protons on F^{19} in channel spin 1 are most suitable and are discussed below. Since it was not possible to measure the inelastically scattered protons leading to the 114-kev state at these resonances, we discuss only the angular distribution of protons leading to the 200-kev state and of the two γ rays.

The protons to the $5/2^+$ state are distributed as $1+A_p\cos^2\theta=1+B_pP_2(\cos\theta)$, where, because of the two channel spins 2 and 3 in the outgoing state, $-7/9\leq A_p\leq 1/3$ or $-0.7\leq B_p\leq 0.2$. The observations (tabulated below) lie within this range. A $3/2^+$ state would also be consistent with the proton distributions.

With an assignment of $1/2^-$ for the 114-kev state, the corresponding γ ray is spherical, in agreement with observation. For the 200-kev γ ray, we expect an angular distribution $f(\theta)=1+A_\gamma\cos^2\theta=1+B_\gamma P_2(\cos\theta)$. If the state were $3/2^+$, decaying by magnetic dipole, A_γ would be less than or equal to zero; the fact that A_γ is positive eliminates this possibility. For a $5/2^+$ state decaying by electric quadrupole radiation, we get $0.23\leq A_\gamma\leq 0.75$ or $0.143\leq B_\gamma\leq 0.4$. Before comparing with experiment, we will discuss some novel features of this problem.

The treatment of the proton spin needs some explanation. In calculating the angular distribution of the inelastically scattered protons, the proton spin is combined with that of the excited F^{19} nucleus to form two channel spins: from each of these, an angular distribution is calculated and the results are the two extreme distributions, the general result being an arbitrary linear combination of the two. In calculating the distributions of the subsequent γ rays, however, the amplitudes from the two channel spins are coherent and the general result contains a term corresponding to the interference of the two channel spins. The extreme distributions can of course be found by diagonalizing the quadratic form. It is interesting to inquire, however, if a different way of combining angular momenta will lead directly to the two extreme distributions which can be combined incoherently. It is readily seen that the appropriate combination for this purpose is the $\mathbf{l}+\mathbf{s}=\mathbf{j}$ of the outgoing proton. The γ-ray distributions for different j values (here 1/2 and 3/2) of the outgoing proton are incoherent and, in fact, for $j=3/2$ we get $A_\gamma=0.23$, whereas for $j=1/2$ we get $A_\gamma=0.75$.

This result leads immediately to the formulation of a general statement as to when we may combine two angular momenta, at a certain stage of a reaction, to form a resultant which may be treated incoherently: Whenever an experiment gives equal weight to all projections of two angular momenta j_1 and j_2 which are to be combined, then we may form $\mathbf{j}_1+\mathbf{j}_2=\mathbf{J}$ and the various J values can be treated incoherently for that particular experiment. For example, in observing the proton angular distribution, equal weight is given to the projections of the spins of proton and of excited F^{19}, whereas in observing the γ-ray distribution, equal weight is given to all directions of the proton (projections of $\mathbf{l}$) and to all projections of the proton spin. We see also when, in the excitation curve of the γ rays from a residual nucleus, two overlapping resonances or states of the compound nucleus can show interference (a term which, as a function of excitation energy, is asymmetric about the resonance center and leads to a rapidly changing angular distribution in the neighborhood of the resonance center). Only those resonances which can lead to the residual state in question by particles of the same j and l can show such interference in the radiations from the residual state.

There is, of course, a correspondence between the angular distributions of inelastically scattered protons and of subsequent γ rays at a given resonance. This is shown by the solid curve in Fig. 1, where B_p, the coefficient of $P_2(\cos\theta)$, is plotted against B_γ. Because of the coherence of the usual channel spins, this correspondence is in the form of an ellipse, instead of a straight line, which is bounded in the B_p and B_γ values by the numbers already computed. Taking the channel spin amplitudes as real numbers, the corresponding experimental points for B_p and B_γ should lie on the perimeter of the ellipse.

