Nitrogen-ion energy loss in Havar, nickel, Kapton, and Mylar foils

J. Räisänen and E. Rauhala
Accelerator Laboratory, University of Helsinki, Hämeentie 100, SF-00550 Helsinki 55, Finland
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The energy loss of 6.1–16.9-MeV $^{14}N^{n+}$ ions in 2.0-μm Havar, 2.8-μm nickel, 10.6-μm Kapton, and 6.5-μm aluminized (40-nm Al) Mylar foils has been determined. The measured energy losses are compared with the calculated values obtained by using Bragg's rule and the Andersen and Ziegler parameters for proton stopping with appropriate scaling for heavy ions. The maximum deviations from the calculated values observed for Havar, nickel, and Kapton foils were 7%, 4%, and 3%, respectively. The experimental results agree with the calculations in the case of the Mylar foil, in the 6–10-MeV energy region for Havar, and in the 15–17-MeV energy region for nickel and Kapton foils.

I. INTRODUCTION

Energy-loss data are needed in cases where foils are used for absorbing and stopping charged particles. In various cases the approximate energy-loss values obtained by theoretical calculations are not adequate. Accurate experimental energy-loss values are important, e.g., in the use of the heavy-ion ERDA (elastic recoil detection analysis) method[1] and in using exit foils for gas targets and external beam methods.[2] Such data are also valuable when ^{15}N beams are used for hydrogen depth profiling and other analytical purposes.

The purpose of the present study was to obtain experimental energy-loss data for $^{14}N^{n+}$ ions in 2.0-μm Havar, 2.8-μm nickel, 10.6-μm Kapton, and 6.5-μm aluminized (40-nm Al) Mylar foils. As no previous experimental values are given for the composite foils in the literature, the present results are also of interest from the point of view of theoretical calculations. In testing, e.g., the possible violations of Bragg's rule in light materials, relevant stopping values of compounds must be presumed.

II. EXPERIMENTAL

The ion beams were generated by the 5 MV EGP-10-II tandem accelerator (^{14}N) and the 2.5-MV Van de Graaff accelerator (^{1}H) of the University of Helsinki. The charge of the nitrogen ion beam was 2+ in the energy range 6–10 MeV, 3+ for energies 11–16 MeV, and 4+ above 16 MeV. The experimental arrangement was similar to that presented in detail in Ref. 3. In the energy-loss measurements the backscattered nitrogen ions from a thick gold target penetrated through the foil placed perpendicularly to the beam in front of the silicon surface-barrier detector (50 mm^2, 100 μm), positioned at a scattering angle $\theta = 150°$. The measuring geometry is shown schematically in Fig. 1. In this way, direct beam exposure, which possibly would modify the properties of the foil,[3] was avoided. The energy loss of the ions in the foil was then determined by observing the shift of the leading edge of the backscattering signal, induced by the foil. This is illustrated in Fig. 1, for the case of Havar and Kapton foils at $E_N = 22$ MeV.

Collimation apertures in front of the gold target and the foil[3] were found to have an insignificant effect on the energy resolution and edge position. To achieve better counting statistics, these apertures were thus removed for most of the experiments. The energy resolution of the detection system was 135 keV at $E_N = 22$ MeV.

Proton backscattering measurements for the areal densities of the foils were performed subsequent to the energy-loss experiments by using a standard backscattering apparatus.[4] The proton beam was 0.5–2.0 mm in diameter. The same spots of the foils were used as for the energy-loss measurements. In addition, the possible local thickness variations of the foils were checked by several backscattering measurements within 3–5 mm of the spot.

III. MEASUREMENTS AND RESULTS

The areal densities of the foils were determined by 2.4-MeV proton backscattering. Semiempirical Andersen and Ziegler stopping parameters,[5] Bragg's rule and the nominal compositions[3] of the foil materials provided the neces-

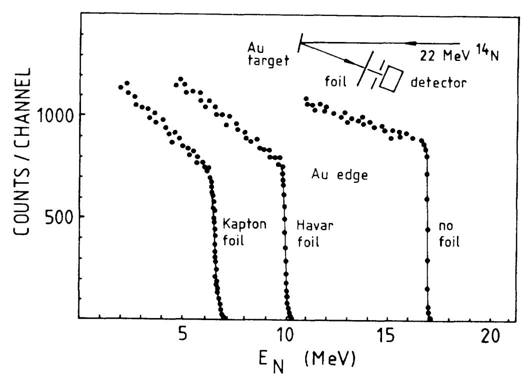

FIG. 1. The shift of the Au backscattering edge due to the energy loss of the 16.9 MeV $^{14}N^{n+}$ ions in Havar (1.99 μm) and Kapton (10.63 μm) foils. The results for nickel and Mylar are not shown for the sake of clarity, since the energy loss in these foils is close to those of Havar and Kapton.

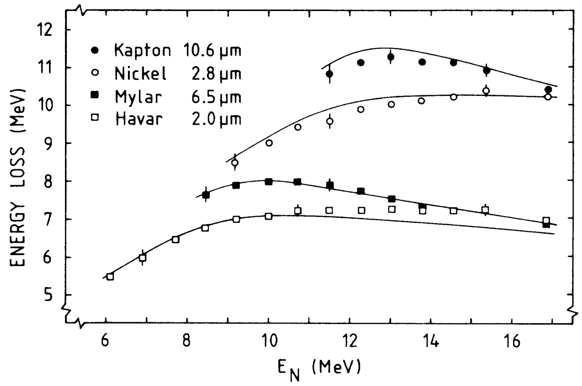

FIG. 2. The energy loss ΔE of $^{14}N^{n+}$ ions in Kapton, nickel, Mylar, and Havar foils as a function of initial ion energy. The solid curves represent the values obtained by using Bragg's rule and the proton stopping parameters (Ref. 5) with scaling (Ref. 7) for N ions.

sary proton stopping cross sections. This procedure has been justified by our previous measurements in Ref. 3. By taking into account the measured thickness variations, the resulting foil thicknesses were 1.99±0.02-μm Havar, 2.80±0.02-μm nickel, 10.63±0.12-μm Kapton, and 6.46±0.05-μm Mylar. For conversion to thickness in μm from units atoms/cm^2, mass densities 8.30, 8.91, 1.42, and 1.39 g/cm^3, respectively, were assumed. This method of determining the foil thicknesses is more accurate than weighing since now the thickness is determined from exactly the same position as the energy-loss measurements.

