CONF-8805142--48

DE89 005836

HYPERNUCLEAR INTERACTIONS AND THE BINDING ENERGIES OF Λ AND ΛΛ HYPERNUCLEI

A. R. Bodmer

Department of Physics, University of Illinois at Chicago, Chicago, IL 60680 and Physics Division, Argonne National Laboratory, Argonne, IL 60439-4843 USA

and

Q. N. Usmani

Department of Physics, Jamia Millia, New Delhi, India and Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801 USA

ABSTRACT

By use of variational calculations a reasonable hadronic description is obtained of the s-shell hypernuclei, of ${}^{9}_{\Lambda}$Be, and of the well depth, with ΛN forces which are consistent with Λp scattering and which are quite strongly spin-dependent, with reasonable TPE ΛNN forces and with strongly repulsive dispersive-type ΛNN forces. For the latter we also consider a spin-dependent version which is somewhat favored by our analysis. ${}^{9}_{\Lambda}$Be is treated as a $2\alpha+\Lambda$ system and is significantly overbound, ≃1 MeV, if only $\alpha\alpha$ and $\alpha\Lambda$ potentials are used. An $\alpha\alpha\Lambda$ potential obtained from the ΛNN forces nicely accounts for this overbinding. The ΛΛ hypernuclei ${}^{6}_{\Lambda\Lambda}$He and ${}^{10}_{\Lambda\Lambda}$Be are treated as $\alpha+2\Lambda$ and $2\alpha+2\Lambda$ systems. Use of the ${}^{10}_{\Lambda\Lambda}$Be event gives ≃1.5 MeV too little binding for ${}^{6}_{\Lambda\Lambda}$He. The ${}^{1}S_{0}$ ΛΛ potential obtained from ${}^{10}_{\Lambda\Lambda}$Be is quite strongly attractive, comparable to the ΛN and also to the NN potential without OPE.

INTRODUCTION

We review our recent work on the calculation of binding energies of Λ and ΛΛ hypernuclei using reasonable ΛN, ΛNN and ΛΛ interactions. Reasonable here means to be generally consistent with meson-exchange models. Effects of baryon quark structure are assumed to be short-range and capable of parameterization in the conventional way through repulsive cores and cutoffs. The aim is to learn about these interactions and in particular whether such a hadronic approach is adequate or whether more explicit quark effects must be invoked. An essential element in our approach is the use of 3-body ΛNN forces considered to be the result of eliminating Σ, Δ, ... degrees of freedom (from a coupled channel approach which includes these and which represents a more sophisticated level of phenomenology) to obtain a reduced description in terms of only Λ and nucleon degrees of freedom. We consider phenomenological ΛNN forces both of "dispersive" and two-pion-exchange (TPE) type. A new feature of our dispersive ΛNN forces is that we not only consider spin independent forces but also spin dependent forces, depending on the nucleon spins, which are suggested by the suppression mechanism due to ΛN-ΣN coupling. The ΛN and ΛNN forces we use are central and so mostly are our NN forces. We have studied the following systems.

1. Λp scattering, the s-shell hypernuclei ($A \lesssim 5$) including the excited state of the A=4 hypernuclei, and also the Λ binding in nuclear matter ($A=\infty$), i.e. the Λ well depth $D \simeq 30$ MeV.[1]
2. The α-cluster hypernuclei ${}^{9}_{\Lambda}$Be(2α+Λ), ${}^{6}_{\Lambda\Lambda}$He(α+2Λ) and ${}^{10}_{\Lambda\Lambda}$Be(2α+2Λ) together with the α-Λ system ${}^{5}_{\Lambda}$He which is used to determine the αΛ potential.[2] The α is considered as an "elementary" constituents for these systems.

For the few-body systems (s-shell hypernuclei and α-cluster hypernuclei) we use well developed variational (MC) methods;[3] D is calculated variationally with the Fermi hypernetted chain method.[4] The needed extensions are discussed in Refs. 1 and 2.

