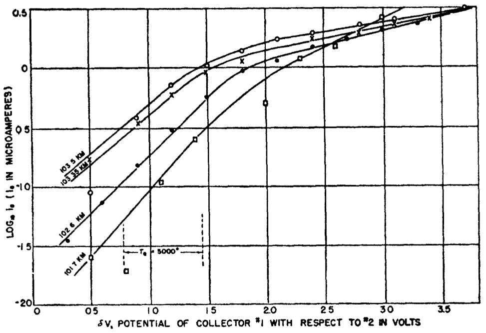

FIG. 3. Log$_{10}i_e$ *vs.* δV for a range of altitudes.

attained. Over the measurable range, 99 to 103.5 km, the results of all three calculations show progressively increasing ion density with altitude. The curves agree within order of magnitude, in spite of the uncertainty in ion energy.

At the time of this firing, the Bureau of Standards radio propagation measurements indicated a virtual E layer height of 110 km and a maximum electron density of $1.45\times 10^5/\mathrm{cm}^3$. This is in good agreement with the experimental results shown in Fig. 2.

In Fig. 3, the logarithm of the electron current measured as a function of the retarding potential δV is also calculated from the region AB of the experimental data in Fig. 1. These plots are essentially integrated electron energy distributions for only the high energy range of the distribution.

For small values of δV (more retarding field), the logi_e curve is very nearly linear. At slightly higher δV, the dependence becomes more quadratic with δV. Beyond 3 volts, the variation with voltage is affected by the current to the rocket.

These curves indicate roughly a distribution which is more nearly Davydov than Maxwellian. Under such circumstances it is not possible to assign a temperature to the electrons. However, as a first approximation, this condition can be interpreted roughly as a Maxwellian distribution with a superimposed drift. The linear portion indicate a temperature for the Maxwellian distribution of around 5000°K. This does not appear to undergo any change with altitude. The existence of a drift tends to make this temperature, calculated from the slope, too high. For an estimated drift around 4 electron volts, a more conservative estimate of the electron temperature would be about 2500°K. The displacement of the logi_e curves, the quadratic dependence on δV, and the voltage for $i_T=0$ in Fig. 1 provide strong evidence for such a drift.

A complete account of the work is being prepared for publication in the very near future. Improved experiments are also planned which should provide more accurate results as to ion density and electron energy distribution.

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A Cloud-Chamber Study of Fission Fragment Ranges in Air

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August 22, 1949

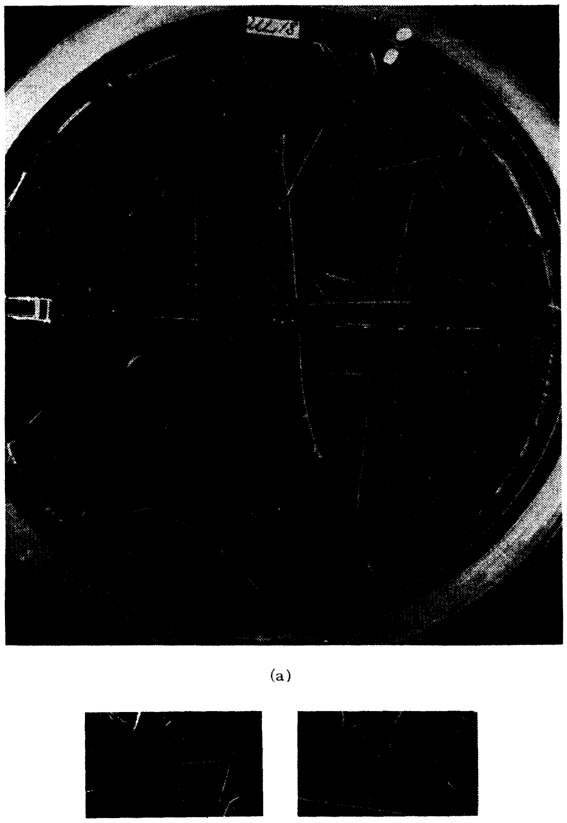
THE mean ranges in air of the ^{235}U fission fragments have been measured by means of a 25-cm cloud chamber. The experimental arrangements were similar to those used in previous investigations of fission fragment ranges in other gases.[1] The uranium layer (thickness about 0.5 mg/cm^2) was evaporated on an extremely thin gold foil and suspended in the middle of the chamber. The gas mixture was air and the vapors of a mixture of ethyl alcohol and water in equal parts, the total pressure being about 20 cm of Hg. The stopping power was determined by means of polonium alpha-particles and was controlled by the tracks of the slow neutron-induced disintegration, $^{14}\mathrm{N}(n,p)^{14}\mathrm{C}$. A photograph of a complete pair of fission fragment tracks is shown in Fig. 1(a) together with two small photographs, Figs. 1(b) and 1(c), showing examples of $^{14}\mathrm{N}(n,p)^{14}\mathrm{C}$ tracks, picked out among numerous such tracks appearing in the same series of about 10,000 pictures.

