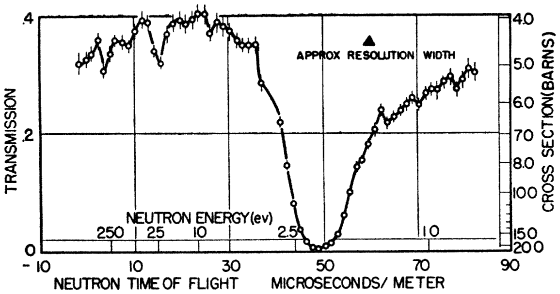

FIG. 1. Neutron cross section of 49.2 g/cm² normal isotopic Te.

2 inches in diameter. Since the quantities available are very small (24 to 3000 mg), these electropolated deposits form extremely thin transmission targets which are effectively transparent at all but resonant energies. Figure 2 shows the energy dependence of the cross section of a 7.9-mg/cm² sample of tellurium containing 60.9 percent of Te^{123}. There are probable resonances at 1.7 ev, 1.4 ev, 1.2 ev, 1.1 ev, and 0.9 ev. The large resonance at 2.2 ev has been assigned to Te^{123} as a result of the following analysis. The best possible theoretical Breit-Wigner single-level resonance curve was fitted[3] to the experimental curves obtained from both the enriched and the normal isotopic tellurium. Taking into account the abundance of each isotope in these two samples, two values of $\sigma_0\Gamma^2$ were calculated for each isotope. For only one isotope was good agreement obtained, namely, for Te^{123}, for which $\sigma_0\Gamma^2$ was found to be 900±100 barns ev. Assignment of the remaining resonances is being carried out in this way with the use of a thinner sample of normal tellurium and better resolution of the spectrometer.

The total cross section of normal isotopic tellurium has also been determined for neutron energies at which there are neither resonances nor diffraction effects, and is given by the equation $\sigma=3.9+0.70E^{-\frac{1}{2}}$ (Fig. 3). This gives a value for the capture cross section at 0.025 ev of 4.43±0.15 barns, in good agreement with that of 4.53 barns found by the pile oscillator method at Oak Ridge.[4] If 78 percent of the thermal cross section is attributed to Te^{123}, as indicated by Pomerance and Arnette,[4] the capture slope for this isotope becomes $0.55E^{-\frac{1}{2}}$. The value of $\sigma_0\Gamma^2$ corresponding to this slope is 825 barns ev, agreeing with the $\sigma_0\Gamma^2$ value obtained from curve fitting in the area of the 2.2-ev resonance.

The incoherent scattering cross section of normal tellurium was determined using the neutron velocity spectrometer and a forward scattering apparatus.[5] The latter consists of two annular rings of BF_3 counter tubes at 18° and 33°, respectively, from the incident neutron beam. For neutrons of sufficiently long wave-

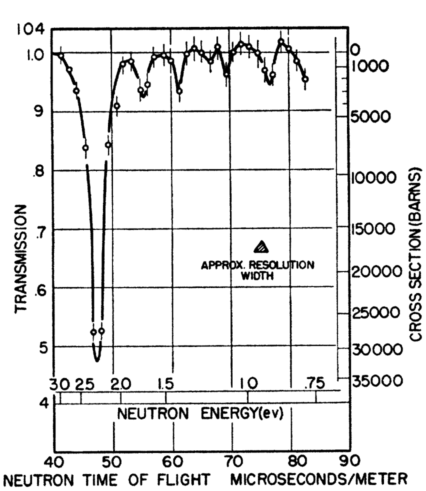

FIG. 2. Neutron cross section of 7.9 mg/cm² enriched Te^{123}.

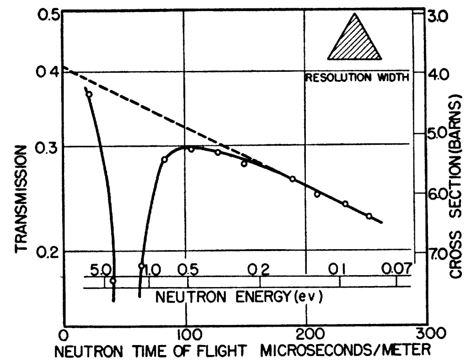

FIG. 3. Neutron cross section of 49.2 g/cm² normal isotopic Te.

length, Bragg reflections fall outside the counter tubes. Thus, only the isotropic incoherent scattering is measured. After correction for multiple scattering, the incoherent scattering cross section was found to be 0.6±0.15 barn.

