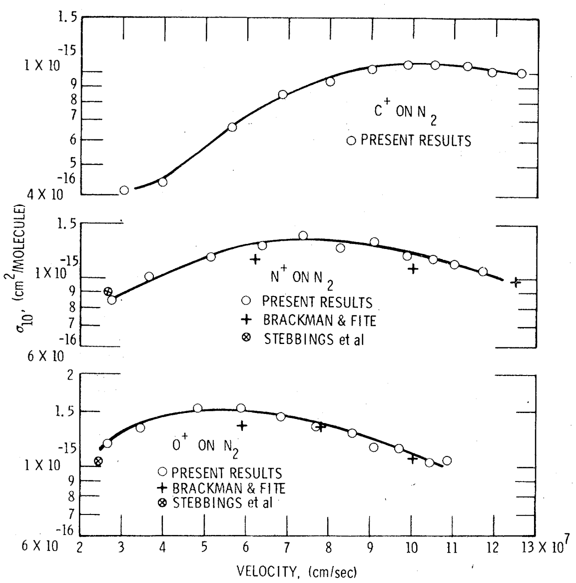

FIG. 4. Total cross section for charge transfer, σ_{10}, of C^+, N^+, and O^+ in N_2 vs velocity of the incident ion.

of our system, therefore, we measured the charge-transfer cross section for H^+ on N_2 at several energies, since this cross section appears to be well established.[1,7-9] A comparison of our present data with those of other investigators and with our earlier work is shown in Fig. 2, where the agreement is seen to be very good.

The results of the present measurements of the total charge-transfer cross section, σ_{10}, for C^+, N^+, and O^+ incident on H_2 and N_2 are shown as a function of velocity in Figs. 3 and 4 and tabulated in Table I. Low-energy (less than 1 keV) measurements for some of the above projectile-target combinations have been reported by Hasted,[10] Potter,[11] McGowan and Kerwin,[12] and Gustafsson and Lindholm.[13] In an energy range comparable with the present work, C^+ on H_2 charge-transfer cross sections have been reported by Gilbody and Hasted[8] for collision energies from 3 to 40 keV and by Sherwin[14] in the energy range 6–24 keV. The cross sections obtained by both of these investigators are below the present results and are shown in Fig. 3. Gilbody and Hasted have also reported cross sections for charge transfer for N^+ on H_2 as have Flaks and Ogustsov[15] and DeHeer, Huizenga, and Kistemaker.[16] In this case, as seen in Fig. 3, the Gilbody-Hasted results are in good agreement with our measurements while the results of the other two groups are lower. Charge-transfer cross sections for O^+ on H_2 at higher energy have been reported by Olsen and Hvelplund[17] and Jorgensen, Kuyatt, Lang, Lorents, and Sauter.[18] Their lower-energy measurements are shown in Fig. 3. Stebbings, Turner, and Smith[19] have reported cross sections for N^+ and O^+ on N_2 in the energy range up to 10 keV, and Brackman and Fite[20] report results for these cross sections from 30 keV to 2 MeV. Results of both groups shown in Fig. 4 are within experimental error of ours in the overlap regions. Brackman and Fite's data extend to 2 MeV; the cross section continually decreases with increasing energy throughout this extended range. Thus, it appears that all six cross sections measured have reached maxima in the energy range covered by this experiment. Stier, Barnett, and Evans[21] have investigated N^+ on N_2 and H_2 in the energy range 20–250 keV. However, they report only the ratio σ_{01}/σ_{10}, and thus their results cannot be directly compared with ours. There are no theoretical calculations to be compared with the present results.

Within the present energy range these are, to our knowledge, the first measurements for C^+ onto N_2. For the other combinations, the previous data range from minimal (i.e., one or two energies) to reasonable detail for 40 keV or less. Between 40 and 100 keV, few measurements are available. We believe that our measurements provide needed reliability because of the method employed. Much of the work previously reported utilized either equilibrium techniques or measurements on the residual slow ions. The interpretation of results obtained by the present method in which measurements are made on the neutralized projectile are much less ambiguous.

TABLE II. Sources of uncertainty.

Source	Uncertainty (%)	Remarks
Target length	1	See discussion, Sec. II, Ref. 1.
Incident ion current I_i	3	Electrometer limitation.
Neutral-beam current I_o	3	Electrometer limitation.
Assumptions of charge independence of γ	5	Based on laboratory studies and Refs. 5, 6.
Pressure	2	Maximum estimated error in pressure determination. This is conservative, based on manufacturer's specifications.
Small-angle scattering	5	Based on laboratory measurements.

The experimental uncertainty in σ_{10} is ±9% and was arrived at by considering the sources of uncertainty listed in Table II. Other known potential sources of error have been reduced to less than 1% by either experimental arrangement or procedures used in data acquisition and reduction.

ACKNOWLEDGMENT

It is a pleasure for the authors to acknowledge the assistance of Laurence Ruggles throughout the conduct of this research. This work was supported by the U. S. Department of Energy.

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