ROLE OF pn-PAIRS INTERACTIONS IN NUCLEAR STRUCTURE

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ABSTRACT
A phenomenological model based on an idea that proton-neutron pairs interactions are responsible for the nuclear structure is proposed. Also it was established that proton and neutron of one pair have equal nuclear potentials. The model leads to the classical alpha cluster liquid drop model with some additions, which helps in obtaining values of energy of inter alpha clusters adherence and some important equations to calculate Coulomb energy and surface tension energy from analysis of experimental binding energies of nuclei with N=Z. Here some results of the approach are presented.

THE ALPHA CLUSTER MODEL
The classic model of alpha cluster liquid drop has been developed recently with an assumption that proton – neutron pn - pairs interactions are responsible for building alpha clusters and for inter clusters adherence with assumption about equivalence of proton and neutron nuclear bound state potentials [1,2,3]. Then the value of difference between single proton and single neutron separation energies ΔEpn can be considered as Coulomb energy of the proton of the last pair in the nuclei with N=Z. The value is known from experimental binding energies with good accuracy. Taking into account that liquid drop is such a material that pn - pairs are put to each other with the highest possible density, the Coulomb energy is supposed to be a sum of the values of ΔEpn of all pairs consisting the nucleus ΣΔEpn. Coulomb repulsion energy between two nearby α clusters has been estimated in frame of the model as εCα=1.925 MeV and Coulomb repulsion energy between pn –pair and 3 α-clusters of its close vicinity has been estimated as εCpn3α=3.003 MeV.
The values of Coulomb energy obtained empirically as $\Sigma \Delta E_{pn}$ is in agreement with the values calculated according to the cluster model for nuclei with few clusters $^6$Li, $^8$Be, $^{10}$B, $^{12}$C, $^{14}$N and $^{16}$O with accuracy of 0.001 MeV (For $^6$Li with 0.006 MeV). The energy of Coulomb repulsion between two alpha clusters in nucleus $^8$Be is estimated as 1.887 MeV. For nuclei with $Z < 30$ the Coulomb radius can be obtained by sum $\Sigma \Delta E_{pn}$ (for nuclei with $22 < Z < 30$ $\Delta E_{pn}$ was estimated in [2]).

Coulomb energy of last proton in nucleus consists of a short range part, which comes from interactions with alpha clusters of its close vicinity, and long range one due to interactions with protons standing in a some distance. This logic allows one to estimate value positioning of last proton $R_p$ on value of $\Delta E_{pn}$ and on value of $Z$. The values obtained different ways are close for nuclei with $N = Z > 16$ and binding energies calculated with these values are close with difference in 1-2 MeV. For nuclei with $Z > 30$ the 2nd way of obtaining radius $R_p = 1.720(Z-8)^{1/3}$Fm is used. Coulomb radius is defined by the number of alpha clusters on the surface of the liquid drop and for nuclei with $Z > 30$ the Coulomb energy is calculated as an energy of charged sphere with radius $R_C = 1.865 N_a^{1/3}$Fm.

A shell model is used to estimate radius of nucleus $R_{ch}$. It is based on the idea of molecules existing in the liquid drop, which are considered in the approach as completed shells. The obtained values are in agreement with experimental values of root mean square radii $R_{\text{exp}}$ with the accuracy in several 0.01 Fm. Here it should be mentioned that root mean square radius $R_{ch}$. Coulomb radius of corresponding charge sphere $R_C$ and radius of positioning last proton $R_p$ are not considered versus mass number $A$, but versus number of pn - pairs disregarding to the number of excess neutrons. The average values per one nucleon are to be calculated relatively to the number of nucleons in the pairs. So $r_{\text{ch/C/p}} = R_{\text{ch/C/p}}/(2Z)^{1/3}$. In such consideration the values of $r_{\text{ch/C/p}}$ for middle and heavy nuclei are not changed crucially from nucleus to nucleus. For nuclei with $Z < 20$ $r_{\text{ch}} \geq 1.1$ Fm, $r_c = 1.35$Fm, $r_p = 1.14 \div 1.3$ fm. For nuclei with $20 < Z < 30$ $r_{\text{ch}} \geq 1.01$ Fm, $r_c \geq 1.2$ Fm, $r_p \geq 1.2$Fm and for nuclei with $Z > 30$ $r_{\text{ch}} \geq 1.01$ Fm, $r_c = 1.175$ Fm, $r_p = 1.2 \div 1.3$ Fm. So for nuclei $Z > 20$ $r_{\text{ch}} \geq 1.01$ Fm and $R_{\text{ch}} < R_C < R_p$. 

