# Analysis of energy dependence of the total cross sections of neutron interaction with nuclei in the energy interval 28–54 GeV

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The experimental data[1] on neutron-nucleus total cross sections are compared with the Glauber theory. It is shown that the theory agrees well with experiment, if account is taken of purely nuclear effects in the energy dependence of $\sigma_{tot}$.

The energy dependence of the neutron-nuclear total cross sections was recently investigated in an experiment with the Serpukhov accelerator in the energy range 28—54 GeV.[1]

We examine the results of[1] from the point of view of modern theory of the interaction of high-energy hadrons with nuclei. The theory in the Glauber approximation[2] makes it possible to calculate the neutron-nuclear total cross sections by using the experimental values of the parameters of the amplitude of elementary nucleon-nucleon scattering.

The calculation of the neutron-nuclear total cross section has been the subject of several studies (see, e.g.,[3–5]), but the accuracy of these calculations is limited, since it is governed mainly by the errors in the nuclear-density-distribution parameters. We are interested primarily in the energy dependence, observed in[1], of the total cross sections for the interaction of neutron with nuclei in the energy interval 30—60 GeV. This energy region is singled out in that respect that the energy dependence of the elementary nucleon-nucleon cross sections is weaker here (at least for $pp$ interactions), and the conditions are therefore favorable for the appearance of purely nuclear effects.

The nucleon-nuclear total cross sections can depend on the energy even when the elementary cross sections are constant. As the energy increases, the ratio of the real to the imaginary part of the amplitude ($\alpha$) changes and the interference cone of the elastic nucleon-nucleon scattering ($B$) becomes narrower. In addition, a change takes place in the correction for the inelastic screening ($\Delta_{in}$).[7] These effects lead to the appearance of an energy dependence of the nucleon-nuclear total cross sections. Theoretical estimates of this dependence can be obtained with greater accuracy than the calculations of absolute cross sections, inasmuch as the uncertainty of the energy-independent parameters of the nuclear density distribution has little effect on the result.

We have calculated the neutron-nuclear total cross sections in the Glauber approximation,[4] using the parameters of the Woods-Saxon distribution of the nuclear density[10] and with allowance for the correction for the inelastic screening,[8] i.e.,

$$\sigma_{tot}(A,E) = \sigma_{\text{Glauber}}(A,E) + \Delta_{in}(A,E),$$

where $A$ is the atomic number, $E$ is the initial neutron energy, and $\Delta_{in}$ is the correction for the inelastic screening (see Fig. 1). We calculated $\sigma_{tot}(A,E)$ at three values of the energy (the same as in the experiment of[1]),[1)] after which we determined the energy-dependence parameters by minimizing the sum of the squares of the deviations of the obtained cross sections from the straight line

$$\sigma_{tot}(A,E) = \sigma - C \cdot E .$$

The calculated energy-dependence parameters

$$\epsilon_{hA} = C/\sigma_{tot}$$

were then compared with those measured in the experiment[1] by minimizing $\chi^2$, the only free minimization parameter being the value $\epsilon_{NN}$ of the energy dependence of the nucleon-nucleon cross section.[2)]

It is seen from Fig. 2, which shows the calculation result (curve 1) together with the experimental data, that the theory describes the experimental data quite satisfactorily ($\chi^2_{min} = 3.4$). To separate the purely

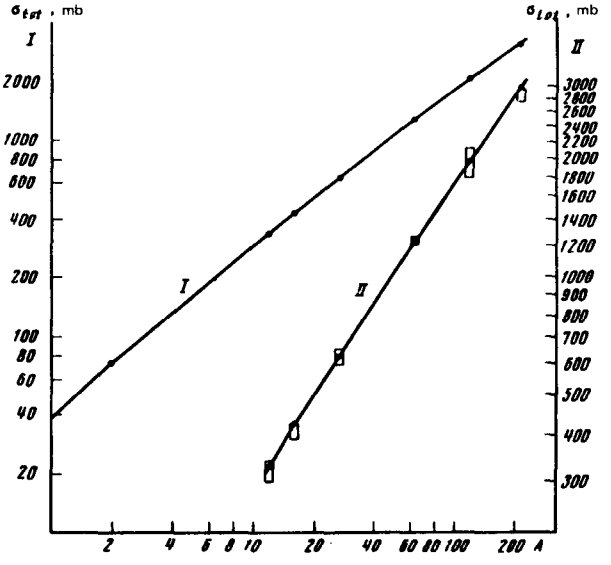


FIG. 1. Total neutron-nuclear cross sections vs the atomic number. The data are presented in two scales. The curves are drawn freehand through the experimental points of[1]. Curve II shows the uncertainties of the theoretically calculated cross sections at those values of A at which the calculations were performed.

