The radiative correction to the energy of an electron in a Coulomb field will produce a shift in the energy levels of hydrogen-like atoms, and modify the scattering of electrons in a Coulomb field. Such energy level displacements have recently been observed in the fine structures of hydrogen,[4] deuterium, and ionized helium.[5] The values yielded by our theory differ only slightly from those conjectured by Bethe[6] on the basis of a non-relativistic calculation, and are, thus, in good accord with experiment. Finally, the finite radiative correction to the elastic scattering of electrons by a Coulomb field provides a satisfactory termination to a subject that has been beset with much confusion.

A paper dealing with the details of this theory and its applications is in course of preparation.

* A classical non-relativistic theory of this type was discussed by H. A. Kramers at the Shelter Island Conference, held in June 1947 under the auspices of the National Academy of Sciences.

[1] J. E. Nafe, E. B. Nelson, and I. I. Rabi, Phys. Rev. 71, 914 (1947); D. E. Nagel, R. S. Julian, and J. R. Zacharias, Phys. Rev. 72, 971 (1947).
[2] G. Breit, Phys. Rev. 71, 984 (1947). However, Breit has not correctly drawn the consequences of his empirical hypothesis. The effects of a nuclear magnetic field and a constant magnetic field do not involve different combinations of μ and $\delta\mu$.
[3] P. Kusch and H. M. Foley, Phys. Rev. 72, 1256 (1947), and further unpublished work.
[4] W. E. Lamb, Jr. and R. C. Retherford, Phys. Rev. 72, 241 (1947).
[5] J. E. Mack and N. Austern, Phys. Rev. 72, 972 (1947).
[6] H. A. Bethe, Phys. Rev. 72, 339 (1947).

Excitation Curves of (α, n); $(\alpha, 2n)$; $(\alpha, 3n)$ Reactions on Silver

S. N. Ghoshal
Department of Physics, University of California, Berkeley, California
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SILVER bombarded with α-particles from the 60-in. cyclotron produces radioactive substances with the following three half-lifes: 65 min., 5.2 hr., and 2.7 d. All of these activities have been chemically attributed to indium and have been assigned by mass-spectrograph separation to In^{110}, In^{109}, and In^{111}, respectively. Tendam and Bradt[1] recently announced similar activities. Their assignment of 65-min. and 2.7-d activities agrees with ours. The 23-min. activity found by them was not looked for in the present experiment.

The excitation curves for the isotopes reported above have been determined for α-energies up to 37 Mev and are reproduced in Fig. 1. The abscissae give the energy in Mev, the ordinates the cross sections in arbitrary units. The ordinate units are, however, the same for reactions leading to the formation of the same isotope. Evaluation of absolute cross sections has not yet been possible due to lack of knowledge regarding the efficiencies of the different radiations for the ionization chamber used.

From the figure it is seen that the 65-min. activity belonging to In^{110} (emitting positrons of 1.7 Mev), a product of $Ag^{107}(\alpha, n)$ reaction, has a threshold of 11 Mev.* The yield after attaining a peak at 17.5 Mev drops rapidly to low values when the $(\alpha, 2n)$ process appears as a competing process. After attaining a minimum, the 65-min. activity again increases and does not reach saturation even at 37 Mev. Apparently this part of the curve is due to $Ag^{109}(\alpha, 3n)In^{110}$. The sharpness of the peak at 17.5 Mev is also interesting. The difference of 4 Mev between (α, n) and $(\alpha, 2n)$ thresholds is much smaller than that between $(\alpha, 2n)$ and $(\alpha, 3n)$ thresholds ($\sim$8 Mev). This difference seems to be due to the Coulomb barrier which cuts off the production of any alpha-reaction below 11 Mev.

The 2.7-d activity belonging to In^{111} has a threshold of about 15 Mev, which is in agreement with that found by Tendam and Bradt.[1] This activity is produced by the $Ag^{109}(\alpha, 2n)$ process, and emits a γ-ray of about 0.2 Mev (no positrons). After attaining a peak around 27 Mev, the yield begins to drop and reaches about 16 percent of maximum at 37 Mev.

The 5.2-hr. period is produced by $Ag^{107}(\alpha, 2n)In^{109}$ reaction. The excitation curve is similar to the excitation curve of In^{111}, as is expected, since both are products of $(\alpha, 2n)$ reactions. The threshold of In^{109} is about 13.5 Mev, slightly lower than that of In^{111}. At higher energies, however, the two curves differ widely. Instead of decreasing, the 5.2-hr. curve goes on increasing even beyond 30 Mev, after which it drops slightly, the yield at 37 Mev being 80 percent of the maximum.

This suggests the production of a different isotope at higher α-energies having a very similar half-life. A comparison with the $Ag^{109}(\alpha, 3n)In^{110}$ curve and with the $Ag^{109}(\alpha, 2n)In^{111}$ curve suggests that this new activity is probably due to $Ag^{107}(\alpha, 3n)In^{108}$. The possibility of its being due to $Ag^{109}(\alpha, 3n)In^{110}$ (an isomer of 65-min. period) is ruled out by the fact that the threshold and low energy part of the curve is similar to the other $(\alpha, 2n)$ curve and not to the (α, n) curve.

