At the time of the original work on sprays,[1] there were several objections to this interpretation.

(1) The large number of particles produced in relatively small thicknesses of Pb (approximately two radiation units) was apparently incompatible with shower theory.

(2) Events related to the spray apparently should have been produced in other Pb plates by the photons associated with the spray.

(3) There was little evidence for the required photon and electron flux at high altitudes.

The first two points are explained qualitatively by the assumption that the core of the event is at a rather small (>45°) angle to the horizontal. The experimental evidence indicates that especially for the larger events this is true. Such an assumption means that the cascade develops through a considerably longer path of Pb than the thickness of the plate. For example, for a photon of 1 to 10 Bev incident on a 1-cm thick Pb plate at 20°–30° to the horizontal, one could expect on the average 10 to 100 electrons at the shower maximum.[3] One can perhaps expect an even larger number of low energy electrons than is predicted by shower theory. For example, if a core is inclined at 25° to the horizontal and is 1 mm from the lower surface of the Pb, its remaining path length in the plate is 3 mm. More low energy electrons will then be scattered out of the Pb than if the core were normal to the Pb surfaces. Furthermore, the photons tend to remain near the core of the cascade and they will be unable to produce related events since it is most likely that the core of the shower will not strike another Pb plate. It is also possible that some large events may result from at least two photons traveling together. If a spray is due to a mixed shower started in the Pb by a high energy primary then it is possible that several photons contribute to the multiplicity of electrons observed. It seems to us that the above explanations are probably sufficient to invalidate the first two objections, provided that a suitable source of photons and electrons exist.

It is clear from the recent experiments of Bjorklund *et al.*[4] that an appreciable number of photons are produced in nucleon-nucleus collisions as a result of the production of $\pi^0$-mesons and their subsequent decay. Furthermore, Carlson *et al.*[5] have determined the energy and angular distribution of photons at 70,000 feet. Extrapolating these results we have estimated the $\gamma$-ray flux expected in the cloud chamber at 90,000 feet.

We assume: (1) The absolute vertical nucleon flux at 55°N geomagnetic latitude and under 15 g/cm$^2$ of air to be that reported by Winckler *et al.*,[6] namely 0.22 primaries per sec. per cm$^2$ per steradian; (2) that the cross section for star production in both Pb and air is geometrical.[7] We can make a check on these assumptions by counting the number of stars produced in the 0.92 mm Pb foils and using the sensitive time of the cloud chamber, 0.15 second. The number of stars which result from these assumptions is about twice that counted. Only stars of 2 or more particles were counted. We find the number of $\pi$-mesons produced per second in air or Pb by extrapolating to energies larger than 1 Bev the number spectrum for charged mesons as found by Camerini *et al.*[7] The $\pi^0$-meson spectrum is determined from the fact that $\pi^0$-mesons are produced with the same spectrum but half the total number.[5] The $\gamma$-ray spectrum can then be easily calculated. From these calculations we find that approximately one $\gamma$-ray per sec. is generated having an energy greater than 1 Bev in a $\frac{1}{4}$-in. thick Pb plate having 200 cm$^2$ area. In estimating the photon flux which passes through a plate in the cloud chamber due to the generation of $\pi^0$-mesons in the air, we take the source function proportional to the density of the air. In order to get a lower limit we neglect the multiplying effect of the cascades in the air and the contributions due to photons at angles lower than 15° to the horizontal. This angular cut-off is due to the experimental arrangement. Under these limitations we find 10 $\gamma$-rays per sec. with energy larger than 1 Bev which traverse a Pb plate in the cloud chamber.

These theoretical estimates must be compared to the 1.5 electromagnetic events per sec. observed in the cloud chamber. A small fraction ($\approx 1/20$) appear to be associated with mixed showers. These numbers are based on a small number of photographs. The theoretical estimates appear to indicate more than a sufficient number of $\gamma$-rays to produce the observed events. The fact that about half of the sprays are produced by ionizing radiation is reasonable since some of the $\gamma$-rays produced in the air will be converted to electrons.

A number of factors in the theoretical estimate: electromagnetic cascades in air, nucleonic cascades, use of the vertical flux at all zenith angles, uncertainties in the $\pi^0$-meson spectrum, could effect the agreement with experiment. However, in view of the fact that a detailed examination of the experimental data has not been completed, we feel that further refinements in the above estimates are premature.