Figure 2 gives the range distribution of 40 complete pairs of fission fragment tracks and, furthermore, the range statistics of the $^{14}\mathrm{N}(n,p)^{14}\mathrm{C}$ tracks and the UI and UII alpha-groups. The latter groups also check the experimental technique since the mean ranges measured were found to be 26.3 and 31.9 mm of air, respectively, in good agreement with the values given by Holloway and Livingstone,[2] *viz.*, 26.5 and 32.1 mm.

The mean ranges of ^{235}U fission fragments in air at S.T.P. were found to be short range group, 19.5 mm; long range group, 25.4 mm; range in total, 44.9 mm.

The method of radiochemical analysis of individual fission products has been used by several authors for determining ranges in air. For the ^{235}U fission masses 139 and 91, Finkle, Hoagland, Katcoff, and Sugerman[3] report maximum ranges of 18.5 and 25.8 mm, respectively. The corresponding mean ranges are bound to be appreciably shorter than those indicated by our cloud-chamber value given above, which should represent the most probable fission masses 139 and 94.

These authors, moreover, report ranges of ^{239}Pu fission fragments, but the values are considerably smaller than those found in recent measurements by Katcoff, Mishel, and Stanley[4] in their extensive study of extrapolated and mean ranges in air of ^{239}Pu


(a)

(b) (c)

FIG. 1(a). Complete pair of fission fragment tracks in air$+\frac{1}{2}\mathrm{C_2H_5OH}+\frac{1}{2}\mathrm{H_2O}$, total pressure about 20 cm of Hg. (b) and (c). Tracks, in the same magnification as (a), of the slow neutron-induced disintegration, $^{14}\mathrm{N}(n,p)^{14}\mathrm{C}$ recognizable by their appearance as proton tracks starting from the small lumpy track of the recoiling ^{14}C nucleus.

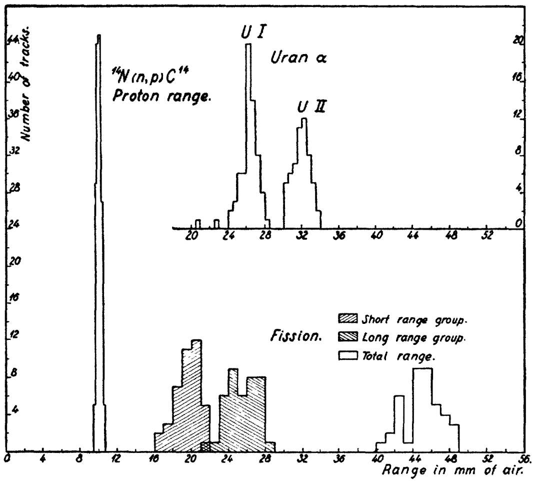


FIG. 2. Histogram of the range distribution of 40 complete pairs of ^{235}U fission fragment tracks and of the ^{14}N$(n,p)^{14}$C tracks used as controls. The range statistics of the UI and UII alpha-groups is given in a separate histogram. Mean range of the combined ^{14}N$(n,p)^{14}$C tracks 10.3 mm; UI and UII 26.3 and 31.9 mm, respectively; heavy and light fragment group 19.5 and 25.4 mm, respectively, and mean total range of paired fragment 44.9 mm.

fission fragments. Since the discrepancy here is ascribed to nonuniformity of the plutonium layer used in the work of Finkle *et al.*, similar defects might possibly be responsible for the diverging results of their and our values.