ΛN POTENTIAL AND Λp SCATTERING

We use a central Urbana-type ΛN potential[5] $V_{\Lambda N}=V_c-V_{2\pi}$ where V_c is a repulsive core close to that for the NN potential and where $V_{2\pi}$ has a TPE (square of the OPE tensor potential) shape involving the (attractive) singlet and triplet strengths as adjustable parameters, or equivalently the spin-average strength $\bar{V}=1/4V_s+3/4V_t$ and the spin-dependent strength $V_\sigma=V_s-V_t>0$. The low-energy Λp scattering data (average over the singlet and triplet states) determines $\bar{V}^{\Lambda p}$ for Λp scattering quite well but V_σ only very poorly. The charge symmetric strength $\bar{V}$ (average over Λn and Λp) can then be determined from $\bar{V}^{\Lambda p}$ using the CSB interaction determined from the A=4 hypernuclei.[6] $\bar{V}$ is essentially the only ΛN strength relevant for hypernuclei with core nuclei having zero spin, i.e. ${}^{5}_{\Lambda}$He, ${}^{9}_{\Lambda}$Be and D. With only ΛN forces one then has the well known problem of overbinding: thus for B_Λ

(experimental) vs. B_Λ (calculated) one has in MeV: 3.1 vs. $\simeq$ 6($^5_\Lambda$He), 6.7 vs. $\simeq$ 12($^9_\Lambda$Be), 11.7 vs. $\simeq$ 2[illegible]($^{13}_\Lambda$C) and 30 vs. $\simeq$ 60(D).

ΛNN POTENTIALS

For a reasonable phenomenology which accounts for this overbinding we include ΛNN forces, assumed to arise mostly from coupling of the ΛN to the ΣN channel, which when eliminated will give many-body ΛNN, etc. forces. An alternate approach is to explicitly include the ΣN channel. However, except for lowest order G matrix calculations of D, this has not been adequately implemented within a variational framework either for A$\lesssim$5 or for D.

We consider both dispersive ΛNN forces, of the form used in Ref. 7 for NNN forces, and two-pion exchange (TPE) ΛNN forces.[8] Both arise from elimination of the ΣN channel, with the former, which are repulsive, assumed to arise mostly from medium suppression of the ΣN channel in the TPE ΛN interaction. For the dispersive-type forces we consider two types: $V^D_{\Lambda NN}$ which is spin-independent, and $V^{DS}_{\Lambda NN}$ which has a novel spin-dependence suggested by a spin-dependence of the ΛN-ΣN suppression mechanism where this operates in the triplet but not in the singlet ΛN channel.[9] (Thus, $V^{DS}_{\Lambda NN} = V^D_{\Lambda NN}\,[1 + 1/6\ \vec{\sigma}_\Lambda \cdot (\vec{\sigma}_1 + \vec{\sigma}_2)]$, where 1 and 2 label the two nucleons.) $V^D_{\Lambda NN}$ and $V^{DS}_{\Lambda NN}$ are completely equivalent when the core nuclei have zero spin, in particular for $^5_\Lambda$He, $^9_\Lambda$Be and D, but differ for A$\lesssim$4. The TPE ΛNN potential $V^{2\pi}_{\Lambda NN}$ is spin-independent but angle-dependent and its effect is quite sensitive to appropriate ΛNN correlations for A$\lesssim$5 which can result in an overall attractive contribution of $V^{2\pi}_{\Lambda NN}$ for the s-shell hypernuclei.[1]

INTERACTIONS FROM THE s-SHELL HYPERNUCLEI AND D

We very briefly summarize, together with appropriate caveats, the main conclusions obtained from Λp scattering, the s-shell hypernuclei and D.[1] Overall, we obtain a satisfactory description of all these systems.

1. Our ΛN potential is consistent with Λp scattering and the CSB interaction as determined from A=4.
2. The s-shell hypernuclei require TPE ΛNN forces whose strength is consistent with theoretical expectation.[8] In particular, these forces cannot account for the overbinding of $^5_\Lambda$He and give only a relatively small reduction in D.

3. Strongly repulsive dispersive ΛNN forces are required, essentially to account for the overbinding obtained with only ΛN forces. For ${}^{5}_{\Lambda}$He ΛN tensor forces could possibly significantly reduce the overbinding;[10] however, for A>5, in particular for D, this seems quite unlikely.[11]
4. The spin-dependent ΛNN potential $V^{DS}_{\Lambda NN}$ is somewhat preferred by our analysis when all systems (A≲5 and D) are considered.
5. We obtain an appreciable spin-dependence V_σ for the ΛN potential, the magnitude of which depends on whether or not a spin-dependence is included in the dispersive ΛNN potential.

