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STOPPING POWER OF ARGON FOR IONS WITH Z RANGING BETWEEN 3 AND 13

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A multilayer ionization chamber is employed for studying the energy dependence of the stopping power of argon for Li, Be, B, C, N, O, Na and Al ions with energies lying between 0.5 and 2 MeV/a.m.u. The experimental data point to the existence of an universal dependence of $\langle Z^2\rangle/Z^2$ on the parameter $\xi = v/Z\alpha c$ where V is the ion velocity and $\alpha = 1/137$.

INTRODUCTION

An investigation of the passage of charged particles through matter is of considerable interest from the point of view of the practical needs of experimental nuclear physics. The deceleration of protons in various media has been quite well investigated[1]. As to the passage of heavier ions in Ar, there are data on the deceleration of He^4, C^{12}, and Ar^{40} at energies 2–10 MeV/a.m.u.[2], data on the deceleration of Li^7 with energy 0.014–0.05 MeV/a.m.u.[3], and data on the deceleration of N^{14} and Ne^{20} with energy 0.01–0.03 MeV/a.m.u.[4]. The deceleration of Li, B, N, and Ne ions at 0.01–0.5 MeV/a.m.u. was investigated in[5]. In the energy region 0.5–2 MeV/a.m.u., there are no experimental data on the deceleration of heavy ions in argon. Since an important role is played in this region by charge exchange of the ions, and the accuracy of the calculations is quite limited, it is of definite interest to obtain experimental data.

We have investigated in this paper the deceleration of heavy ions in argon at energies 0.5–2 MeV/a.m.u.

MEASUREMENT METHOD

The accelerated ions with a continuous energy spectrum were obtained by the Coulomb repulsion of nuclei by the fission fragments of U^{235}.[6] The ions passed through a collimator and were registered in a multilayer ionization chamber filled with Ar at a pressure of 1 atm[6]. The particles passed through a thin (8 mm) proportional counter, and then through an organic barrier film 0.3 mg/cm^3 thick, falling into a large chamber with a grid, where they were stopped. The recording apparatus made it possible to measure the amplitude of the pulses in the counter and in the chamber for each particle simultaneously. From the pulse in the chamber we determined E_0 (the energy of the ion on entering the chamber), E_2 (the energy on leaving the chamber), and E_1 (the energy on entering the counter). The magnitude of the pulse in the counter is proportional to $-\Delta x dE/dx$, where dE/dx is the stopping ability of Ar for the given ion, and Δx is the thickness of the counter. It is assumed that the ionization in Ar is proportional to the energy release. The measured values of dE/dx were assigned energy values $E = \frac{1}{2}(E_1 + E_2)$. The averaging over the thickness of the counter does not lead to significant errors, since the f(E) curves, where f = dE/dx, are sufficiently smooth.

The calibration of E_0 was against α-particles from Po^{212}, Bi^{212}, and Po^{214}. The dE/dx scale was calibrated against the counter pulses due to the α-particles from Po^{212} and Bi^{212} and the Be^9 ions with $E > 18$ MeV. The value of dE/dx for all these ions was calculated from the formula $(dE/dx)_i = \langle Z^2\rangle (dE/dx)_p$, where $(dE/dx)_p$ is the stopping ability of Ar for a proton having a velocity equal to the ion velocity, $\langle Z^2\rangle$ is the mean-square charge of an ion of given velocity. The value of $(dE/dx)_p$ in the energy region 0.5–1 MeV was determined from the data of[7–9]. In the energy region 1–3 MeV, the value of $(dE/dx)_p$ was calculated by the formula[10]:

$$-\frac{dE}{dx}\left[\frac{\text{MeV-cm}^2}{\text{mg}}\right] = 3{,}072\cdot 10^{-4}\left(\frac{Z^2}{\beta^2 M}\right) Z_0 \ln\frac{2m_e v^2}{I},$$

where Z_0 and M are the charge and mass of the atom of the medium, and I is the excitation energy. The value of I was chosen such as to satisfy the data of[7] and[9] at E = 1 MeV and the data of[11] at E = 4.43 MeV. The value of $\langle Z^2\rangle$ was determined from the data of[12,13]; the difference between $\langle Z^2\rangle$ and Z^2 did not exceed 4%.

