SHORT COMMUNICATIONS

SINGLE PARTICLE STATES OF THE MASS–4 NUCLEI†

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Recently, Tombrello (1965, 1966) has established that ^{4}Li and ^{4}H have a spectrum of broad *P*-wave resonances from phase shift analyses of the ^{3}He(p, p) and ^{3}H(n, n) elastic scattering reactions respectively. The reduced widths of these resonances are large, being approximately equal to the Wigner limit, so that these states must be considered as true single particle states. Other states of the mass-4 nuclei have been found by Parker *et al.* (1965), who studied the excited states of ^{4}He as final state interactions between outgoing protons and tritons in the reaction ^{3}He(d,p)^{4}He*:

$$^3\mathrm{He}+\mathrm{d}\rightarrow \mathrm{p}+{}^4\mathrm{He}\rightarrow \mathrm{p}+\mathrm{p}+\mathrm{t}.$$

The states given by the above authors, with excitation energies given as equivalent excitations in ^{4}He, are shown in Table 1.

It seemed of interest to discover whether these states could be accounted for within the framework of single particle excitations in the particle–hole model of ^{4}He. The purpose of this note is to report the results of such an investigation.

The first requirement of the particle–hole model is the establishment of an unperturbed energy spectrum for ^{4}He. This is relatively simple, as the only states required are the $1s_{1/2}$, $1p_{3/2}$, and $1p_{1/2}$ single particle states. The energy separation of the $1p$ states has been taken from experimental data on ^{5}He (Lauritsen and Ajzenberg-Selove 1966). The separation of the $1s_{1/2}$ and $1p_{3/2}$ states is $B_{\mathrm{n}}(^4\mathrm{He})-B_{\mathrm{n}}(^5\mathrm{He})$, where B_{n} is the separation energy for a neutron. These considerations give the $1s_{1/2}$ state at $-20\cdot58$ MeV, the $1p_{3/2}$ state at $+0\cdot96$ MeV, and the $1p_{1/2}$ state at $+3\cdot56$ MeV.

The calculational procedure has been discussed in many places (e.g. Brown, Castillejo, and Evans 1961; Gillet 1962). The results presented here are based on a residual interaction of the form

$$V=-V_0(1-\eta+\eta\,\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\,\delta(\mathbf{r}_1-\mathbf{r}_2),$$

where the parameters are taken to be $\eta=0\cdot135$ and $V_0\,a^3/4\pi=40$ MeV. Here a is the harmonic oscillator range parameter. The effects of ground-state correlations have not been included.

The results of the calculation are shown in Table 1. This single particle calculation gives four $T=1$ states, whose positions agree quite well with the results of analyses by Tombrello (1965, 1966) for the $T=1$ members of the isospin triad.

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The calculation also predicts three $T = 0$ levels that are at present unobserved. It should be noted that the observed states in ^{4}He are at 20·1 and 22·0 MeV, and that the lowest of these is a 0^+; $T = 0$ state. The spin, parity, and isospin of the 22·0 MeV state are probably 2^-; 0 (Meyerhof and McElearney 1965).

One of the 1^-; $T = 0$ states is known to be the spurious state corresponding to translational motion of the centre of mass (Elliott and Skyrme 1955). The wave function for this spurious state may be constructed according to the prescription of Baranger and Lee (1961), and it gives the result

$$\psi_{\text{spurious}} = (1/\sqrt{3})\,\psi(1s_{1/2}^{-1}\,1p_{1/2}) - \sqrt{(2/3)}\,\psi(1s_{1/2}^{-1}\,1p_{3/2}).$$

The wave functions found for the two 1^-; $T = 0$ states are

$$\psi_{\mathrm{H}} = 0\cdot 84\,\psi(1s_{1/2}^{-1}\,1p_{1/2}) + 0\cdot 54\,\psi(1s_{1/2}^{-1}\,1p_{3/2}),$$

$$\psi_{\mathrm{L}} = 0\cdot 54\,\psi(1s_{1/2}^{-1}\,1p_{1/2}) - 0\cdot 84\,\psi(1s_{1/2}^{-1}1p_{3/2}),$$

where the subscripts H and L refer to the states higher and lower in energy respectively. Thus, the particle–hole calculation gives the spurious state correctly.

TABLE 1

EXCITED STATES OF ^{4}He

Spin, Parity, and Isospin	Excitation Energy (theoretical) (MeV)	Excitation Energy (experimental) (MeV)
0^+; 0		20·1 *
2^-; 0	22·5	22·0 *
1^-; 0	24·6	
0^-; 0	25·1	
2^-; 1	25·2	24·0 †
1^-; 1	25·2	25·6 †
0^-; 1	27·8	27·4 †
1^-; 1	29·2	29·2 †
1^-; 0 (the spurious state)	12·6	

* Meyerhof and McElearney (1965).
† Results of Tombrello (1965, 1966) averaged.

It must be emphasized that the present calculation can give no more than a guide to the locations of the excited states of the mass-4 nuclei. Because of the small number of particles in the ^{4}He nucleus, the nature of the residual interaction must be expected to play an important part. The zero-range approximation for the two-nucleon force is not a good approximation to the real nucleon–nucleon force, and, because of the factors previously mentioned, one should expect to get a more precise answer in this case using a realistic two-nucleon force.

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