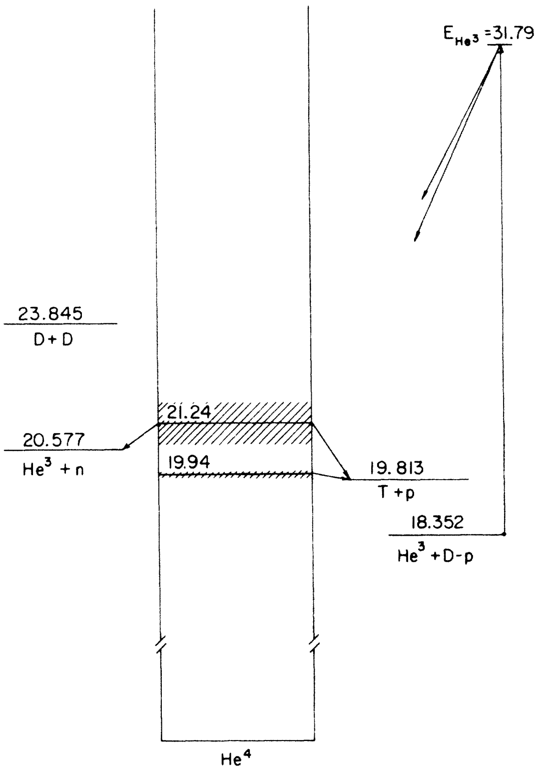

FIG. 3. Energy-level diagram of He^4.

proton emission and is presumably the same level that has been reported recently by a large number of groups.[1-6] The 21.24-MeV level does not appear to have been reported elsewhere; it is observed to decay by both proton emission and neutron emission. These results are summarized in the level diagram in Fig. 3. Further measurements are planned with the object of determining the spins of these levels from the angular correlation patterns of their decays.

It is a pleasure to express our appreciation to the operating crew of the Brookhaven 60-inch cyclotron, to Dr. C. P. Baker and Dr. H. E. Wegner for their help and cooperation on this experiment, and to Professor Č. Zupančič for many helpful discussions.

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[1] H. W. Lefevre, R. R. Borchers, and C. H. Poppe, Rev. 128, 1328 (1962).

[2] C. Werntz, Phys. Rev. 128, 1336 (1962).

[3] C. H. Poppe, C. H. Holbrow, and R. R. Borchers, Phys. Rev. 129, 733 (1963).

[4] N. Jarmie, M. G. Silbert, D. B. Smith, and J. S. Loos, Phys. Rev. 130, 1987 (1963).

[5] C. Werntz, Phys. Rev. 133, B19 (1964).

[6] P. G. Young and G. G. Ohlsen, Phys. Letters 8, 124 (1964); 11, 192(E) (1964).

[7] P. F. Donovan, J. V. Kane, J. F. Mollenauer, and P. D. Parker, Bull. Am. Phys. Soc. 9, 389 (1964).

[8] P. F. Donovan, J. V. Kane, J. F. Mollenauer, and P. D. Parker, Proceedings of the International Congress of Nuclear Physics, Paris, July 1964 (to be published).

[9] We are grateful to T. C. Madden of Bell Telephone Laboratories, Inc., for the fabrication of these detectors.

[10] V. Radeka, Brookhaven National Laboratory Report No. BNL 7448, 1963 (unpublished).

[11] For a detailed discussion of the kinematics of multiparticle reactions see Č. Zupančič, Nuklearni Institut Jozef Stefan Report No. R-429, 1964 (to be published).

[12] P. D. Parker, P. F. Donovan, J. V. Kane, and J. F. Mollenauer, to be published.

[13] Č. Zupančič, Gatlinburg Conference on Two-Particle Correlations in Nuclear Reactions, 1964 (to be published).

[14] W. E. Meyerhof, Gatlinburg Conference on Two-Particle Correlations in Nuclear Reactions, 1964 (to be published).