A closer comparison of our values with those of Katcoff *et al.* is hardly feasible as the two fission processes are somewhat different; however, it is noteworthy that their mean range values of 19.3 and 25.1 mm for the masses 131 and 94, respectively, in the ^{239}Pu fission are rather close to our values for the two groups of ^{235}U fission fragments, *viz.*, 19.5 and 25.4.

Measurements of the mean total range of ^{235}U fission fragments in photographic emulsions were made by various observers.[5] In Ilford nuclear research emulsions B1 and C2, the mean total track length was found to be about 24–25μ, which is about 1835 times smaller than the total range in air of 44.9 mm given above. The corresponding figures for UII alpha-particle tracks in these emulsions, as examined by Green and Livesey[5] and Lattes, Fowler, and Cuer,[6] were found to be about 1680 times smaller than the range in air. This means that the relative stopping power of the emulsion is somewhat different for fission fragments and for UII alpha-particles and, as an average over the range, about 8 percent larger for the fragments.

Keeping in mind that the stopping characteristics of the emulsion due to its large content of silver and bromine is similar to those of heavy gases, this is in agreement with present and previous cloud-chamber studies. Here the range of fission fragments in argon and xenon as compared with the range of polonium alpha-particles was found to be shorter than in air by about 3.5 and 9 percent, respectively. Incidentally, it may also be noted that the content of hydrogen is expected to contribute moderately to the diminution of the fragment ranges in the emulsion, since the fragment ranges relative to the range of alpha-particles were found shorter in hydrogen than in any other substance.

The authors wish to express their hearty thanks to Professor Niels Bohr for his continual interest and advice during these investigations.

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Erratum: Bremsstrahlung in High Energy Nucleon-Nucleon Collisions

[Phys. Rev. **76**, 58 (1949)]

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THROUGH an unfortunate oversight one set of intermediate states was omitted in the matrix element for the γ-emission accompanying proton-proton or neutron-neutron collisions. With the approximations of neglecting the nucleonic recoil energies in the energy denominators and of neglecting the γ-ray momentum compared to $\mathbf{p}_0 \pm \mathbf{p}$ in the Fourier transforms of the nuclear potential, there is found to be *no* γ-emission in the collision of like particles. (Equations (8) and (9) are incorrect.) For the magnetic emission this might have been anticipated from the fact that in the neutron-proton collision the effect is proportional to $(\mu_P - \mu_N)^2$. For the electric emission in the collision of two protons it is evident that in the center of mass system the total electric dipole moment is initially zero and remains zero if the recoil due to the γ-emission is neglected. There is therefore no electric dipole emission with the approximations made.

This classical argument in the electric case can be justified by the fact that the formula (6) given for the electric emission in the neutron-proton collision can be deduced from a completely classical treatment of the bremsstrahlung. According to classical electromagnetic theory the total energy radiated by a charged particle with trajectory $\mathbf{x}(t)$ (velocity $\mathbf{v}(t)$) is distributed in frequency and direction according to

$$dQ_{\nu,\,\Omega} = \nu^2 d\nu d\Omega / 4\pi^2 c^3 |\mathbf{I}|^2,$$

where

$$\begin{aligned} \mathbf{I} &= \int\int d\mathbf{r} dt \mathbf{n} \times e\mathbf{v}\delta(\mathbf{r} - \mathbf{x}(t)) \exp[i\nu(t - \mathbf{n}\cdot\mathbf{r}/c)] \\ &= e\int_{-\infty}^{\infty} dt \mathbf{n} \times \mathbf{v} \exp[i\nu(t - \mathbf{n}\cdot\mathbf{x}/c)] \\ &= \frac{ie}{\nu}\int_{-\infty}^{\infty} ds \exp[i\nu s] \frac{d}{ds}\left[\frac{\mathbf{n}\times\mathbf{v}}{1 - \mathbf{n}\cdot\mathbf{v}/c}\right]. \end{aligned}$$

