About the Flaky Neutron-Optical Potential. Further Development of Approach

Yu.A. Alexandrov[1], G.V. Anikin[2], V.G. Anikin[2]

[1]*FLNP, Joint Institute for Nuclear Research, Dubna, Russia*
[2]*Institute of Phisics and Power Engineering, Obninsk, Russia*

Abstract. The correlations of resonance structure in energy dependencies of different characteristic of neutron interaction with nuclei (full cross sections, cross sections of fission, et cetera) presented in [1]. The diagram presenting cross section correlations of neutrons [2] and gamma-rays [3] at equal wave lengths was shown in [4] and also in [5].

In paper [5] are given some calculated energy dependencies of total cross section of fast neutrons with lead nuclei interaction (in interval $E_n \sim 0.1-15$ MeV) and their comparison with the experimental cross sections of the work [6]. The calculations are performed with some variants of the flaky potential, and shown in Fig.1 of work [1].

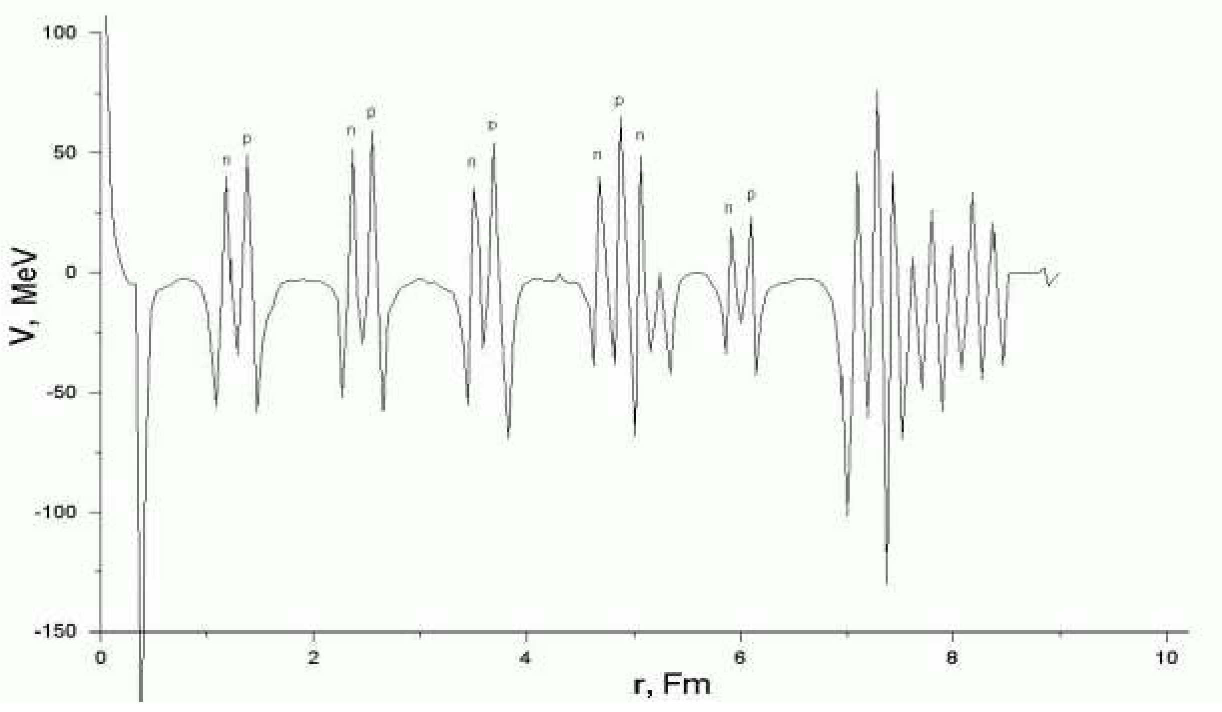

Fig. 1. The real part of potential no.1 for Pb-208 (without structural elements in peripheral area).

The results of comparison of the calculated and experimental cross sections are following. Similarities of resonant structures are observed especially in the field of low-energy neutrons (less 0.5 MeV). However the most eye-catching element of the total cross sections of the curve (deep interference minimum at the energy near 0.5 MeV) has not been reproduced. At high neutron energies the gap between calculated cross sections and the experimental data is also great.

