Possible Evidence for the Existence of Strangeness Analog States*

J. P. Schiffer
Argonne National Laboratory, Argonne, Illinois 60439, and University of Chicago, Chicago, Illinois 60637

and

H. J. Lipkin†
Argonne National Laboratory, Argonne, Illinois 60439, and
Fermi National Accelerator Laboratory, Batavia, Illinois 60510
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Evidence supporting the validity of a simple symmetry in hypernuclei, suggested ten years ago, is found in recently published data on ${}_{\Lambda}{}^{9}\mathrm{Be}$, ${}_{\Lambda}{}^{12}\mathrm{C}$, and ${}_{\Lambda}{}^{16}\mathrm{O}$.

The suggestion of the existence of strangeness analog resonances (SAR's) was made some time ago,[1] and has been discussed repeatedly in the literature.[2] Such a state, or resonance, in a hypernucleus would have the same wave function and symmetry as a (ground) state of a normal nucleus. A Λ replaces one neutron, averaged over all occupied neutron orbits, in the same way as in the isobaric analog resonances[3] a proton replaces a neutron in neutron-excess orbits. For ${}^{16}\mathrm{O}$ such a wave function is shown schematically in Fig. 1.

Although the Λ-N and N-N interactions are different from one another, Λ-nucleus and N-nucleus interactions are both expected to be described by potential wells having the same general shape determined by the size of the nucleus. The wells will differ only in depth; the nucleon potential is deeper than the Λ well. The energy required to transform a nucleon into a Λ in the same orbit would be approximately equal to the difference in the well depths, and should not depend very much on the individual orbits. The different components in the SAR state thus all have nearly the same single-particle excitation energies.

More recently it has been suggested[4] that the Λ-nucleus and N-nucleus interactions cannot be described in terms of simple local wells, and that the energy required to transform an s-shell nucleon into a Λ might be considerably greater than that required for a p-shell nucleon. In this case the SAR state in p-shell nuclei would split into two states having a nucleon hole and a Λ in the s shell and p shell, respectively. However, there have been no experimental measurements of the energy required to transform s- and p-shell nucleons into Λ's, and therefore no conclusive tests of this question. This is, of course, relevant to whether the SAR configuration is confined to a single, well-defined resonance or is split or smeared over a wide energy interval. The estimates of energies required to transform nucleons into Λ's have been computed indirectly from other measured and estimated parameters, e.g., single-particle energies from $(e,e'p)$ or $(p,2p)$ experiments (where rearrangement energies are never completely understood) and binding energies of the ground states of hypernuclei. The purpose of this note is to point out that data now exist to give a direct experimental test of the SAR hypothesis. The results in ${}^{9}_{\Lambda}\mathrm{Be}$, ${}^{12}_{\Lambda}\mathrm{C}$, and ${}^{16}_{\Lambda}\mathrm{O}$ are, in fact, consistent with the original suggestion of a simple analog resonance.

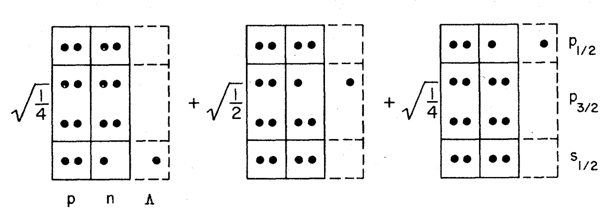

FIG. 1. Schematic representation of the strangeness analog resonance in ${}_{\Lambda}{}^{16}\mathrm{O}$, corresponding to the ground state of ${}^{16}\mathrm{O}$.

The strangeness-exchange (K^-,π^-) reaction was studied by Brückner *et al.*[5] under conditions of near-zero momentum transfer on ${}^{9}\mathrm{Be}$, ${}^{12}\mathrm{C}$, and ${}^{16}\mathrm{O}$. This reaction should populate the SAR configuration selectively over all other possibly hypernuclear configurations, just as the (p,n) reaction selectively populates the isobaric analog resonance. Brückner *et al.*, however, have interpreted their data in terms of the strangeness-symmetry-breaking concepts of Ref. 4, assigning particular particle-hole components to bumps in the spectrum. It is the purpose of this note to point out that the principal structures observed in ${}^{9}_{\Lambda}$Be, ${}^{12}_{\Lambda}$C, and ${}^{16}_{\Lambda}$O are consistent with the original simple suggestion of an analog resonance.