Here $\mathbf{n}$ is the direction in which the radiation propagates. A change from t to the variable $s = t - \mathbf{n}\cdot\mathbf{x}/c$ and a partial integration yields the last expression for $\mathbf{I}$. Let the trajectory describe a collision of short duration in a region of dimensions a (the range of the nuclear forces). If we restrict ourselves to frequencies for which $\nu a/c \ll 1$ or to wave-lengths larger than a (γ-ray energies smaller than 137 $mc^2 = 70$ Mev) the integral $\mathbf{I}$ becomes

$$\mathbf{I} = \frac{ie}{\nu}\Delta\left[\frac{\mathbf{n}\times\mathbf{v}}{1 - \mathbf{n}\cdot\mathbf{v}/c}\right],$$

where Δ means the change in the quantity as a result of collision. The formula (6) for the electric emission results if the classical radiation formula (with the $\mathbf{n}\cdot\mathbf{v}/c$ in the denominator neglected) is multiplied by the quantum mechanical cross section for a given change in velocity as a result of the nuclear collision. $\mathbf{n}\times\Delta\mathbf{v}$ becomes $\mathbf{n}\times(\mathbf{p}_0 - \mathbf{p})$ times $1/M$ and its square gives directly the angular dependence expressed in (6).

For a collision of two protons the integral $\mathbf{I}$ is a sum of two terms corresponding to the change in velocity of each proton. Neglecting the recoil due to the photon and the $\mathbf{n}\cdot\mathbf{v}/c$ in the denominator, we obtain zero for the total. These approximations are clearly no longer valid for relativistic energies of the nucleons.

The Existence of Stable Nuclei as Related to the Principle of Regularity and Continuity of Series and the Ends of Nuclear Shells

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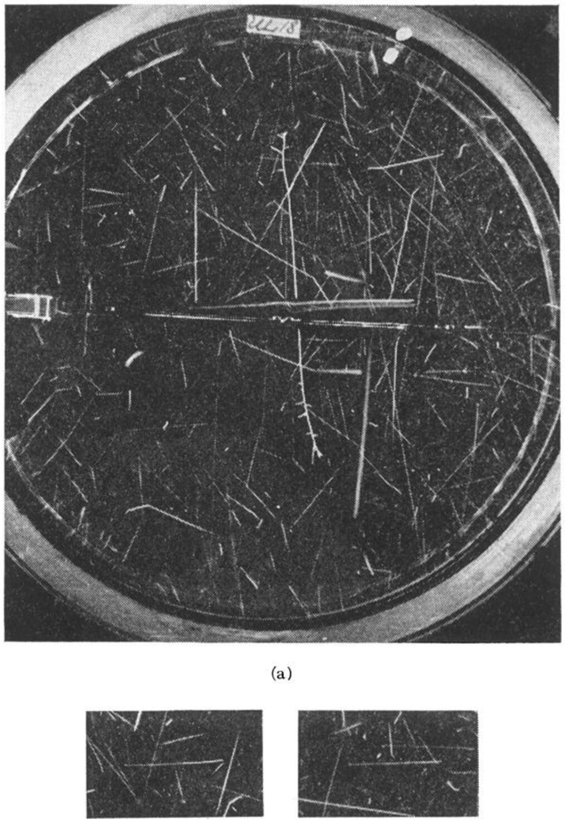
IN 1916, when the atomic nucleus of Rutherford was only five years old, Harkins submitted a paper[1] which introduced a new



(a)

(b) (c)

FIG. 1(a). Complete pair of fission fragment tracks in air $+\frac{1}{2}C_2H_5OH$ $+\frac{1}{2}H_2O$, total pressure about 20 cm of Hg. (b) and (c). Tracks, in the same magnification as (a), of the slow neutron-induced disintegration, $^{14}N(n,p)^{14}C$ recognizable by their appearance as proton tracks starting from the small lumpy track of the recoiling ^{14}C nucleus.