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Charge Exchange Cross Sections for Li^- Ions at 6 MeV

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CHARGE EXCHANGE CROSS SECTIONS FOR Li^- IONS AT 6 MeV

by

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ABSTRACT

Charge fractions for charge exchange of 6 MeV $^7Li^-$ ions in H_2, N_2, O_2, and He have been measured. Cross sections for Li^- and Li^0 destruction are derived from the target thickness dependence of the charge fractions.

Introduction

Cross sections for charge exchange of negative ions in low pressure gases may be obtained by observing the charge fractions as a function of the areal target density (gas density - path length product). At high velocity, the cross sections are only large for processes leading to increasingly positive ions until the equilibrium charge state is achieved. The target thickness dependence of the charge distribution provides sensitive measures of the mechanisms by which such an equilibrium is achieved.

The validity of the "high velocity" approximation depends on the speed of the ion being large compared to the electron velocity. If we use a value of 75.6 eV as the binding energy of the s-electrons (75.6 eV is the ionization potential for Li^+ and thus is an upper limit) we estimate that 1 MeV is approximately the onset of the high energy region. The accelerator used in these measurements operated conveniently in the 6 MeV range and thus measurement should provide data indicative of the high energy behavior.

In these measurements, we obtained charge fractions as functions of areal target thickness for incident 6 MeV $^7Li^-$ ions. From these data, we obtain the maximum fraction of Li^0 formed by gas neutralization. We also derive cross-section values for destruction of Li^- ions and Li^0 projectiles by H_2, N_2, O_2, and He.

Experimental Apparatus

The 6 MeV $^7Li^-$ ions were prepared by the Los Alamos Vertical Van de Graaff Accelerator and analyzed by an 80-inch radius-of-curvature magnet. The arrangement of the apparatus following the analyzing magnet is shown schematically in Fig. 1. The beam passed through slits into a 15.5 cm long gas cell located in a vacuum box. About 3 cm from the exit end of the cell, the beam entered a second vacuum box through a differential pumping aperture. The pressure ratio was 30-100 between the two boxes. At the end of the second box, the beam was analyzed for charge state by a permanent magnet dipole. The separated beams were introduced into Faraday cups for the separate species through a 50 microinch thick nickel foil. The Faraday cups were suppressed electrostatically by -900 volts and magnetically by small permanent magnets (see Fig. 2). The nickel foil stripped the incident projectiles to an equilibrium charge with the result that the current observed in the Faraday cups was proportional to the number of Li projectiles per unit time independent of the incident charge state.

The Ni foil was electrically isolated from the apparatus and provided a monitor for total current for tuning purposes.

We had three current integrators (BIC Model 1000) available for recording the currents to the Faraday cups. These were used in one of two modes. First, the negative, neutral, and total positive currents were monitored. This provided three charge fractions f^-, f°, f^+ as the target pressure was varied. Quartz disks at the rear of each Faraday cup provided visual observation of the beam spot positions. Second, the integrators were used to record the three positive ion equilibrium currents to establish the division of the f^+ into Li^+ Li^{++}, and Li^{+++} components at selected target densities near the f° peak and at the largest target density where the f^+ fraction was largest.

The gas cell effective length was derived previously for various gases by using cells of identical exit geometry but differing length. An illustration of the measurement for H^- destruction in the 15.5 cm cell for N_2 gas is shown in Fig. 3. The pressure was monitored by a MKS Baratron capacitance manometer with a 0-1 torr absolute head. The reading was monitored by a digital voltmeter on the analog output terminals of the Baratron electronics.

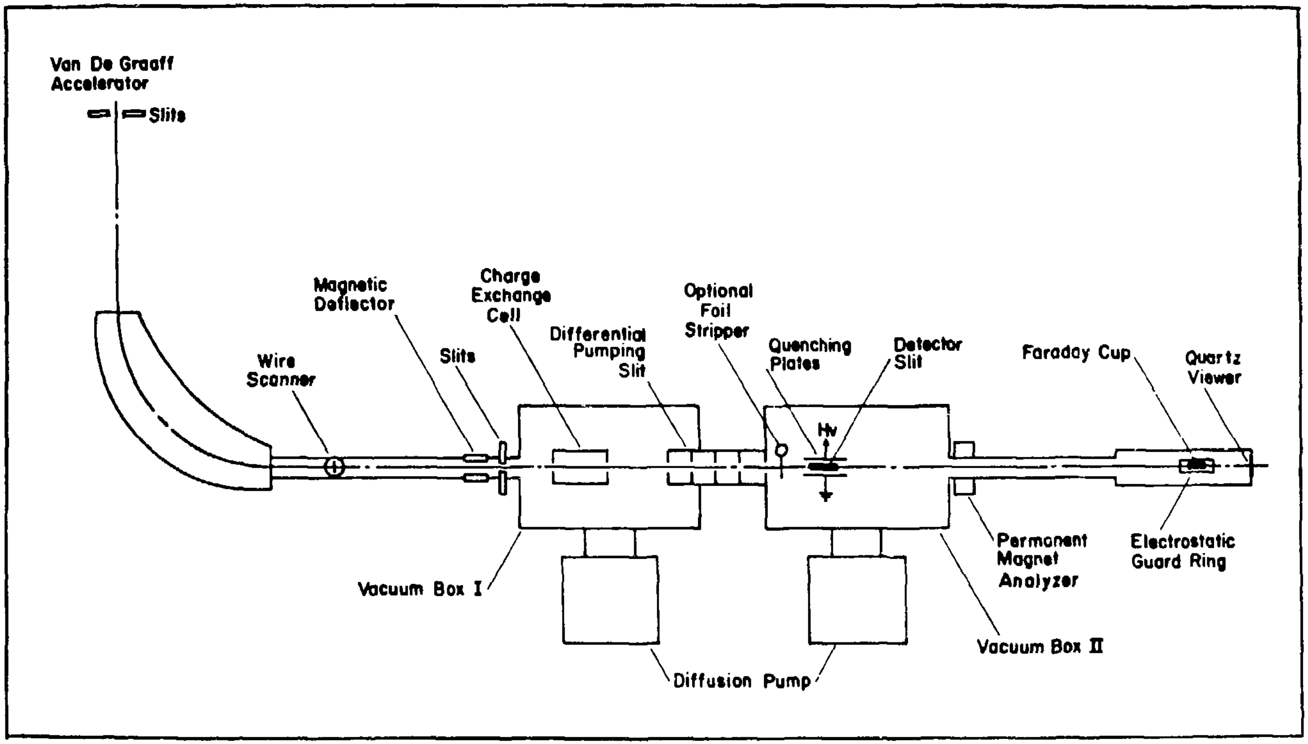

Fig. 1.
Schematic diagram of experimental apparatus. The foil stripper was used to evaluate the equilibrium charge fraction. The quench plates were not used for this experiment.

