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NEW DIFFRACTIONAL APPROACH TO PROTON-NUCLEUS SCATTERING

*Institute of Nuclear Research and Nuclear Energetics, Bulgarian Academy of Sciences, Sofia 13, Bulgaria.

Антонов А.Н., Николаев В.А., Петков И.Ж. E2 - 11283

Новый дифракционный подход к протон-ядерному рассеянию

Предложена модель "когерентных вибраций" ядра, дающая новые возможности при изучении рассеяния частиц на ядрах. Она основывается на данных о распределении плотности ядерного вещества, и с ее помощью вычисляется энергия основного состояния конечных Ферми-систем. Модель "когерентных вибраций" применена к рассеянию протонов с энергией 1 ГэВ на ядрах ^{28}Si, ^{32}S, ^{40}Ca, ^{48}Ca, ^{58}Ni, ^{208}Pb. Согласие между расчетами по модели и экспериментальными данными говорит в пользу идеи "когерентных вибраций" ядра.

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Antonov A.N., Nikolaev V.A., Petkov I.J. E2 - 11283

New Diffractional Approach to Proton-Nucleus Scattering

High-energy scattering of protons on the ^{28}Si, ^{32}S, ^{40}Ca, ^{48}Ca, ^{58}Ni, ^{208}Pb nuclei has been studied in the framework of the "coherent flucton" nuclear model.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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1. A new model of the coherent vibrations of the nucleus has been proposed recently [1], and it provides new possibilities in the study of particle scattering on nuclei. This model is more consistent in the quantum-mechanical interpretation of nuclear matter theory results. It is also based upon the available knowledge of the density distribution of nuclei and is aimed at the determination of the ground state energy of finite Fermi systems. Unlike statistical nuclear theory [2] where nuclear matter calculations are approximated by a definite energy functional of the local density $E(\rho)$, we come to the following expression from the ground state energy:

$$E = \langle f(x) \,|\, -\frac{h^2}{2 m_{ef}} \frac{d^2}{dx^2} + \mathcal{E}(x) \,|\, f(x) \rangle , \qquad (1)$$

where

$$f(x) = \left(-\frac{1}{\rho(x)} \frac{d\rho(r)}{dr} \Big|_{r=x} \right)^{1/2}, \quad \rho(x) = 3A/4\pi x^3 , \qquad (2)$$

$\rho(r)$ is the nuclear density distribution, and A is the mass number. $\mathcal{E}(x)$ in formula (1) is given by:

$$\mathcal{E}(x) = A\,\mathcal{E}_0(\rho(x)) + \mathcal{E}_c . \qquad (3)$$

In (3) the energy per nucleon in nuclear matter with density equal to the density of the flucton is determined by:

$$\mathcal{E}_0(\rho(x)) = 37{,}53[(1+\alpha)^{5/3} + (1-\alpha)^{5/3}]\rho^{2/3} - 741{,}28\rho +$$
$$+1179{,}89\rho^{4/3} - 467{,}54\rho^{5/3} + \alpha^2(148{,}26\rho + 372{,}84\rho^{4/3} -$$
$$- 769{,}57\rho^{5/3}) - 0{,}7386\, e^2 \rho_p^{4/3} \rho ,$$

$$\rho = 3A/4\pi x^3 , \quad \rho_p = 3Z/4\pi x^3 , \quad \alpha = (A-2Z)/A , \qquad (3a)$$

$\mathcal{E}_c$ is the Coulomb energy of a homogeneously charged sphere with radius x. The right-hand side of (3a) has been defined in Ref. /2/.

Expression (1) leads to a Schrödinger type equation with a solution $f(x)$, that can be interpreted as the flucton wave function. The square of the latter determines the probability to find all the nucleons homogeneously distributed within a sphere of radius x. We call this virtual formation of nucleons a "coherent flucton". The flucton wave function $f(x)$ satisfies the following condition of normalization:

$$\int_0^\infty |f(x)|^2 dx = 1. \qquad (4)$$

This condition corresponds to the usual normalization of the local density:

$$4\pi \int_0^\infty \rho(r) r^2 dr = A .$$

2. The model of zero-coherent nuclear vibrations gives a possibility to calculate basic static and dynamical nuclear quantities and also to analyse different nuclear processes where these quantities are of great importance. We will study in this paper high-energy elastic scattering of protons on nuclei within the framework of the flucton model using the diffraction approximation. We can write the scattering amplitude of protons on a single flucton with radius x as follows /3/:

$$A(q,x) = -2\pi \frac{x^2}{L^2} \frac{J_1(qx)}{qx} , \qquad (5)$$

where $J_1(z)$ is the first order Bessel function, L is the normalization length and q is the transfer momentum.

The total amplitude can be obtained by averaging $A(q,x)$ with the square of the wave function:

$$F(q) = \langle f(x) \,|\, A(q,x) \,|\, f(x) \rangle . \qquad (6)$$

The corresponding cross section is:

$$\frac{d\sigma}{d\Omega} = |F(q)|^2 \frac{L^4 k^2}{4\pi^2} , \qquad (7)$$

where k is the initial momentum of the protons. The weight factor $|f(x)|^2$ can be determined by electron scattering experiments. Hence, expressions (6) and (7) do not contain any free parameters.

