MESIC DECAY OF HYPERFRAGMENTS

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(presented by E. C. G. Sudarshan)

This note states the principal results of a systematic investigation on the theory of hyperfragments which were not included in earlier publications[1]. We use the same model, namely one in which the ground state involves the unexcited nuclear configuration and the Λ hyperon is in the s-state. The wave functions are written out in j-j coupling scheme and the radial integrals are treated as phenomenological parameters in discussing the hyperfragment decay branching ratios. The repeated use of the Wigner-Eckart theorem and Racah algebra enables us to express all the decay matrix elements in terms of the phenomenological radial parameters of the model (which are determined from observed ratios) and the elementary amplitudes for free Λ decay. In the two- and three-body mesic decay modes one has to classify the outgoing pion wave in terms of its angular momenta with respect to the nucleus; in connection with this classification it is convenient to call those terms arising from the s-wave and p-wave terms for free Λ decay as " direct " and " derivative " terms. We restrict ourselves to a simplified model in which only pure nuclear configurations are involved, but for three-body mesic decays we distinguish between non-resonant channels and resonant channels. The latter is treated by a method analogous to that used for treating two successive radiations from an excited nucleus[2].

Let us first consider charged mesic modes. By a direct calculation we find that the two-body mesic decay ${}_{\Lambda}B^{11} \to C^{11} + \pi^-$ is allowed only for a spin $^5/_2$ for the hyperfragment and would thus favor antiparallel spin coupling for $p^3/_2$-shell hyperfragments. Similarly, the decay ${}_{\Lambda}C^{14} \to N^{14} + \pi^-$ is forbidden for decay into the first excited state of spin 0 of N^{14} and hence if antiparallel spin coupling is favored in $p\frac{1}{2}$-shell hyperfragments, this decay must not be observed.

More detailed experimental information is available for the s-shell hyperfragments. If ${}_{\Lambda}He^4$ has spin 1 we will expect polarized hyperfragments from kaon absorption in flight in helium; for completely polarized ${}_{\Lambda}He^4$ the degree of alignment of the momentum of the neutral pion from the decay ${}_{\Lambda}He^4 \to He^4 + \pi^0$ is about 70%. For the three-body mesic decays of ${}_{\Lambda}H^3$ and ${}_{\Lambda}H^4$ no appreciable final state interaction is expected between the s-wave nucleons and the residual nucleus; accordingly if for ${}_{\Lambda}H^4$ $J=0$ or $J=1$ only the " direct " or " derivative " term will contribute. The ratio of the appropriate radial parameters for the two- and three-body mesic decays for ${}_{\Lambda}H^4$ is determined from the experimental branching ratio $({}_{\Lambda}H^4 \to He^4 + \pi^-)/({}_{\Lambda}H^4 \to H^3 + p + \pi^-)$ which is known[3] to be $^{19}/_5$. Assuming the same ratio of the radial parameters for ${}_{\Lambda}H^3$ decay we predict the ratio $({}_{\Lambda}H^3 \to He^3 + \pi^-)/({}_{\Lambda}H^3 \to d + p + \pi^-)$ to be 1 or $^1/_4$ depending upon the spin of ${}_{\Lambda}H^3$ being $^1/_2$ or $^3/_2$ respectively. The experimental [3] ratio of $^4/_1$ (from 5 events !) favors antiparallel spin for s-shell hyperfragments. If we accept this result, we can again conclude from the charge independence of N-Λ forces, that the spin of ${}_{\Lambda}He^4$ is zero and hence from the observed reaction $K^- + He^4 \to He^4 + \pi^-$ that the kaon is pseudoscalar.

The decay ${}_{\Lambda}He^5 \to He^4 + p + \pi^-$ proceeds through two resonant channels ($p_{3/2}$ and $p_{1/2}$) and their branching ratio is $^{54}/_{18} = {}^3/_1$ which gives the fraction of p-wave decay rate for free Λ decay to be

$$p^2/(s^2+p^2) \simeq 0.4$$

which is to be compared with the result

$$0.2 \leq p^2/(s^2+p^2) \leq 0.8$$

obtained by Dalitz and Liu from the up-down asymmetry in free Λ-decay[6]. If we accept the value 0.4 (obtained here from ${}_{\Lambda}He^5$ decay), the calculation of Dalitz and Liu for the ratio of two-body mesic decays to all mesic decays of ${}_{\Lambda}H^4$ definitely gives again spin 0 for this hyperfragment; thus it supports anti-parallel-spin-favored configurations and, consequently, odd kaon parity.

Now for the isotopic spin rules : if we assume that the ratio of the direct and derivative terms is the same for charged and neutral pion decay modes, it follows that in the approximation of neglecting final state pion interactions the decay branching ratios for the charged and neutral modes will depend on the ${}^2/_1$ ratio in free Λ decay and cannot distinguish between the $\Delta I = \frac{1}{2}$ rule and the mixture of $\Delta I = \frac{1}{2}$ and $\Delta I = {}^3/_2$ which gives the ${}^2/_1$ ratio[7]. More detailed experimental data on branching ratios are needed to analyze the results if one treats the ratio of direct to derivative terms to be different for the charged and neutral decay modes of the free Λ decay. The pseudoscalar parameter in the decay $\Lambda \rightarrow n + \pi^0$ is known only poorly and in any case this does not determine $p^2/(s^2+p^2)$ uniquely. More experimental data is needed on the decay data for s-shell and p-shell hyperfragments, especially for neutral mesic modes for more definitive predictions.

LIST OF REFERENCES AND NOTES

1. Iwao, S. and Sudarshan, E. C. G. Phys. Rev. Letters **4**, p. 140 (1960). Iwao, S. " A theory of hyperfragments ", Nuovo Cimento (in press). Sudarshan, E. C. G. and Iwao, S. " A model of hyperfragments ", Proc. Ind. Acad. (in press).
2. Biedenharn, L. C. and Rose, M. E. Rev. Mod. Phys. **25**, p. 729 (1953).
3. Ammar, R. et al. Nuovo Cimento **15**, p. 181 (1960).
4. Block, M. M. et al. Phys. Rev. Letters **3**, p. 291 (1959).
5. Ammar, R. et al. Nuovo Cimento **13**, p. 1156 (1959).
6. Dalitz, R. H. and Liu, L. Phys. Rev. **116**, p. 1312 (1959).
7. Okubo, S., Marshak, R. E. and Sudarshan, E. C. G. Phys. Rev. **113**, p. 944 (1959).

DISCUSSION

MILLER : I would like to ask whether your calculation includes automatically three-body effects or have these been neglected?

SUDARSHAN : The three-body effects are taken account of in a very peculiar fashion by the simple artifice of saying that we have a nuclear shell model. The major part of the three-body forces are taken into account when we form the individual particle shells; so this is similar to the ordinary nuclear shell model where the three-body forces are important between the bare nucleons, but are taken into account once you have considered the individual particle orbits. Therefore, to the extent that we have taken into account the shells we should not further include the three-body forces. If everything is consistent there should be no large corrections and we should be able to fit observed binding energies with the minimum number of parameters that we have used. This we have done. As a check we have tried to analyze the ordinary nuclear binding energies for low atomic numbers with this model (throwing out a couple of nuclei which we know are very loosely bound), and if we throw these out we get an excellent fit, better than in the higher shells and therefore I think the assumption is consistent although we have no way of testing it directly.