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Fig. 1 The pn-pair interactions in alpha cluster model.
CALCULATION OF BINDING ENERGY

Nuclear forces energy of alpha cluster is estimated as $\varepsilon_{n\alpha} = 28.296\text{ MeV} + 0.764\text{ MeV} = 29.060\text{ MeV}$. The energy of nuclear forces of adherence between 2 alpha clusters is estimated equal to $\varepsilon_{\alpha\alpha} = 4.350\text{ MeV}$. Odd - odd nuclei with $N=Z$ have proton and neutron tied in the pair with energy $\varepsilon_{pn}$, which can vary within $\varepsilon_{pn} = 1.7 \pm 2.5\text{ MeV}$ in dependence of $Z$. The pair has energy of nuclear binding with three nearby clusters estimated as $\varepsilon_{npn\alpha} = 13.0 \pm 15.2\text{ MeV}$. So total nuclear binding energy of single pn – pair in odd nuclei is estimated as $\varepsilon_{npn\alpha} + \varepsilon_{pn} = 15.5 \pm 16.9\text{ MeV}$. The pair is stuck to the clusters and it’s positioning radius differs from the radii of the clusters on small value of about 0.08 Fm, which explains the fact that radius of nucleus with odd $Z$ is close to the value of the radius of nucleus with $Z-1$.

Binding energy of nucleus is calculated as sum of nuclear attraction forces energy, Coulomb repulsion energy, surface tension energy and energy of excess neutrons.

$$E_b = E^n - E^C + E^{ST} + E_n$$

(1)

where $E^n = N_a\varepsilon_n^a + 3(N_a - 2)\varepsilon_{n\alpha\alpha}$, $E_C = 3/5(\frac{Z^2}{R_C})$, $E^{ST} = \sum N_a 0.471 R_p^2$ (for $N_a < 5$ $E^{ST} = 0$, for $N_a \geq 15$ $R_p = R_C$), $E_n = \sum E_{mn}$ ($E_{mn}$ indicates empirical value of binding energy of $i$-th nn-pair. $E_{mn} = 23\text{ MeV}$ for nucleus $^{58}\text{Ni}$). Here the particular feature of nn-pairs of excess neutrons to have quite stable values of binding energy smoothly decreasing with value of $i$ is used. Therefore in the approach only even - even or odd - odd nuclei are to be considered. The nuclear binding energies of the most abundant isotopes (or nearest to them) of all known nuclei and their isotopes with big and small amount of excess neutrons calculated in frame of the model are in agreement with experimental values with accuracy in 0.5% in average.

To test the equation (1) in independence from excess neutron binding energy the deuteron’s and alpha particle's separation energies have been calculated. The agreement with experimental values is in most of the cases within 1-2 MeV deviation.

CONCLUSIONS

In the approach proposed in [1, 2, 3] even-even nuclei are considered as alpha clusters liquid drop. In case of odd-odd nucleus there is one single pn –pair on the drop’s surface. Most of the elements of such a structure are spinless objects (those are the alpha cluster, nn-pairs and there is only one pn-pair with spin equal to 1), which allows one to reduce the approach to simple terms like those used in the Weizsacker formulae [4]. Principle of equivalence of proton and neutron nuclear bound state potentials helps one to obtain the main formulas to calculate Coulomb energy, surface tension energy and all inter-cluster interactions energy from analysis of nuclei with $N=Z$. The rules were spread for heavier nuclei to calculate charge radii with average deviation of 0.05 fm and binding energy with average deviation of 0.5% as well as alpha particle and deuteron separation energies for nuclei of the most abundant isotopes (or nearest to them) of all known elements with deviation of 1-2 MeV.

REFERENCES