Equilibrium Distribution of Nitrogen Ion Charges

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The equilibrium distribution of charges in a beam of nitrogen ions after traversal of films of beryllium, celluloid, nickel and gold was determined in the energy range from 0.95 to 9.4 Mev. The dependence of the mean charge on the velocity was obtained. A small difference was detected in the charge distribution after traversal of various substances by the ions.

RECENTLY PUBLISHED PAPERS on the equilibrium distribution of nitrogen ion charges after passage through matter[1-4], contain no data for energies from 1 to 6 Mev. The present experiment deals with the measurement of the charge distribution in a nitrogen ion beam after its passage through plates of beryllium, celluloid, nickel and gold, in the energy range from 0.95 to 9.4 Mev.

$^{14}N^{+2}$, $^{14}N^{+3}$ and $^{14}N^{+4}$ ions were accelerated in the 72-cm cyclotron. The beam was focused at a distance of 8 meters from the cyclotron, traversed the target, and was then analyzed by a magnet which deflected the ions in a horizontal direction. The beam was limited, in front of the target, by a 1 mm slit. The metallic target was prepared by evaporating the metal in vacuum on celluloid films. The thickness of the celluloid film was $\sim$ 10 μg/cm^2, The thickness of the beryllium or nickel layer was $\sim$ 10 μg/cm^2, and that of gold was 15 and 30 μg/cm^2. The particles were registered by two consecutive proportional counters with an entrance window in the form of a horizontal 110×0.1 mm slit covered by a 70 μg/cm^2 celluloid film. Particles of all charges passed through the first counter which acted as a monitor; only particles with a given charge were allowed to pass through the second counter, through a movable partition between the counters. The position and the degree of separation of the charge groups were determined by the measurement of the dependence of the number of pulses in the second counter on the position of the 2 mm slit between the counters (Fig. 1). When measuring the intensity of the charge groups, the slit between the counters was widened to 14 – 20 mm in order that the second counter register the entire given charge group.

The error in the relative intensity Φ_i of the charge groups with $\Phi_i \geqslant 0.02$ was caused, for large velocities, by the small differences in the thicknesses of the entrance slit – in front of the first counter – and by the inaccuracy in placing this slit in the direction of the beam's deflection; this error amounted to 2%. For small velocities, the error was principally due to the incomplete separation of the charge groups because of scattering in the target and amounted to 6 – 8%. This is related to the fact that there were no diaphragms between the target and the entrance slit of the counter to limit the beam in the horizontal plane. In order to reduce the errors in the comparison of the equilibrium charge distribution after traversal of different elements, targets were prepared with different elements on the opposite side of the film. By turning the target, it was possible to compare independently the distribution after traversal of Be and celluloid, celluloid and Au, or Au and Ni. With this method, the inaccuracy was due entirely to the statistical error which, in almost all the cases, was considerably smaller than the errors mentioned above.

The velocity of the particles was calculated from the intensity of the magnetic field of the focusing magnet, which was calibrated using protons and deuterons of known energy. The error in the determination of the ion velocity, taking into account the energy loss in the target, did not exceed 1.5 – 2%.

The results of the measurements of equilibrium charge distribution in a beam after the ions traversed a celluloid film are shown on Fig. 2 for different velocities v. Fig. 3 shows the dependence of the intensity ratio Φ_{i+1}/Φ_i of two neighboring ion groups with charges $i+1$ and i on the particle velocities. As can be seen from the graph, our results for large velocities agree very well with the results of the measurement of charge distribution of a beam of ions passing through formvar (polyvinyl of formal), for energies above 6.2 Mev[1]

On the basis of the obtained data, one can conclude that Φ_{i+1}/Φ_i is proportional to v^{k_i}, where k_i

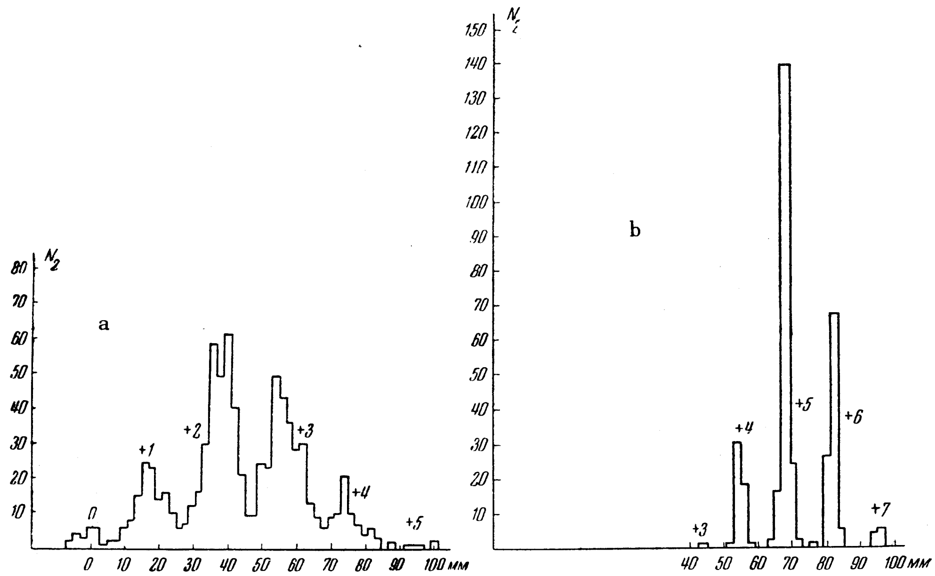

FIG. 1. Dependence of the number of pulses N_2 in the second counter on the position of the 2-mm slit between the counters: a – $v = 3.6 \times 10^8$; b – $v = 11.4 \times 10^8$ cm/sec.