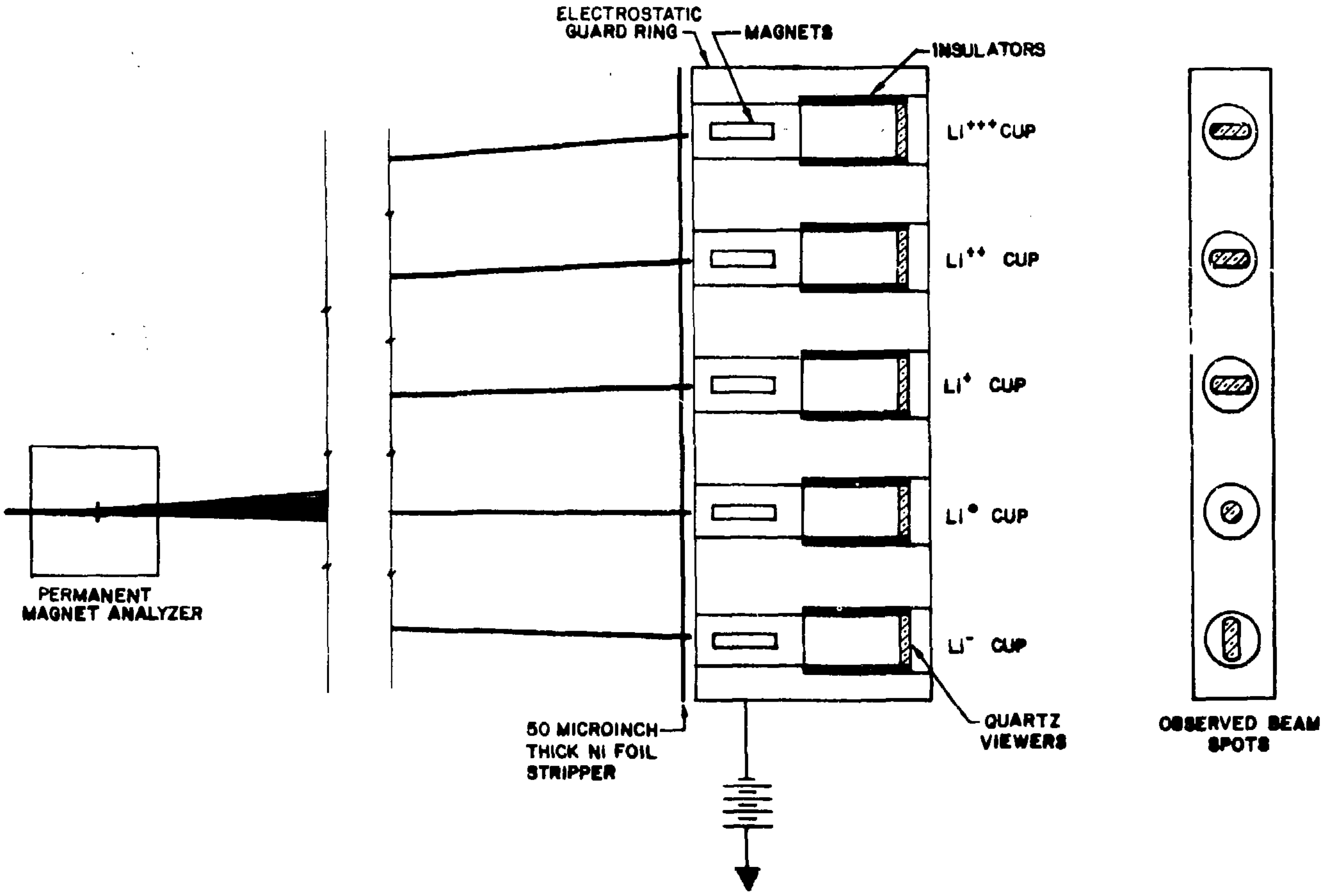

FIG. 2. TOP VIEW OF FARADAY CUP CONFIGURATION FOR Li^{-} CHARGE EXCHANGE EXPERIMENT

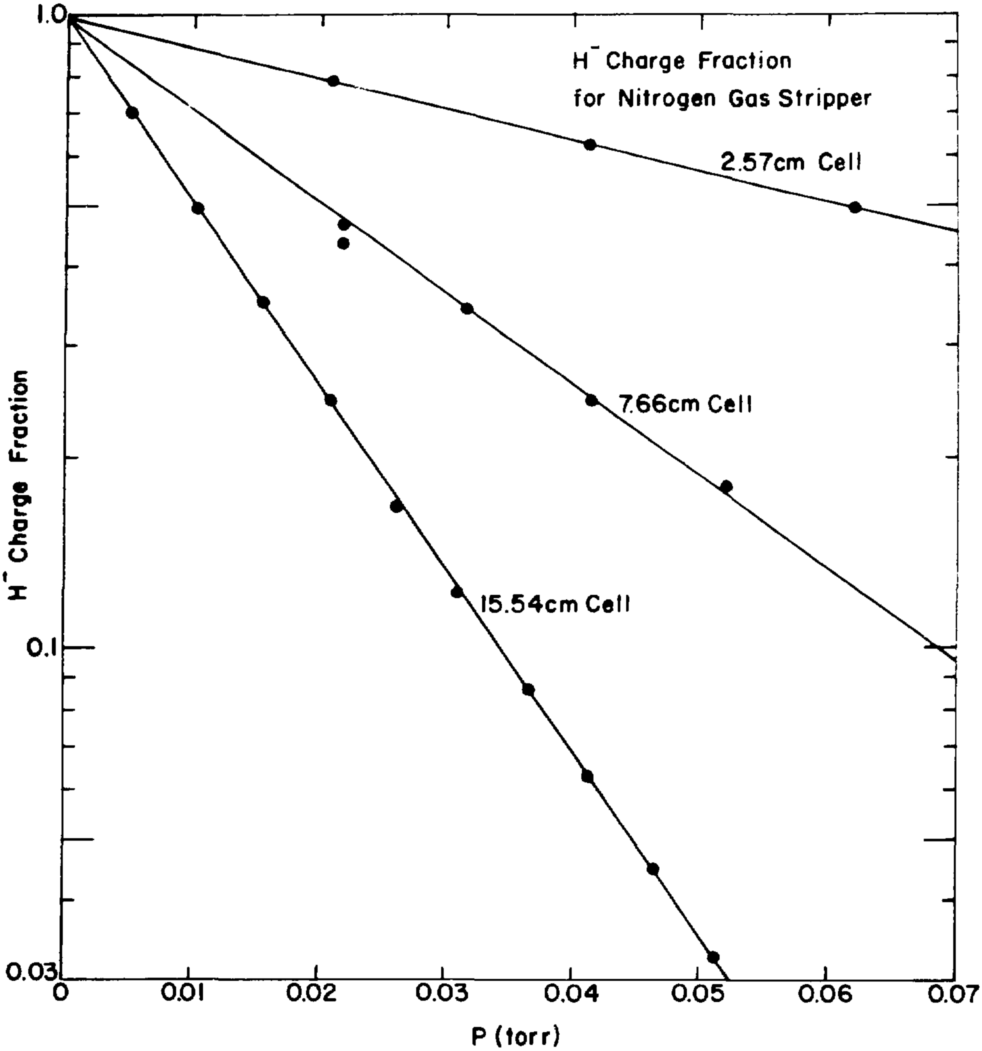

Fig. 3.
H^- charge fraction data from Ref. 5.