To verify this conclusion, two foils were bombarded, one with 37-Mev alphas (foil 1) and the other with 20-Mev alphas (foil 2). The latter is not likely to have any In^{108} in it, while the former should mostly contain In^{108} with little In^{109}. The absorption curves for the radiations from the two foils, corrected for In^{111}, showed marked differences. Foil 1 showed a γ-ray of about 0.65 Mev, while foil 2 showed a γ-ray of about 0.5 Mev. No positrons were detected. These conclusions were also corroborated by

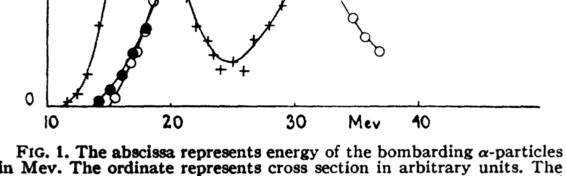

FIG. 1. The abscissa represents energy of the bombarding α-particles in Mev. The ordinate represents cross section in arbitrary units. The curve with open circles represents the cross section for the formation of In^{111}. The one with crosses represents the cross section for the formation of In^{110}, while the curve with solid circles represents the cross section for the formation of In^{109}, and at the higher energies probably of In^{108} also.

mass-spectrograph work, though the evidence is not yet conclusive.

It is a pleasure to thank Professor Emilio Segrè for suggesting the problem and for his kind interest and continued guidance during the progress of the work. Thanks are also due the 60-in. cyclotron crew for their valuable cooperation and to Dr. B. Moyer and his associates for the mass-spectrograph work.

* Tendam and Bradt[1] obtained a threshold of 12 Mev.
[1] D. J. Tendam and H. L. Bradt, Phys. Rev. **72**, 1118 (1947).

High Altitude Measurements on Extensive Showers

Roland Maze, André Fréon, and Pierre Auger
Laboratoire de physique, Ecole Normale Supérieure, Paris, France
December 19, 1947

An apparatus was built in order to study extensive showers at high elevations. It is possible to discriminate all the coincidences, from threefold to ninefold, between nine counters.

The efficiency of such a disposition is 466 times greater than those of a conventional one, and about 10 times greater than Rogosinsky's "master group" apparatus.

A band of perforated paper is used to record the coincidences; a longitudinal line of dots corresponds to each counter. The transverse alignment of dots indicates the order of each coincidence, and identifies also the counters which have been operated. Two or three papers can be perforated at the same time in order to obtain duplicate records.

Experiments were carried out during the months of July and September, from sea level to 22,000 feet in a Halifax airplane.

Nine counters of 120-cm^2 effective area were put under the roof of the plane. For the narrow showers three of them were placed 12.5 cm from each other in the middle of the arrangement; the other counters were about two meters apart, the total width of the arrangement being 15 meters.

In the first part of the experiments counters were unshielded; in the second part, shells of 4 mm of lead were placed close to the counters in order to estimate the ratio between photons and electrons in the showers by means of the photon-electron transition effect.

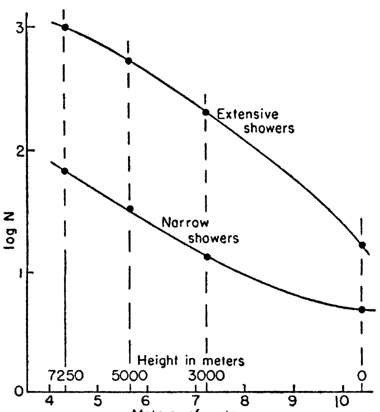

FIG. 1. Variation with altitude of the number of showers N per 100 minutes. The statistical error for extensive showers is 3 percent, for narrow showers, 10 percent.

The main features of the data are the following (see Fig. 1):

1. No striking change is to be observed in the structure of extensive showers between sea level and 22,000 ft.
2. Apart from an appreciable number of narrow showers at sea level, due to secondary effects from mesons, the relative increase of intensity for extensive and narrow showers is the same between sea level and 22,000 ft. The absolute intensity of big showers is 50 times greater, at this height, than at sea level.
3. The density δ of extensive showers increases with height. The number *versus* density curve can be represented by the empirical law $N=k\delta^{-\gamma-1}$; the integral exponent γ varies from 1.67 ± 0.1 at sea level to 1.41 ± 0.05 at 22,000 ft.
4. Many showers of weak density can be observed in altitude, giving threefold coincidences; this fact is in good agreement with Mr. Della Corte's experiments.

New experiments will be soon performed at higher altitudes and other ones with lead screens above the counters, in order to investigate penetrating rays in the showers.

More details concerning both the apparatus and the experimental results will be shortly published in the Journal de Physique.

Beta-Rays and Gamma-Rays from Arsenic (76)*

M. V. Scherb and C. E. Mandeville
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania
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The 26-hour activity was induced in As_2O_3, irradiated by slow neutrons in the Clinton pile. The beta- and gamma-rays of this isotope have been investigated by absorption and coincidence methods.

By inserting thin aluminum foils before a single G-M counter, the absorption limit of the beta-rays was found to be 1.34 g/cm^2, 2.76 Mev as calculated by Feather's equation.[1] The beta-ray absorption curve is shown in Fig. 1.

Two G-M counters were placed in coincidence; a source of radioactive As^{76} was placed behind a thick aluminum radiator, and coincidences produced by the secondary electrons were observed as a function of the aluminum absorber thickness placed between the two counters. The coincidence absorption curve, given in Fig. 2, shows an end point at 0.84 g/cm^2. From an accurately constructed calibration curve for the G-M coincidence counting set, this absorber thickness was found to correspond to a quantum energy of 1.98 Mev. This calibration curve will soon be published in The Physical Review.

A thin source of As^{76} was placed between two counters in coincidence, and the beta-gamma coincidence rate was observed as a function of aluminum absorber thickness before the beta-ray counter. The curve of Fig. 3 was thus obtained. The coincidence rate is seen to decrease from an extrapolated value of 0.184×10^{-3} coincidence per beta-ray at zero absorber thickness to zero at 1.00 g/cm^2. One of the