metastable polarization attainable, hence the optical-pumping signal in He^3 relative to that in He^4.

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[1]F. D. Colegrove and P. A. Franken, Phys. Rev. 119, 680 (1960).

[2]See E. M. Purcell and G. B. Field, Astrophys. J. 124, 542 (1956), for a comprehensive discussion of processes involving electron exchange during collisions.

[3]M. Fred, F. S. Tomkins, J. K. Brody, and M. Hamermesh, Phys. Rev. 82, 406 (1951).

[4]F. Bloch, Phys. Rev. 70, 460 (1946).

[5]M. A. Bouchiat, T. R. Carver, and C. M. Varnum, Phys. Rev. Letters 5, 373 (1960).

[6]G. Weinreich and V. W. Hughes, Phys. Rev. 95, 1451 (1954).

EXCITED ISOBARIC STATES IN MEDIUM-A NUCLEI*

J. D. Anderson and C. Wong
Lawrence Radiation Laboratory, University of California, Livermore, California
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The importance of isotopic spin considerations ($\Delta T = 0$) in "mirror-nuclei" (p,n) reactions has been pointed out by Bloom et al.[1] For nonmirror nuclei we have previously demonstrated the existence of isobaric states[2,3] using the (p,n) reaction. The (p,n) reaction was assumed to go as follows[4]: The incoming proton reacts with an "excess neutron" (a neutron corresponding to an unfilled proton state), exchanges its charge, and is emitted as a neutron. Although previously published V^{51}-Cr^{51} spectra[2,3] showed no evidence for excited isobaric states, Rost[5] suggested that the excitation of excited isobaric states was more probable in even-even nuclei than in odd-even nuclei. Herein we present experimental evidence for the existence of excited isobaric states from the (p,n) reaction on medium-A nonmirror even-even nuclei and show that these states correspond to the excited states of the target nucleus.

The Livermore Variable-Energy Cyclotron and time-of-flight techniques[6] have been used to study (p,n) spectra from selected target nuclei. We have previously reported[3] measurements up to a proton bombarding energy of 14.8 MeV where all spectra show one strong neutron group at an energy corresponding in excitation in the final nucleus to the isobaric counterpart (analog state) of the target ground state, i.e., the Q value is the usual Coulomb energy displacement. The modification of the rf cavity of the cyclotron enabled us to obtain protons with energies in excess of 18 MeV. This higher proton energy permits us to look at higher excitations in the residual nucleus in the region of the isobaric ground state (analog state) with considerable reduction in background, since the principal background obscuring neutrons from the isobaric state is composed of neutrons from compound nucleus decay.

The time-of-flight spectra resulting from 17-MeV proton bombardment of even-even target nuclei Fe and Ni are shown in Fig. 1. The analog state neutron group is clearly seen, as in a first excited isobaric state. Excited isobaric states are also seen for Ar, Ti, Zn, and Se. The Q values for the excited isobars are listed in Table I along with the first excited states of the target nuclei. It seems clear then that excited isobaric states exist corresponding to the excited

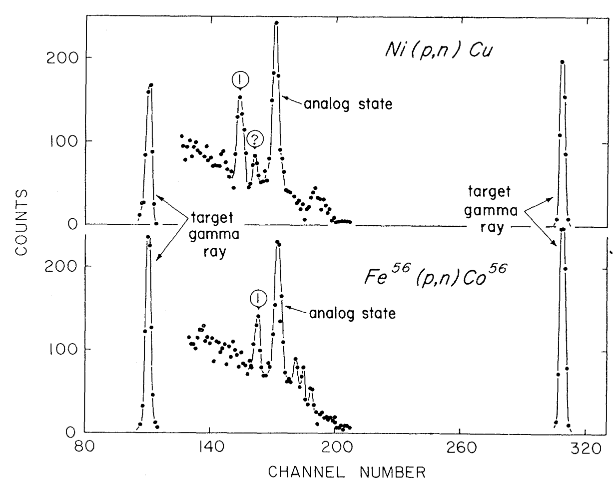

FIG. 1. Time-of-flight spectra from 17-MeV proton bombardment of Fe and Ni. Time calibration of the system is 1.9 nsec/channel and increasing time of flight is toward the left. The flight path was 11.4 meters.

Table I. Q values for low-lying states in target nuclei and excited isobaric states (measured from the analog state) in residual nuclei.