The integrators provided 100 counts per second at a full scale current of 6 na. The outputs of the three integrators were directed to individual scalers and combined to provide total count to a master scaler that gated the three individual scalers. Data were accumulated for 1000 counts of the master scaler. Thus the individual scalers provide the charge fraction for on-line monitoring. The integrators were checked by introducing a current from a battery source into each input and running the system for a fixed time. In this instance a 60 Hz pulse generator was switched into the master scaler through the AND circuit and the integratrator outputs were switched out.

Beam currents of about 1 to 3 na were available for this experiment.

Experimental Results

Following conversion of the target pressures to areal density, the charge fractions were plotted linearly and f^- was plotted semilogarithmically. These results are shown in Figs. 4 througn 11 for the various target gases.

A model for the charge exchange process was used to extract the total destruction cross section for Li^- and Li° from the data. The processes considered were

$$Li^- + M \rightarrow Li^\circ + M + e^- \quad (\sigma_{-10})$$
$$Li^\circ + M \rightarrow Li^+ + M + e^- \quad (\sigma_{01}) \qquad (1)$$

The processes

$$Li^- + M \rightarrow Li^+ + M + 2e^- \quad (\sigma_{-11})$$
$$Li^- + M \rightarrow Li^{++} + M + 3e^- \quad (\sigma_{-12})$$
$$Li^- + M \rightarrow Li^{+++} + M + 4e^- \quad (\sigma_{-13})$$
$$Li^\circ + M \rightarrow Li^{++} + M + 2e^- \quad (\sigma_{02})$$
$$Li^\circ + M \rightarrow Li^{+++} + M + 3e^- \quad (\sigma_{03}) \qquad (2)$$

were expected to be less probable than the processes considered, in analogy to the hydrogen case,[1] and were ignored. The functional dependences for the model considered are[2]

$$f^- = \exp(-\sigma_{-10}x)$$

$$f^\circ = \frac{-\sigma_{-10}}{\sigma_{-10} - \sigma_{01}} \left[\exp(-\sigma_{01}x) - \exp(-\sigma_{-10}x)\right]$$

$$f^+ = 1 - f^\circ - f^-$$

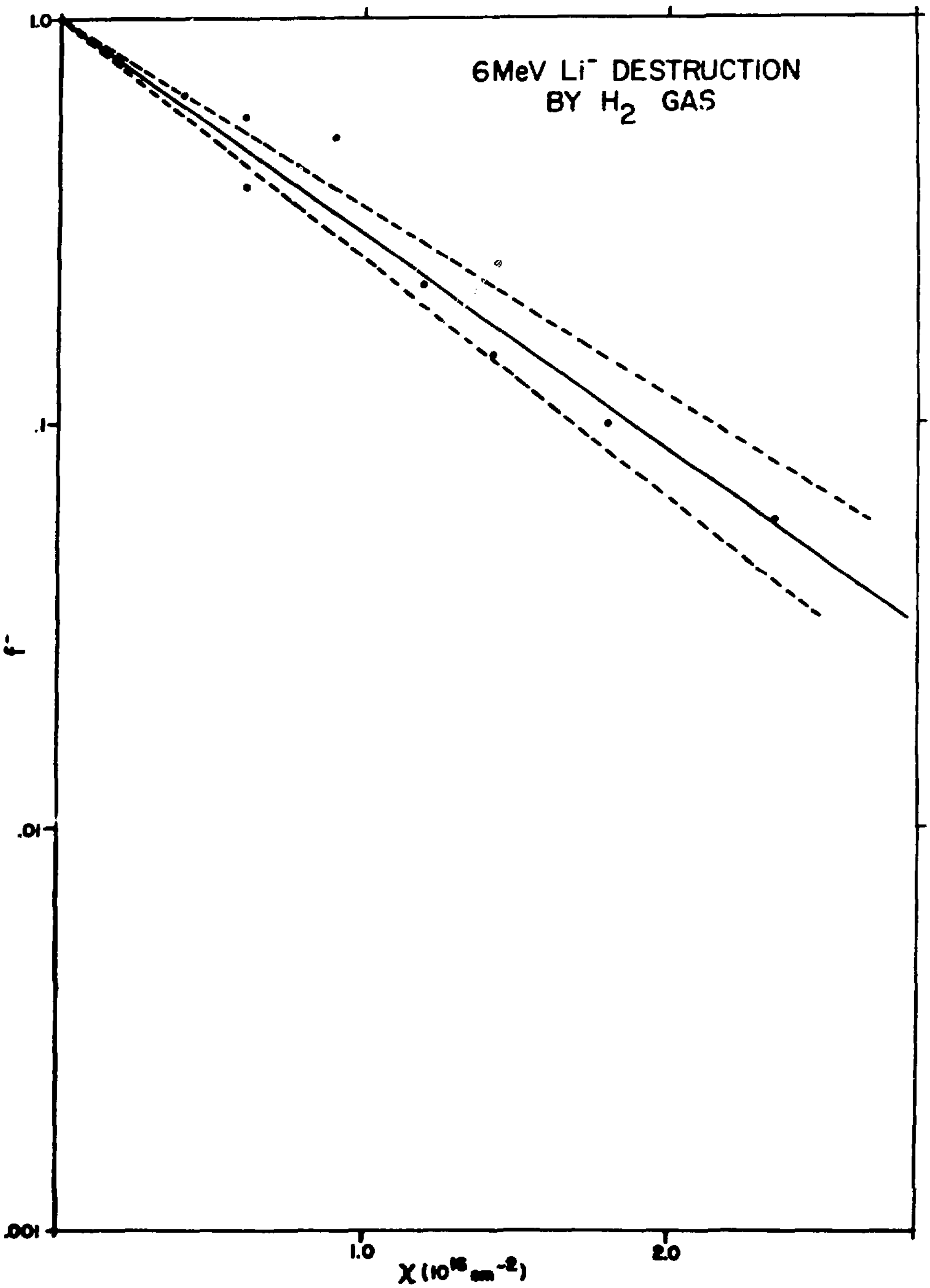

Fig. 4.
Semilog plot of Li^- charge fraction in H_2 gas target. The dashed lines represent the extreme cross section in Table I.

