p. 55.

[4]S. C. Agarwal, Phys. Rev. B 7, 685 (1973).

[5]F. J. DiSalvo, A. Menth, J. V. Waszczak, and J. Tauc, Phys. Rev. B 6, 4574 (1972).

[6]R. A. Street, T. M. Searle, and I. G. Austin, J. Phys. C: Proc. Phys. Soc., London 6, 1830 (1973), and Phil. Mag. 30, 1181 (1974).

[7]S. G. Bishop and D. L. Mitchell, Phys. Rev. B 8, 5696 (1973).

[8]P. C. Taylor, H. M. Kriz, and J. F. Baugher, to be published.

[9]Low-temperature induced absorption near the band edge (1.4–1.7 eV) in As_2Se_3 glass has been reported previously: J. Cernogora, F. Mollot, and C. Benoît à la Guillaume, in *Proceedings of the Twelfth International Conference on Physics of Semiconductors, Stuttgart, Germany, 1974*, edited by M. H. Pilkuhn (B. G. Teubner, Stuttgart, Germany, 1974), p. 1027.

[10]F. Stern, in *Solid State Physics*, edited by H. Ehrenreich, F. Seitz, and D. Turnbull (Academic, New York, 1963), p. 378.

[11]C. M. Hurd and P. Coodin, Phys. Chem. Solids 20, 523 (1966).

[12]P. W. Atkins and M. C. R. Symons, *The Structure of Inorganic Radicals* (American Elsevier, Amsterdam, 1967).

[13]S. G. Bishop and U. Strom, in "Proceedings of the International Conference on the Optical Properties of Highly Transparent Solids, 1975," edited by B. Bendow and S. S. Mitra (Plenum, New York, to be published).

[14]J. Cernogora, F. Mollot, and C. Benoît à la Guillaume, Phys. Status Solidi (a) 15, 401 (1973).

[15]R. A. Street, I. G. Austin, and T. M. Searle, to be published.

High-Spin States in ^{20}F†

J. N. Bishop* and H. T. Fortune
Physics Department, University of Pennsylvania, Philadelphia, Pennsylvania 19174
(Received 5 March 1975)

Results of the reaction $^{14}N(^7Li,p)^{20}F$ identify several levels below 5 MeV as candidates for high-spin states predicted by shell-model calculations, but heretofore undiscovered. The 2.97-MeV level is found to be a doublet.

We did this experiment to look for high-spin states, because shell-model calculations[1-3] predict significantly more high-spin states in ^{20}F than are known[4] experimentally. We made use of the University of Pennsylvania tandem, multiangle spectrograph, and Ilford K5 nuclear-emulsion plates with 0.015–0.025-in. Mylar absorber. The target was natural N_2 gas in a windowless