In summary, we have presented in the preceding letter experimental evidence that the smaller sprays (<25 particles) are electromagnetic cascades. In this letter we argue that recent work on $\pi^0$-mesons provides experimental evidence for a source of $\gamma$-rays adequate to account for the observed electromagnetic cascades.

† Assisted by the joint program of the ONR and AEC.

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## On the Half-Life of Actinium*

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THE half-life of $Ac^{227}$ has not been established with certainty. The most widely quoted[1] values are 21.7 years[2] and 13.5 years.[3] In the interest of resolving this discrepancy, we have followed the decay of a sample of actinium using the differential ionization chamber employed by Segrè, Wiegand, and Leininger in the course of their studies[4,5] of the influence of chemical binding on the decay constant of $Be^7$.

The sample of actinium used in these measurements was produced and separated in 1947 from pile irradiated radium at the Argonne National Laboratory. Because of its age, the actinium can safely be assumed to be in secular equilibrium with the daughter products in its decay chain. A second sample, kindly furnished us by F. Hagemann in January, 1950, has also been observed. This sample, however, has not yet reached equilibrium and will be followed further. At present, therefore, the results obtained with the older sample alone should be considered as preliminary.

Determination of long periods by the differential technique rests upon the fact that during the course of the measurement $\lambda t \ll 1$ and that the decay is essentially linear. By expansion of the exponential in the first-order decay law $N(t)=N(0)e^{-\lambda t}$ and retention of only the linear term, one has

$$N(t)=N(0)-\lambda N(0)t$$

or in terms of activities,

$$A(0)-A(t)=A(0)\lambda t.$$

One uses a sample of actinium of strength $A_x(t)$ balanced in activity as closely as possible with a Bureau of Standards radium source of strength $A_r(t)$ such that $A_x(0)=A_r(0)$. Because of the constancy of the radium standard, $A_r(t)=A_r(0)=A_x(0)$. Thus, $A_r(t)-A_x(t)=A_x(0)\lambda t$. Defining the quantity $A_r(t)-A_x(t)$ as $\delta(t)$, the unbalance of the samples at time $t$, one has

$$\lambda=\delta(t)/A_x(0)\cdot t.$$

One must therefore measure $\delta(t)$ as a function of time. Provided

that $A_x(0)$ can be determined with comparable relative precision, the decay constant of the actinium can be found.

Differential measurement enjoys several advantages over separate measurement of standard and unknown: measuring the samples at the same time and interchanging them minimizes systematic errors; the readings on the difference of the two activities are always small and with ionization chambers are much more convenient to take than readings on the activities; it is practical to use considerably stronger samples than for single readings.

The differential chamber has been amply described by Segrè and Wiegand.[4]

Our measuring procedure was as follows. The actinium sample is placed in chamber 1 and the radium standard in chamber 2; the rate of drift of the galvanometer is then

$$p=A_x(t)S_1-A_r(t)S_2,$$

where $S_1$ and $S_2$ are the sensitivities of chambers 1 and 2, respectively, and are very nearly equal. When the samples are interchanged, the rate of drift becomes

$$q=A_r(t)S_1-A_x(t)S_2,$$

from which

$$p-q=[A_x(t)-A_r(t)](S_1+S_2)$$
$$\cong -2\delta(t)\cdot S$$
$$\delta(t)\cong -(p-q)/2S.$$

The initial rate of drift due to the actinium sample alone, $a(0)$, is then measured. Since $a(0)=A_x(0)\cdot S$,

$$A_x(0)=a(0)/S.$$

But we had from the decay law that

$$t_{\frac{1}{2}}=0.693A_x(0)\cdot t/\delta(t).$$

Substituting from above for $\delta(t)$ and $A_x(0)$, we obtain

$$t_{\frac{1}{2}}=-0.693\cdot a(0)/(p-q/2t).$$

We have measured $(p-q)$ over a period of about 100 days and have found $(p-q)/t$ to be $-0.05916\pm0.00020$ (mm/sec.)/day. Also, the initial activity of the actinium sample, corrected for decay, was $a(0)=343.7\pm2.9$ mm/sec.

From these data, the half-life of actinium is calculated to be $22.0\pm0.3$ years, comparing favorably with the value offered by Curie and Bouissières.

