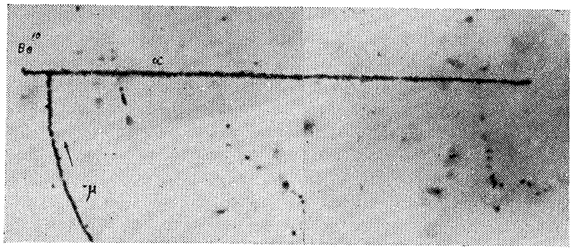

FIG. 2. A two-prong star caused by a negative μ-meson is shown in the photograph. The star is tabulated as event 3 in Table I. The two tracks of the nuclear particles are nearly collinear, but a definite departure from collinearity of about 8° is observed in the original event. The departure from collinearity is in a direction perpendicular to the plane of the photograph. The event is interpreted as the nuclear capture of a negative μ-meson by a nitrogen nucleus with the emission of a Be^{10} fragment, an α-particle, and a neutrino.

than the other three events because the Be^{10} track is short. A comparison of the residual momentum of the two charged particles from the star (column 6, Table I) with the difference between the rest energy of the μ-meson and the energy of the star (column 7, Table I) strongly indicates that a light neutral particle, presumably a neutrino, accompanies the nuclear capture of a negative μ-meson.

TABLE I. Characteristics of μ^- meson stars.

Event	Type of plate	Nuclear reaction	Range of short track in microns	Range of long track in microns	Residual momentum of two fragments Mev/c	Energy[a] of neutrino (calculated) Mev
1	G-5	$(\mu^-,O^{16}; B^{12},\alpha)$	3.4	47.5	$20<p<80$	70
2	G-5 2X	$(\mu^-,O^{16}; B^{12},\alpha)$	1.2	9.3	$0<p<80$	77
3	G-5	$(\mu^-,N^{14}; Be^{10},\alpha)$	5.6	86	$40<p<80$	71
4	G-5 2X	$(\mu^-,N^{14}; Be^{10},\alpha)$	1.7	12.5	$30<p<80$	84

[a] The energy of the neutrino is estimated from the difference between the rest energy of the μ-meson and the sum of the threshold energy of the nuclear reaction plus the kinetic energy of the charged nuclear particles.

The author is indebted to Professor H. L. Anderson for permission to use the facilities of the University of Chicago cyclotron. A portion of the plates was searched by Mr. T. Thwaites, Mr. K. Benson, and Mr. J. Behrendt. The author is grateful to Mr. H. Morinaga for several discussions.

---

* Supported in part by the Research Committee of the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

[1] W. F. Fry, Phys. Rev. **85**, 676 (1952); Phys. Rev. **89**, 325 (1953); H. Morinaga and W. F. Fry, Nuovo cimento **10**, 324 (1953); W. F. Fry, Nuovo cimento (to be published).

[2] J. J. Wilkins, Atomic Energy Research Establishment (Harwell) Report G/R-664 (unpublished).

[3] Lees, Morrison, and Rosser, Proc. Phys. Soc. (London) **66**, 13 (1953).

[4] C. H. Millar and A. G. W. Cameron, Phys. Rev. **78**, 78 (1950).

[5] W. F. Hornyak and T. Lauritsen, Phys. Rev. **77**, 160 (1950).

Spins and Parities of Excited States in Even-Even Nuclei. I*

MICHAEL J. GLAUBMAN
Physics Department, University of Illinois, Urbana, Illinois

(Received April 9, 1953)

MUCH experimental information has been gathered recently on spins and parities of excited states in even-even nuclei.[1] Most of these levels have even parity and are considered to have the same configuration as the ground state. There exist, however, cases in which the parity is odd; according to the shell model these must be due to excited configurations in which at least one of the nucleons is excited to a neighboring orbit with different parity. There are also even-parity examples in which one must assume that the excited states have a different configuration than the ground state. These occur when the proton and neutron groups in the ground state form closed shells (or subshells). States for which one has reason to believe that one nucleon is excited to a different orbit are summarized in Table I.[2–7]

TABLE I. Excited states of even-even nuclei of configurations different from that of the ground state.