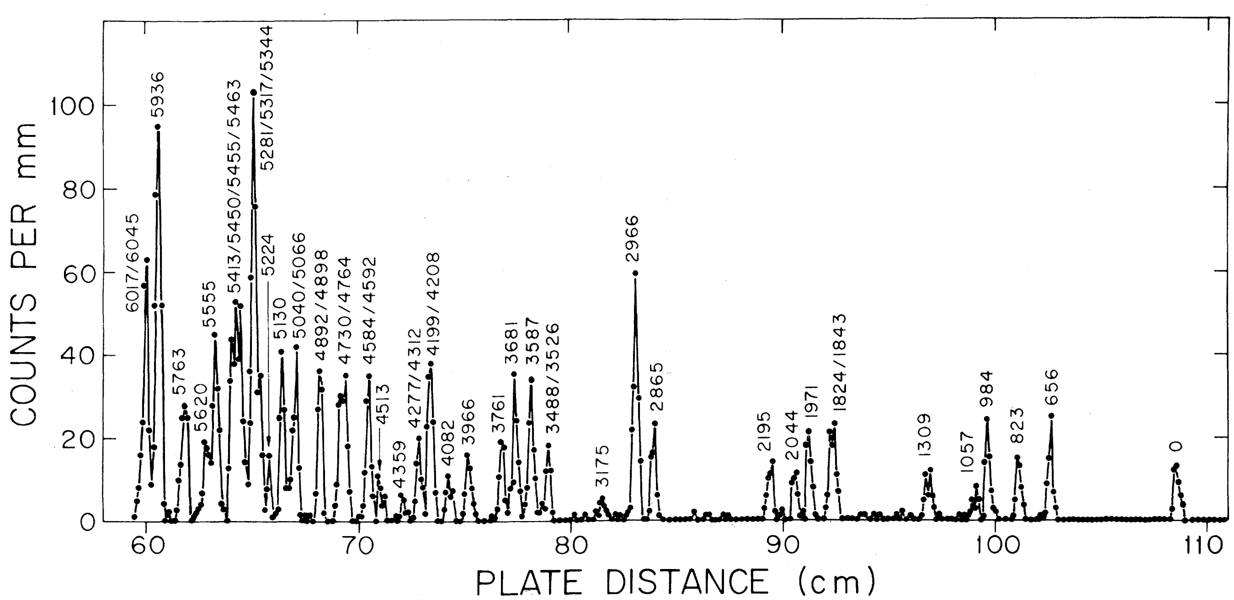

FIG. 1. Spectrum of the reaction $^{14}N(^7Li,p)^{20}F$ at 16 MeV and $7\frac{1}{2}°$.

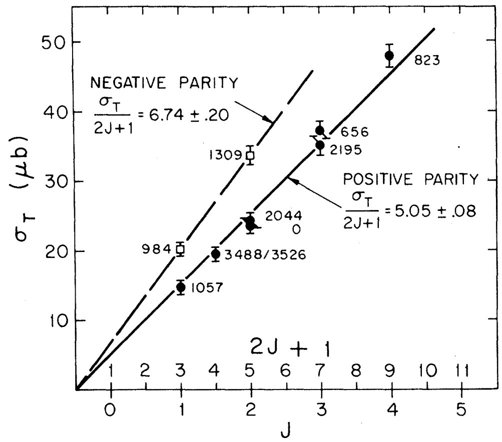

FIG. 2. Plot of $\sigma_{tot}=\int_{0°}^{180°}\sigma(\theta)\sin\theta\, d\theta$ for all levels below 5 MeV with known J^π (Refs. 4, 10, 11, and references therein).

gas cell.[5] The bombarding energy was 16.0 MeV. A spectrum is displayed in Fig. 1. The energy resolution of about 35 keV arises predominantly from the target thickness.

Typically,[6-9] (^{7}Li, p) reactions are compound-nuclear in nature, with 90°-symmetric angular distributions and total cross sections, σ_{tot}, proportional to $2J+1$, where J is the final-state spin.

The (^{7}Li, p) reaction thus provides an excellent method of looking for high-spin states, the population of which is usually forbidden in direct-transfer reactions. We have used this reaction to investigate ^{20}F. Only the essential results of the present experiment are given here. The details, with complete analysis, will be published elsewhere.

Values of σ_{tot}, obtained by integrating 21-point angular distributions, are plotted in Fig. 2 for all states (below 5 MeV) of known J^π (Ajzenberg-Selove,[4] Fortune and Bett,[10] Crozier and Fortune,[11] and references therein). A linear relationship between σ_{tot} and $2J+1$ is apparent, with slopes of 5.05 ± 0.08 μb for positive-parity states and 6.74 ± 0.20 μb for negative-parity states. Using these ratios, we find that the measured values of σ_{tot} for other states imply that several of them are excellent candidates for having high spin. These are the states at 2.87, 2.97, 3.59, 3.68, 4.51, 4.73, and 4.76 MeV and one, or both, members of doublets at 4.2, 4.6, and 4.9 MeV. Since a state at 2.97 MeV is already known[11] to have $J^\pi=3^+$, this "state" must also be a doublet, because of its very large value of σ_{tot}. The state at 4.51 MeV is new.

Results for these states, and for states of known J^π, are tabulated in Tables I and II. The quantities $\frac{1}{2}(\sigma_{tot}/5.05-1)$ and $\frac{1}{2}(\sigma_{tot}/6.74-1)$ should be equal to the spin for positive- and negative-parity states, respectively. For states of known J^π, the deviation is in no case larger than 0.3, perhaps indicating the reliability of this method for estimating probable spins. Of course, for higher spins a constant percentage deviation would imply a larger absolute deviation. These

TABLE I. Results for states below 5 MeV, of known J^π.

E_x(MeV)	J^π	σ_{TOT}(μb)	$\frac{\sigma_{TOT}}{2J+1}$($\mu$b) Pos.Par.	Neg.Par.	$1/2\left(\frac{\sigma_{TOT}}{5.05}-1\right)$	$1/2\left(\frac{\sigma_{TOT}}{6.74}-1\right)$
0.0	2^+	23.8	4.76	-	1.9	-
0.656	3^+	37.4	5.34	-	3.2	-
0.823	4^+	48.2	5.36	-	4.3	-
0.984	1^-	20.2	-	6.73	-	1.0
1.057	1^+	15.0	5.0	-	1.0	-
1.309	2^-	33.8	-	6.76	-	2.0
1.824 }	5^+	85.7 { [a] 53.3	4.85	-	4.8	-
1.843 }	2^-	32.4	-	6.48	-	1.9
1.971	(3^-)	48.9	-	6.99	-	3.1
2.044	2^+	24.5	4.90	-	1.9	-
2.195	3^+	35.4	5.06	-	3.0	-
3.488 }	1^+	19.6 { [a] 14.7	4.9	-	1.0	-
3.526 }	0^+	4.9	4.9	-	0.0	-

[a]Divided according to the known J^π values and the results of Fig. 2.

