We present here the cross section for the production of π^- mesons of energy $\omega(k_-)$ and momentum k_- by an incident gamma-ray of energy E_γ. This cross section is obtained from a straight forward third-order perturbation calculation of the S matrix ($\sim ef^2$), and in writing the formula here we assume for simplicity that the nucleon is infinitely heavy. With this approximation the result is the same if we use Eq. (1) or Eq. (2) to describe the meson-nucleon interaction, indicating that the pair term is responsible for the entire contribution. The cross section is

$$\frac{d\sigma}{d\omega(k_-)}=\frac{8}{137}\left(\frac{g^2}{4\pi}\right)^2\left(\frac{2M}{\mu}\right)^2\frac{k_-k_+}{\mu^2E_\gamma{}^3}\left\{\frac{\omega(k_+)}{k_+}\ln\frac{\omega(k_+)+k_+}{\omega(k_+)-k_+}+\frac{\omega(k_-)}{k_-}\ln\frac{\omega(k_-)+k_-}{\omega(k_-)-k_-}-4\right\},\quad (3)$$

where $\omega(k_+)$ and k_+ represent the energy and momentum, respectively, of the π^+.

This result is quite analogous to the Bethe-Heitler pair production cross section.[6] The energy is shared symmetrically by the π^+ and π^- pair. The energy distribution is plotted in Fig. 1 for 400-Mev gamma-rays. The total cross section increases with gamma-ray energy near threshold as

$$\sigma=\frac{8\pi}{3}\cdot\frac{1}{137}\left(\frac{g^2}{4\pi}\right)^2\left(\frac{2M}{\mu}\right)^2\frac{\mu}{E_\gamma{}^5}\left(\frac{E_\gamma}{\mu}-2\right)^3.\quad (4)$$

Near the low energy end of the π^- spectrum the cross section increases for given gamma-ray energy, as the square root of the

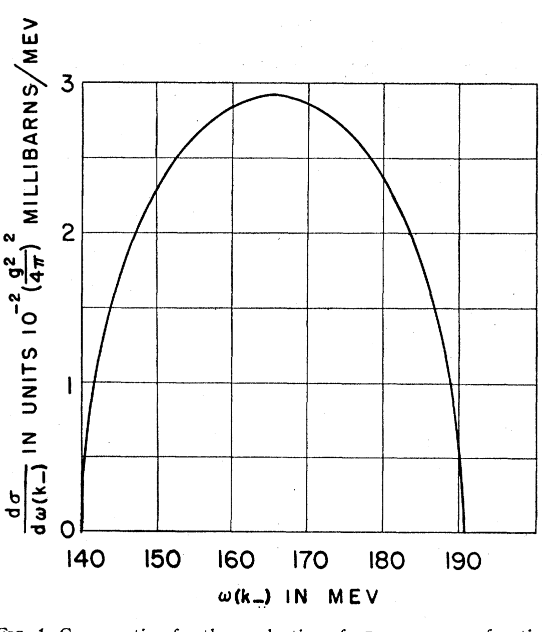

FIG. 1. Cross section for the production of π^- mesons as a function of the energy of the π^- meson. The curve is plotted assuming the incident gamma-ray to have an energy of 400 Mev in the laboratory coordinate system.

kinetic energy of the π^- meson. For 400-Mev gamma-rays the cross section, Eq. (3), integrated over all meson energies, equals 1.15 $(g^2/4\pi)^2$ millibarns,[7] where $g=(\mu/2M)f$ is the usual coupling constant in the derivative coupling theory.

From Eqs. (3) and (4), by dimensional considerations, one may argue that the probability of finding two mesons about the nucleon is $(g^2/4\pi)^2(2M/\mu)^2$. Hence the constant $g^2/4\pi$ must be less than $\sim 1/13$ in order to permit a reasonable physical statement that this probability is less than unity. Lévy's[2] recent analysis of the deuteron suggests a value $g^2/4\pi\sim 1/18$.

Thus a measurement of the photoproduction of π^- mesons by gamma-rays on protons serves as a direct test of the important pair term in the pseudoscalar meson theory.

