for this purpose. Using these results, the total cross section for the production of all the particles observed in this experiment taken together is

$$\sigma = 24 \pm 12 \text{ millibarns.}$$

Cross sections for various phenomena calculated on the basis of this value are given in Table II.

The authors wish to thank Dr. Evans Hayward and Walter D. Hartsough for their many contributions to this work which was done under the auspices of the Atomic Energy Commission.

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Cloud-Chamber Study of Mesons Stopping in Aluminum Foils*

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A STUDY has been made at Climax, Colorado (elevation 3410 m) of mesons stopping in 0.02 cm Al foils mounted in a large Wilson cloud chamber. The experimental arrangement is shown in Fig. 1. To favor the observation of particles stopping in the chamber, the chamber was expanded by anticoincidences $A_iA_i'B_jB_j'-(C+C')$, the notation indicating a double coincidence in any one of the four pairs A_1A_1', A_2A_2', A_3A_3', A_4A_4' coincident with a double coincidence in any one of the four pairs B_1B_1', B_2B_2', B_3B_3', B_4B_4' but unaccompanied by a pulse from any one of the C or C' counters. The crossed counter arrangement makes this equivalent to using 16 telescopes each defining a cone just fitting the bottom Pb plate in the cloud chamber. The 10 cm Pb filter above the counters reduced the frequency of expansions due to the electronic component.

In 12,100 pairs of photographs (the cameras being 20° to each side of the axis of the chamber), we have identified 10 cases of mesons stopping in the Al foils. Only tracks of counter-control age which pass through the top Pb plate and which stop well within the illuminated region are reported here; of the 10 stoppings, 3 show a light track appearing to originate at the stopping point, 1 shows a heavy track appearing to originate there, and 6 show no associated ionizing particle.

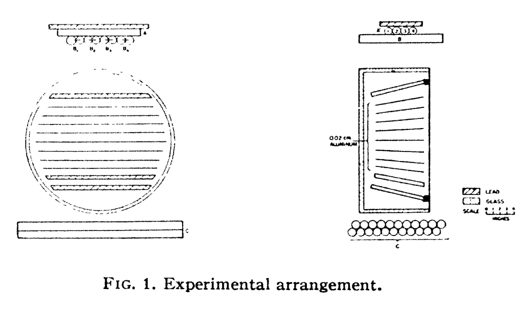

FIG. 1. Experimental arrangement.

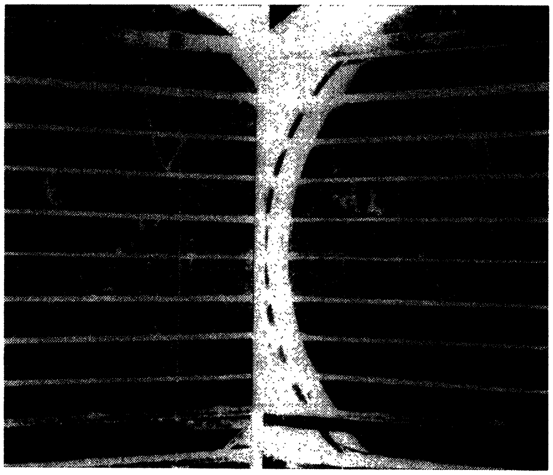

FIG. 2. A meson stops in the third Al foil from the top of the chamber. A heavily ionizing particle emerges from the stopping point and stops in the second Al foil. The electron track visible between the second and third foils is not associated with the event.

The identification of the stopped particles was made on the basis of relative ionization in the different compartments and average projected scattering angle in the various plates. Thanks to the 1.1 cm Pb plate at the top of the chamber, we could, however, readily distinguish between π- and μ-mesons on the one hand and protons on the other. These methods are not sufficiently sensitive to separate π- from μ-mesons. In one respect, the top Pb plate was disadvantageous—mesons whose energy is in the correct range to stop in the foils scatter strongly in the Pb plate, and many are thus lost from the illuminated region. An estimate of this number can be made by calculating from Kraushaar's data[1] the number of mesons expected to stop. It turns out that 30 are to be expected in 12,100 expansions. The fact that only 10 are found is chiefly due to scattering in the Pb plate. Use of a thinner plate of lower Z would be a desirable change.