In this problem, the situation is further complicated by the long lifetime[2] of the $5/2^+$ state (10^{-7} sec) which permits some precession of the nuclear spin before γ emission. This will result in a B_γ reduced by multiplying with some factor $\alpha<1$. In this case it does not seem possible to calculate α since the environment of the radiating F^{19} nucleus is quite uncertain after the $p-F^{19}$ collision which will leave the atom perhaps excited and in a strange lattice position. It should be possible, by correlating sufficiently precise measurements of B_p and B_γ at different resonances, to test the conclusions given here and to find the reduction factor α. The dotted ellipse is drawn for $\alpha=0.6$. The observations listed below are shown as rectangles in the figure and are not inconsistent with $\alpha\approx 0.6$. In addition, the angular distribution of the 200-kev γ ray as excited by Coulomb excitation under alpha-particle bombardment[3] is consistent with α in the range 0.6 to 0.8.

Resonance	A_p	B_p	A_γ	B_γ
873 kev	0 ±0.1	0 ±0.07	0.17±0.02	0.11 ±0.015
1355 kev	0 ±0.1	0 ±0.07	0.40±0.03	0.235±0.015
1381 kev	−0.45±0.1	−0.35±0.1	0.44±0.03	0.255±0.015

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* Assisted by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

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Short-Lived Isomeric States of Ag^{110} and In^{116}†

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BETA and gamma radiations from the short-lived isomeric states of Ag^{110} and In^{116} have been investigated using a scintillation spectrometer. The detector arrangements were conventional, using RCA 5819 photomultipliers in conjunction with sodium iodide (thallium activated) or anthracene crystals for the detection of gamma or beta rays, respectively. Data were recorded photographically as dots on 35-mm film. This recording technique provides information concerning both the energy spectrum and decay rate of the sample. Details concerning the photographic dot recording method have been described elsewhere.[1]

Ag^{110} was obtained by irradiating 0.001-inch silver foil in the

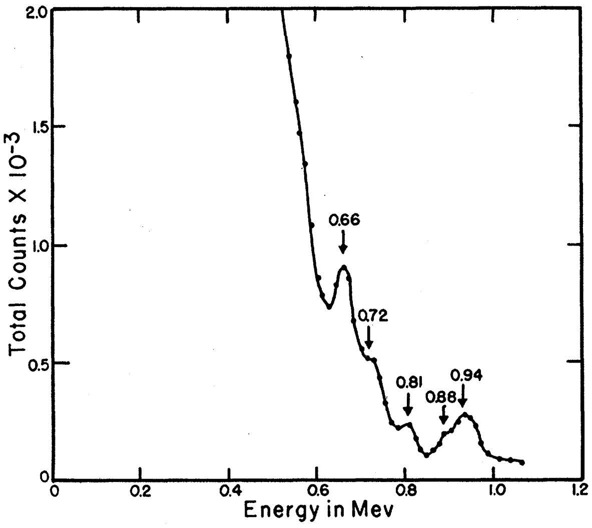

FIG. 1. Gamma spectrum of 24-second Ag^{110}. Energies are in Mev.

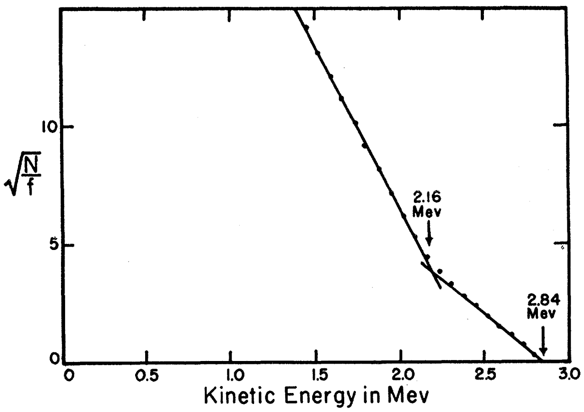

FIG. 2. Fermi plot of beta spectrum of 24-second Ag^{110}.

Brookhaven reactor for a period of approximately two seconds. The transit time from the pile to the spectrometer was approximately ten seconds. The decay rate of the activity indicated a half-life of 24±2 seconds thus insuring proper identification as Ag^{110}.

The Ag^{110} gamma spectrum is shown in Fig. 1 and a Fermi plot of the beta spectrum appears in Fig. 2. Energy calibrations were obtained from the 0.661-Mev gamma ray of Cs^{137} and its conversion line. Gamma rays of 0.66±0.02 Mev and 0.94±0.02 Mev are observed as well as weak, poorly resolved peaks at 0.72±0.02 Mev, 0.81±0.02 Mev, and 0.88±0.02 Mev. The beta spectrum consists of two groups with end points at 2.84±0.05 Mev and 2.16±0.05 Mev. These emissions may be arranged in the decay scheme shown in Fig. 3. The 0.37-Mev beta group was not observed. If present this group undoubtedly would have been masked by the higher-energy groups. This decay scheme meshes with the one given by Cork *et al.*[2] for the decay of the 270-day isomeric state of Ag^{110}.