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The β^- Half-Life of Pu^{241}

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AN estimate of about 10 years for the β^- half-life of Pu^{241} was made by Seaborg and co-workers[1] in 1948. Thompson *et al.*[2] in 1950 reported a value of 14 years for this half-life, based on measurements of the growth rate of the Am^{241} daughter. Recent work in this laboratory gives a new value of 13.0 ± 0.2 years, based on mass-spectrometer and α-pulse analyses of the plutonium and americium daughter.

Writing N_{ZA}, λ_{ZA}, and T_{ZA} for the number, decay constant, and half-life of atoms with atomic number Z and mass number A, and contracting the subscripts to the last digits so that ${}_{95}Am^{241}$ is denoted by 51 and ${}_{94}Pu^{241}$ by 41, the growth of Am^{241} after a time t, in a sample consisting initially of plutonium alone, is given by

$$(N_{51}/N_{41})_t=\exp(t\lambda_{41})-1,\quad (1)$$

if $t\ll T_{51}$ and $T_{51}\gg T_{41}$.

A sample of plutonium containing isotopes of mass 238 to 241 was chemically freed from americium, and then allowed to decay for 2.39 years. Part of this sample was then used for α-pulse analysis and part for mass-spectrometer analysis.

For α-pulse analysis, thin sources were prepared by vaccum sublimation of the oxides on platinum source disks. Care was taken to sublime the whole sample each time in order that the composition of the material on the source disk would be identical with that of the original sample. The analysis was done with a 24-channel NRC-Marconi pulse analyzer, using essentially the technique of Hanna and Harvey.[3] Two completely resolved peaks, at 5.15 Mev (Pu^{239} and Pu^{240}) and 5.48 Mev (Pu^{238} and Am^{241}) were obtained. This measurement gave $(\lambda_{51}N_{51}+\lambda_{48}N_{48})/(\lambda_{49}N_{49}+\lambda_{40}N_{40})$. A similar analysis of the plutonium, after removal of americium, gave $(\lambda_{48}N_{48})/(\lambda_{49}N_{49}+\lambda_{40}N_{40})$. The ratio $(\lambda_{51}N_{51})/(\lambda_{49}N_{49}+\lambda_{40}N_{40})$ was determined by difference, with a standard deviation of ±0.3 percent from eight separate experiments.

For mass-spectrometer analysis, thin sources were prepared by deposition of PuO_2 from nitric acid solution on a Sauereisen-coated tungsten filament.[4] The plutonium was freed of americium prior to analysis. Isotopic abundances were obtained with an 8-inch-radius mass spectrometer[5,6] employing a thermal ionization source. Twenty determinations were made of the abundance of Pu^{239} and Pu^{240} relative to Pu^{241}, and the standard deviation of the mean was ±0.7 percent.

Using $T_{49}=24\,360$ years,[7] $T_{40}=6600$ years,[8] and $T_{51}=470$ years,[9] the ratio N_{51}/N_{41} after 2.39 years was found to be 0.1359 ± 0.0009. From Eq. (1) this gives T_{41}, the half-life of Pu^{241} for β^- decay to Am^{241}, as 13.0 ± 0.2 years. The uncertainty quoted is twice the standard deviation calculated from the experimental results. This allows for possible experimental errors involved in the chemistry, but does not include the uncertainties in the half-lives used in the calculation.

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Excitation of a 16-Microsecond State in Ta^{181} by Capture of Bremsstrahlung*

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A TWENTY-TWO microsecond isomeric state of Ta^{181} has been investigated extensively by others by means of delayed coincidence techniques[1] involving the beta-particles from Hf^{181}. The gamma-ray energies have been obtained from spectrometer-conversion data[2] and from delayed-coincidence, scintillation-spectrometer measurements.[3] The decay scheme is not generally agreed upon, but the main branch involves three gamma-rays, two near 133 kev and one of 481 kev.