3. We study as an example the scattering of 1 *GeV* protons on the ^{28}Si, ^{32}S, ^{40}Ca, ^{48}Ca, ^{58}Ni, ^{208}Pb nuclei. The nuclear density distribution $\rho(r)$ is approximated by the well-known Fermi distribution $\rho(r) = \rho_0(R,b)/(1+e^{\frac{r-R}{b}})$. The comparison between present theoretical results and the experimental data for ^{28}Si, ^{32}S /4/, ^{40}Ca, ^{48}Ca /5/, ^{58}Ni, ^{208}Pb /6/ is shown in *Figs. 1,2.* The parameters R and b used in the calculations have the following values: ^{28}Si (R = 2.7 *fm*; b = 0.563 *fm*), ^{32}S (R = 2.9 *fm*; b = 0.56 *fm*), ^{40}Ca (R = 3.45 *fm*; b = 0.56 *fm*), ^{48}Ca (R = 3.74 *fm*, b = 0.52 *fm*), ^{58}Ni (R = 4.153 *fm*; b = 0.566 *fm*), ^{208}Pb (R = 6.8 *fm*; b = 0.515 *fm*). For ^{40}Ca the dashed line represents the cross section in the hypothetical case of proton scattering on a single flucton with radius x = R = 3.45 *fm*. We can see the necessity of using a superposition of all fluctons which form the real nuclear density distribution. The agreement between the theoretical cal-

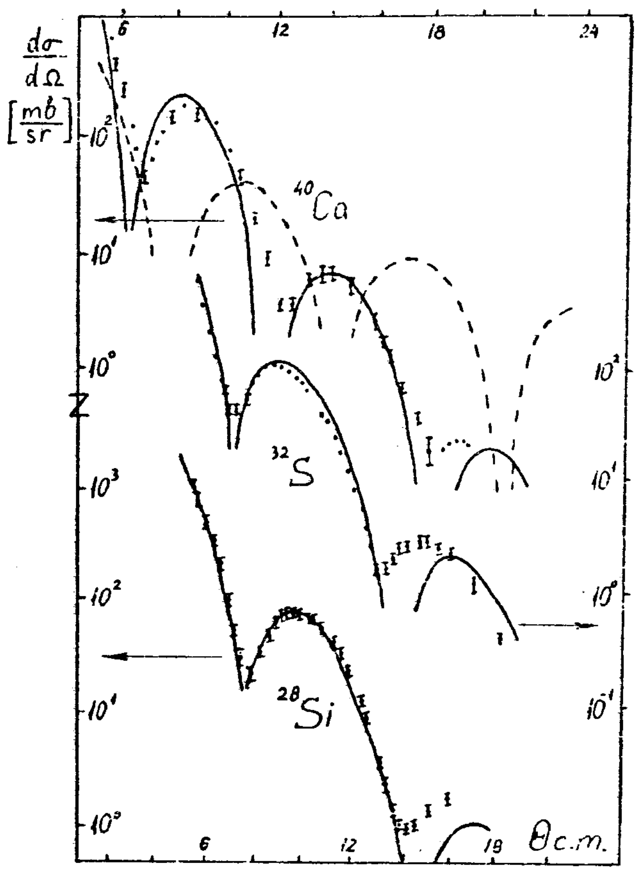

Fig. 1. Differential cross section for 1 GeV elastic proton scattering on ^{28}Si , ^{32}S , ^{40}Ca. *The upper scale* ($\Theta_{c.m.}$) *corresponds to* ^{40}Ca.

culations and the experimental data supports the idea of the zero-coherent vibration nuclear model.

There is some discrepancy between theory and experiment in the vicinity of the cross section minima, and there seems to be two reasons for this disagreement. First, we do not take into account the fact that the fluctons absorb differently due to the difference in the flucton densities, and second, we do not consider the change of the

fluctuon picture during the time of the projectile propagation, i.e., we employ an approximation of "frozen" fluctons. The second shortcoming can be avioded by introducing Δx, which depends on the energy of projectile particle in the weight function (Δx is a length of averaging) $\left(\frac{1}{\Delta x} \int_{x}^{x+\Delta x} | f(y) |^2 dy \right)$.

That should improve the agreement between theory and experiment in the region of the minima of the cross section curves. We would like to point out that when the

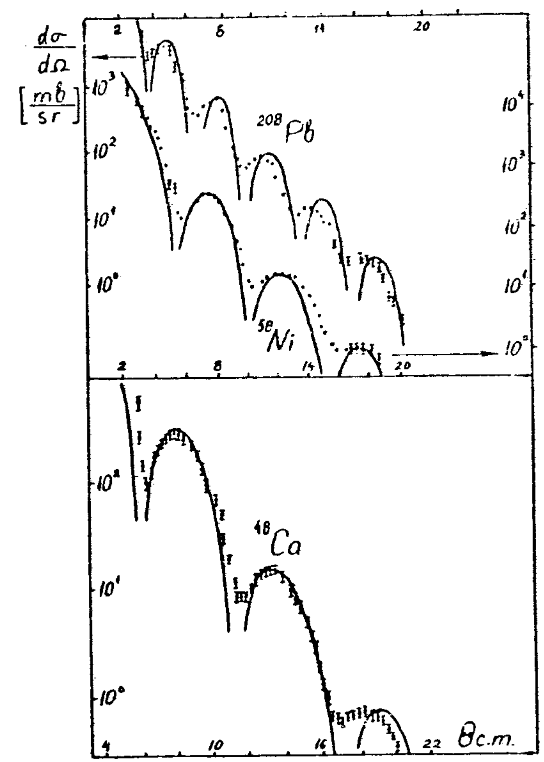

Fig. 2. Differential cross section for 1 GeV elastic proton scattering on ^{48}Ca , ^{58}Ni , ^{208}Pb.

energy of the projectile particle increases, the interaction effective radius might also increase because there exist fluctons of large radii in the model.

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