The present experiment is similar to one performed by Goodrich[3] who found indications supporting the suggestion of Siegbahn[4] that a lower-energy beta transition may occur between the 24-second state and one of the higher Cd^{110} levels. The present experiment yields a beta-to-gamma intensity ratio of 200. Considering the two-second irradiation time and the 40-to-1 ratio of cross sections in favor of the excitation of the 24-second over the 270-day isomer, the 200-to-1 intensity ratio strongly supports the existence of a low-energy beta transition. The above data indicate an end point energy of approximately 0.37 Mev for the group.

The 13-second isomeric state of In^{116} was excited by irradiating finely powdered indium in the Brookhaven reactor for approximately two seconds. Identification was made on the basis of half-life as in the case described above. No gamma rays were detected. The end point of the single beta-ray group was determined to be 3.29±0.06 Mev. There appears to be no transition between the isomeric states of In^{116}. These results support the findings of Slätis *et al.*[5]

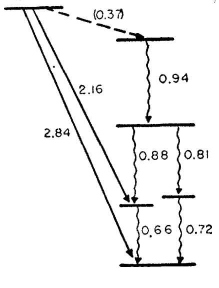

FIG. 3. Proposed decay scheme of 24-second isomeric state of Ag^{110}. Energies are in Mev.

Grateful acknowledgment is made to Mr. C. M. Gordon who assisted with the equipment used in taking the data, to Dr. Marvin Fox and other members of the Brookhaven reactor group for irradiation assistance, and to Dr. D. J. Zaffarano at Iowa State College for the use of an automatic "dot counter."

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Half-Life and Beta Decay of the Long-Lived Niobium-94

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THE properties of the nuclide Nb^{94} have so far not been observed directly but have only been inferred from other experimental data owing to the difficulty of freeing even the purest niobium, element or compound, from impurities which become activated in the pile. From yield considerations, the most recent tentative assignment of the half-life to this beta-decaying nuclide[1] only indicates a lower limit of 5×10^4 years. Lately an efficient means of separating tantalum from niobium by solvent extraction was indicated,[2] based on the fact that tantalum and niobium have been found to extract into certain polar organic solvents. This enabled us to obtain the residual activity, due to Nb^{94}, of a niobium sample irradiated in the pile.

Spectroscopically pure metallic niobium as well as some niobium salts have been irradiated for 23 days with thermal neutrons in the nuclear reactor "JEEP." The short-lived 6.6-minute Nb^{94m} beta activity was confirmed. The bulk of the slow-decay activity is due to Ta^{182} beta and gamma radiations. Many ways have been tried to free efficiently the niobium metal from the tantalum impurity: anion exchange column, coprecipitation of Ta as potassium fluotantalate, and Ta/Nb solvent extraction using di-isopropyl ketone. Only the last one proved successful. In a Nb_2O_5 sample to which inactive tantalum was first added and then extracted successively four times, the residual activity was brought down to a stable value of 9.5 counts/min per mg Nb_2O_5 counted in a standard end-window Geiger tube assembly for a window-to-sample distance of 9 mm.

Absolute beta counting was carried out on this purified niobium pentoxide, resulting in a specific activity of 4.757×10^{-8} curies/g of irradiated niobium metal. From this value a half-life of 2.7×10^4 years was computed for the nuclide, the average value of the neutron flux during the 23-day irradiation being 1.5×10^{11} neutrons per cm^2 per sec. Considering the necessary approximations used, we estimate that the half-life of Nb^{94} is determined with an accuracy of ±15 percent of the indicated value.

From an aluminum absorption curve the energy of the residual Nb^{94} beta radiation was found to be 0.61 Mev.

The neutron irradiation and the measurement of the short-lived Nb^{94m} were carried out at the Joint Establishment for Nuclear Energy Research (JENER), Kjeller, Norway, the further research at the Institute of General Chemistry of the Polytechnic in Milan (Italy).

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