In the present work, an isomeric state of tantalum was formed by the reaction $Ta^{181}(\gamma,\gamma')Ta^{181m}$ using bremsstrahlung from the small betatron. A 0.015 inch-thick tantalum target was placed in the x-ray beam, and the gamma-radiation detected in a NaI(Tl) crystal placed, out of the beam, about one inch away from the sample. The pulse-height distribution was observed in a ten-channel differential analyzer, sensitive for a period of 50 to 75 microseconds following each x-ray burst. The start of the "on" period could be delayed by a continuously variable amount in order to measure the decay rate of the counts between the bursts.

Although the crystal was shielded from the direct beam by 16 inches of lead, scattered radiation from the target produced a considerable amount of light in the crystal. This overloaded the amplifier, and it was necessary to reduce the gain of the photomultiplier during each burst. This was done by applying a ten-microsecond negative gate to the first dynode.

With an "on" period of 75 microseconds, the pulse-height spectrum shown in curve (a) of Fig. 1 was obtained. The ordinates are the sum of two runs at delays of 13 and 30 microseconds. Upon comparing with the 280-kev gamma from Hg^{203}, curve (b), the Ta photopeak is seen to correspond to about 130 kev.

The presence of a target, whatever its composition, affected the background of the crystal. This background consisted of delayed scintillations (half-life 200 to 250 microseconds) arising from x-rays scattered into the crystal by the target. Such effects have been observed by others.[4] Here it is apparent (see curve (c), obtained with a tungsten target of the same dimensions as the tantalum) that the background was not serious near 130 kev.

Evidence for radiation near 500 kev was also observed. No well-defined photopeak was found, however, owing to much poorer statistics.

A decay curve of pulses corresponding to energies between 88 and 226 kev was plotted. The time delays were measured on an oscilloscope whose sweep was calibrated to within two percent. The half-life, after background correction, was 16 ± 3 microseconds. The uncertainty is due only to statistical errors. It is assumed that this 16-microsecond state is identical to the metastable state reported previously.[1]

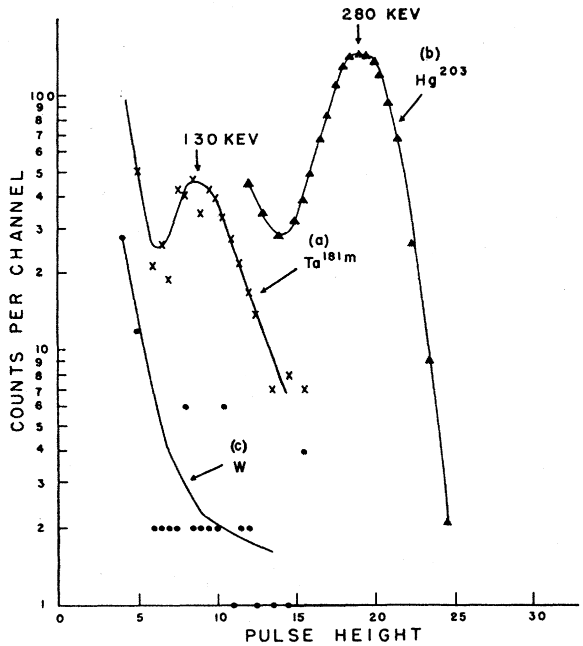

FIG. 1. Pulse-height spectrum of delayed gamma-rays from Ta^{181m}.

All measurements were made at 6.5-Mev maximum energy, below the neutron threshold of lead because of the otherwise large neutron background. This low bombarding energy seriously reduced the beam intensity. The Ta^{181m} activity, ideal because of the short lifetime and because a 100 percent isotope is involved, was just above the threshold of detection. An activity with half-life four times or more that of Ta^{181m} would not have been detectable with the geometry used. Improved geometry and neutron shielding may allow the detection of longer-lived transitions, although it is expected that delayed background pulses from the scintillation crystal would cause trouble.

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Spin and Parity of the 2.3-Mev Excited State of Te^{124}†

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IT has been reported[1] that the gamma-rays emitted in the disintegration of Sb^{124} do not show any directional correlation. Definite conclusions cannot be drawn from this isotropy as several γ–γ cascades contribute to the observed coincidence rate.