tion, and (3) the relative contribution of the photopeak to the total intensity.[5] The graphical resolution of the 137–166 kev doublet and the allowance for background were somewhat arbitrary, but the latter correction was guided by results obtained with absorbers which had a very small transmission for the 166-kev radiation while attenuating the 303-kev radiation only moderately. The ratio of the crossover to the cascade transitions was found to be 0.8. Using the result that 85 percent of the 166-kev radiation is due to $M1$ transitions,[4] the magnetic moment of the ground state of Ta was calculated[7] to be 3 nm. This is to be compared with the value of 2.8 nm obtained by Huus and Bjerregaard using a somewhat less direct method and a spectroscopic value of 2.1 nm.[6]

Further interest in the energy levels of tantalum arises from the agreement of the spacing of these levels with that predicted by the rotational model of the nucleus of Bohr and Mottelson.[7] For an even-odd nucleus with ground-state spin 7/2, (Ta^{181}) the model predicts excited states of spins 9/2 and 11/2 having energies above the ground state in the proportion of 9 to 20. This proportion agrees well with that found in experiments. Additional evidence supporting the spin assignments can be obtained from the angular distributions of the gamma radiation from these levels with respect to the beam. Figure 2 shows the experimental distribution obtained

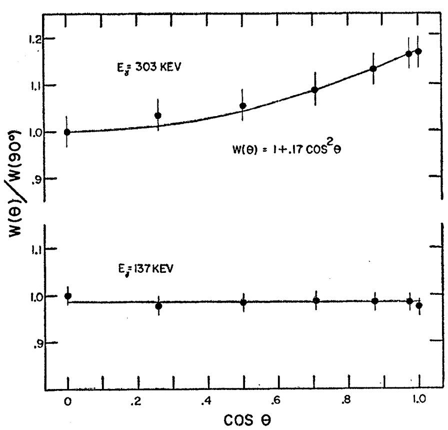

FIG. 2. The angular distributions of the 137-kev and 303-kev gamma rays from tantalum measured between 0° and 90° to the beam at $E_p=3$ Mev. The theoretical distribution is shown for the 303-kev radiation.

for a proton energy of 3 Mev with the counter subtending a solid angle of 0.13 steradian. The data were taken with a 3 mm Cu absorber which transmitted a strong 137-kev line relative to background but did not impair the resolution of the 303-kev line. The intensity of the 166-kev line was then only about 15 percent of that of the 137-kev line so that these two lines were not resolved. The data of Fig. 2 were corrected for the absorption of the radiation in the target (5 mils of tantalum) and for background. Errors shown in the curves are statistical. A systematic error due to uncertainties in the background subtraction could change the asymmetry by about 3 percent.

The theoretical form of the angular distributions has been predicted by Alder and Winther[8] assuming electric quadruple transitions from the ground state to the excited state in question ($E2$ in keeping with the B-M theory[7] according to which such transitions are especially favored) followed by $E2$ transitions back to the ground state. The distributions are obtained in a manner analogous to that giving the angular correlation between two gamma rays in cascade. However, the special nature of the excitation process modifies the distributions through energy dependent factors $a_k(\xi)$ which multiply the Legendre polynomials. The angular distribution function is then

$$W(\theta)=1+a_2(\xi)B_2P_2(\cos\theta)+a_4(\xi)B_4P_4(\cos\theta),$$

where the B_k are the gamma-gamma correlation coefficients tabulated by Biedenharn and Rose.[9] Expressing the theoretical distributions in a form easily compared with experiment gives $W(\theta)=1+0.171\cos^2\theta+0.006\cos^4\theta$ for the 303-kev gamma ray, which is the curve shown in Fig. 2, and $W(\theta)=1-0.032\cos^2\theta+0.037\cos^4\theta$ for the 137-kev gamma ray, which is isotropic within the accuracy of this experiment. The $a_k(\xi)$ were calculated for 3-Mev protons[10] and the B_k were determined by assuming the spins of the 137-kev and 303-kev states to be 9/2 and 11/2, respectively.