We are indebted to Miss Estelle Marder for the preparation of the tellurium isotope samples, and to Drs. W. W. Havens, Jr., L. J. Rainwater, and R. J. Weiss for advice and suggestions in the course of this work.

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Isomeric State of Y^{89} and the Decay of Zr^{89}

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THE decay of Zr^{89} (78 hr) is accompanied[1] by the emission of a partially converted 0.92-Mev gamma-ray which does not coincide with the positrons or with the x-rays due to K capture. This suggests the existence of a metastable state with 0.92-Mev excitation either in Zr^{89} or in its product Y^{89}. In this mass region the longest lived states expected from the shell model and empirical evidence[2] are those which combine with the ground state by transitions of the type $g_{9/2}\leftrightarrow p_{1/2}$ yielding magnetic 2^4-pole ($M4$) radiation. For such transitions the semi-empirical formula[2] $\tau_\gamma=10^4(2I+1)/A^2E^9$ gives an approximate mean life in seconds as a function of the mass number A, the energy E in Mev, and the angular momentum I of the excited state. For $A=89$ and $E=0.92$ Mev, we expect half-lives of $T_{1/2}\simeq18$ sec if $I=9/2$ or $T_{1/2}\simeq3.5$ sec if $I=1/2$.

These considerations make it unlikely that we are dealing with a metastable state of Zr^{89} with $T_{1/2}=78$ hr. In addition, an isomeric state of Zr^{89} with a 4.5-min half-life is already known. On the other hand, if the transition takes place in Y^{89}, where the ground state is known to have $I=\frac{1}{2}$, the expected half-life of 18 sec should permit observation separate from the zirconium parent. We have succeeded in observing Y^{89m} in several ways.

The production of Y^{89m} by excitation with fast neutrons was demonstrated in a very pure, cadmium-covered, sample of Y_2O_3 exposed to fast neutrons from the Brookhaven reactor. A strong gamma-ray activity with a half-life of 16±3 sec was established.

The energy of the gamma-rays, as measured on a scintillation spectrometer, was found to be about 0.92 Mev. An attempt to excite yttrium with x-rays from a 2-Mev Van de Graaff generator yielded an indication of a short-lived activity which was, however, too weak to permit measurement of the half-life. Finally we showed that this activity is indeed due to an isomeric transition in Y^{89} by separating it from Zr^{89}. The latter was prepared by deuteron bombardment of Y_2O_3 and separated from yttrium by repeated extraction of the *TTA* complex. The yttrium daughter activity was then re-extracted into 2*M* $HClO_4$. A half-life of 13 ± 2 sec was found for the daughter activity and a scintillation spectrometer showed that it emits 0.92-Mev gamma-rays.

The Zr^{89} parent activity showed the 0.92-Mev gamma-ray and 0.51-Mev annihilation radiation. A careful search by means of magnetic, scintillation, and proportional counter spectrometers failed to produce any evidence for other gamma-rays ascribed to the decay of Zr^{89} by Hyde and O'Kelley.[3] The relative numbers of yttrium *K* x-rays and 0.92-Mev gamma-rays from Zr^{89} were compared with the corresponding numbers for Y^{88} which emits close to one 0.91-Mev gamma-ray per strontium *K* x-ray. Scintillation and proportional counter spectrometers were used for this comparison. The results showed that there are about 1.3 times as many 0.92-Mev gamma-rays as *K* x-rays in the decay of Zr^{89}. A similar comparison, using calibrated sources of Y^{88} and Na^{22} as intensity standards showed that there are about four times as many nuclear gamma-rays as positrons from Zr^{89}. These results show that the isomeric state of Y^{89} is indeed formed by the positron decay as well as by electron capture. The approximate ratio 3:1 for electron capture to positron emission deduced from these data is in good agreement with the theoretical value[4] for an allowed transition after a small correction for *L* electron capture. The *ft* value of 1.2×10^6 also indicates that the transition is allowed, unfavored.[4]

From the observed ratios of 0.04:1 of conversion electrons to positrons[1] and 4:1 of gamma-rays to positrons we obtain the value 10^{-2} for the total conversion coefficient. Allowing for a small contribution from the *L*-shell we find good agreement with the theoretical value for the *K* conversion coefficient of 8×10^{-3} for an *M*4 transition.[5]