In Ref. 5 the expectation for systematics of SAR energies in the various nuclei is not discussed. In fact, for the concept to be valid a very specific behavior in energy is expected, in close analogy with the isobaric analog states. In the case of the isobaric analog resonances, the effect became apparent when spectra from (p,n) reactions were studied and a prominent final state was seen corresponding to an energy loss or Q value which was the Coulomb energy: the energy required to replace a neutron by a proton, with the nuclear configuration unchanged.[3] This Q value changed as $Z/A^{1/3}$ throughout the periodic table; it is nonzero because of the Coulomb interaction that breaks the isospin symmetry.

The strangeness symmetry is broken by the difference in the Λ-nucleus and N-nucleus potentials. Unlike the Coulomb energy this difference has its origin in short-range forces and thus should be roughly constant in different nuclei. The relevant energies to compare then are those for replacing a neutron by a Λ, or the (Λ,n) Q values. The SAR's would be expected to occur at about the same, constant Q value throughout the periodic table. In Ref. 5 the (K^-,π^-) spectra are plotted against B_Λ, the binding energy of the Λ, and against the excitation energy of the hypernucleus. The smooth curves drawn through the spectra of Ref. 5 are reproduced in Fig. 2(a), plotted as a function of binding energy. In Fig. 2(b) the same data are replotted as a function of the relevant (Λ,n) Q value. It is quite clear that in the lower plot the most prominent peak in each spectrum occurs at nearly the same Q value: about -21 MeV. [The (K^-,π^-) Q value differs from this by a constant, and would be an equally useful energy scale.]

The case of ${}^{9}_{\Lambda}$Be is slightly different in that ^{9}Be has isospin $T=\frac{1}{2}$ and thus its SAR could be broadened, or even split into $T=0$ and $T=i$ components; the centroid should be unaffected. The slight difference seen in Fig. 2(b) between ^{9}Be on the one hand and ^{12}C and ^{16}O on the other may have its origin in such an effect. This broadening is again a function of the difference between the N-N and Λ-N effective interactions and for ^{9}Be should, at most, be on the order of 2–3 MeV.

We thus wish to point out that the most recent experimental data on excited hypernuclear states seem consistent with the simple symmetry predicted ten years ago. The states are, in fact,

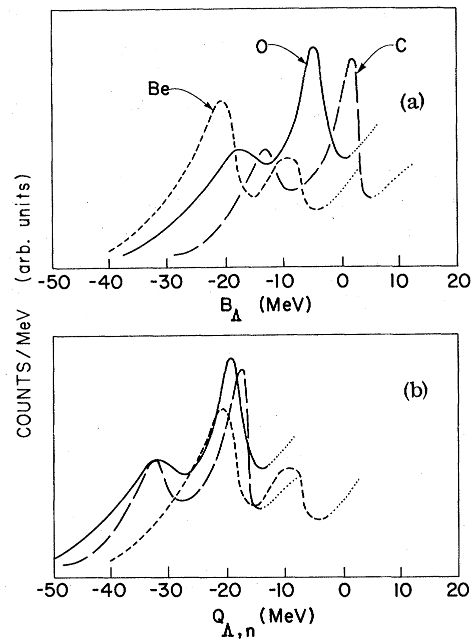

FIG. 2. (a) Smooth curves drawn through the data in Ref. 5 for π^- spectra (counts/MeV in arbitrary relative units) from low-momentum-transfer (K^-,π^-) reactions as a function of the binding of the Λ. (b) The same data plotted against the (Λ,n) Q value. The rise on the right-hand side is from the $K^- \rightarrow 2\pi$ process.

seen in the low-momentum-transfer, strangeness-changing reaction, as was the original expectation. Similar experiments on heavier nuclei would be of interest, to see whether a peak occurs at about the same Q value throughout the periodic table. Clearly much work still remains to be done before the matter will be unambiguous, but the experimental developments of the last few months are encouraging.