Element	Q Values (MeV) Excited isobars	Target state[a]
Ar^{40}	1.56 ± 0.10	1.464
Ti^{48}	0.95 ± 0.07	0.99
Fe^{56}	0.83 ± 0.05	0.845
Ni	1.44 ± 0.10	1.452[b]
Zn	1.07 ± 0.10	0.99[b]
Se	0.58 ± 0.07	0.665[b]

[a]H. H. Landolt and R. Börnstein, "Energy Levels of Nuclei: $A=5$ to $A=257$," Group I: Nuclear Physics and Technology, edited by A. M. Hellwege and K. H. Hellwege (Springer-Verlag, Berlin, 1961).

[b]Q's listed are for the dominant isotope.

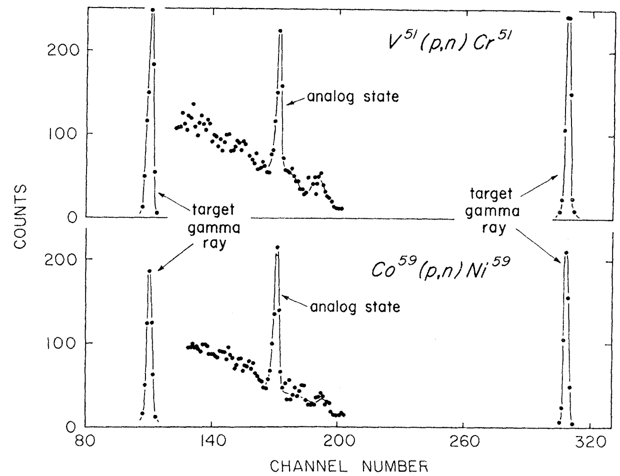

FIG. 2. Time-of-flight spectra from 17-MeV proton bombardment of V and Co. Time calibration and flight path are the same as in Fig. 1.

states of even-even target nuclei. Spectrum measurements (Fig. 2) on odd-even targets V^{51} and Co^{59} indicate no such structure.

Lane and Soper[7] have recently shown that in addition to the excitation of the isobaric state, the (p,n) reaction should also excite states of the same configuration as that of the target, i.e., "isobaric configuration selection." The observed excited isobaric states are possibly configuration states which have the same isotopic spin as the target nucleus. With the assumption that isotopic spin is a valid quantum number[8] one may consider the correspondence between isobaric states of the ${}_{28}Ni_{30}{}^{58}$ target and the ${}_{29}Cu_{29}{}^{58}$ residual nucleus as analogous to the correspondence of excited states in light nuclei such as in the $T=1$ triad C^{14}-N^{14}-O^{14}.

Although the detailed mechanism inhibiting the formation of low-lying excited isobaric states in even-odd nuclei is uncertain, it depends upon a spin statistical weight factor $W \equiv (2J_f+1)/(2J_i+1)$ and a nuclear matrix element which is model-dependent.[5] The relative importance of these terms is not yet clear but may be determined by additional measurements.

We are indebted to Dr. A. M. Lane for making available several articles before publication and for many communications regarding the nature of isobaric states. We are also indebted to Dr. E. Rost for his suggestions regarding excited isobaric states. This experiment was made possible by the increase in proton energy resulting from recent cyclotron modification. It is a pleasure to acknowledge the work of Dr. Robert Jopson in redesigning the cyclotron cavity, Mr. Philip Frazier for rf modification, and Mr. Donald Rawles and the cyclotron crew for running the machine under new and sometimes trying conditions.

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[1]S. D. Bloom, N. K. Glendenning, and S. A. Moszkowski, Phys. Rev. Letters 3, 98 (1959).

[2]J. D. Anderson and C. Wong, Phys. Rev. Letters 7, 250 (1961).

[3]J. D. Anderson, C. Wong, and J. W. McClure, Phys. Rev. (to be published).

[4]What may be an intuitively more attractive description in terms of the optical model is offered by A. M. Lane, Phys. Rev. Letters 8, 171 (1962).

[5]E. Rost (Princeton), prior to our measurements, informed us that crude arguments based on seniority wave functions would indicate the excitation of excited isobaric states to be more probable in even-even nuclei than in odd-even nuclei.

[6]J. D. Anderson and C. Wong, Nuclear Instr. (to be published).

[7]A. M. Lane and J. M. Soper (to be published).

[8]A. M. Lane and J. M. Soper (to be published).