From the data of Ticho and Valley[2] all of the μ^+ and about 35 percent of the μ^- mesons should decay in Al with the emission of an electron. The bias against the detection of mesons with decay electrons is small due to the shielding of the anticoincidence tray by the lead plates at the bottom of the chamber. The chance that a meson stopped and the electron track was unobserved is believed to be negligible. In this small number of cases, the fact that fewer decay electrons are observed than are to be expected on the average is probably not significant and may well be due to statistical fluctuation.

Figure 2 exhibits the one case in which a heavy particle appears to originate at the point where the meson stops. This particle is ionizing many times the minimum value, and stops in the next foil well within the illuminated region. This event cannot be the decay of a positive π-meson for the following reasons: (1) no electron is associated with the end of the short heavy track, (2) the emitted μ-meson would be expected to have a unique energy of 3.8 Mev,[3] sufficient to penetrate three foils. If the particle is a proton its energy is less than 7.8 Mev, if an alpha-particle, less than 31.4 Mev.

As to the 6 cases in which a meson stops in the Al foils and no ionizing particle is observed to emerge—in a single case of a meson stopping at a random point within the foils, the probability of observing that a proton of energy 7.8 Mev emerges is 0.75; of 5.2 Mev, 0.5; of 3.5 Mev, 0.25. The evidence of these 6 cases indicates that, at least in a large fraction of the cases, if an ionizing particle is emitted when a negative μ-meson suffers nuclear capture, it is of very low energy.

The single case in which a heavy particle, probably a proton, is emitted may be either that of the capture of a negative μ- or π-meson. If it is indeed a π-meson, the result would not be unexpected from photographic plate evidence, and further the event observed is similar to that observed by Valley[4] in argon gas in which he interprets the meson to be most probably a negative π. The possibility that the Al nucleus occasionally receives enough energy in capturing a negative μ-meson to emit a proton cannot be eliminated and further investigation of the possibility is planned.

* Supported by Joint Program of the Office of Naval Research and the Atomic Energy Commission.

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Radioactive Gadolinium and Terbium Isotopes

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An investigation by Krisberg and Pool[1] of the activities produced by the neutron activation of gadolinium showed three β-emitter products with half-lives of 3.5 min., 18 hr., and 5.5 d. The two latter periods were also reported in deuteron-bombarded gadolinium. There was not, however, sufficient evidence definitely to assign the activities to elements or mass numbers. Seren, Friedlander, and Turkel[2] measured approximate activation cross sections, σ, for thermal neutrons in gadolinium, for half-lives of 20 hr., 8.6 d., and 9.5 hr. (It seems likely that the latter is due to a trace of europium.)

An investigation of these activities has been made, including determinations of σ by a pile activation method similar to that of Seren *et al.*,[2] and chemical separations on an ion-exchange column as used by Ketelle and Boyd.[3] Beta- and γ-energies were determined by the usual technique of absorption in Al, Cu, and Pb.

The results for neutron activation of gadolinium oxide are summarized in Table I.

TABLE I. Results for the neutron activation of gadolinum oxide.

Half-life	Element	σ, barns in natural Gd	Radiation energy Mev β	γ
218±5 sec.	—	0.18	—	—
18.0±0.2 hr.	Gd	1.1	0.95	0.055, 0.38
6.75±0.1 d.	Tb	0.16	0.52	0.05 (no harder γ)

The identity, within experimental error, of σ for the 218 sec. and 6.75 d. activities suggests that they must be assigned as follows.

$$\mathrm{Gd}^{161} \xrightarrow[218\text{ sec.}]{\beta} \mathrm{Tb}^{161} \xrightarrow[6.75\text{ d.}]{\beta} \mathrm{Dy}^{161}\text{ stable.}$$

The value of σ for the 18 hr. Gd shows that it cannot be an isomer of Gd^{161}, and this activity is presumably, therefore, to be assigned to Gd^{159}.

Investigation of proton- and deuteron-bombarded gadolinium showed that the 5.5 d. activity, regarded by Krisberg and Pool[1] as being the same as that produced on neutron activation, is actually a mixture of two activities with slightly different half-lives. One is the 6.75 d. Tb described above. The other has a half-life of approximately 5.9 d. and emits low energy electrons and γ-rays of energy 1.1 and ~0.3 Mev. Its radiation characteristics seem to distinguish it from the 5.1 d. Tb^{153} found by Wilkinson and Hicks,[4] which could also hardly be produced, in the intensity found, from the low abundance (0.2 percent) Gd^{152}. It is probably, therefore, a new Tb isotope, decaying by orbital electron capture, and having a mass number of 156–157–158. A more detailed account will be published later.

