Generalized Jastrow factor applied to cluster calculation of cluster structure of light nuclei with meson theoretical force

W. Sakai
Akashi College of Technology, Akashi Japan

To analyze the structure of light nuclei, generalized Jastrow factor including tensor and L.s component is very useful for many purpose (corresponding to Akashi's ATM method). This factor satisfies many body condition ($n+1$ to n body transition condition) and controls effect of central and noncentral components of nuclear force to give good physical results. As realistic nuclear force one boson exchange potential given by Bryan & Scott is employed. Corresponding to Mainly 5 body He problem is discussed.

Generalized Jastrow factor is given (1st ordinary, 2nd tensor and 3rd spin-orbit components)

$$F = f + p \cdot f(T) + q \cdot f\vec{L} \cdot \vec{s} \tag{1}$$

Last two terms include additional exponent factors to satisfy the many body condition, and p and q are variational parameters. Alpha cluster approximate F.I.Y method is given (E_4 4body cluster term etc). Kinetic energies and nuclear radii can be treated as 2 body operators connected with center of mass problem. (Used unites are fm and MeV for length and energy)

$$\langle O \rangle = E_4 - mE_3 + nE_2 \tag{2}$$

where m and n are positive integers and for the five-body case, they are $m = n = 1$. The most important fact is that tensor force has decisive role to construct the alpha cluster structure of light nucleus (central force against this). Wildermus wave function is used. Smallness of b/a indicates feature of clusterization

$$R \exp(-0.5a(r_1^2 + r_2^2 + r_3^2 + r_4^2) - (2/5)bR^2)Y\,. \tag{3}$$

For fixed value of a ($a = 0.7$ this case) values of b is varied smaller and smaller. Letter t and c means tensor and central. 2 body calculations of potential do not show cluster feature. (Large letters mean 4 and 3, small letters mean 2 body results.) The best value is $b = 0.2$, we must add 3 and 4 body kinetic energies and radius term.

$a = 0.7$	$E_4 - E_3$	$E_4 - E_3$	$T + C$	e_2(total)	Tensor	Central
$b = 0.65$	$T = -240 - (-322) = 82$	$C = -78 - (-75) = -3$	79	-2	$t = -53$	$c = -18$
$b = 0.25$	$T = -224 - (-203) = -21$	$C = -52 - (-63) = 11$	-10	-10	$t = -50$	$c = -16$
$b = 0.2$	$T = -222 - (-196) = -26$	$C = -49 - (-58) = 9$	-17	-14	$t = -52$	$c = -16$
$b = 0.12$	$T = -219 - (-199) = -20$	$C = -48 - (-54) = 6$	-14	-13	$t = -52$	$c = -16$

$$\begin{aligned} &K_4 - K_3 = 57 - 54, \quad \text{Total energy} = e_2 + K_4 - K_3 + T + C = -14 + 3 - 17 = -28 \\ &R_4 - R_3 = 4.8 - 4.3 = 0.5\,, \quad \text{Radius} = 1.9 + (4.8 - 4.3) = 2.4 \end{aligned} \tag{4}$$

It is very interesting that in the 3 and 4 body calculation tensor force does most important contribution to clusterization and central force against that. It is explicitly given by the generalized Jastrow factor. Similar phenomenon occurs for s doublet states of ^{6}Li, central force gives wrong order of energy levels and using above method we can get right results by tensor force. (Results is 2 and 3 body calculation, 4 body calculation is on the way.)

About spin-orbit splitting of helium 5 body problem e_2 contribution is mainly given by the spin-orbit component of nuclear force and $(E_4 - E_3)$ contribution is mainly given by the central force term coupled with L.s Jastrow factor and this two contribution give good total results and the latter is a little larger than the former [2].

About alpha particle itself F.I.Y method is applied exactly (not approximate). Tensor force gives main part of binding energy and good result. Also calculational result of radius gives almost experimental value [2].

References

[1] J.W. Clark and M.L. Rustiq NUOVO CIMENT 50a N.3 p313 (1970).

[2] W. Sakai, Memoirs of Akashi Colledge of Technology N40 (1997);
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