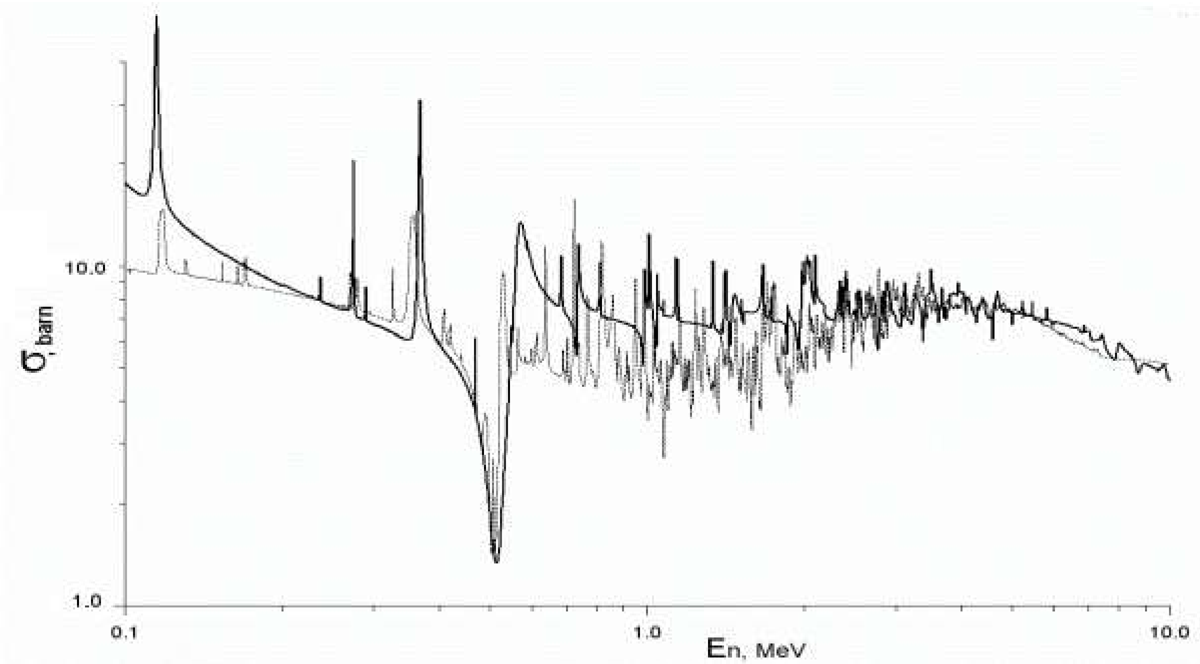

Fig. 2. The total cross section for interaction of neutron with Pb-208 (calculation with potential no.1, solid curve) in comparing with experimental data of the work [6] (dotted curve).

This paper presents the results of calculations with the modified (mainly the real part) of neutron-nuclear potential.

A new approach to the evaluation of all parts of the potential is as follows. Internal part of potential (Internal area of nuclei) is represented by discrete set of values varied independently. Imaginary and spin-orbital components of potential are calculated as derivatives of real part calculated as difference of nearby values of real part.

Outside the central part, given discretely, all components of the potential are represented by smooth curves:

$$-V_r = 0.38/r^8 + 0.05/r^4 + 0.02/r,$$
$$V_{so} = 0.0012/r^3,$$
$$-V_{im} = 0.7/r^2$$

All ordinate the internal and external parts of the potential are multiplied by energy dependency coefficients: ED_r – coefficient for the real part, ED_{im} – for the imaginary part, ED_{so} – for the spin-orbital part of potential.

For the first variant presented here:

$$ED_r = 1.15$$
$$ED_{so} = 1/\mathrm{sqrt}(E_n)+2.62E_n$$
$$ED_{im} = 0.00023,$$

where E_n – energy of scattering neutron, integration step – 0.0476 Fm.

Fig. 1 shows the real part of the potential for Pb^{208}. Peaks of this curve correspond to twin neutron-proton layers. The outer part of each layer consists of proton (because of the Coulomb repulsion). The inner part is neutrons. According to the table 3 of [1] two twin layers under the most outer one consist only of one sublayer. But this calculation shows that complete omission of sublayer does not occur. On the contrary, there is partial filling of sublayer without which nuclear structure probably would not be stable.

The peripheral area of the potential demonstrates forming neutron coat above nuclei surface. This part of the curve shows decomposition of periodical structure inherent to the central part.

Excess neutrons of heavy nuclei at the nuclei periphery cannot exist separately from the proton, so they are taken out of the filled underneath shell. Groups of neutrons and taken out protons form clusters above the outer layer of nuclei.