The results of the energy-loss measurements for energies 6.1–16.9 MeV are given in Fig. 2 and in Table I. The experimental errors (Fig. 2) of the energy-loss data include the possible errors in determining the edge position (±1.0% at the higher energies) and the signal width (±1.5%) in the backscattering experiments. At the lower energies the uncertainty in edge position increases by a factor of 2–3. The inaccuracy in calculating the areal densities of the foils, due to the possible errors in the adopted proton stopping cross sections and the possible invalidity of Bragg's rule, was not considered.

The results of the present study are compared in Fig. 2 with the calculated values obtained by using the restricted nuclear stopping power[6,7] and the Ziegler scaling[7] of proton stopping for the heavy-ion stopping cross sections. The present experimental values were found to be 3–7% higher for Havar in the energy range 11–17 MeV, 2–4% lower for nickel between 9 and 13 MeV, and about 3% lower for Kapton in the region 12–14 MeV. For Mylar the agreement is good within the whole range of our experimental data.

IV. DISCUSSION

The amount of ion energy lost, ΔE, per distance, Δx, traversed in the foil, $\Delta E/\Delta x$, approaches the differential energy loss per unit path length dE/dx as the distance Δx reduces. For finite distances and for small ΔE as compared to ion energy, the observed $\Delta E/\Delta x$ may be approximated as dE/dx for the arithmetic mean energy $E_{av}=(E_i+E_f)/2$ of the initial energy E_i and exit energy E_f of the ions. If dE/dx is a linear function of energy, the approximation is accurate. For a power-law energy dependence of dE/dx, i.e., $dE/dx=AE^B$, a small correction to the mean energy E_{av} must be applied.[8] At least in the higher-energy region of the present measurements, where $\Delta E < E_{av}$, the energy loss ΔE may thus be scaled to other somewhat different foil thicknesses.

The comparison of the present data with literature values is difficult due to the lack of experimental results in the energy interval studied in the present work. Furthermore, no previous data are given for the composite foils. Therefore only the nickel data may be examined in more detail. In the case of nickel targets, data may be

TABLE I. The energy loss ΔE of 6.1–16.9-MeV $^{14}N^{n+}$ ions in Havar, nickel, Kapton, and Mylar foils.

	ΔE (MeV) in			
E (MeV)	Havar (1.99 μm)	Nickel (2.80 μm)	Kapton (10.63 μm)	Mylar (6.46 μm)
6.14	5.50			
6.90	6.00			
7.67	6.45			
8.44	6.77			7.64
9.20	6.96	8.51		7.89
9.97	7.11	9.06		8.02
10.70	7.22	9.46		8.00
11.51	7.26	9.69	10.81	7.91
12.27	7.26	9.90	11.17	7.77
13.04	7.28	10.05	11.32	7.60
13.81	7.24	10.18	11.19	7.32
14.57	7.24	10.26	11.17	7.26
15.34	7.28	10.43	10.94	7.26
16.87	7.00	10.24	10.45	6.88

found at slightly higher and lower energies than the present values.[9–13] The approximate procedure for obtaining stopping-power values from the present thick-foil energy-loss data is valid only for the point obtained at the highest energy of $E_{av} = 11.75$ MeV. At the lower E_{av} energies the comparison is not justified. The present value of 4.1 ± 0.1 MeV/(mg cm^{-2}) at $E_N = 11.75$ MeV may therefore be compared with the value of 4 MeV/(mg cm^{-2}) obtained by Bethge and Sandner[11] at $E_N = 10.7$ MeV. An accurate value is difficult to obtain as no exact data were given in this previous study. Another value for comparison may be obtained by interpolating from the values given in Refs. 10, 12, and 13 (E_N up to 7.4 MeV) to the values of Roll and Steigert[9] (E_N values from 28 MeV). The value obtainable by this procedure for $E_N = 11.75$ MeV is about 4.0 ± 0.2 MeV/(mg cm^{-2}). All values are in excellent agreement.

The possible effect of charge-changing events[14] could in principle be investigated by the present method. According to Cowern *et al.*[14] about 2.8% of the total stopping power at maximum is associated with these events in the case of 3 MeV/amu C ions in thin carbon films. Due to the approximations needed, sufficiently accurate stopping-power values from thick-foil energy-loss data are not obtainable unless very thin films or foils having thicknesses very close to each other are used. Unfortunately the foils studied in the present work are not available in such thicknesses.

The durability of the organic foils when placed in an ion beam is rather poor. For example, in the case of protons a rapid decrease of the energy loss in Mylar foils when subject to ion bombardment, was detected in our earlier study,[3] i.e., the foil became thinner. In the case of nitrogen ions, Mylar and Kapton foils deteriorated rapidly when subjected to even a few nA of direct beam in the present investigations. Thus the experimental arrangement where a scatterer is employed, as in the present study, should be used for measuring the ion energy loss in the foils.

The observed differences from the calculated energy-loss values are clearly significant and the theoretical calculations are thus insufficient in many applications. When accurate data are needed, experimental energy-loss values must be used.

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