The ΛN spin-dependence is rather directly related to the observed splitting ≃1 MeV between the ground 0^+ and the excited (spin flip) 1^+ state of ${}^{4}_{\Lambda}$H, ${}^{4}_{\Lambda}$He. With $V^{D}_{\Lambda NN}$, i.e. no ΛNN spin-dependence, this splitting is essentially determined entirely by the ΛN spin-dependence, whereas with $V^{DS}_{\Lambda NN}$, i.e. with a ΛNN spin-dependence, ≃1/3 of this splitting is due to $V^{DS}_{\Lambda NN}$, leading to a reduced ΛN spin-dependence. The effect of the ΛNN spin-dependence is consistent with a larger ΛN-ΣN suppression (more repulsion) in the triplet than in the singlet state since the former is more heavily weighted in the 1^+ than in the 0^+ state.[9] Our ΛNN spin dependence should be considered as a phenomenological representation of this differential suppression effect which maximizes this. However, our results show that even with ΛNN spin-dependence there is still a very appreciable ΛN spin-dependence. Thus, the scattering lengths we obtain are:

With $V^{D}_{\Lambda NN}$: $a_s \simeq -3.0$ fm, $a_t \simeq -1.5$ fm

With $V^{DS}_{\Lambda NN}$: $a_s \simeq -2.5$ fm, $a_t \simeq -1.6$ fm

Our analysis thus shows that the 0^+-1^+ splitting for A=4 makes it very difficult to avoid the conclusion that there is an appreciable ΛN spin-dependence even if a significant part of the splitting is due to the spin-dependence of a ΛNN force. This strong ΛN spin-dependence is not consistent with the Nijmegen potential D and F,[12] but is in better agreement with the more recent potential of the Nijmegen group.[13]

THE α-CLUSTER HYPERNUCLEUS ${}^{9}_{\Lambda}$Be

Calculations for ${}^{9}_{\Lambda}$Be are made with a 2α+Λ cluster model.[2] The potential between the constituents are local and accurately describe the component subsystems ^{8}Be and ${}^{5}_{\Lambda}$He. A variety of (s-state) αα potentials $V_{\alpha\alpha}$ (which include the Coulomb interaction) are used, all fitted to the $\alpha\alpha$ scattering data. Several $\alpha\Lambda$ potentials $V_{\alpha\Lambda}$ were used, all determined from ${}^5_\Lambda$He for some $V_{\Lambda N}$ and $V_{\Lambda NN}$ and all giving the experimental $\alpha\Lambda$ separation energy of $B_\Lambda({}^5_\Lambda He)=3.12$ MeV.

In particular, some of our $V_{\alpha\Lambda}$ were obtained from our 5-body (ΛNNNN) variational Monte-Carlo (MC) calculations of ${}^5_\Lambda$He.[1] Thus from the 5-body wave function the Λ density $\rho_\Lambda(r_{\alpha\Lambda})$ relative to the four nucleons (i.e. relative to the α particle) in ${}^5_\Lambda$He is obtained numerically. The "trivially equivalent" local $\alpha\Lambda$ potential is then obtained from the $\alpha\Lambda$ "wave function" $\phi_\Lambda=\rho_\Lambda^{1/2}(r_{\alpha\Lambda})$ by solving the corresponding Schrödinger equation for $V_{\alpha\Lambda}$. These (MC) $V_{\alpha\Lambda}$ include many-body effects not present in $\alpha\Lambda$ potentials which are the variational equivalent of Brueckner-Hartree calculations. The latter are obtained with effective ΛN and ΛNN potentials which include just the effect of 2-body ΛN correlations obtained from well depth calculations for a Λ in nuclear matter. In particular, these many-body effects give a central repulsion in the MC $V_{\alpha\Lambda}$ even with only ΛN potentials (adjusted in strength to fit $B_\Lambda({}^5_\Lambda He)$ but then no longer fitting the Λp data). This effect was first pointed out in the context of reaction matrix calculations.[14] Repulsive ΛNN potentials give an additional large central repulsion in $V_{\alpha\Lambda}$.