We wish to thank Professors E. Segrè and I. Perlman for their helpful suggestions during the course of this experiment.

* This work was performed under the auspices of the AEC.

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## Large Angle Scattering of $\pi^-$-Mesons*

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An investigation is being made of the mean free path for large angle scattering and nuclear interaction of $\pi^-$-mesons in G-5 emulsion. Mesons entering the edge of a plate with approximately 38-Mev energy are identified by measurement of grain density *versus* small angle scattering. These mesons are then followed for several millimeters until they leave the 600 $\mu$-thick emulsion or reach an energy of 30 Mev. In a scan of 568 cm of meson track the scatters tabulated in Table I have been observed. There were also five cases in which an energetic meson produced a star, and two cases in which a meson ended abruptly with no visible star or scatter.

The average nuclear area for the elements in a G-5 emulsion is equivalent to a mean free path of 23 cm. Within the limits of the poor statistics it appears that the cross section for large angle scattering and star production of 20–38 Mev $\pi^-$-mesons in emulsion are each roughly equal to one-half of the nuclear area. The disappearance of mesons in flight may be evidence for charge exchange scattering on a proton, although we cannot rule out the possibility that there was a star in which only a neutron was emitted, or a large angle scatter in which we were unable to follow the outgoing meson.

TABLE I. Observed scattering for 20–40 Mev $\pi^-$-mesons in emulsion.

| Scattering angle | | | Meson energy (Mev) | |
|---|---|---|---|---|
| Horizontal projection | Actual | No. events | By position in plate | By grain count (±5 Mev) |
| 5°– 9.9° | 1@46° | 96 | 1@36.0 | 40 |
| 10°–19.9° | | 29 | | |
| 20°–29.9° | 1@30.5 | 2 | 1@35.0 | 35 |
| 29° | 36.6 | 1 | 34.5 | 40 |
| 30° | 35 | 1 | 26.5 | 40 |
| 40° | 48 | 1 | 37.0 | 40 |
| 47° | 76 | 1 | 36.0 | 25 |
| 108° | 105 | 1 | 28.5 | 30 |
| 119° | 112 | 1 | 32.0 | 25 |
| 143° | 123 | 1 | 37.0 | <20* |
| 158° | 154 | 1 | 26.0 | 30 |
| 171° | 155 | 1 | 36.0 | 25 |
| 178° | 160 | 1 | 34.5 | 40 |

* Definitely inelastic scattering.

Scatters less than 30° for 30 Mev $\pi$-mesons can certainly not be considered as "nuclear," since either Coulomb scatter or decay in flight could result in nearly that angle. Grain density *versus* scattering measurements cannot distinguish with certainty between a $\pi$-scatter and a $\pi$-$\mu$-decay in our energy region. The mean free path for decay in flight is approximately 230 cm. A frequency plot of scatters between 5° and 30° is in agreement with single Coulomb scattering.

Dr. G. Bernardini of Columbia University has kindly communicated to us the prepublication results on a very similar experiment being performed on the Columbia cyclotron. The two experiments show a difference in relative numbers of stars *versus* scatters which seems to be outside of statistics. We believe that this is probably due to a difference in scanning techniques. Bernardini scans an area of plate looking for stars and scatters whereas we follow individual tracks to determine what happens to them.

We wish to express our appreciation to O. Piccioni who originally suggested the experiment, and to L. W. Alvarez for helpful discussion. Edith Goodwin has done much of the plate scanning.

* This work was performed under the auspices of the AEC.

## The Branching Ratio of $K^{40}$ Radioactive Decay

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The ratio of $K$-capture to beta-emission for the naturally occurring radioactive isotope $K^{40}$ has been determined using the mass spectrometric isotopic dilution method.[1] In this method the amounts of the daughter isotopes $A^{40}$ and $Ca^{40}$ in a geologically old potassium sample are determined by addition of a known quantity of a tracer isotope of the element in question, and determining the element content of the ore from the resulting change in the isotopic composition of the tracer material. Previous measurements of the branching ratio have used counting techniques or age data to get the beta-decay rate, and counting techniques or argon extraction data to get the $K$-capture.[2–7]

The sample used in this investigation was a $1\times10^8$-year old KCl sample from the Stassfurt sylvite deposits. The sample was divided into four aliquots. Two were used for the $A^{40}$ content and two for the $Ca^{40}$ content. The agreement between the various runs