The good agreement between the experimental and theoretical distributions lends further support to the spin assignments and the excitation process which was postulated.

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10 The error in the coefficients due to the neglect of the effect of the thick target is small because of the form of the yield curve and the slow variations of $a_k(\xi)$ with energy.

$\pi^- - p$ Interactions at 1.5 Bev*

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Stacks of 400μ G-5 stripped emulsion were exposed to the 1.5-Bev π^- beam at the Brookhaven cosmotron. The plates were aligned with respect to each other by means of x-ray dots so that it was possible to trace even minimum ionizing tracks through many emulsions.

The primary interest was in finding π^- – proton interactions. It was found that the only efficient way to detect these interactions is by "on-track" scanning. The work reported here is the result of scanning about 300 meters of track. The mean free path for a $\pi^- - p$ interaction was found to be about 4 meters of track. According to counter measurements of the total $\pi^- - p$ cross section at 1.5 Bev by Cool, Madansky, and Piccioni,[1] the mean free path

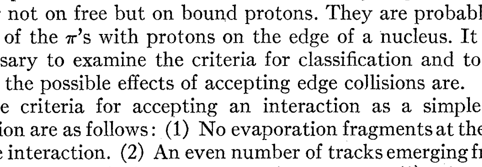

FIG. 1. A $\pi^- - p$ collision in which a π^0 is produced. The more heavily ionizing track is a proton of about 40-Mev energy.

in nuclear emulsion should be about 9–10 meters. This means that 50–60 percent of the interactions classed as hydrogen interactions occur not on free but on bound protons. They are probably collisions of the π's with protons on the edge of a nucleus. It is thus necessary to examine the criteria for classification and to decide what the possible effects of accepting edge collisions are.

The criteria for accepting an interaction as a simple $\pi^- - p$ collision are as follows: (1) No evaporation fragments at the vertex of the interaction. (2) An even number of tracks emerging from the interactions of which at most one is a proton. (3) The protons must of course be in the forward hemisphere, and if the proton emerges at an angle θ it cannot have an energy greater than an elastically scattered proton at this angle.

To date 4 cases have been rejected on this basis. The results of the search to date are as follows:

(a) $\pi^-+p\rightarrow\pi^-+p$ — 16 events,

(b) $\pi^-+p\rightarrow\pi^-+\pi^0+p$ — 31 events,

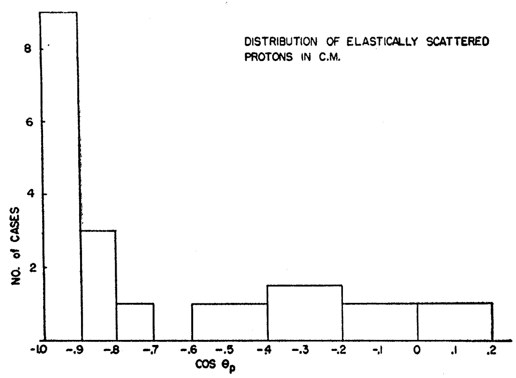

FIG. 2. Angular distribution in the c. m. system of 22 elastically scattered protons.

(c) $\pi^-+p\rightarrow\pi^++\pi^-+n$ — 20 events,

(d) $\pi^-+p\rightarrow\pi^0+n$, $2\pi^0+n$, $\Lambda^0+\theta^0$, etc. . . . — 22 events,

(e) $\pi^-+p\rightarrow\pi^++2\pi^-+p$ — 1 event.

It is possible that some of the cases which appear to be π^0 production are cases of elastic collisions in which one of the products has struck a neutron. However, it seems likely that this does not happen often for the following reasons: (1) Frequent secondary interactions would tend to scatter protons to large angles which in turn should result in many rejections by criterion (3). (The inelastic protons actually seem to come out very much in the forward direction in the lab system.) (2) In a three-particle reaction the energy of one of the particles with its angle and the angle of one other track uniquely specifies the reaction. In 12 cases good momentum measurements on both charged particles could be made, and on this basis 2 were rejected.