Experimentally one has $B_\Lambda=6.71\pm0.04$ MeV for the ground state of ${}^9_\Lambda$Be. Our variational calculations give $B_\Lambda\simeq8.2\pm0.2$ MeV where the error is mostly due to uncertainties in $V_{\alpha\alpha}$ and $V_{\alpha\Lambda}$. For ${}^9_\Lambda$Be the ΛN p-state potential V_p can made a significant contribution. The Λp scattering data is consistent with $V_p\simeq1/2V_{\Lambda N}$ ($V_{\Lambda N}$ is the s-state potential) which gives a reduction of $\simeq0.4$ MeV from a number of independent estimates[1,15] (see Ref. 1 for a discussion). With this reduced p-state interaction we then obtain $B_\Lambda\simeq7.8$ MeV.

Thus our calculations predict ${}^9_\Lambda$Be to be overbound by about 1 MeV for $\alpha\alpha$ and $\alpha\Lambda$ potentials which accurately describe the component two-body systems. Because we have made a variational calculation any improvement in the trial wave function can only given even more overbinding. Furthermore, the α-cluster model is internally consistent in that the calculated rms $\alpha\alpha$ separation of $\simeq3.7$ fm is appreciably larger than twice the rms α-particle radius of 1.47 fm. We thus believe that this overbinding is a significant result whatever its detailed explanation may be.

In fact it is quite striking that this overbinding is quite naturally and quantitatively accounted for by the repulsive ΛNN dispersive forces. Thus, the ΛNN potential not only gives a repulsive contribution to $V_{\alpha\Lambda}$ (due to the Λ interacting with a pair of nucleons in the same α, and required to avoid overbinding ${}^{5}_{\Lambda}$He), but will also give a contribution due to the interaction of the Λ with a pair of nucleons each in a different α. By a suitable folding procedure this gives an effective ααΛ potential $V_{\alpha\alpha\Lambda}$ which is repulsive and completely determined. With inclusion of this $V_{\alpha\alpha\Lambda}$ our variational calculations then give $B_{\Lambda} \simeq 6.9$ MeV, corresponding to $\langle V_{\alpha\alpha\Lambda} \rangle \simeq 1$ MeV, i.e. just about the necessary decrease in B_{Λ} to compensate for the overbinding obtained with only $V_{\alpha\alpha}$ and $V_{\alpha\Lambda}$!

THE ΛΛ HYPERNUCLEI ${}^{6}_{\Lambda\Lambda}$He AND ${}^{10}_{\Lambda\Lambda}$Be

These provide the only presently available information about the ΛΛ potential $V_{\Lambda\Lambda}$ in the ${}^{1}S_{0}$ state, appropriate to the ground state of ΛΛ hypernuclei. Our variational calculations treat ${}^{6}_{\Lambda\Lambda}$He as an α+2Λ system and ${}^{10}_{\Lambda\Lambda}$Be as a 2α+2Λ system. The potentials $V_{\alpha\alpha}$, $V_{\alpha\Lambda}$ and $V_{\alpha\alpha\Lambda}$ are those discussed for ${}^{9}_{\Lambda}$Be. For $V_{\Lambda\Lambda}=V_{c}-V_{A}$ we used a variety of shapes, with a range of repulsive cores V_c (including the same V_c as used for $V_{\Lambda N}$, and also ω-exchange potentials), and attractive potentials V_A (including a TPE potential $V_{2\pi}$ and a σ-meson exchange potential V_{σ}). The experimental separation energy $B_{\Lambda\Lambda}$ of both Λs then determines, through the variational calculations, just one strength parameter, that of V_A, for each ΛΛ hypernucleus. We give more weight to the ${}^{10}_{\Lambda\Lambda}$Be event[16] since this has been thoroughly checked and since also the quoted error for $B_{\Lambda\Lambda}$ is smaller than for the ${}^{6}_{\Lambda\Lambda}$He event.[17]