Nuclide	Level energy (Mev)	Spin and parity	Reference	Probable configurations
$_8O^{16}$	6.05	3 −	2	$p_{1/2}d_{5/2}$ [a]
$_{14}Si^{28}$	1.38	2 +	1	$(d_{5/2})^{-1}s_{1/2}$ [a]
$_{18}A^{38}$	3.75	3 −[b]	3, 4	protons $d_{3/2}f_{7/2}$ or $(d_{3/2})^2s_{1/2}f_{7/2}$
$_{38}Sr^{88}$	1.85	2 +	5, 6	protons $(p_{3/2})^{-1}p_{1/2}$ or $(f_{5/2})^{-1}p_{1/2}$
	2.76	3 −	5, 6	protons $(p_{3/2})^{-1}g_{9/2}$ or $(f_{5/2})^{-1}g_{9/2}$
$_{52}Te^{124}$	2.3	3 −	7	protons $d_{5/2}h_{1/2}$ or $g_{7/2}h_{11/2}$ or neutrons $(h_{11/2})^7d_{5/2}$
	2.66	3 −	7	
$_{82}Pb^{204}$	1.279	7 −	1	neutrons $(i_{13/2})^{-1}(p_{3/2})^{-1}$ or $(i_{13/2})^{-1}p_{1/2}$
$_{82}Pb^{208}$	2.614	2 +	1	protons $(h_{11/2})^{-1}f_{7/2}$ or neutrons $(i_{13/2})^{-1}g_{9/2}$

[a] These states may be the result of an excited configuration of neutrons or protons or a combination of the two.

[b] The parity assignment is based on the beta-decay data.

Considering these examples together with the states which have the ground state configuration (the spins of which are 0, 2, and 4), it can be seen that all the states that are known to have even spins are known to have even parity, and that all the states that are known to have odd parity are known to have odd spin. One may perhaps generalize and say that in even-even nuclei the low-lying odd-parity states have odd spins and the low-lying even-parity states have even spins.

There are a few cases quoted in the literature[1] in which an odd-spin even-parity assignment had been made. Two of these cases, the 2.73-Mev level in Mo^{94} [8] and the 0.764-Mev level in Os^{186},[9] could and probably should be interpreted as being 2+ states. In the other two cases, the 3.75-Mev level in A^{38} [3,4] and the 2.185-Mev level in Nd^{144},[10] the spin is known to be odd but the parity assignment is doubtful. A definitive determination of the parities of these, and other odd-spin states would provide a useful check for the rule suggested above.

The rule suggested here for the coupling of identical particles is in a sense the opposite of the "strong" Nordheim[11] rule for the coupling of nonidentical particles. Thus the ground state of an odd-odd nucleus with the configuration $j_1=l_1\pm s_1$, $j_2=l_2\mp s_2$, will have the spin $J=|j_1-j_2|=|l_1-l_2\pm 1|$; i.e., the spin will be even if the parity is odd and the spin will be odd if the parity is even. Furthermore, eight of the configurations listed in Table I would, in the case of odd-odd nuclei, be expected to satisfy the "weak" Nordheim rule, i.e., $J>|j_1-j_2|$ (for $j_1=l_1\pm s_1$, $j_2=l_2\pm s_2$). However, it can be seen from Table I that only the $(i_{13/2})^{-1}(p_{3/2})^{-1}$ neutron configuration, suggested as an alternative to the $(i_{13/2})^{-1}p_{1/2}$ neutron configuration for the 7-state in Pb^{204}, satisfies this rule.

---

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

[1] G. Scharff-Goldhaber, Phys. Rev. **90**, 587 (1953).

[2] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 376 (1952).

[3] L. M. Langer, Phys. Rev. **77**, 50 (1950).

[4] Rolf M. Steffen, Phys. Rev. **80**, 115 (1950).

[5] F. R. Metzger and H. C. Amacher, Phys. Rev. **88**, 147 (1952).

[6] Rolf M. Steffen, Phys. Rev. **90**, 321 (1953).

[7] F. R. Metzger, Phys. Rev. **90**, 328 (1953).

[8] H. Medicus, Helv. Phys. Acta **24**, 300 (1951).

[9] F. R. Metzger and R. D. Hill, Phys. Rev. **82**, 646 (1951).

[10] D. E. Alburger and J. J. Kraushaar, Phys. Rev. **87**, 448 (1952).

[11] L. W. Nordheim, Revs. Modern Phys. **23**, 322 (1951).