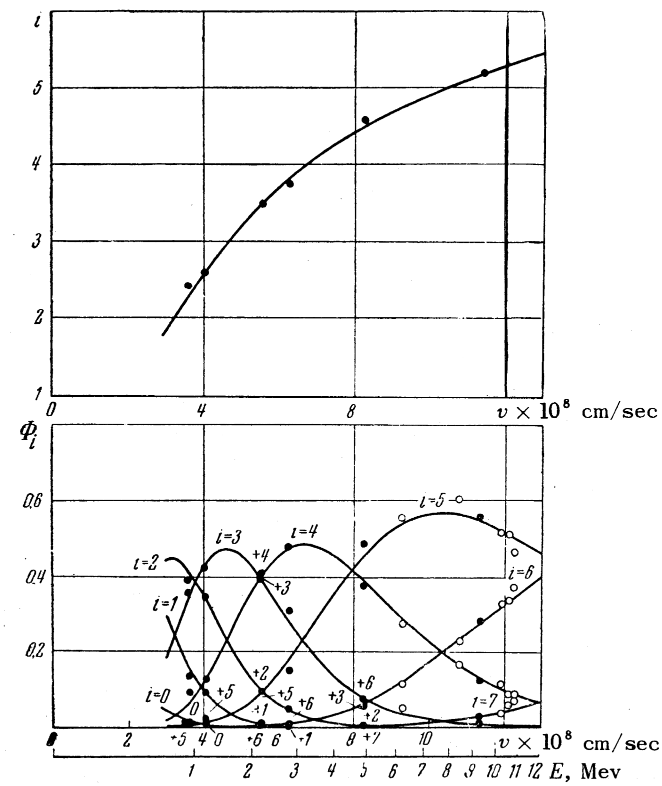

FIG. 2. Equilibrium distribution and mean charge of nitrogen ions after passing through: ●–celluloid (our data) and ○–formvar (Ref. 1).

increases in general with i (see Fig. 3). The equilibrium distribution and the mean charge were computed in the energy range from 3×10^8 to 13×10^8 cm/sec from the most probable values of k_i (see solid lines of Fig. 2).

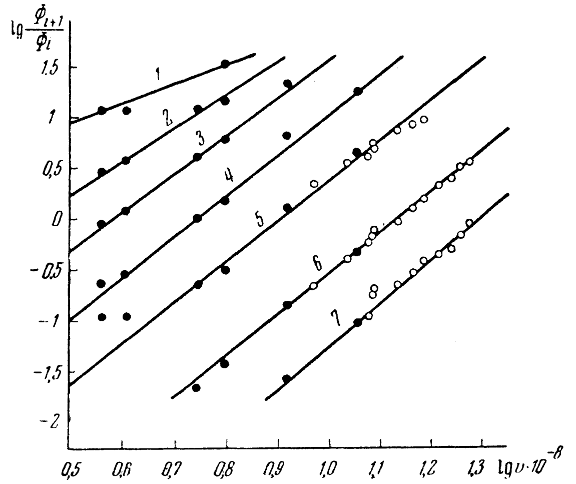

FIG. 3. Dependence of the ratio Φ_{i+1}/Φ_i on the velocity after the passage of nitrogen ions through: ● – celluloid (our data) and ○ – formvar (Ref. 1).
$1 - \Phi_1/\Phi_0$, $k_0 = 2 \pm 1$; $2 - \Phi_2/\Phi_1$, $k_1 = 3{,}3 \pm 0{,}3$; $3 - \Phi_3/\Phi_2$, $k_2 = 3{,}8 \pm 0{,}2$; $4 - \Phi_4/\Phi_3$, $k_3 = 4{,}0 \pm 0{,}2$; $5 - \Phi_5/\Phi_4$, $k_4 = 4{,}0 \pm 0{,}2$; $6 - \Phi_6/\Phi_5$, $k_5 = 4{,}0 \pm 0{,}2$; $7 - \Phi_7/\Phi_6$, $k_6 = 4{,}3 \pm 0{,}2$

When investigating the mean ion charge, one sometimes uses the coefficients γ_1 and γ_2 introduced by Brunings, Knipp and Teller, which equal respectively the ratio of the velocity of the least bound and of the most remote electrons of the ion to the velocity of the ion. If the above mentioned velocities are computed from the Thomas-Fermi model, it follows from the obtained mean value for the nitrogen ion charge that, as the parameter $v/v_0 Z^{2/3}$ (where $v_0 = e^2/\hbar$, Z – nuclear charge) is varied from 0.5 to 1.5, γ_1 changes approximately from 1.3 to 0.9; if the velocity is increased further γ_1 increases again[1]. As far as γ_2 is concerned, it is of the order of 0.6 in the mentioned velocity region and increases by about 10% as the velocity is increased. As the velocity is further increased, γ_2 approaches the value of γ_1, *i.e.*, it rises sharply.