For <u>any</u> $V_{\Lambda\Lambda}$ (including some strength for V_A) our variational calculations of both ${}^{6}_{\Lambda\Lambda}$He and ${}^{10}_{\Lambda\Lambda}$Be give the $B_{\Lambda\Lambda}$ of each. From calculations for a large variety of $V_{\Lambda\Lambda}$ one then obtains essentially a linear relation between ${}^{6}B_{\Lambda\Lambda} \equiv B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}\mathrm{He})$ and ${}^{10}B_{\Lambda\Lambda} \equiv ({}^{10}_{\Lambda\Lambda}\mathrm{Be})$: ${}^{6}B_{\Lambda\Lambda} \simeq -4.17+0.76\ {}^{10}B_{\Lambda\Lambda}$ (MeV). The experimental value ${}^{10}B_{\Lambda\Lambda}=17.7\pm0.1$ MeV then predicts, effectively independently of any details of $V_{\Lambda\Lambda}$, that ${}^{6}B_{\Lambda\Lambda}=9.25\pm0.08$ MeV[16] compared to the quoted value of 10.92±0.6 MeV.[17] Thus, ${}^{6}_{\Lambda\Lambda}$He is underbound by ≃1.5 MeV. In view of the uncertainties associated with the ${}^{6}_{\Lambda\Lambda}$He event, the significance of this underbinding is unclear. However, this comparison of the $B_{\Lambda\Lambda}$ of two

$\Lambda\Lambda$ hypernuclei does demonstrate very clearly that more $\Lambda\Lambda$ hypernuclear events could lead to valuable information about both the $\Lambda\Lambda$ and Λ-nuclear interactions.

THE $\Lambda\Lambda$ INTERACTION FROM $^{10}_{\Lambda\Lambda}$Be

We use the $^{10}_{\Lambda\Lambda}$Be event to obtain the $\Lambda\Lambda$ interaction since the experimental errors are less than for $^{6}_{\Lambda\Lambda}$He and also since this event has been thoroughly checked. For each $V_{\Lambda\Lambda}$ the experimental $^{10}B_{\Lambda\Lambda}$, through the use of the variational calculations, determines the strength of the attractive part V_A of $V_{\Lambda\Lambda}$ and hence the corresponding scattering length $a_{\Lambda\Lambda}$ (and also the effective range). For a given intrinsic range b (the effective range when $V_{\Lambda\Lambda}$ just gives a bound state) $a_{\Lambda\Lambda}$ is found to be approximately independent of the detailed shape of $V_{\Lambda\Lambda}$. A $V_{2\pi}$ potential together with the same V_c as for $V_{\Lambda N}$ has $b \simeq 2$ fm and gives $a_{\Lambda\Lambda} \simeq -4$ fm, whereas a σ exchange potential with this same V_c has $b \simeq 2.5$ fm and gives $a_{\Lambda\Lambda} \simeq -6$ fm. As the range b increases $-a_{\Lambda\Lambda}$ increases and becomes ∞ at $b \simeq 3$ fm corresponding to a bound state. Since such large repulsive cores seem implausible, it seems quite unlikely that the $^1S_0$ $\Lambda\Lambda$ system has a bound state. (In fact, quark exchange models of the repulsive core suggest this could be appreciably softer for the $\Lambda\Lambda$ than for the NN system.) In any case, the $\Lambda\Lambda$ interaction obtained from $^{10}_{\Lambda\Lambda}$Be is quite strongly attractive with $2 \lesssim -a_{\Lambda\Lambda} \lesssim 5$ fm.

The phenomenological $V_{\Lambda\Lambda}$ obtained from $^{10}_{\Lambda\Lambda}$Be is more or less consistent with at least one published meson-exchange potential, namely the Nijmegen potential D.[11] Thus, Bando et al.[18] have shown that this potential gives a reasonable value for $^6B_{\Lambda\Lambda}$ and hence will also give a more or less reasonable value for $^{10}B_{\Lambda\Lambda}$. Thus, the large value of $-a_{\Lambda\Lambda}$ cannot be taken as a possible indication of an H dibaryon which is just unbound.

The existence of $\Lambda\Lambda$ hypernuclei would seem to exclude an H strongly bound with respect to $2M_\Lambda$. Clearly, further $\Lambda\Lambda$ hypernuclear events would very much strengthen this argument. However, the binding of $\Lambda\Lambda$ hypernuclei would permit a weakly bound H with $2M_\Lambda$-$M_H \lesssim 18$ MeV, in which case the strong decay $^{10}_{\Lambda\Lambda}\text{Be} \rightarrow {}^8\text{Be}+\text{H}$ would be energetically forbidden.