HYPERNUCLEAR SPECTROSCOPY, UNITARY SYMMETRY, AND POSSIBLE ANALOG STATES*

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The application of unitary symmetry to multibaryon states such as complex nuclei and hypernuclei is not straightforward because of the following two difficulties: (1) Severe symmetry-breaking effects can be expected[1,2] from the π-K and Σ-Λ mass differences. Nuclear binding forces of the meson-exchange type can be expected to change appreciably with the type of meson being exchanged. Furthermore, the hypernuclear states of strangeness -1 which belong in a given SU(3) multiplet contain a mixture of Λ and Σ. Since the Σ-Λ mass difference is an order of magnitude larger than the binding energy per baryon in a nucleus, the observable hypernuclear states contain only Λ's and are therefore mixtures of states from different

SU(3) multiplets. (2) Even under the assumption of pure unitary symmetry, the ground state of a hypernucleus of mass greater than 4 will not belong to the same SU(3) multiplet as any nucleus or nucleon system.

This second point is illustrated by the simple example of the two-baryon system. The states can be classified into the SU(3) multiplets arising in the coupling of two octets: $\underline{1}$, $\underline{8}$, $\underline{8}'$, $\underline{10}^*$, and $\underline{27}$. The two-nucleon state $(Y=+2)$ can only be in the $\underline{10}^*$ and $\underline{27}$, corresponding to states of $T=0$ and $T=1$, respectively. The Λ-N system $(Y=+1, T=\frac{1}{2})$ can be either in an $\underline{8}$ or $\underline{10}^*$, while the Σ-N system has also the possibility $(Y=+1, T=\frac{3}{2})$ which can be in a $\underline{10}$ or $\underline{27}$. Hyperon-nucleon systems can thus be in $\underline{8}$ or $\underline{10}$ multiplets which have no $Y=+2$ state and therefore do not contain any two-nucleon states. If a hyperon-nucleon resonance is found, it is not clear a priori whether it belongs in a $\underline{10}^*$ or $\underline{27}$ multiplet which contains a two-nucleon state, or in an $\underline{8}$ or $\underline{10}$ which cannot contain a two-nucleon state.

For systems of more than four baryons, it is clear that the ground state of a hypernucleus of strangeness -1 must be in a multiplet which does not contain a state of zero strangeness. The ground state of the hypernucleus will be one in which the Λ is in the lowest possible orbit, namely, the $1s$ orbit which is already occupied by four nucleons. Since this state has five baryons in the $1s$ orbit, it has a permutation symmetry which is not allowed for a system containing only nucleons. It must belong to an SU(3) multiplet containing no nucleon states, analogous to the $\underline{8}$ and $\underline{10}$ for the two-nucleon system.

The purpose of this Letter is to point out a possible significance for the hypernuclear states that would be formally classified in the same SU(3) multiplet as the ground states of stable nuclei.[3] These states can be considered as "SU(3) analog states" similar to the isobaric analog states which have recently been excited in nuclear experiments.[4] Such a state might be excited in reactions of the type

$$K^- + (Z,A) \to \pi^- + {}_{\Lambda}(Z,A). \tag{1}$$

The experiment should be designated for minimum momentum transfer to the nucleus to give the optimum probability for producing a state in which all the nucleons are in the same orbits as in the initial state but one nucleon has been transformed into a hyperon. If SU(3) symmetry were exactly valid, the analog state produced in Reaction (1) would be stable against particle emission. Although it is not the ground state of the hypernucleus and is in fact a highly excited state, it belongs to the same SU(3) multiplet as the target nucleus. It is therefore the lowest state of that particular SU(3) symmetry in the hypernucleus. Since all lower states have different SU(3) symmetry, the decay of the analog state is forbidden by SU(3). Because of symmetry breaking, one would expect the analog state not to be stable but to decay relatively rapidly. However, unless this decay is extremely rapid it should be observable as a bump in the spectrum of the outgoing pions in Reaction (1).

One can also consider the SU(3) analog state from a somewhat different point of view, without assuming unitary symmetry. A Λ in a complex nucleus should be described to some approximation as moving in an optical potential similar to that used for nucleons. Although the strengths of the optical potentials may be considerably different for a nucleon and a Λ, the general shapes should be similar, since they are determined primarily by the density distribution of nuclear matter. The wave functions for the nodeless single-particle states should also be similar, since they are spherical harmonics multiplied by a radial function whose general shape is not highly dependent on the strength of the potential. Thus changing a neutron in a nucleus into a Λ without changing its wave function might well produce a state having a reasonable overlap with the correct optical-model wave function for the Λ. Such states should then be seen in a reaction of the type (1), with a width similar to those of comparable single-nucleon giant resonances.

