A method of numerical calculation of the effect of short-range correlations for a wide range of nuclei

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Traditionally, mean-field methods, such as the Shell Model, have been used to describe the nuclear properties, but since the 1980s experiments like elastic scattering that measure charge distributions and knockout experiments that measure spectral functions have shown that mean-field methods have difficulty in describing the ground state of atomic nuclei. Hence, we need to consider the effects that mean field methods omit.

The effects omitted in the mean-field model have been generically named correlations, which are usually distinguished between short- and long-range correlations. The former ones are those acting at short interparticle distances, modifying the mean-field single-particle wave functions to account for the repulsive and attractive parts of the nuclear interaction that differ from the mean-field in short range. The latter one-long-range correlations act on the whole system and are produced by collective phenomena like sound waves or surface vibrations. Here we focus on the short-range correlation.

Jastrow function [1] has long been used to describe the short-range correlation within the nucleus. However, unless the number of nucleons (A) is very small, it is impossible to calculate the density and form factor directly by using the Jastrow function. To address this case, Iwamoto and Yamada have developed the Cluster Expansion method [2], and M. Gaudin et al. have applied this method to the nucleus with simple correlation factor $g(r) = e^{-\beta^2 r^2}$ [3]. Many papers have used this formula to calculate nucleons' density and form factor for light nuclei, but most of them use the harmonic oscillator model, which can simplify the calculation. Hence, we developed a method that can be applied to any potential, see Ref. [4]. Also, it is common to only consider the part of short-range correlation that comes from the repulsive N-N interaction. To account for the effects of all components of the effective N-N interaction, it is common to employ the Bethe-Goldston approach [5], which can be approximated by contribution of attractive and repulsive part of short-range correlation necessary to consider the effect of the attractive part of the N-N interaction on the short-range correlation.

So, in this work we first develop a method to numerically calculate the effect of short-range correlation that can also be applied to heavier nuclei, and second, develop a model that can include the contribution of the attractive part of the N-N interaction to it.

We evaluated the proton density and its root-mean square (RMS) radius, and form factor of many different closed-shell nuclei: ^{4}He, ^{16}O, ^{28}Si, ^{32}S, ^{40}Ca, ^{60}Ni, ^{90}Zr, ^{140}Ce and ^{208}Pb as shown in Table I.. In the short-range correlations, we have included the effects of repulsion and attraction parts of the solving the Bethe-Goldstone Equation.

Table I. Calculated proton RMS radius under different models							
Model \ Nucleon	shell model	With only repulsion	radius change/ %	Full short-range correlation	radius change/ %	with only attraction	radius change/ %
^{4}He	1.616133fm	1.623337fm	0.445%	1.599541fm	-1.026%	1.592230fm	-1.479%
^{16}O	2.529441fm	2.536559fm	0.281%	2.511430fm	-0.712%	2.504242fm	-0.996%
^{28}Si	3.053236fm	3.058935fm	0.187%	3.038796fm	-0.473%	3.033163fm	-0.657%
^{32}S	3.181507fm	3.187865fm	0.200%	3.165370fm	-0.507%	3.159112fm	-0.704%
^{40}Ca	3.330245fm	3.337304fm	0.212%	3.312034fm	-0.547%	3.304950fm	-0.760%
^{60}Ni	3.741023fm	3.746461fm	0.145%	3.727012fm	-0.375%	3.721639fm	-0.518%
^{90}Zr	4.148163fm	4.154109fm	0.143%	4.132789fm	-0.370%	4.126891fm	-0.513%
^{140}Ce	4.781949fm	4.787179fm	0.109%	4.768432fm	-0.283%	4.763277fm	-0.391%
^{208}Pb	5.428307fm	5.432899fm	0.085%	5.418376fm	-0.183%	5.414423fm	-0.256%

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