DETERMINATION OF THE RANGE-ENERGY RELATION FOR NITROGEN AND OXYGEN IONS IN PHOTOGRAPHIC EMULSIONS

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Submitted to JETP editor March 8, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 343-345 (August, 1957)

The dependence of range on energy has been measured for nitrogen and oxygen ions in Ilford E-1 emulsions for the energy interval 3 — 120 Mev. The results are compared with theoretical predictions. The energy at which the nitrogen and oxygen ions lose all their electrons traversing the matter has been estimated.

THE experimental determination of the range-energy dependence for N and O ions is of interest because theoretical estimates meet with considerable difficulties. The phenomena of electron loss and capture in traversing the matter manifest themselves for these ions in a wide range of energies. The Bethe-Bloch formula, which does not account for charge variation, cannot therefore be applied in this case.

Several authors calculated the range-energy relation in photographic emulsions for ions with $3 \leq Z \leq 10$.[1-3] These calculations, involved semi-empirical constants connecting the probability of electron loss and capture with the ion velocity. A few experimental points were obtained for C ions by Miller[4] and for N ions by Chaminade et al.[5] Reynolds et al. measured the range of N ions in the emulsion[6] and in nickel[7] in the energy interval 5 — 30 Mev.

We carried out an investigation of the range-energy dependence for the N and O ions in emulsion in the energy range 3 — 120 Mev, using for this purpose a beam of ions accelerated by a 150 cm cyclotron. The N and O ions were accelerated to large energies by the multiple frequency method in which the ions are initially accelerated while doubly charged and then are stripped on the atoms of the residual gas and as sextuply ionized are accelerated to high energies. Since the process of electron loss takes place in the whole volume of the cyclotron chamber, ions with different energies, up to a maximum of 130 Mev are present at the final orbit. No special measures for beam ejection were used but a part of the ions scattered by the dee walls found its way into the ejection system.

The beam passed through a magnetic analyzer in order to obtain monochromatic lines. An aluminum foil 6 μ thick in which high energy ions lost their electrons completely and low-energy ions attained the equilibrium charge was placed before the analyzer. The foil had also as its purpose to prevent doubly-charged ions from reaching the photographic plate. The plates were placed in a vacuum chamber, at the focal point of the analyzer. The magnetic field of the analyzer was calibrated by means of protons and molecular hydrogen. The proton energy was measured by N. D. Fedorov. Accurate test experiments demonstrated that in the region in which the measurements were carried out the magnetic field depends linearly on the current in the magnet coil. The ion energy, corresponding to a certain value of the current I_i could, therefore, be found from the relation

$$E_i = \frac{M_H}{M_i}\left(\frac{Z_i}{Z_H}\right)^2\left(\frac{I_i}{I_H}\right)^2 E_H,$$

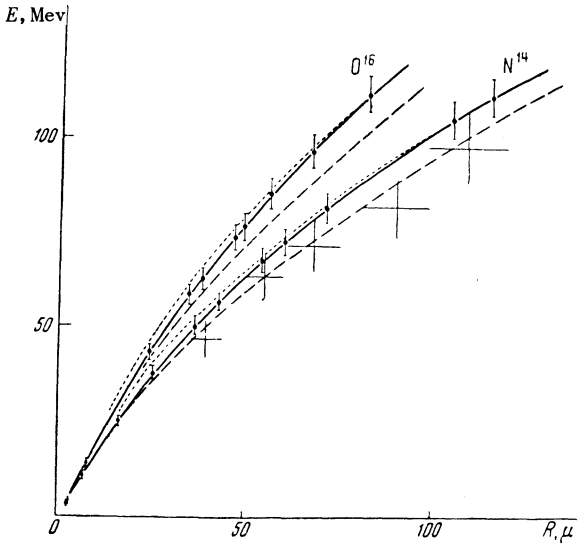
where Z_i, M_i are the charge and the mass of the ion, Z_H and M_H are the charge and mass of molecular hydrogen, I_H is the coil current for which molecular hydrogen of a known energy passes through the analyzer.

Varying the magnetic field of the analyzer it was possible to obtain on the photographic plate N and O ions of different energies up to 130 Mev. Besides the group of ions corresponding to the maximum charge (nuclear charge) groups, corresponding to smaller values of the charge were always observed on the plates. The energies of these groups go as the square of the charge. This made it possible to determine with great accuracy the relative curves of the range-energy dependence for the N and O ions. Unfortunately, it was impossible to determine the equilibrium charge of ions for various energies in the

course of the experiment since the ion energy spectrum before the stripping foil was unknown.

The foil was removed for the determination of range-energy dependence at low energies. As it had been shown in course of the experiment essentially singly and doubly charged ions arrived in that case at the plate, with the energy between 3 and 15 Mev. The ion beam was incident at a fixed angle of 30° to the emulsion surface. This made it possible to determine the actual track length measuring the horizontal projection only and excluded errors connected with the variation of the emulsion shrinkage coefficient.

The ion ranges were measured by means of a microscope of 2000× magnification with an accuracy of 0.3 μ. 200 — 300 tracks were measured for each energy value. The distribution of particle ranges, obtained for each value of energy, was represented in the form of a Gaussian curve from which the mean range and the half-width of the line were computed. The half-width at ion energies of ~ 100 Mev amounted to 3 Mev.



Range-energy dependence for N and O ions in Ilford E-1 emulsion. Solid curves and black circles represent the data of the present work; + — data of Chaminade et al.; dashes — curves calculated by Papineau; dots — curves calculated by Longchamp.

Ilford E-1 plates were used in the experiments. In experiments with low-energy ions, when tracks were a few micron long, NIKFI-Ia plates were used which, unlike the Ilford plates, are not coated with a protective gelatine layer. According to our measurements, carried out by means Po, ThC and ThC′ α-particles and N and O ions of various energies, the stopping power of the NIKFI-Ia emulsion is 10% less than that of Ilford E-1.

The obtained range-energy relations for N and O ions in the Ilford E-1 emulsion are shown in the figure. Data on the range of N and O ions with energy < 15 Mev obtained with the NIKFI-Ia emulsion are normalized to the ranges in the Ilford E-1 emulsion accounting for the difference in their stopping power. The accuracy of the determination of each point amounts to 5% for ions of more than 30 Mev and 10% for the ions of less than 15 Mev. The accuracy of the relative curve shape is, as it was mentioned above, considerably greater. It is limited only by range straggling and amounts to 2%.

The results obtained by us for the N ions in the range below 25 Mev are in a good agreement with the data of Reynolds and Zucker[6] and Chaminade et al.;[7] these are not shown in the figure for sake of clarity. For high energies the ranges obtained in Ref. 7 are slightly larger than the results of the present work.

Theoretical curves for N and O ions calculated by Longchamp[1] and Papineau[2] are also shown in the figure. For low energies the results of Papineau are in good agreement with the experimental data while for higher energies the curves calculated by Longchamp represent a better approximation. In the calculations of Papineau it was assumed that nitrogen ions lose all their electrons at ~ 230 Mev and the oxygen ions at ~ 320 Mev; Longchamp assumed that both N and O ions are completely stripped at 22 — 25 Mev already. According to our estimates, nitrogen ions reach their maximum charge at 70 — 90 Mev, oxygen ions at 100 — 120 Mev.

We are obliged to Academician I. V. Kurchatov for his advice given in the discussion of the present work. We are indebted to A. M. Bidnaia, K. I. Merkulova and L. E. Soboleva for the measurements of ion ranges in the photographic plates.

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Translated by H. Kasha
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