TABLE II. Results for states that are candidates for having high spin.

E_x (MeV)	σ_{TOT} (μb)	$1/2(\frac{\sigma_{TOT}}{5.05} - 1)$	$1/2(\frac{\sigma_{TOT}}{6.74} - 1)$	Restrictions on J^π	Most Likely J^π
2.87	40.7	3.5	2.5	$2^-, 3^\pm, 4^+$	3^-
2.97	103.6 68.2[a]	9.8 6.2[a]	7.2 4.6[a]	$4^-, 5^\pm, 6^+, 7^+$	4^-
3.59	47.6	4.2	3.0	$2^-, 3^\pm, 4^\pm, 5^+$	
3.68	58.6	5.3	3.8	$3^-, 4^\pm, 5^\pm, 6^+$	
4.51	63.8	5.8	4.2	$3^-, 4^-, 5^\pm, 6^+, 7^+$	
4.76	61.4	5.6	4.0	$3^-, 4^-, 5^\pm, 6^+$	
Doublets[b]					
4.20 4.21	130	11.9[b]	8.6[b]	one member has $J \geq 4^-$ or 5^+	
4.58 4.59	80	6.9	4.9		
4.89 4.90	54	4.4	3.0		

[a]After subtraction of contribution from a known 3^+ state.
[b]For doublets, third and fourth columns are $\frac{1}{2}(\sigma_{tot}/5.05-2)$ and $\frac{1}{2}(\sigma_{tot}/6.74-2)$, respectively.

results restrict the possible spins of the other states to the values listed, where we have accepted all spins lying within 1.3 units of the values listed in columns 3 and 4 of Table II.

Most of the known states below 5 MeV can be grouped[2] into four rotational bands, with $K^\pi = 2^+$ (g.s.), 1^+ (1.06 MeV), 1^- (0.98 MeV), and 2^- (1.31 MeV).

The energies of these states are plotted in Fig. 3, along with the predicted[2,3] energies for members of these four bands from recent shell-model calculations. The candidates for missing mem-

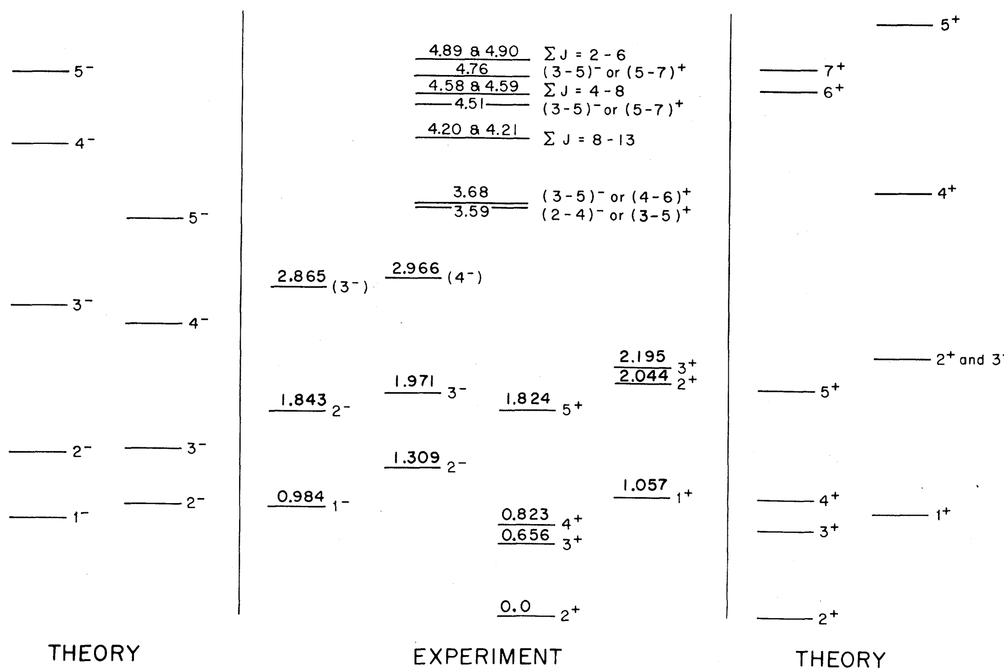

FIG. 3. Experimental and theoretical (Refs. 2 and 3) energy-level diagrams of ^{20}F. Experimental states in the center contain known and suspected members of the four low-lying rotational-like bands and the present high-spin candidates. Theoretical negative-parity states are shown on the left and positive-parity states on the right. At most two levels of any J^π are given.

