section factor[5] would be 2.3×10^{-7} kev-barn. In such an instance, the stars would consume He^3 via the $He^3(p,\gamma)Li^4$ process rather than by the $He^3(He^3,He^4)2p$ reaction. Indeed, a cross section 10^{10} times smaller than the present experimental upper limit would enable the $He^3(p,\gamma)Li^4$ reaction to compete with the direct process $He^3(p,\beta^+\nu)He^4$, which[6] is of significance at very low temperatures ($T<2\times10^6$ °K). Thus, the observations reported in this paper cannot absolutely deny an astrophysical role to Li^4, but the implication of the data and theory is strong that Li^4 is not particle-stable and hence does not in fact have such a role.

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[1]H. Reeves, Phys. Rev. Letters 2, 423 (1959).

[2]W. A. Fowler has summarized these arguments in the Proceedings of the Ninth International Colloquium of Astrophysics, Liège, 1959 (to be published). See also A. Baz' and Ya. Smorodinskiĭ, Uspekhi Fiz. Nauk 55, 215 (1955).

[3]G. Breit and J. S. McIntosh, Phys. Rev. 83, 1245 (1951).

[4]R. F. Christy (private communication).

[5]Burbidge, Burbidge, Fowler, and Hoyle, Revs. Modern Phys. 29, 547 (1957).

[6]E. E. Salpeter, Phys. Rev. 88, 547 (1952).

MEASUREMENT OF THE SPIN AND PARITY OF THE ANOMALOUS INELASTIC STATES IN Ni^{58} AND Ni^{60}†

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In the inelastic scattering of charged particles of intermediate energy as measured with low-resolution detectors, a number of experimenters have observed structure in the spectra at an excitation energy where one previously would have expected only a continuum.[1-3] The details of the structure observed by the different experimenters depend rather critically on the precise resolution used, but generally speaking these experiments have shown a strong peak corresponding to leaving the nucleus excited to about 2.5 Mev for elements with $Z\geqslant30$. Further structure is seen particularly for elements with $Z<30$ at an excitation energy of about 4.5 Mev. In this note we wish to report on the experiments establishing the spin and parity of the 4.5-Mev structure in Ni^{58} and Ni^{60} as 3^-

Figure 1 shows the angular distributions of alpha particles scattered from Ni^{58} and Ni^{60}, respectively, leaving the target nucleus in the ground state and first excited state. Also shown in these figures are the angular distributions of the alpha particles which leave the nucleus with the excitation indicated and constitute the anomalous peak at the respective energies. The spectra from which these angular distributions were deduced are similar to those published earlier by Sweetman and Wall.[3] The scintillation spectrometer used for experiments was a NaI crystal cut sufficiently thin (~0.02 inch) so that the largest proton or deuteron light pulse produced in the crystal was smaller than the alpha-particle pulses of interest.

In a subsequent experiment a 3×3 inch NaI γ-ray spectrometer was used to measure the γ-ray spectrum in coincidence with the anomalous alpha-particle groups. A fast-slow coincidence circuit was used that enabled us to simultaneously measure the elastic alpha-particle–γ-ray counting rate as well as the inelastic–γ-ray coincidence rate. This enabled us to show that the chance coincidence rate was in fact practically negligible and to make any minor correction (< 10%) for it. Details of this scheme will be published later. Figure 2 shows typical γ spectra in the case of Ni^{58} and Ni^{60}. By calibrating with a Na^{24} source we were able to determine the absolute efficiency of our γ-ray detector. Taking into account solid angle as well as intrinsic efficiency, the over-all efficiency was typically of the order of 7×10^{-3}. By summing all the counts in the energy interval