The equilibrium charge distribution after the nitrogen ions pass through different elements turns out to be somewhat different. A decrease of the mean charge $\bar{i}$ with increasing atomic number is observed in all the cases; in comparison with the celluloid film, the mean charge after traversal of Be is bigger by about 0.1 – 0.3%, whereas after passing through Ni and Au, it is smaller by 0.5% and 1 – 2% respectively, with the statistical error of $\bar{i}$ being approximately 0.1%.

In the experiments using targets maintained in vacuum for a longer time, the observed difference is smaller; this is probably due to the thin film of oil from the diffusion pump forming on the surface of the target. One also observes a certain difference in the charge distribution with the same mean charge. In those cases where these differences exceed the statistical errors, the charge distribution of the beam after the ions pass through lighter elements turns out to be smoother, *i.e.*, the relative intensity Φ_i of the most probable states decreases, while for the low-intensity group Φ_i increases. This law shows up most clearly in the comparison of the charge distributions of a nitrogen ion beam passing through beryllium and celluloid at large velocities (Fig. 4). For low velocities, the differences in the distribution are considerably smaller and do not exceed the statistical errors. The smoother charge distribution in a nitrogen ion beam passing through beryllium corresponds to a smaller value of the exponent k_i for beryllium compared to the value of k_i for a celluloid plate. The difference between the exponents for beryllium and celluloid amounts to 0.1 – 0.2.

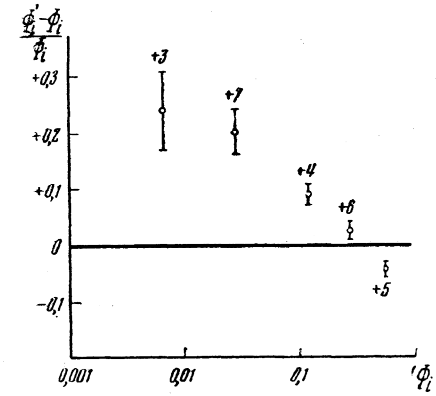

FIG. 4. Difference between the charge distribution Φ_i' after passage of nitrogen ions through beryllium and the distribution Φ_i after passage through celluloid at $v = 11.4 \times 10^8$ cm/sec. The value i of the charge is indicated close to each point.

In conclusion, we express our deep gratitude to C. C. Vasil'ev who initiated the work on multiple charge ions as well as to the cyclotron group, es-

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Multiple Electron Production in a High Energy Electron-Photon Shower

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An unusual electron-photon shower produced by an electron of > 10^{11} ev initial energy has been detected in a stack of emulsion layers without backing, exposed in the stratosphere. Experimental data obtained on the basis of a study of this shower are presented which indicate the occurrence of three cases of simultaneous formation of four electrons (two electron-positron pairs).

THE INVESTIGATION of electron-photon showers by means of nuclear emulsions exposed in the stratosphere has considerable interest in view of the possibility of elucidating the details of high energy electromagnetic processes. Despite some contradictions in the existing experimental data on certain aspects of electron-photon showers, one can definitely say that anomalies exist with respect to accepted theoretical views. Among these one can mention problems such as the occurrence of multi-photon showers[1] and in connection with this, the question of the source of closely correlated gamma rays; the bremsstrahlung spectrum and its possible deviations from theoretical[2]. Indications[3] also exist that the cross section for electron-positron pair formation directly by the electron without intermediaries exceeds considerably the theoretical value at energies greater than 10^{10} ev. These conclusions cannot be considered final, however, because in certain other experiments similar effects have not been found[4]. The solutions to these problems have great significance, not only for quantum electrodynamics, but as noted by Heisenberg[5], for quantum field theory in general.

Examples of multiple formation of electrons detected in an electron-photon shower are described below. Information on similar cases, together with data on pair formation by electrons, will permit the evaluation of the role (at higher energies) of higher-order processes than pair formation by photons.

GENERAL CHARACTERISTICS OF SHOWERS. EXPERIMENTAL DATA ON CORRELATED PAIRS

During a systematic investigation of electron-photon showers, using stacked emulsions without backing exposed in the stratosphere, an unusual electron-photon shower was discovered.

The emulsion stack consisted of 150 layers of type R, having a thickness of 400 μ and a diameter of 10 cm. Irradiation took place at an altitude of 20–24 km for about 10 hours. Grain density in the minimum ionizing paths was 37 grains (or 31 conglomerates) per 100 μ.

The shower was initiated by a single electron entering the stack from outside. In each emulsion layer the electron travelled $\sim$ 0.5 cm, its total path in the emulsion was 8 cm. On the first two radiation lengths from its point of entry into the stack are registered 21 secondary electron-positron pairs, of which 12 had energies $E_i > 10^8$ ev. The most probable value of the primary electron's energy, deter-