The transition in Y^{89} is the most energetic *M*4 transition definitely identified as such. The excellent agreement of the observed lifetime of 14 ± 2 sec with the semi-empirical formula derived mostly from data at much lower energies gives strong support to the E^9 dependence[6] over the E^{11} law implied in older formulas.[7] The $g_{9/2}-p_{1/2}$ separation in Y^{89} (0.92 Mev), which contains 50 neutrons, is greater than in either[2] Y^{87} (0.39 Mev) or Y^{91} (0.61 Mev). It seems reasonable that the contraction of the core for a magic number of nucleons leads to a smaller binding energy for orbits of high angular momentum.

We wish to thank Dr. A. O. Allen of the Chemistry Department of Brookhaven National Laboratory for kindly placing the Van de Graaff x-ray generator at our disposal. Thanks are also due to Mr. A. Smith for help with the neutron exposures, and to the MIT cyclotron crew for the deuteron bombardments.

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Production Ratio of Photomesons from Beryllium*

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By the irradiation of targets with a high energy x-ray beam, both negative and positive π-mesons are produced. An investigation was made to determine the ratio of the numbers of mesons of either sign produced in beryllium, because its single isotope $_4Be^9$ has one neutron with only 1.6-Mev binding energy which might affect this ratio.

For this study, the same arrangement was used with which Peterson, Gilbert, and White[1] had determined the corresponding ratio for carbon. The x-ray beam of the 320-Mev synchrotron was collimated and hit the target, a beryllium sphere of about ½-inch diameter. The target was surrounded by a copper absorber in which were imbedded the nuclear emulsion plates, Ilford C2, of 200μ thickness. They were oriented in such a way that the planes of the emulsions were approximately radial. Thus the mesons give relatively long tracks in the emulsion. The plates were scanned for mesons stopping in the emulsion. From the thickness of the traversed material (beryllium, copper, glass, and emulsion) and the energy-range relation one can determine the initial energy of the mesons. The discrimination between negative and positive mesons was made by observing their type of endings. As in the work of Peterson *et al.*, the fact was used that in emulsions negative π-mesons are captured by nuclei and form stars with visible prongs 73 percent of the time; the remaining 27 percent stop without showing a visible track at their end.[2] Positive mesons are not captured and decay to μ-mesons. By counting the meson-produced stars and the π-μ decays, one therefore can calculate for each energy interval the π^-/π^+ ratio. Only mesons emitted at an angle of $90°\pm7°$ to the x-ray beam and in the energy range of 30 to 70 Mev were investigated in this experiment. Because stars are much more conspicuous events in emulsions than π-μ decays, the probability of missing stars in the scanning process is slightly lower than that of overlooking π-μ decays. For this reason, a correction in the ratio of 5 percent, derived from scanning certain areas of the emulsions twice, was applied. Only mesons ending more than 5 microns away from the surface of the emulsion after processing were counted. The ratios were determined from a total of 661 π-μ decays and star forming mesons. The errors given include standard deviations and estimated systematic errors.

TABLE I. π^-/π^+ ratio of mesons produced by x-rays on beryllium.

Meson energy (Mev)	π^-/π^+ ratio
30–40	2.5 ± 0.6
40–55	2.0 ± 0.3
55–70	2.2 ± 0.3
30–70	2.2 ± 0.25

The results are given in Table I. It is seen that the ratio of negative to positive mesons depends little, if any, on the energy in the investigated range. The over-all ratio for mesons of 30 to 70 Mev is 2.2. This value is, within the limits of accuracy, the same which Littauer and Walker[3] got for mesons of about 50 Mev at an angle of 135° to the x-ray beam direction. In their measurements the discrimination between the mesons of both signs was made by means of a magnetic field.

This high minus-plus ratio cannot be explained only by the fact that the beryllium nucleus has one more neutron than protons. Rather it seems as if this one neutron of the low binding energy would act as a free particle, and, therefore, would have a higher production cross section. This is analogous to the case of the production of positive mesons, where free protons have a higher production cross section for π^+ mesons than bound ones, because of the action of the exclusion principle.[4,5] In light elements in which no particle has such a preferred position, as in deuterium, helium, and carbon, the respective minus-plus ratios are 1.0,[6] 1.0 (angle 45°),[6] and 1.06 (angle 135°).[3]

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