We made three series of measurements with different amplifications of the pulse from the counter. In the first series, the measurements were made with Li^7, Be^9, and B^{11} ions, in the second with B^{11}, C^{12}, N^{14}, and O^{16} ions and in the third with O^{16}, Na^{23}, and Al^{27} ions. The dE/dx scale for the first series was calculated from the results of a calibration, while the scales for the second and third series were related to the scale for the first series with the aid of the results of measurements made with B^{11} and O^{16} ions.

The measurement results are shown in Fig. 1, where the abscissa represents E/m, where m is the ion mass; the ordinates are the values of $(1/Z^2)(dE/dx)$. The solid line corresponds to protons. The errors in the ordinate correspond to the relative accuracy in each series of measurements. The absolute accuracy of the ordinate scale, connected with the error in the calibration and the error in the calculation of $(dE/dx)_p$, amounts to 6%. The obtained data do not contradict, within the limits of errors, the data of[2] and[5].

Northcliffe has shown[14] that for ions with $2 \le Z \le 10$ in Al, $\langle Z^2\rangle/Z^2$ depends in the same manner on $\xi = v/Z\alpha c = v/v_B$, where v is the ion velocity,

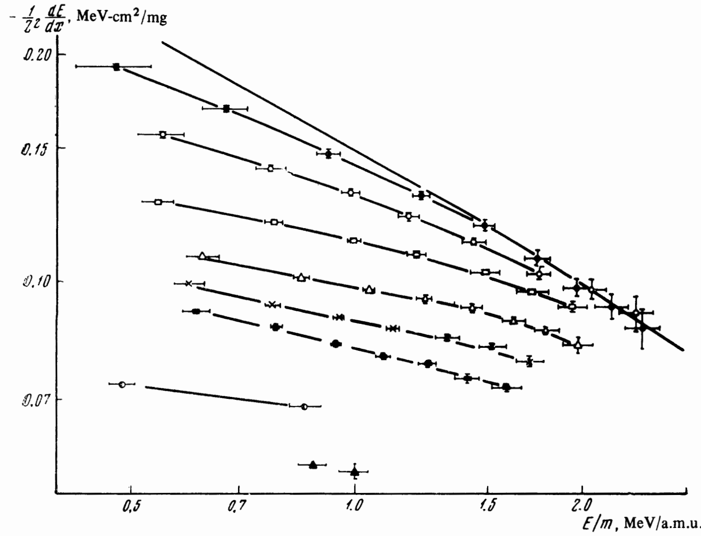

FIG. 1. Stopping ability of Ar as a function of the ion energy: ●–Li, ○–Be, □–B, △–C, ×–N, ■–O, ●–Na, ▲–Al.

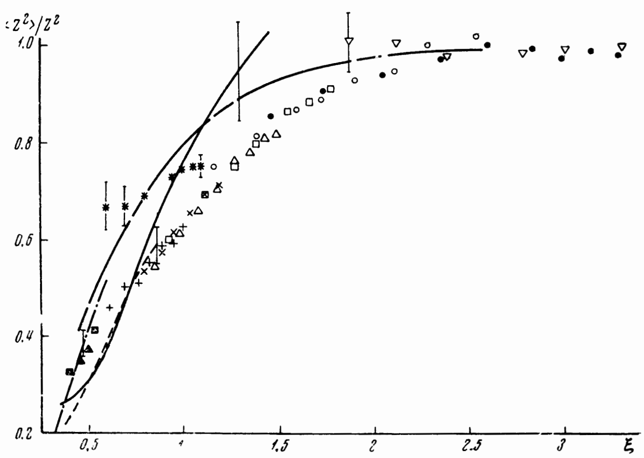

FIG. 2 Dependence of the mean-square charge on the ion velocity. Present work: ●–Li, ○–Be, □–B, △–C, ×–N, +–O, ■–Na, ▲–Al: Ref. 2: ▽–C, ∗–Ar: Ref. 5: solid curve–Li, dashed–B, dash-dot–N: Ref. 14: long dashes–deceleration in Al.

$\alpha = 1/137$, and v_B is the electron velocity on the first Bohr orbit. The verification of the universal dependence of $\langle Z^2 \rangle / Z^2$ on ξ for ions decelerated in Ar is illustrated in Fig. 2. The values of $\langle Z^2 \rangle$ calculated from the formula $\langle Z^2 \rangle = (dE/dx)_i (dE/dx)_p^{-1}$. Figure 2 shows also the data by others, dealing with the deceleration of the particles in Ar[2,5]. Our data fit well on a single curve. This curve differs from the universal curve obtained by Northcliffe for Al.

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