The evidence for subsidiary peaks at higher excitation energy (more negative Q value) in ${}^{12}_{\Lambda}$C and ${}^{16}_{\Lambda}$O appears to be barely on the edge of statistical significance; the subsidiary peak at lower excitation energies in ${}^{9}_{\Lambda}$Be seems somewhat better established. It is premature to speculate whether such effects may be related to isospin, as mentioned above, to other possible fragmentation of the SAR configuration, or to more complicated processes in the reaction mechanism such as are certainly seen in charge-exchange reactions. One might think that SAR's based on collective states of the parent nucleus might be excited, or states of lower symmetry quantum number closely related to the parent state (e.g., antianalogs). In this note we have restricted our discussion to the strongest, statistically well established peak in each spectrum; the understanding of possible subsidiary structures must await better data.

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†On leave from Weizmann Institute of Science, Rehovot, Israel.

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Gamma Decay of the 9.042- and 9.805-MeV States in ^{23}Na†

G. J. KeKelis, A. H. Lumpkin, and J. D. Fox
Department of Physics, The Florida State University, Tallahassee, Florida 32306
(Received 24 June 1975)

^{12}C(^{12}C,$p\gamma$)^{23}Na proton-γ angular correlations were measured at $E_B = 38.82$ MeV for the 9.042- and 9.805-MeV states in ^{23}Na which decay to levels at 7.270, 6.235, and 5.534 MeV with branching ratios of 20%, 60%, and 20%, respectively, for the 9.042-MeV state, and 30%, 50%, and 20%, respectively, for the 9.805-MeV state. Angular correlations and lifetime data eliminate $\frac{17}{2}$ assignments for either state.

The 9.042- and 9.805-MeV states in ^{23}Na have recently been shown to be populated with unusual strength at a number of resonant energies in the reaction ^{12}C(^{12}C,p)^{23}Na.[1] It has been suggested that these two states are the $\frac{15}{2}^+$ and $\frac{17}{2}^+$ members of the ground-state rotational band in ^{23}Na.[2] Verification of these assignments would help to clarify both the nature of the resonance phenomena which favors their formation and the nuclear structure of ^{23}Na. If these are high-spin states, they should show γ decay, even though they are unbound to proton emission. A proton escaping from a state at this excitation energy in ^{23}Na can only go to the ground state of ^{22}Ne. Such a decay from a $\frac{15}{2}$ state in ^{23}Na would therefore require $7\hbar$ units of orbital angular momentum to be associated with the proton emission, and the centrifugal barrier associated with this angular momentum, in combination with the Coulomb barrier, greatly hinders proton emission.

In order to study the details of the γ decay of the 9.042- and 9.805-MeV states, a ^{12}C(^{12}C,$p\gamma$)^{23}Na particle-γ angular-correlation experiment has been performed at an incident ^{12}C beam energy of 38.82 MeV. The ^{12}C beam was obtained from the Florida State University super FN tandem Van de Graaff accelerator with an inverted sputter source.[3] The beam entered a particle-γ angular-correlation chamber and after bombarding a 60-μg-cm^2 carbon target was stopped in a gold foil. The protons were detected at zero degrees to the beam by ΔE-E solid-state counters which subtended a solid angle of 50 msr with an angular acceptance of $\pm 7°$. Proton-γ angular correlations were determined from γ-ray spectra obtained at angles of 54°, 70°, 90°, 144°, and 160° to the beam. The γ rays were detected by three Ge(Li) detectors. Coincidence events between γ rays and protons were identified by time gates in an on-line computer. Coincidences were accumulated in a four-parameter list mode and stored on magnetic tape for subsequent playback and analysis.

Included in this experiment were states from 2.0 to 16.0 MeV excitation in ^{23}Na. The resultant γ-ray spectrum, gated on the 9.805-MeV state in ^{23}Na taken at 160° to the beam, is shown in Fig. 1. Doppler-broadening effects were observed in