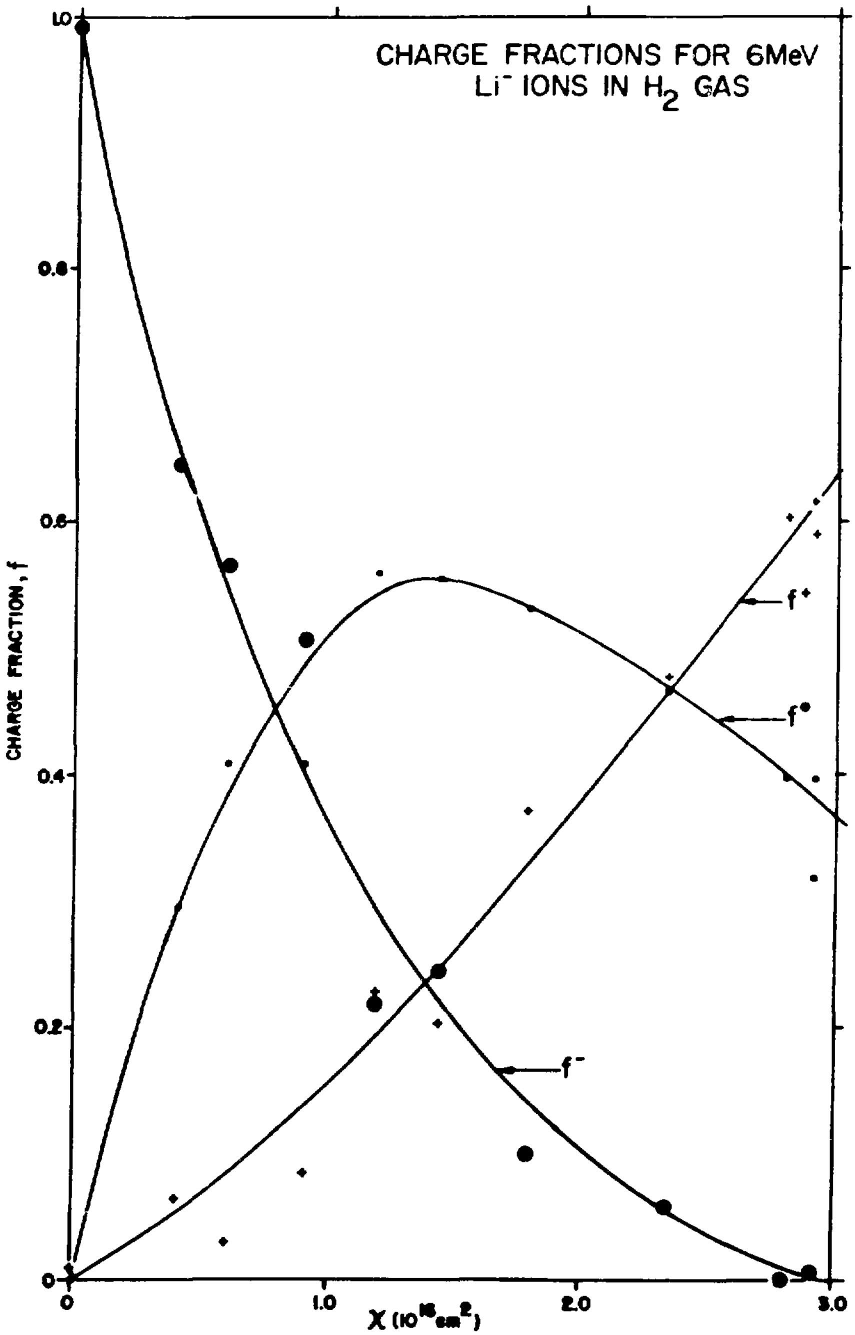

Fig. 5.

Charge fractions for Li^- ion in H_2 gas.

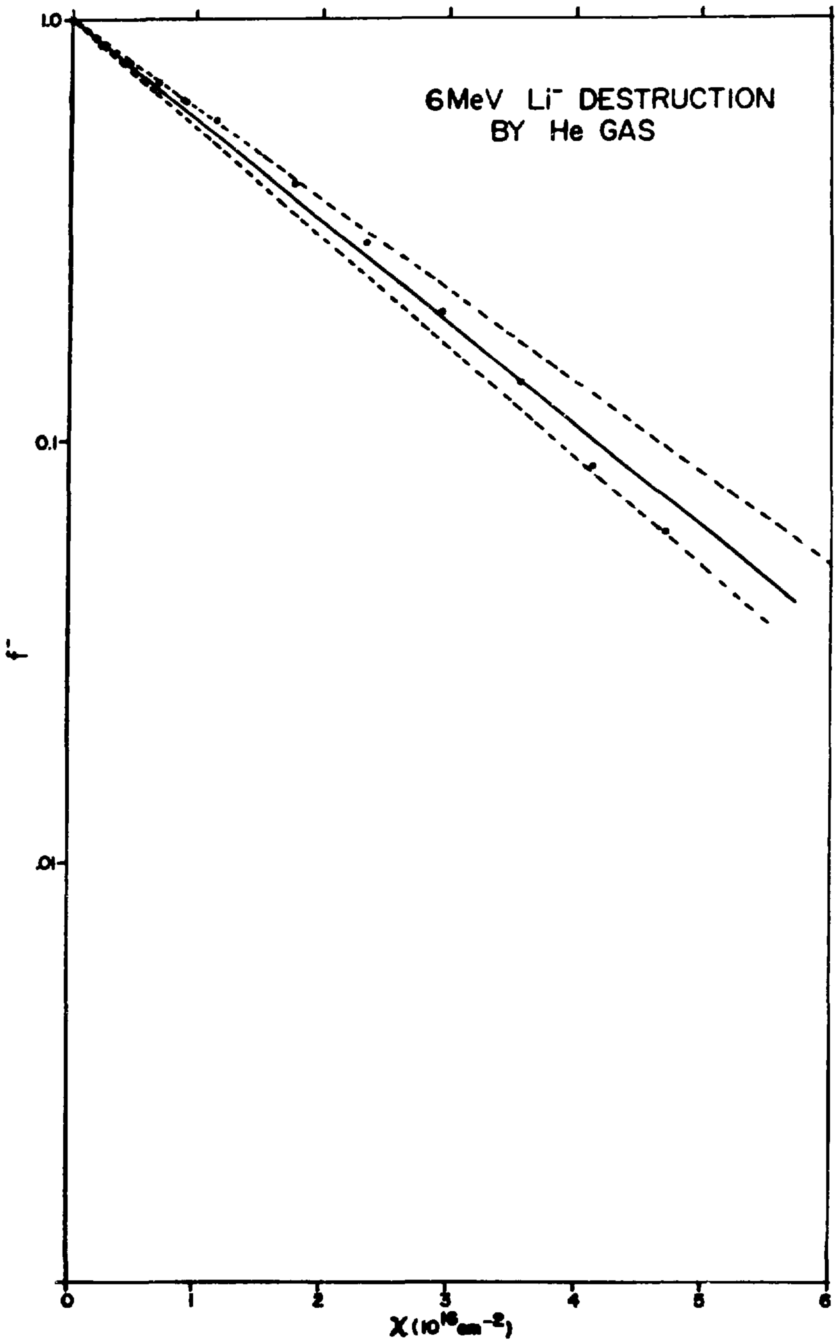

Fig. 6.

