Equilibrium Charge Fractions of Aluminum Ions in Nitrogen from 0.4 to 4.0 MeV

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Equilibrium charge fractions have been measured for aluminum ions at energies from 0.4 to 4.0 MeV passing through nitrogen gas. Charge states from 0 to 7^+ were observed. The mean charge increased from 1.47 at 0.4 MeV to 3.84 at 4.0 MeV.

INTRODUCTION

The charge of a fast ion moving through matter fluctuates as a result of electron loss and capture in collisions with the atoms of the target. After the ions have made a sufficient number of collisions with the target atoms, an equilibrium distribution of charges is established which is dependent only on the velocity of the ions and the target material.

In this experiment, equilibrium charge fractions have been measured for aluminum ions, at energies between 0.4 and 4.0 MeV, passing through nitrogen gas. Aluminum chloride negative ions ($AlCl_2^-$) generated by a diode ion source[1] were injected into the Robert J. Van de Graaff Laboratory's 3-MV tandem accelerator. Positive aluminum ions produced by dissociative ionization in the tandem terminal were further accelerated and analyzed before entering the experimental apparatus. This apparatus, as well as the data collection and analysis, was identical to that described by Ryding, Wittkower, and Rose.[2,3]

RESULTS AND DISCUSSION

A typical charge-fraction growth curve as a function of target thickness is shown in Fig. 1; in this case, the incident ion was Al^+ at 1.14 MeV. The growth curve using a different incident-charge state, such as the Al^{2+} ion, has an appreciably different character at low target thicknesses, but beyond a minimum thickness the set of equilibrium fractions is independent of the incident-charge state. It can be seen from the figure that the charge distribution is in equilibrium at target thicknesses greater than ~ 450 mTorr cm. (The cell pressure measured with a differential pressure manometer was ~ 150 mTorr and the cell length was ~ 3 cm.) In practice, it is not always necessary to generate complete growth curves to

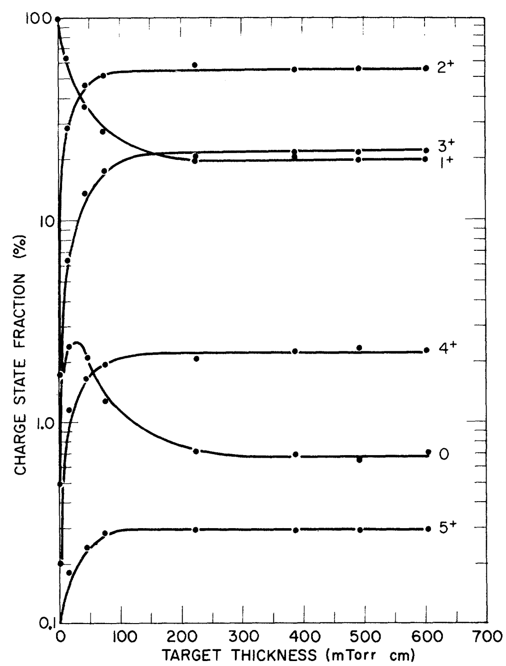

FIG. 1. Charge-state fractions as a function of the nitrogen target thickness for incident Al^+ ions at 1.14 MeV.

obtain the equilibrium values F_i, and fractions which were in good agreement at two substantially different target thicknesses were accepted.

Errors in the measured fractions were estimated from the repeatability of the data and from statistical errors associated with the pulse counting of each beam component. Errors involved in the determination of beam energy were negligible. For fractions F_i greater than ~1%, the total estimated probable error is less than ±5%, whereas for fractions less than ~1%, the probable error may be as large as ±10%.

The measured equilibrium fractions are displayed in Fig. 2 as a function of the projectile energy. Open squares at 0.95 MeV represent the results of Nikolaev *et al.*[4]; the agreement between the two sets of results appears to be within 6% for all charge states. The mean charge $\bar{i}$ and distribution width $\sigma[\bar{i} = \sum i F_i, \sigma^2 = \sum (i - \bar{i})^2 F_i]$ are presented at each energy in Table I. Since the *m* shell of aluminum is totally depleted after three electrons have been removed, the data were studied for shell-effect discontinuities of the type observed by Moak *et al.*[5] in bromine and iodine equilibrium distributions. However, for aluminum ions in nitrogen gas at energies used in the present experiment, no effects could be positively identified with shell-structure discontinuities.

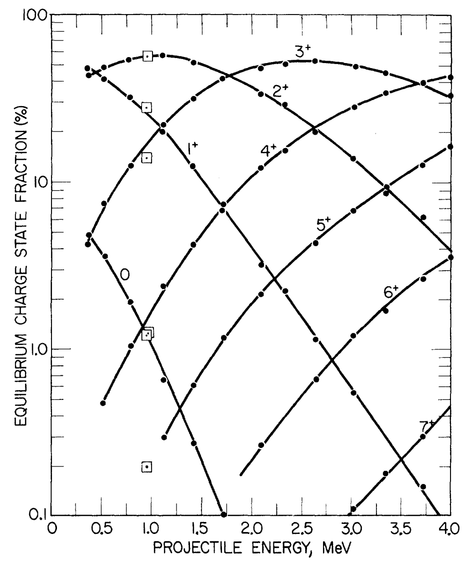

FIG. 2. Charge-state fractions at equilibrium for Al in N_2 as a function of the incident projectile energy. The open squares at 0.95 MeV are the results of Nikolaev *et al.* (Ref. 4).

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TABLE I. Mean charge $\bar{i}$ and distribution width σ for aluminum ions in nitrogen gas.

E(MeV)	0.40	0.52	0.80	1.14	1.40	1.72	2.09	2.35	2.65	3.03	3.35	3.72	4.00
$\bar{i}$	1.47	1.61	1.80	2.06	2.29	2.52	2.78	2.91	3.08	3.32	3.50	3.67	3.85
σ	0.65	0.70	0.72	0.75	0.76	0.78	0.81	0.82	0.83	0.87	0.87	0.90	0.91

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