It is interesting to consider the "evolution" of the clusters in transition from spherical magic nuclei with completely filled shells to not magic nuclei. Surface clusters turn into unfinished shell, which may take the form of one or two (maybe more) groups of nucleons - "caps" over of the outer filled shell. Changing of properties of thallium isotopes can be explained by formation of "caps"

Six even isotopes of this element (from Tl^{194} to Tl^{204}) have $\mathbf{2}^-$ basic state (that is a property of pear-shape deformation: nucleus has one "cap"). But Tl^{206} has $\mathbf{0}^-$ basic state: "cap" is overloaded with protons and splits into two. Nucleus takes ellipsoid form. However, the first excited state of the isotope – again $\mathbf{2}^-$. Thus, at the first small impact two parts are combined again.

In its turn excess neutrons forming "coat" of heavy nuclei (such as Pb) can penetrate into upper layers making the ratio of neutron number to this of protons in them close to 2:1. So the layers seem to consist of tritium nuclei.

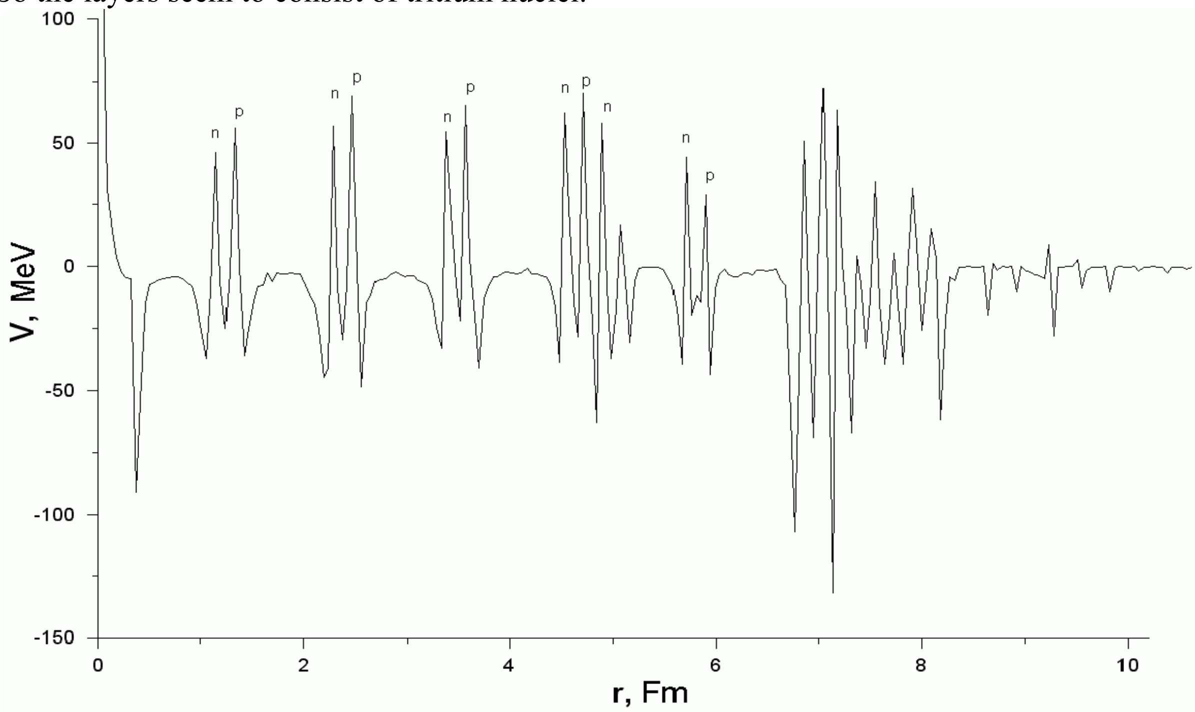

Fig. 3. The real part of potential no.2 for Pb-208 (with structural elements in peripheral area).

The second calculation is made with potential presented at Fig.3 (also real part), which differs of the one at Fig.1 extended (up to 10 Fm) discrete part. Parameters of potentials:

$$-V_r = 0.21/r^8 + 0.063/r^4 + 0.0262/r,$$
$$V_{so} = 0.000182/r^3,$$
$$-V_{im} = 3.6/r^2.$$

Energy dependency coefficients:

$$ED_r = 1.15,$$

$$ED_{so} = 1/sqrt(E_n)+2.62E_n,$$
$$ED_{im} = 0.00023.$$

It is necessary to examine the question of the most remote (r > 8 Fm) structures of the real part of the potential that can be seen in Fig.1 in [1]. The absence of any comments about these structures led to criticism of some reviewers. The potential in Fig.1 of this work contains one of the maximum on the periphery, which significantly helped description of the total cross section. Calculation was carried out with the inclusion and other peripheral structures. The following possible explanation for their existence can be done: the real part of potential contains value const/r which may refer to neutrons. So around the nucleus can rotate single nucleons and small clusters like Solar system Planets. This can cause irregularity in the peripheral part of the potential. In the works [7] and [8] is also raised a question about the nucleon clusters in the periphery of heavy nuclei.