Semilog plot of Li^- fraction in He gas. Dashed lines are the cross section extremes reported in Table I.

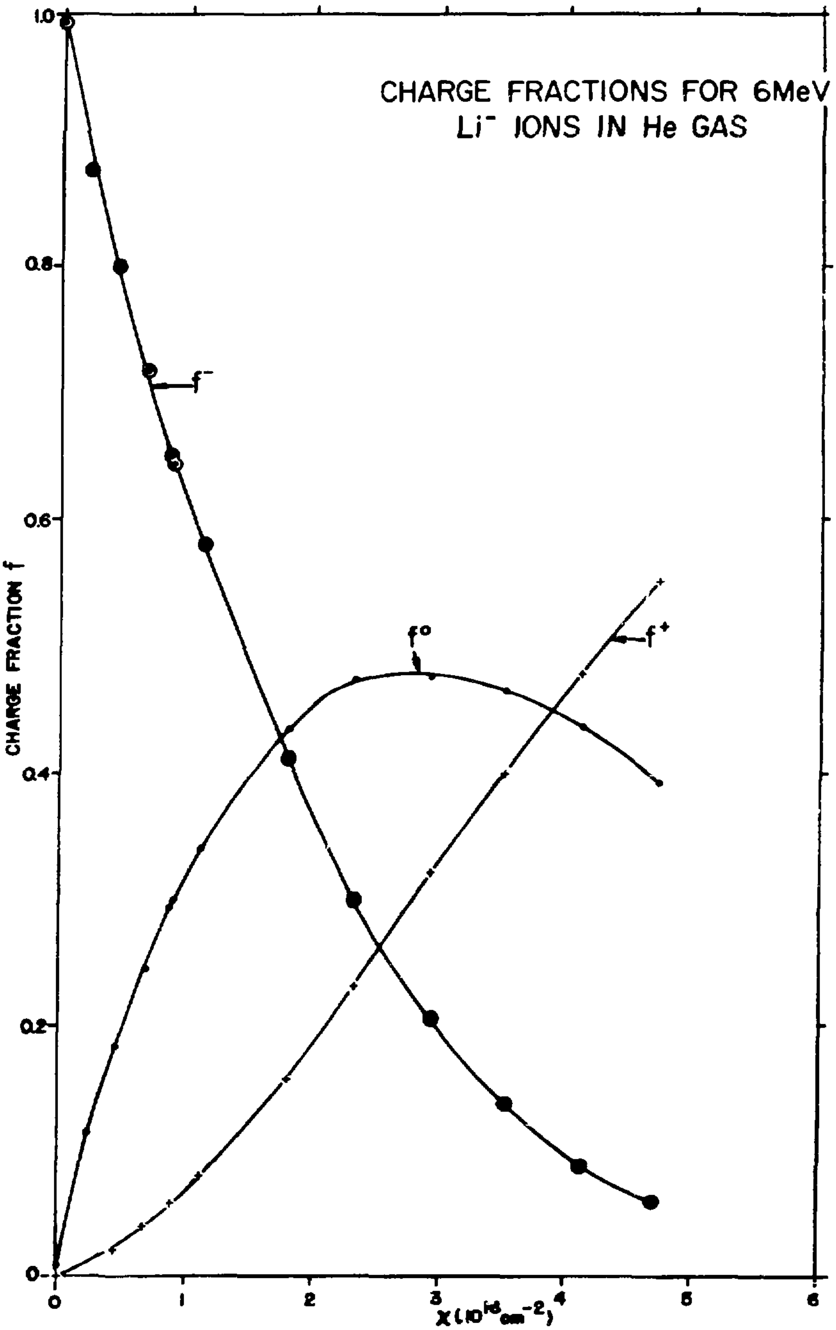

Fig. 7.

Charge fractions for Li^- ions in He gas target.

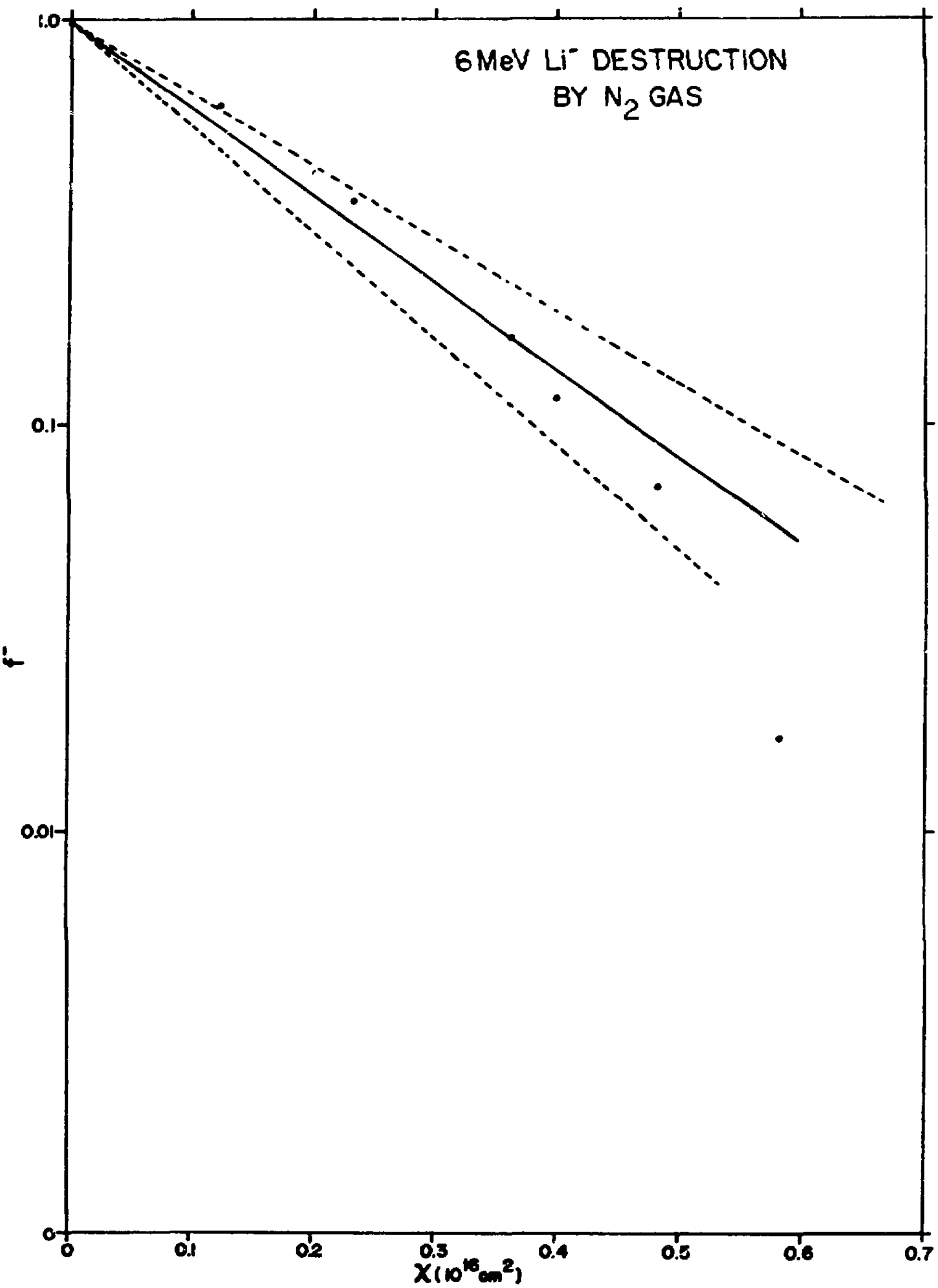

Fig. 8.