Some of the cases classed as single π^0 production might be double π^0 production. There are not thought to be many of these since there are so few cases of multiple production of charged π's. By momentum and energy balance one can occasionally check for multiple π^0 production.

If a collision appears to be elastic within a momentum discrepancy of 200 Mev/c it is classed as an elastic collision. Figure 1 shows an example of π^0 production in a π^--p collision. Figure 2 shows the angular distributions of the protons in elastic scattering. Figures 3 and 4 show the angular distributions of the protons, π^- and π^0, and angles between π^- and π^0 in the production cases.

The angular distributions show that in both the elastic and π^0 production cases the protons tend to go backward and the π^-

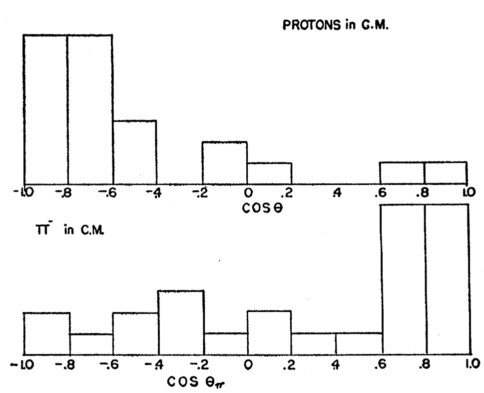

FIG. 3. Angular distribution of p and π^- from the reaction $\pi^-+p\rightarrow\pi^-+p+\pi^0$.

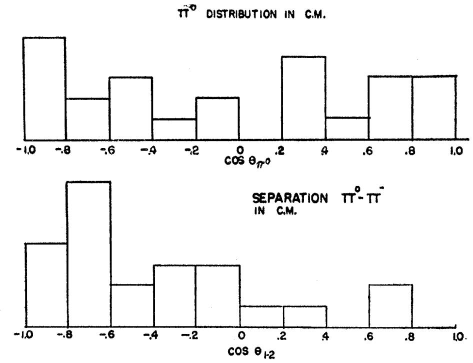

FIG. 4. Angular distribution of π^0 in the c. m. system and the distribution of π^0 with respect to the π^- in the c. m. system.

forward in the center-of-mass system. The elastic scatterings seem to break into two categories: a diffraction-type scattering which gives deflections of 10°–30° in the center-of-mass system, and a low-angular-momentum interaction which gives a big deflection and change of momentum in the center-of-mass system. The π^- and π^0 have rather different angular distributions. The π^- and π^0 seem to have a tendency to come apart with a rather large angular separation. This angular separation between mesons seems to be characteristic of the cases in which $\pi^++\pi^-+n$ are produced. In the center-of-mass system the π^0, π^-, and proton have on the average about equal momenta.

If the angular distributions of the π^0 and π^- are different, it seems to rule out the possibility of a statistical-type theory of these interactions.

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Nuclear Potential Well Depth*

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FESHBACH, Porter, and Weisskopf[1] have shown that the pattern[2] of variation of the total cross sections of heavy nuclei with neutron energy and nuclear size can be explained by representing the neutron-nucleus interaction as that of a square well with absorption

$$V(r)=-19\text{ Mev}(1+i0.05),\quad 0\leq r\leq R\equiv1.45A^{\frac{1}{3}}\times10^{-13}\text{ cm};$$
$$V(r)=0,\qquad r>R.$$

Bohr and Mottelson[3] have pointed out that the value of 19 Mev used for the real part of the potential is considerably smaller than that necessary to account for the bound levels of heavy nuclei as described by the shell model. It is the purpose of this note to show that a well depth of about 40 Mev, consistent with the shell model, is indicated by the scattering data.

A most striking characteristic of the total cross-section pattern is the variation of the average low-energy neutron-nucleus cross section as the value of A, the number of nucleons in the nucleus, increases from about 100 to about 200. A characteristic well-type S-wave resonance behavior occurs at about $A=150$. Using a square-well shape, and neglecting absorptive effects for simplicity, it is clear that κr will at resonance be equal to $(N+\frac{1}{2})$ for $r=R$,