The preceding argument does not assume any symmetry, and would lead to the existence of many states, each corresponding to a neutron in a different shell being transformed into a Λ. One can now ask to what extent these states are degenerate; i.e., how does the energy required to change a neutron into a Λ depend upon the shell in which the transformation takes place? If there is an appreciable degeneracy, then there can be created in Reaction (1) states which are coherent linear combinations of states each having a Λ replacing a neutron in a different orbit of the target nucleus. The cross section for the production of such a coherent state should be enhanced by a factor of the order of the number of contributing states. The extreme assumption of perfect unitary symmetry implies an equivalence of nucleons and hyperons such that it costs the same energy to change a neutron to a Λ in any orbit. The SU(3) multiplets contain coherent linear combinations of all these states and also include states in which a nucleon is transformed into a Σ as well. Because of symmetry breaking, the Σ component of the SU(3) analog state must clearly be rejected in view of the large Σ-Λ mass difference, while the Λ component of the SU(3) state must be split by the difference between Λ-nucleon and nucleon-nucleon interactions. However, some coherence and enhancement may still remain if there are groups of states which are approximately degenerate. One should then expect to see some kind of a peak, possibly with some structure, in the pion spectrum at low momentum transfer in Reaction (1). The observed cross section should be smaller and the observed width greater than that predicted from pure SU(3) symmetry.

Another reaction which might be of interest is

$$K^- + (Z,A) \to \pi^+ + \pi^- + {}_{\Lambda}(Z-1,A). \qquad (2)$$

This reaction has two outgoing charged particles which can be measured. This is analogous to the $(p,2p)$ experiments for probing nuclear structure.[5] The advantage of this type of reaction is that the angles and energies of the outgoing pions can be set at values corresponding to zero momentum transfer to the residual nucleus.

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[1] R. H. Dalitz, Proceedings of the Athens Topical Conference on Recently Discovered Resonant Particles, Athens, Ohio, 1963 (unpublished), p. 234.

[2] A. Deloff and H. H. Wyld, Phys. Letters 12, 245 (1964).

[3] Such states have been examined by R. J. Oakes, Phys. Rev. 131, 2239 (1963); V. I. Ogievetskij and H. Ting-Chang, Phys. Letters 9, 354 (1964); Y. Tomozawa, Phys. Rev. Letters 13, 512 (1964).

[4] J. B. French, Argonne National Laboratory Report No. ANL-6878, 1964 (unpublished), p. 181.

[5] H. Tyren, P. Hillman, and Th. A. J. Maris, Nucl. Phys. 7, 10 (1958); H. J. Lipkin, Argonne National Laboratory Report No. ANL-6878, 1964 (unpublished), p. 481.

NEW APPROACH TO THE DETECTION OF SOLAR NEUTRINOS VIA INVERSE BETA DECAY[*]

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Theoretical calculations for the energy generation processes in the sun predict[1] the production of B^8 in such quantities that a neutrino flux at earth of $(2.5\pm1)10^7\ \nu_e/\mathrm{cm}^2$ sec and end point of 14.06 MeV results from beta decay of this nuclide. It is of great interest to check this prediction since it relates to the entire theoretical picture of the sun's deep interior condition. To date, two methods of detection have been suggested, that of Davis[2] which employs a radiochemical technique to observe inverse beta decay of Cl^{37}, and the direct counting approach of Reines and Kropp[3] in which it is proposed to detect the recoil electron from elastically scattered solar neutrinos. The point of this communication is to discuss yet another approach to the problem, using inverse beta decay.

It is desirable to measure the neutrino spectrum and the direction from which the signals emanate in order to label separately the source and the responsible reaction. The radiochemical approach is limited in that it gives the response averaged over a spectrum and with a time constant determined by the half-life of the product nucleus. Also in the radiochemical approach the direct association with the sun can only be made by use of the 7% annual inverse-square variation of intensity. The elastic-scattering experiment, although capable of fairly precise[4] (~15°) directional and energy determination (e.g., by using a multiplate spark