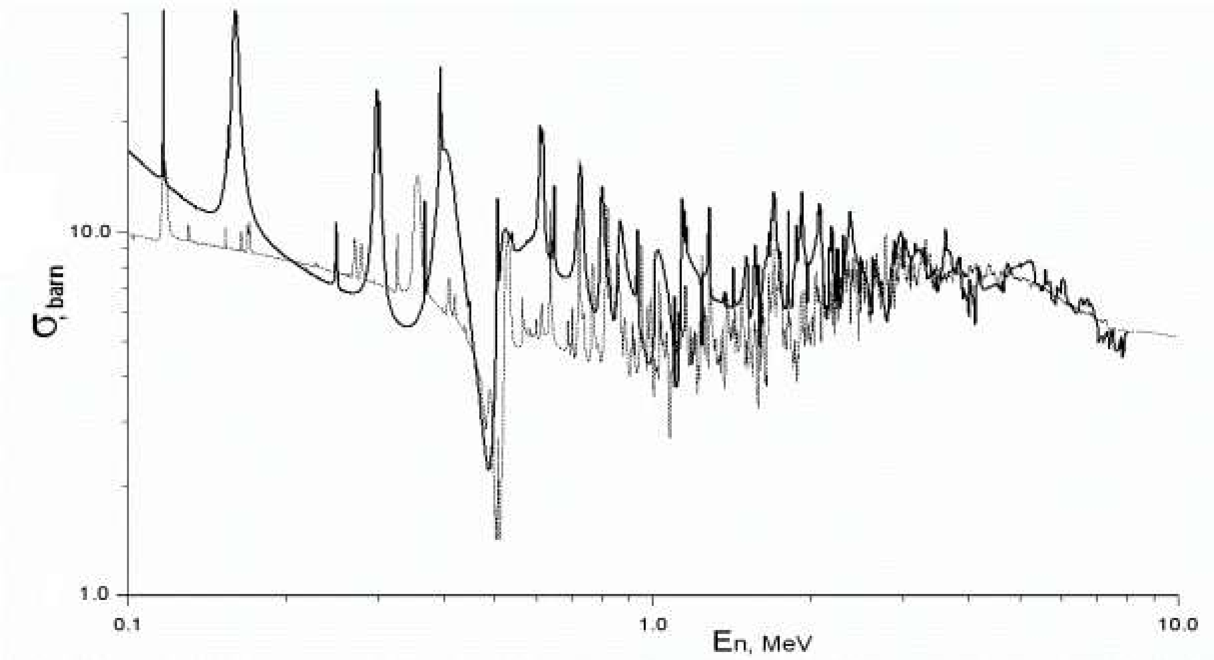

Fig. 4. The total cross section for interaction of neutron with Pb-208 (calculation with potential no.2, solid curve) in comparing with experimental data of the work [6] (dotted curve).

References

1. Anikin G., Anikin V. Atom. Energ., **94**, 2003, iss.4, p.309.
2. Migneco E. et.al. The fission cross section of U-235 with neutron energy 0.7 KeV–1.1 MeV. In Proc. of Conf. Wash., 1975, p.607.
3. Iskhanov B.S., Kapitonov I.M., Lazutin E.V. et al. Yad. Fiz., **12** (1970) 682.
4. G.V. Anikin, V.G. Anikin. Preprint IPPE-3031, Obninsk, 2004.
5. Yu. Alexandrov, G. Anikin, V. Anikin. Prospects of using the complicated (‘flaky’) Neutron-Optical Potential. ISINN-19, Dubna, June 2011.
6. R.F. Carlton, R.R. Winters and J.A. Harvey at al. Bull of Am. Phys., **36** (1991).
7. P.G. Hansen and B. Jonson. The Neutron Halo of Extremely Neutron-Rich Nuclei. Europhys. Lett., **4** (4), (1987) 409–414.
8. Wilkinson D.H. Nucleon Clusters in the Nuclear Surface. Phil. Mag., **4** (1959) 215.