Semilog plot for Li^- fraction in N_2 gas. The dashed lines represent the extremes for cross sections reported in Table I.

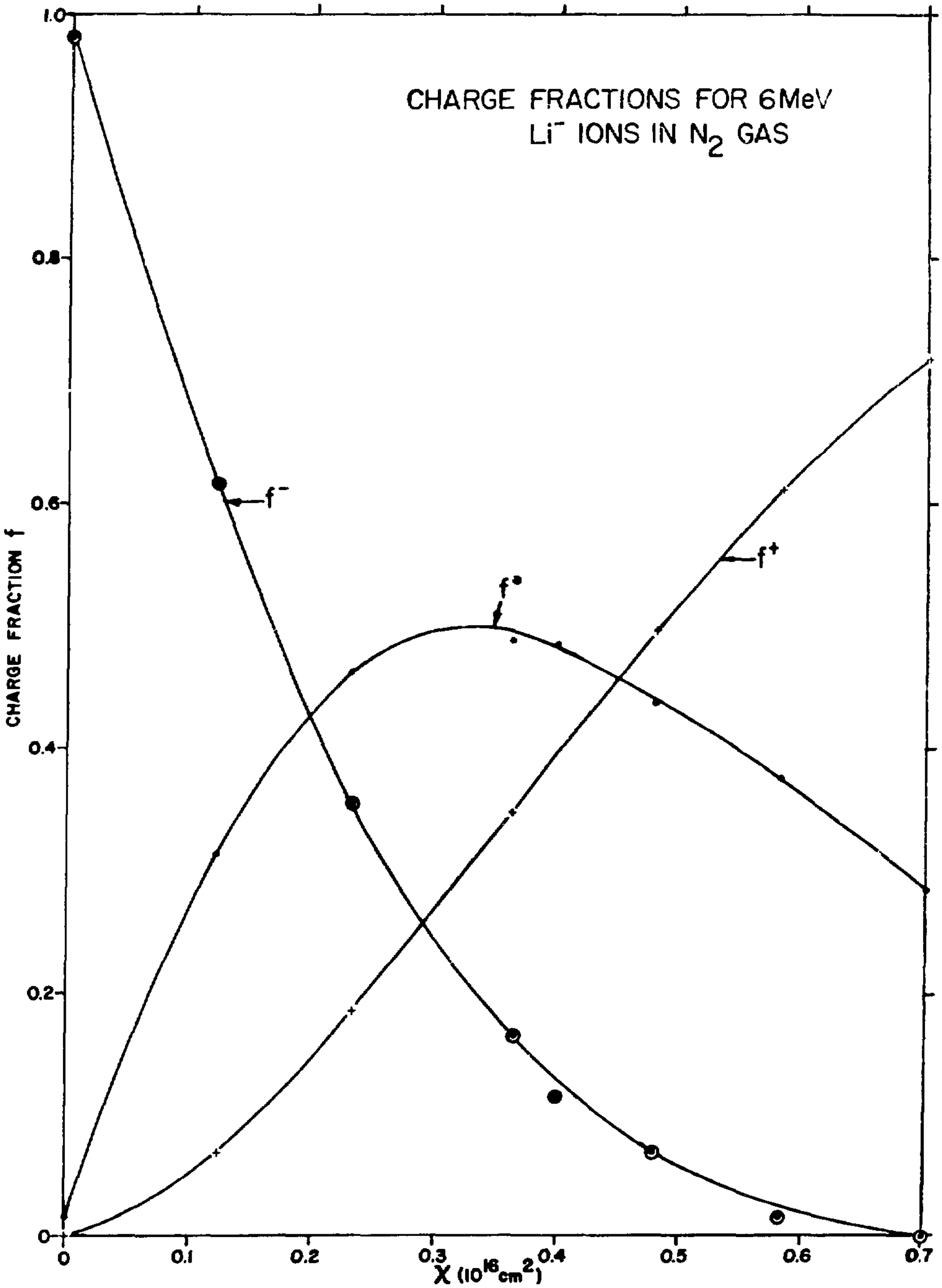

Fig. 9.

Charge fractions for Li^- ions in N_2 gas.