Finally, it is interesting to compare the $^1S_0$ NN, ΛN and $\Lambda\Lambda$ potentials. For this comparison to be significant the same shape V_c-

$V_{2\pi}$ is used for all three potentials, and for the NN potential we consider V_{NN}-V_{π}, i.e. with the OPE part subtracted out. Then a_{NN}= -3.5 fm, instead of -17.5 fm as for V_{NN}, which is to be compared with $a_{\Lambda N} \simeq$ -3 fm, and $a_{\Lambda\Lambda} \simeq$ -4 fm. It seems remarkable that these (and the corresponding strengths of $V_{2\pi}$) are so close to each other, indicating that, excluding OPE for V_{NN}, the three $^1S_0$ interactions are effectively very similar.

Work supported in part by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-ENG-38, and by grants NSF-PHY-84-15064 and NSF-INT-8319827.

REFERENCES

1. A. R. Bodmer and Q. N. Usmani, Nucl. Phys. A477, 621 (1988); Nucl. Phys. A450, 257c (1986).
2. A. R. Bodmer and Q. N. Usmani, Nucl. Phys. A463, 221c (1987); A468, 653 (1987); A. R. Bodmer, Q. N. Usmani and J. Carlson, Nucl. Phys. A422, 510 (1984).
3. J. Lomnitz-Adler, V. R. Pandharipande and R. A. Smith, Nucl. Phys. A361, 399 (1981).
4. Q. N. Usmani, Nucl. Phys. A340, 397 (1980); J. Dabrowski and W. Piechocki, Ann. Phys. 126, 317 (1980); W. Piechocki and J. Dabrowski, Acta Physica Polonica B12, 475 (1981).
5. I. E. Lagaris and V. R. Pandharipande, Nucl. Phys. A359, 331 (1981).
6. A. R. Bodmer and Q. N. Usmani, Phys. Rev. C 31, 1400 (1985).
7. J. Carlson and V. R. Pandharipande, Nucl. Phys. A371, 301 (1981); J. Carlson, V. R. Pandharipande and R. B. Wiringa, Nucl. Phys. A401, 59 (1983).
8. R. K. Bhaduri, B. A. Loiseau and Y. Nogami, Ann. Phys. 44, 57 (1967); A. Gal, Adv. in Nucl. Phys., ed. M. Baranger and E. Vogt, 8, 1 (1975); R. H. Dalitz, R. C. Herndon and Y. C. Tang, Nucl. Phys. B47, 109 (1972).
9. J. Dabrowski and E. Fedorynska, Nucl. Phys. A210, 509 (1973); B. F. Gibson and D. R. Lehman, in Proc. of Int. Conf. on Hypernuclear and Kaon Physics, Heidelberg, Germany 1982, ed. B. Povh (Max-Planck Institute für Kernphysik, Heidelberg, 1982); Phys. Rev. C 23, 573 (1981).
10. H. Bando and T. Shimodaya, Prog. Theor. Phys. 63, 1812 (1980); S. Shinmura, Y. Akaishi and H. Tanaka, Prog. of Theor. Phys. 71, 546 (1984).
11. A. R. Bodmer, D. M. Rote and A. L. Mazza, Phys. Rev. C 2, 1623 (1970).
12. M. M. Nagels, T. A. Rijken and J. J. deSwart, Phys. Rev. D 15, 2545 (1977); 20, 1633 (1979).
13. J. J. deSwart and T. A. Rijken, Proc. of 1986 INS Int. Sym. on Hypernuclear Physics, August 1986, Tokyo, eds. H. Bando, O. Hashimoto and K. Ogawa (Institute of Nuclear Study, Univ. of Tokyo, 1988), p. 303.
14. Y. Kurihara, Y. Akaishi and H. Tanaka, Prog. Theor. Phys. 71, 561 (1984); Phys. Rev. C 31, 971 (1985).

15. Wang Xi-chang, H. Takaki and H. Bando, Prog. Theor. Phys. 76, 865 (1986).
16. M. Danysz et al., Nucl. Phys. 49, 121 (1963); Phys. Rev. Lett. 11, 29 (1963); J. Pniewski and D. Zieminska, Proc. of Conf. on Kaon-Nuclear Interaction and Hypernuclei (Zvenigorod, Moscow, 1977) p. 33.
17. J. Prowse, Phys. Rev. Lett. 17, 782 (1966).
18. K. Ikeda, H. Bando and T. Motba, Prog. Theor. Phys. Sup. 81, 147 (1985).