bers of these bands are also plotted. Comparison of experiment with theory suggests that the 2.87-MeV state is likely the 3^- member of the 1^- band and that the new member of the 2.97-MeV doublet is likely the 4^- member of the 2^- band. The comparison also suggests that either the 3.59- or 3.68-MeV state is the 4^+ member of the 1^+ band, with perhaps a slight preference for the 3.59-MeV level.

Clearly, one or both members of the 4.20-MeV doublet have high spin. In any case, one member must have $J^\pi \geqslant 4^-$ or $\geqslant 5^+$. Thus a state here is a candidate for identification as the 4^- member of the 1^- band or the 5^- member of the 2^- band, or the 5^+ member of the 1^+ band or the 6^+ or 7^+ member of the 2^+ band. If one member is 4^-, the other is probably 5^-, 6^+, or 7^+, while if one is 5^-, the other is probably either 4^-, 4^+, 5^+, or 6^+. It is thus very likely that one of the members of this doublet is a 6^+ state.

The 4.51-MeV state appears to be a good candidate for the 4^- member of the 1^- band, or the 6^+ member of the g.s. band. One of the members of the 4.6-MeV doublet may be the 5^- member of the 2^- band, or the 5^+ member of the 1^+ band, or the 7^+ member of the g.s. band. If the 7^+ state is not contained in the 4.20-MeV doublet, then one of the 4.6-MeV states is the only other good candidate below 5 MeV. However, if the two 4.6-MeV states have comparable spins, then neither need be larger than 3. The 4.73- and 4.76-MeV states are candidates for either the 4^- member of the 1^- band, or the 5^+ member of the 1^+ band, or the 6^+ member of the g.s. band. If one of the 4.9-MeV states has low spin, the other might be the 5^+ member of the 1^+ band. Clearly, the γ decays of these levels must be studied in order to pin down their spins. But the present reaction provides a powerful tool for determining which states may have high spin.

†Work supported by the National Science Foundation.

*Present address: Center for Nuclear Studies, University of Texas, Austin, Tex. 78712.

[1]E. C. Halbert, J. B. McGrory, B. H. Wildenthal, and S. P. Pandya, in *Advances in Nuclear Physics*, edited by M. Baranger and E. Vogt (Plenum, New York, 1971), Vol. 4, p. 315.

[2]B. H. Wildenthal, private communication.

[3]J. B. McGrory and B. H. Wildenthal, Phys. Rev. C 7, 974 (1973).

[4]F. Ajzenberg-Selove, Nucl. Phys. A190, 1 (1972).

[5]R. R. Betts, H. T. Fortune, and R. Middleton, Phys. Rev. C 8, 660 (1973).

[6]R. R. Carlson and R. L. McGrath, Phys. Rev. Lett. 15, 173 (1965).

[7]J. L. Wiza, H. G. Bingham, and H. T. Fortune, Phys. Rev. C 7, 2175 (1973).

[8]F. Ajzenberg-Selove, H. G. Bingham, and J. D. Garrett, Nucl. Phys. A202, 152 (1973); J. D. Garrett, F. Ajzenberg-Selove, and H. G. Bingham, Phys. Rev. C 10, 1730 (1974).

[9]H. T. Fortune and H. G. Bingham, Phys. Rev. C 10, 2174 (1974).

[10]H. T. Fortune and R. R. Betts, Phys. Rev. C 10, 1292 (1974).

[11]D. J. Crozier and H. T. Fortune, Phys. Rev. C 10, 1697 (1974).

Superdense Matter: Neutrons or Asymptotically Free Quarks?

J. C. Collins and M. J. Perry
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge CB3 9EW, England

(Received 6 January 1975)

We note the following: The quark model implies that superdense matter (found in neutron-star cores, exploding black holes, and the early big-bang universe) consists of quarks rather than of hadrons. Bjorken scaling implies that the quarks interact weakly. An asymptotically free gauge theory allows realistic calculations taking full account of strong interactions.

There are several astrophysical and cosmological situations where one needs the equation of state for matter of densities greater than 10^{15} g cm^{-3}: in particular, the center of a neutron star,[1,2] the early phases of the big-bang universe,[3] and black-hole explosions.[4] However, such densities might at first sight appear to be outside the range of normal physics, so that nothing can