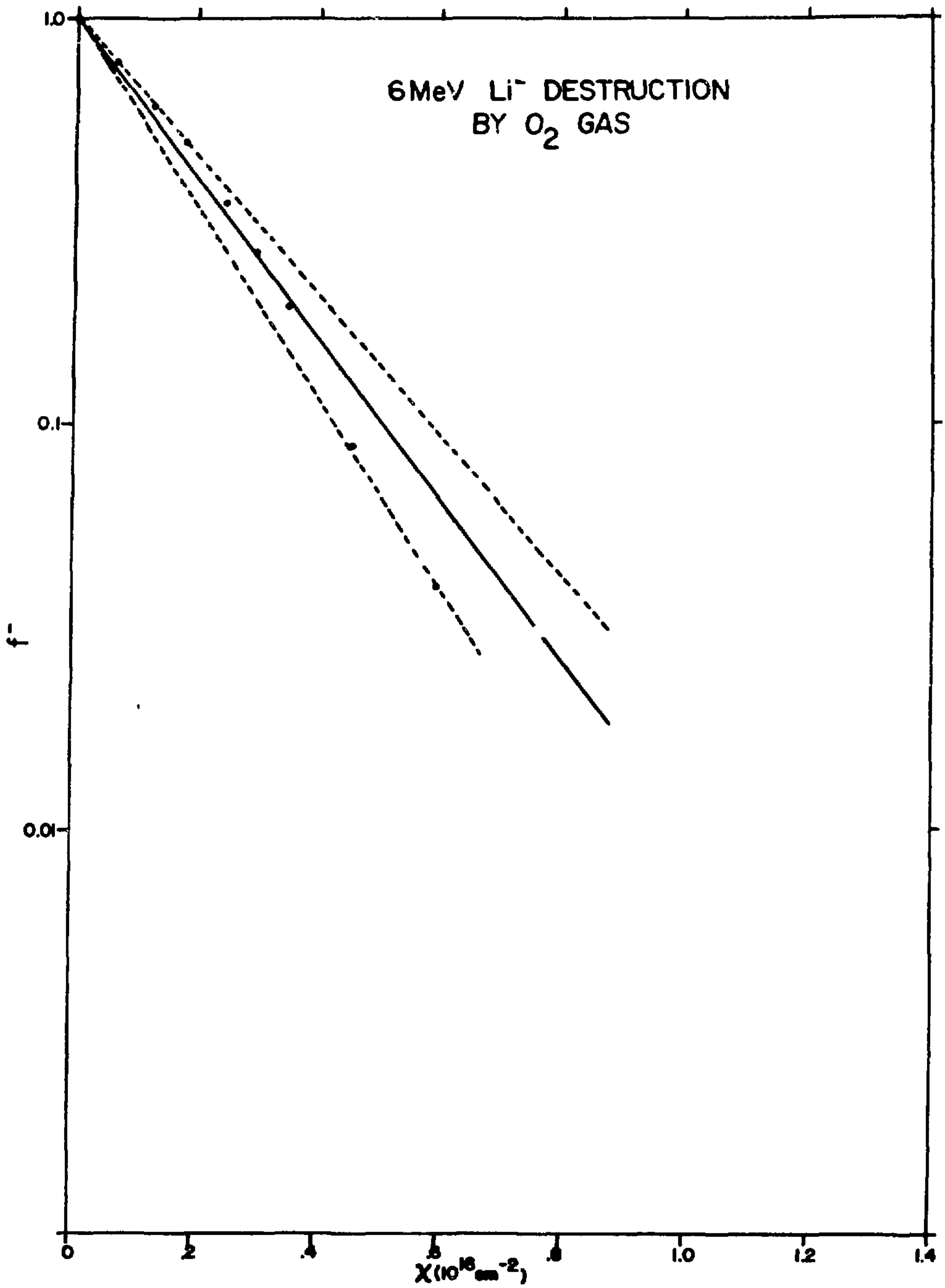

Fig. 10.

Semilog plot of Li^- fraction in O_2 gas. The dashed lines represent the extremes of cross sections reported in Table I.

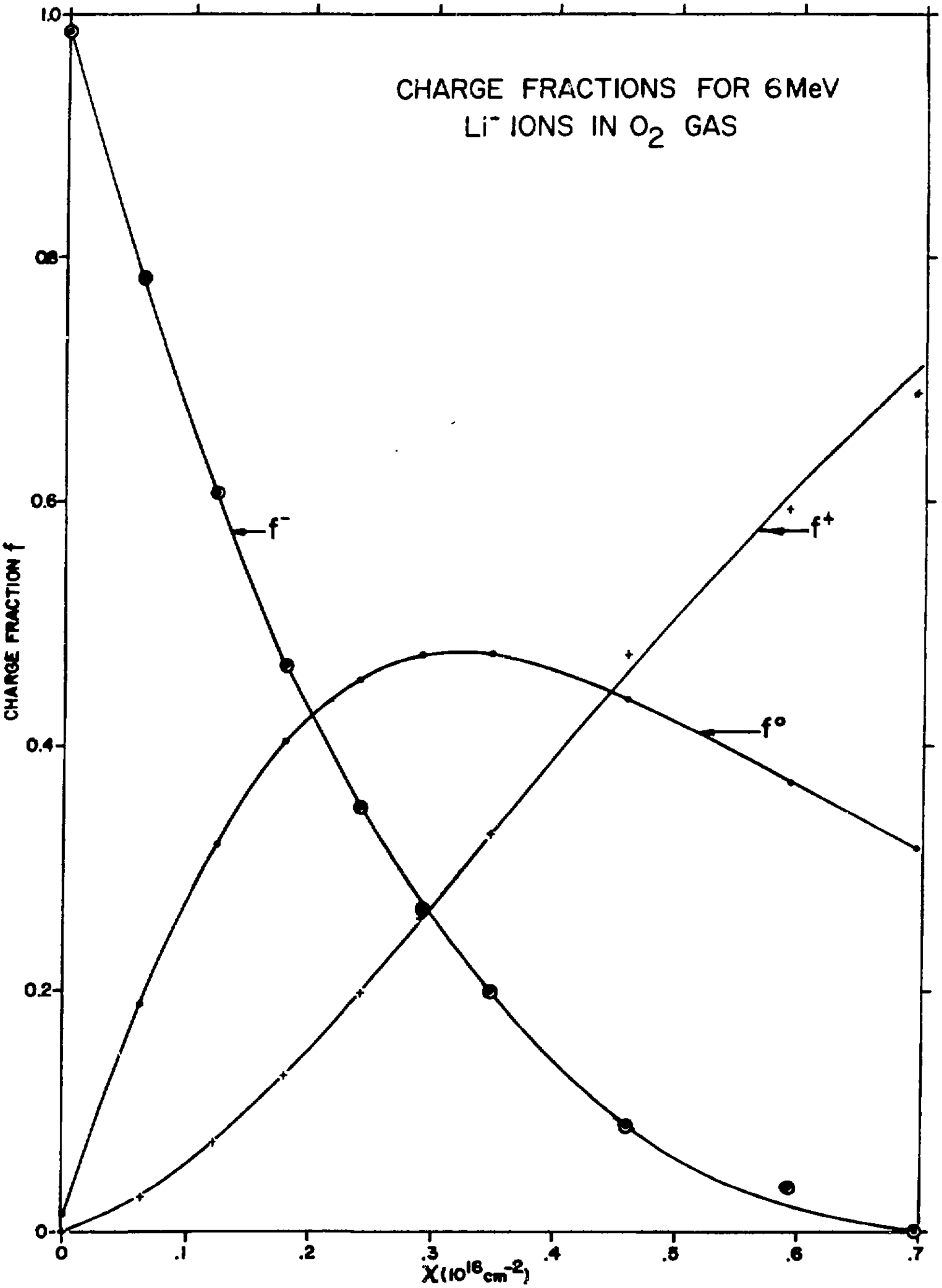

Fig. 11.
Charge fractions for Li^- ions in O_2 gas.

Thus the f° distribution assumes a maximum at

$$x_m = \frac{\ln(\sigma_{-10}/\sigma_{01})}{\sigma_{-10} - \sigma_{01}} = \frac{1}{\sigma_{-10}} \quad \frac{-\ln x}{1 - x}$$

where $x = \sigma_{01}/\sigma_{-10}$. Thus, after σ_{-10} was derived from the slope of the semilog plot of f^-, the value of σ_{01} was derived from x_m. The universal function, $[-\ln x/(1-x)]$, is plotted in Fig. 12. The resultant values of cross section and maximum f° are shown in Table I. The errors represent a range due to extreme slopes shown dotted in the corresponding figures.

The source of the nonlinearity of the semilog plots is not presently understood since the curves were straightline for the H^- measurements made earlier (see Fig. 3). Possible nonlinear response of the Baratron is being checked.