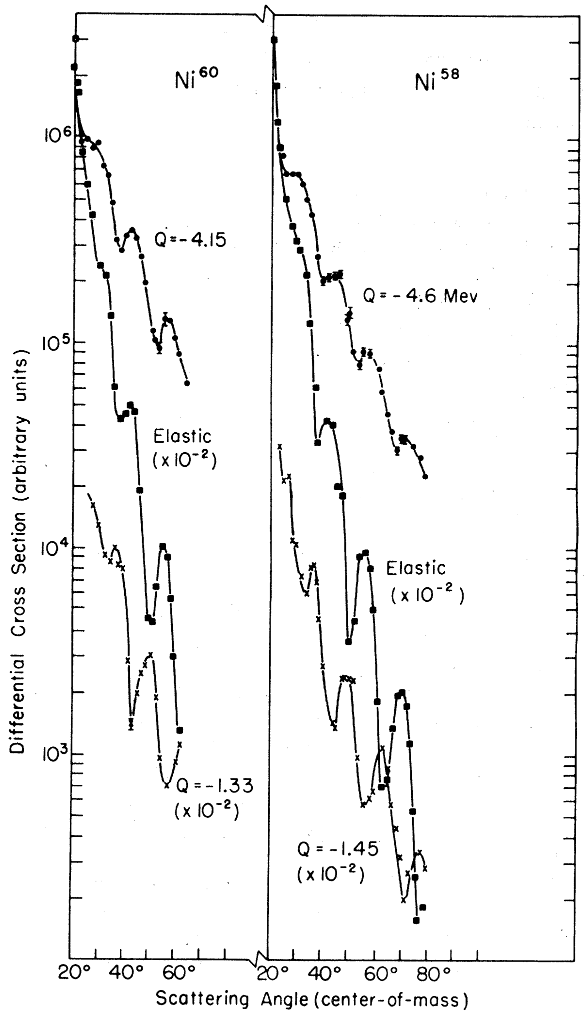

FIG. 1. Angular distribution of alpha particles scattered from Ni^{58} and Ni^{60}.

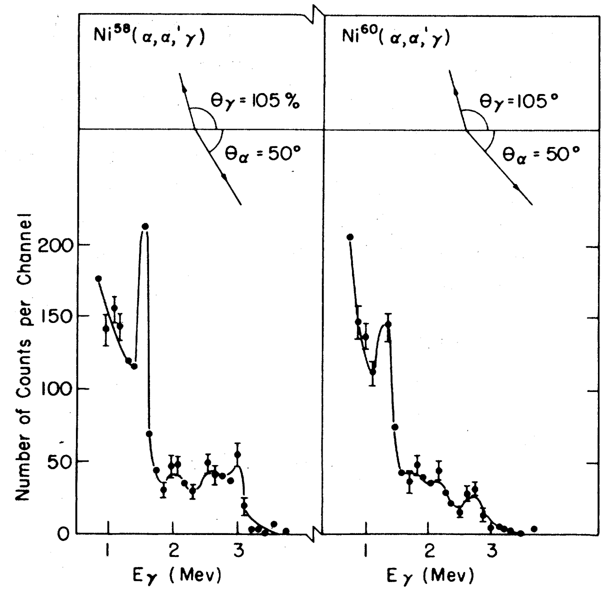

FIG. 2. Gamma spectra from Ni^{58} and Ni^{60} coincident with alpha particles inelastically scattered by the anomalous state.

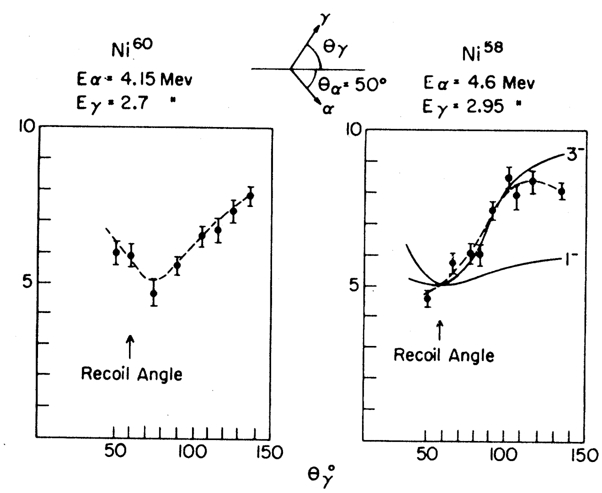

FIG. 3. Alpha-gamma angular correlations from Ni^{58} and Ni^{60}.

from 1.6 to 3.0 Mev in Ni^{60} and 1.85 to 3.35 Mev in Ni^{58}, we were able to show that approximately $(62 \pm 20)\%$ of the time the anomalous structure was excited in Ni^{58} and $(50 \pm 20)\%$ in Ni^{60} the level or levels involved decayed to the first excited state of these nuclei.

Using this same arrangement, the angular correlation of the γ ray from the "anomalous level" to the first excited of each of these nuclei relative to the outgoing alpha particle (and therefore recoiling nucleus) was determined. The results of these measurements are shown in Fig. 3.