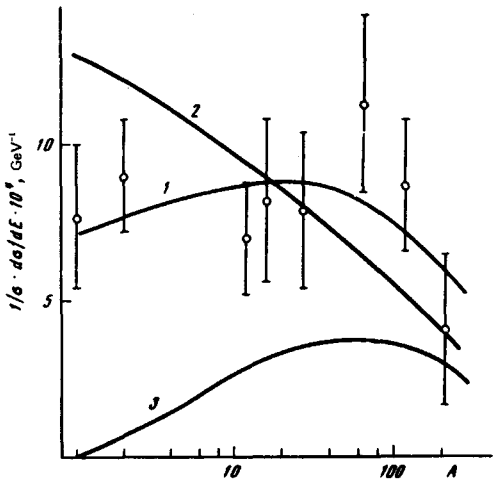


FIG. 2. Comparison of the measured[1] energy dependence of the neutron-nuclear total cross section in the energy range 26—54 GeV, $\epsilon = c/\sigma_{tot}(\sigma_{tot} = \sigma - CE)$ with the theory (see the text). The results of the calculations are shown by the following curves: 1) $\Delta_{in}$ from[8], $B(E)$ and $\alpha(E)$ from[9]; 2) $\Delta_{in} = 0$, $\alpha = 0$, $B = \text{const}$; 3) $\epsilon_{NN} = 0$, $\Delta_{in}$ from[8], $\alpha(E)$ and $B(E)$ from[9].

nuclear effects, an anlogous calculation was performed under the assumption that $A_{in} = 0$, $\alpha = 0$, and $B = \text{const}$ (curve 2 in Fig. 1). The result

$$\epsilon_{NN} = 13 \cdot 10^{-4}\ \text{GeV}^{-1} \quad (\chi^2_{min} = 7.6), \tag{1}$$

can be compared with the measured quantity[1]

$$\epsilon_{np} = (7.7 \pm 2.3) \cdot 10^{-4}\ \text{GeV}^{-1}$$

The difference exceeds two standard deviations. Taking also the $pp$ data[6] into account and comparing $\epsilon_{NN}$ with the quantity $(\epsilon_{np} + \epsilon_{pp})/2$, the difference exceeds four standard deviations.[3)]

Similar results are obtained if the $nd$ and $pd$ data[1,6] are also considered.[4)] Although the agreement with the experiments of[1] ($nd$) and[6] ($pd$) is problematic, it is difficult in any case to reconcile them with the result of (1). We can thus conclude that a comparison of the experiment[1] with theory points to the presence of purely nuclear effects.

The influence of the $B(E)$ relation on the energy dependence of the total cross sections can be easily taken into account by formulas of[4], inasmuch as the value of $B(E)$ is known well enough from experiment[9] and leads to a weak growth of $\sigma_{tot}$ with energy. The experimentally observed decrease of the total cross section with energy is therefore due to the influence of at least one of two other effects, namely the $\alpha(E)$ and $\Delta_{in}(E)$ relations.

The derivative $d\alpha/dE$ can be obtained from the data of[9] with a rather large error (50—100%), but on the other hand the accuracy of the theoretically estimated correction $\Delta_{in}$ is likewise low (20—50%). Under these conditions, as shown by the calculations, it is difficult to distinguish between the two indicated effects; the experimental data can be described under the assumption $\Delta_{in} = 0$, by increasing somewhat the influence of $d\alpha/dE$, as well as by assuming $\alpha = 0$ and increasing the contribution of $d\Delta_{in}/dE$.

Curve 3 of Fig. 2 was calculated under the assumption that the elementary nucleon-nucleon cross section is constant in the considered energy region. The calculation result agrees poorly with the experimental data, although the agreement can be improved somewhat by varying $d\alpha/dE$ within the range of the experimental errors of[9] and by varying $\Delta_{in}$ within the range of the theoretical uncertanties. The probability of the compatibility of the hypothesis $\epsilon_{nn} = 0$ with experiment can be then raised to a level of several per cent.

Our analysis shows thus that the data of[1] are adequately described by the theory in the Glauber approximation and point to the presence of purely nuclear effects in the energy dependence of the total neutron-nuclear cross sections. The data of[1] agree also with the assumption that the elementary nucleon-nucleon cross section decreases when the energy changes from 26 to 54 GeV.

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[1)] The experimentally obtained[9] parameters $d(E)$ and $B(E)$ of the nucleon-nucleon scattering amplitude were used in the calculation.

[2)] The data for $A > 2$ were used to determine the minimum of $\chi^2$.

[3)] When estimating $\epsilon_{pp}$ from the data of[6] [$\epsilon_{pp} = (2.8 \pm 1.4) \times 10^{-4}\ \text{GeV}^{-1}$], we did not take the systematic errors[6] into account.

[4)] The nuclear effects in deuterium were estimated using the formulas of[11] and turned out to be small, as expected.

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