TABLE I

CROSS SECTIONS FOR Li^- CHARGE EXCHANGE AT 6 MeV

Target gas	σ_{-10} (10^{-16} cm^2)*	σ_{01} (10^{-16} cm^2)**	f°_{max}
H_2	1.23 ± 0.15	0.43	0.56
N_2	$4.95 {}^{+1.1}_{-0.8}$	1.61	0.49
O_2	$3.25 {}^{+0.6}_{-0.4}$	2.99	0.48
He	$0.56 {}^{+0.04}_{-0.05}$	0.24	0.40

* Derived from log f^- vs x plot
** Derived from x_m

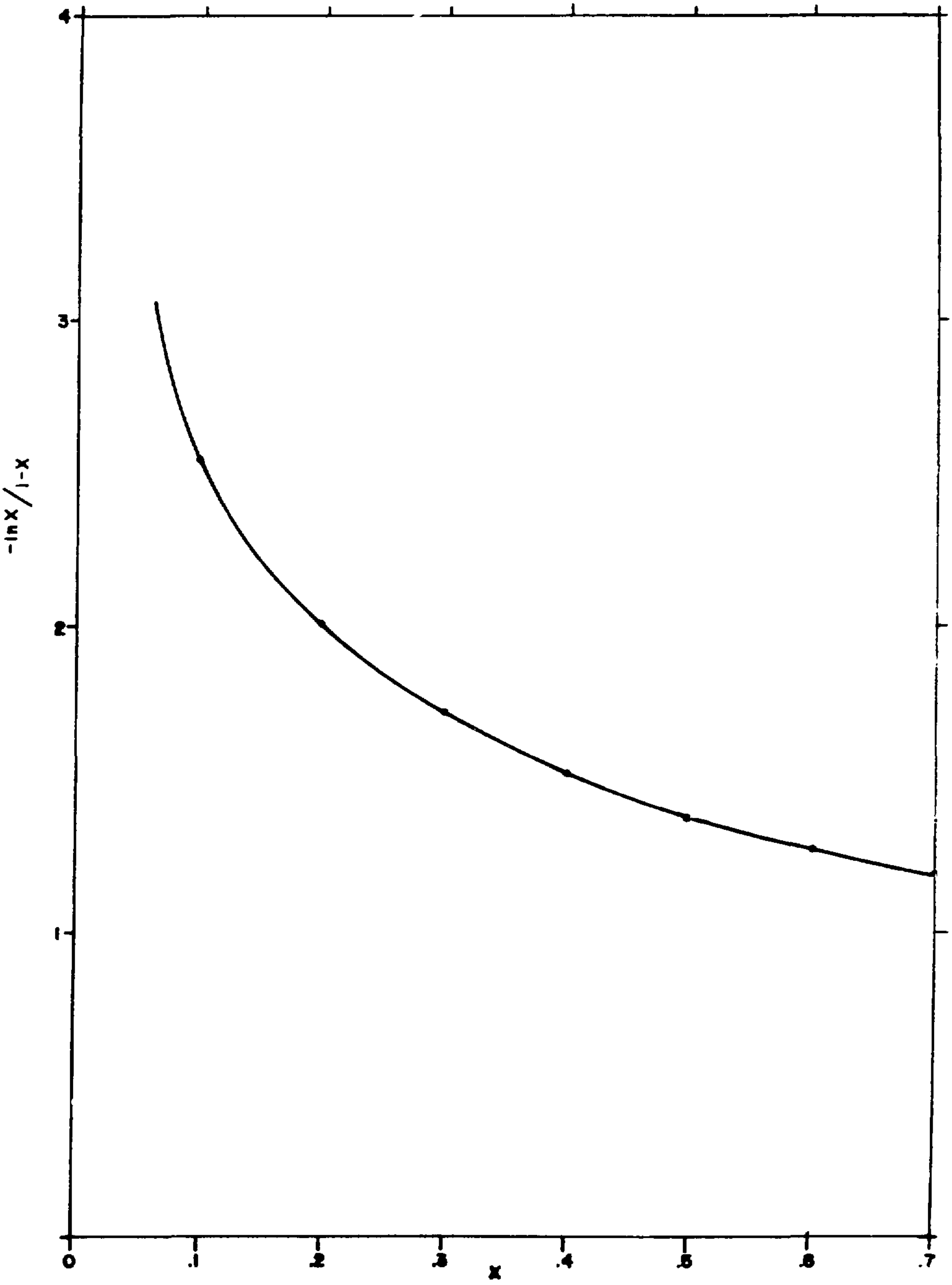

Fig. 12.
Universal graph for extracting σ_{01} from σ_{-10} and x_m. $x = \sigma_{01}/\sigma_{-10}$.

The charge distributions for the positive beams are summarized in Table II The values of f^+ (total positive charge fraction) are taken from a measurement of the charge fractions f^-, f°, f^+ at the same density. The small values of the higher charge fractions support our neglect of more than one electron processes.

Discussion

In order to compare the present results for Li^- ions to those measured[5] at 4 MeV for H^- we adopt a E^{-1} (or β^{-2}) scaling suggested by previous workers.[1,4] Table III contains the comparison.

Conclusions

The measurements of the charge exchange cross sections for Li^- ions show strong agreement with those for H^- ions, provided the increase in the nuclear charge of the Li^- ions is accounted for. This suggests that similar processes are involved and that angular dependence of the charge exchange possibly scales as for hydrogen. A direct measurement is the only sure way to determine this.

TABLE II

CHARGE FRACTIONS FOR POSITIVE Li^- BEAMS AT SELECTED DENSITIES

Target Gas	$x(10^{16}\ cm^{-2})$	f^+	f^{1+}	f^{2+}	f^{3+}	Effective charge
H_2	2.9	0.32	0.28	0.04	0	1.12
N_2	0.76	0.25	0.14	0.11	0	1.43
	0.4	0.48	0.37	0.11	0	1.24
O_2	0.67	0.32	0.19	0.13	0	1.40
	0.27	0.46	0.37	0.09	0	1.20
He	2.3	0.47	0.43	0.04	0	1.09
	4.7	0.39	0.32	0.07	0	1.19
Equilibrium at 4.53 MeV*				Experimental		2.5
				Calculated**		2.8

* 6 MeV minus energy loss for 1.13 mg/cm^2 Nickel foil.
** Reference 3.

TABLE III

COMPARISON OF CROSS SECTIONS FOR Li^- AND H^- IONS OF THE SAME ENERGY

Gas		$\sigma(H^-*)$	$\sigma(Li^-)$	Ratio**
H_2	σ_{-10}	0.103	1.23	11.9
	σ_{01}	0.035	0.43	12.1
N_2	σ_{-10}	0.81	4.95	6.1
	σ_{01}	0.32	1.61	5.0
He	σ_{-10}	0.069	0.56	8.1
	σ_{01}	0.021	0.24	11.5

* All cross sections scaled to 6 MeV and in are units of 10^{-16} cm^2.
** Expected value = 8.7 for dE/dx scaling.[3,6]

The pressure measurement will be checked. However, the departure of the f^- dependence on target thickness is consistent with the onset of a two-step destruction involving excitation[7] of the Li^- ion followed by detachment in a second collision at increased cross section.[2] Such processes are not possible for H^- as there are no excited states of appreciable lifetime.

References

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