Acknowledgment is made to the Director, Atomic Energy Research Establishment, for permission to publish these results. The writer is indebted to Dr. A. E. Kempton and Mr. F. Morgan for providing facilities for cyclotron irradiation and ion-exchange separation, respectively.

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The Beta-Spectrum of A^{41}

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March 3, 1949

A beta-ray spectrometer of the semicircular focusing type has been constructed for the investigation of the spectra of radioactive gases. The radius of curvature is 13.4 cm. Detection is by means of a thin mica (1.4 mg/cm²) end-window counter. A source chamber containing the gas fits into the spectrometer chamber, being separated from it by a 2.5 mg/cm² cellophane window; the chamber backing is $\frac{1}{32}''$ Al. The first defining slit is about 3 cm from the nearest part of the gaseous source, whose equivalent thickness was about 0.7 mg/cm². Calibration of the spectrometer was by means of photoelectrons from Cu^{64} annihilation radiation, with the source being placed at the same position as was the first slit in the case of the gaseous source. The distribution of electrons leaving the first slit in the gaseous case was assumed to be the same as that leaving the solid source for that portion of the beam which can reach the counter. This design eliminates single scattering into the beam except from the window, the first slit and a small section of the backing. The large average distance (2 to 5 cm) of the gaseous emitter from any of these scatterers should reduce scattering when compared to a solid source of the same total equivalent thickness as the source and window used. We regard the spectra obtained as less reliable below 300 kev, because scattering in that region becomes more pronounced.

Using a gas-flow probe,[1] spectroscopically pure argon was bombarded by 8 Mev deuteron beams of about 15–25 microamps. for 40–50 minutes to produce A^{41} by a (d, p) reaction (other activities were negligible); the gas was then transferred to the source chamber. A monitor counter, magnetically shielded by an iron cylinder, was placed next to the filling line, about 5 cm from the source chamber. The ratio of spectrometer counts to monitor counts (after subtraction of respective backgrounds) gave the spectrum, with a resolution of about 2.5 percent; the monitor simultaneously gave a decay

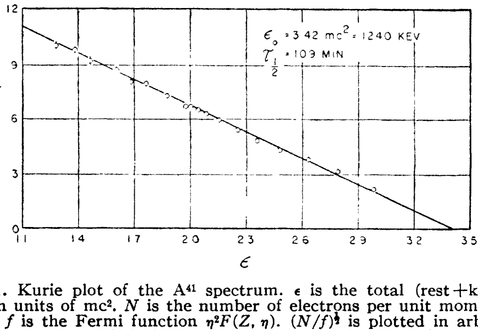

FIG. 1. Kurie plot of the A^{41} spectrum. ϵ is the total (rest+kinetic) energy in units of mc². N is the number of electrons per unit momentum interval. f is the Fermi function $\eta^2F(Z, \eta)$. $(N/f)^{\frac{1}{2}}$ is plotted in arbitrary units. Where the statistical error is greater than the size of the points, it is shown by vertical lines.

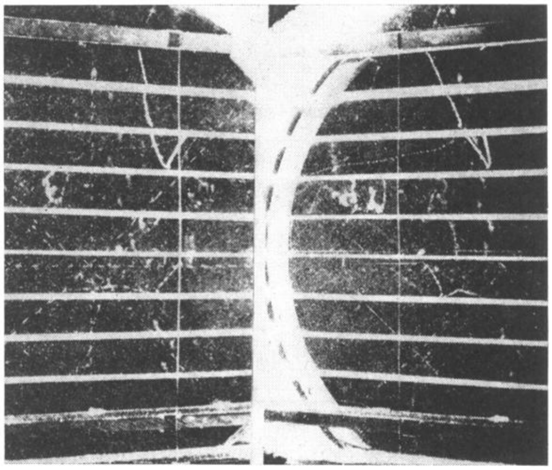

FIG. 2. A meson stops in the third Al foil from the top of the chamber. A heavily ionizing particle emerges from the stopping point and stops in the second Al foil. The electron track visible between the second and third foils is not associated with the event.