The results of the angular distribution measurements can be interpreted as showing that the parity of the "anomalous state" in Ni^{58} and Ni^{60} is different from that of the ground state whereas the parity of the first excited state is the same as that of the ground state. This result follows from either a Born approximation calculation of direct inelastic alpha-particle scattering or the more recent inelastic diffraction calculation of Blair.[4] Inasmuch as both isotopes are even-even, we assume that the ground-state parity is even.

Our results on the first excited states are then in agreement with the known spin and parities of the first excited states of Ni^{58} and Ni^{60},[5] and give negative parity for the anomalous state. The ambiguity in what value of the radius to use prevents a unique deduction of the spin of the state from the inelastic-scattering angular distribution.[4] On the other hand, the angular correlation results can be interpreted as showing that the "anomalous state" is 3^- and decays to the first excited 2^+ state through the emission of electric dipole radiation[4,6]. The results of a Born approximation calculation for the angular correlation are also illustrated in Fig. 3 for the two assumptions of electric dipole radiation from either a 1^- or 3^- state. By virtue of the fact that the gamma-ray spectrum shows transition directly from the anomalous level to the first and the relatively large number of levels[7] between 1.5 and 4 Mev in both nuclei, it would seem unlikely that the state had any spin higher than 3^-.

A possible interpretation of this level is that it is a collective octupole oscillation.[4,8] On the basis of a classical hydrodynamic approach to nuclear structure Bohr and Mottelson estimate the energy of the lowest octupole surface oscillation to be in the range of 4 to 7 Mev.[9] However, further data relative to the transition probabilities will be necessary to establish this collective nature.[8] Goodman[10] has emphasized the single-particle explanation of the "anomalous levels." While accounting for a level in the inelastic particle spectrum at about 4-Mev excitation, he makes no definite prediction as to its spin.

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[1]B. L. Cohen and A. G. Rubin, Phys. Rev. 111, 1568 (1958).

[2]J. L. Yntema and B. Zeidman, Phys. Rev. 114, 815 (1959).

[3]D. R. Sweetman and N. S. Wall, Comptes Rendus à Congrès International de Physique Nucléaire (Dunod, Paris, 1958), p. 547.

[4]J. S. Blair (to be published); see also Yntema, Zeidman, and Raz (to be published).

[5]Strominger, Hollander, and Seaborg, Revs. Modern Phys. 30, 585 (1958).

[6]G. R. Satchler, Proc. Phys. Soc. (London) A68 1037 (1958); C. A. Levinson and M. K. Banerjee, Ann. Phys. 2, 499 (1957). The expression given in these references has been corrected by a phase factor and has been normalized to the experimental data.

[7]C. H. Paris and W. W. Buechner, Comptes Rendus à Congrès International de Physique Nucléaire (Dunod, Paris, 1958), p. 515.

[8]A. M. Lane and E. D. Pendelbury (to be published).

[9]A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 27, No. 16 (1953).

[10]C. D. Goodman, Phys. Rev. Letters 3, 230 (1959).

EXPERIMENTAL EVIDENCE FOR D WAVES IN $\pi^- $-$p$ SCATTERING AT 370 AND 427 Mev*

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The differential elastic scattering of pions on protons furnishes information on the magnitude of the various partial waves included in the interaction. Precise measurements of this process up to 333 Mev[1,2] have been interpreted in terms of S and P waves and their six associated charge-independent phase shifts. No D or higher waves were necessary to give a statistically significant fit to the data. In this Letter, we report our values of the elastic-scattering cross section for negative pions on protons at 370 ± 9 and 427 ± 10 Mev (lab energies).

The experimental setup is shown in Fig. 1. The pion beam from an internal Be target in the 184-in. cyclotron was deflected out of the machine by its magnetic fringing field. The beam was then momentum-analyzed and focused by the wedge and quadrupole magnets shown. The intensity of the 2-in. diam beam was greater than 15 000 negative pions per second. The beam energy and its muon and electron contaminations were determined from ranges in copper.

The pion beam was scattered in a 4-in.-thick liquid-hydrogen target. The elastically scattered pions were detected by a three-scintillator counter telescope which discriminated against recoil protons and inelastic pions on the basis of range in the copper absorbers placed between