HIGH ENERGY NEUTRON-NUCLEUS TOTAL CROSS-SECTION

G. V. BOCHMAN ‡
McGill University, Montreal

and

O. KOFOED-HANSEN * and B. MARGOLIS **
CERN-Geneva, Switzerland

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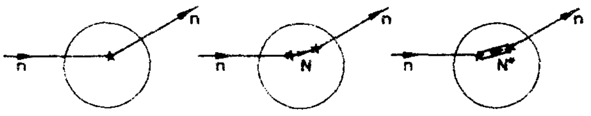
The total neutron cross-section on nuclei is calculated from 5 to 21 GeV/*c* and compared with experiment. One can only tolerate a modest amount of regenerative amplitudes, following diffractive production. Arguments are given for including only intermediate N* states in the diffractive production component.

Recently there have been measurements [1] performed of neutron total cross-sections on Be, C, Al, Cu and Pb with one per cent accuracy at avergage neutron momenta of 8, 11, 14 and 21 GeV/*c*. For all elements there is a smooth drop of about 3% between 8 and 21 GeV/*c*, very similar to that for the corresponding p-p and n-p total cross-section. Normalizing the cross-sections to the n-p total cross-section, no momentum dependence is observed. This is a little puzzling for the heavy nuclei since one expects to be approaching the physical situation of a "black target" with a geometrical cross-section, for a nucleus as heavy as lead. On the other hand, the energy dependence under consideration is rather weak and the blackness of the heavy nucleus is weakened if one includes the regenerative amplitude resulting from first producing diffractively nucleon isobars on one nucleon and then having them regenerate a neutron (see fig. 1c). To what extent the regeneration contributes is at this point to be answered through calculation.

The object of this letter is to describe the results of detailed calculations of the elastic scattering of neutrons from nuclei which includes regenerative effects. Pumplin and Ross [2] have suggested that regenerative effects are quite strong, depleting total cross-sections of heavy nuclei by some 20% at energies of the order of 20 to 30 GeV. The data do not bear this out, however, and we shall return to a discussion of this question below.



1-Step scattering (a)

2-Step scattering (b)

2-Step regeneration (c)

Fig. 1. The one-step and two-step processes contributing to neutron-nucleus elastic scattering.

We have made calculations of the elastic scattering of neutrons from nuclei using a coupled channel eikonal approach [3] taking into account regeneration of neutrons after production of the neutral charge state of the isospin $\frac{1}{2}$ isobars N^*_{1400}, N^*_{1520}, N^*_{1688}, N^*_{2190}. The method allows for any number of back and forth transitions between the neutron and these isobars. The forward amplitude for these processes, required in the calculations are taken from ref. [4]. Specifically, we calculate the elastic scattering amplitude [3].

$$F(q) = \frac{ik}{2\pi} \int \exp(\mathrm{i}\,\boldsymbol{q}\cdot\boldsymbol{b})[1 - \phi_1(\boldsymbol{b}, \infty)]\,\mathrm{d}^2 b \qquad (1)$$

where $\phi_1(\boldsymbol{b}, z)$ is obtained from numerical solution of the coupled wave equations

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* On leave from the Danish AEC, Risö, Roskilde.

** Address after September 1970: McGill University, Montreal, 110, Canada.

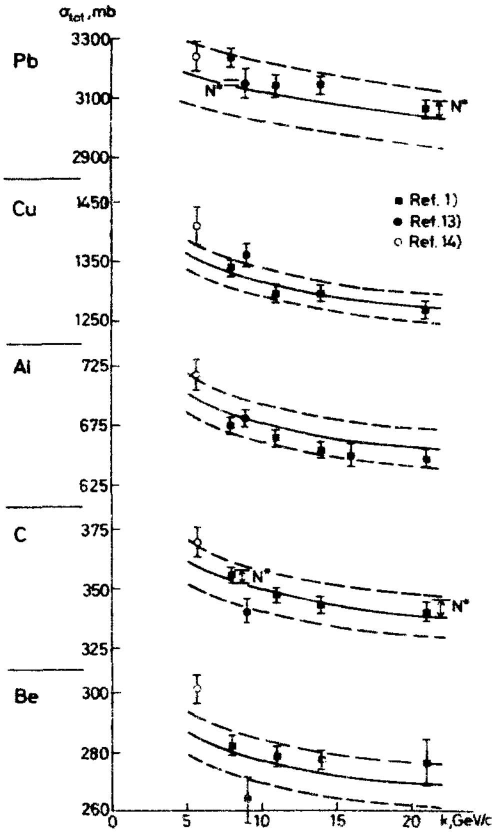

Fig. 2. Calculated and experimental values of neutron-nucleus total cross-sections. The experimental data are from refs. [1], [13] and [14]. The solid lines are obtained using nuclear parameters from ref. [5]. The dotted lines are calculations using values of the nuclear radii at the upper and lower values of the experimental uncertainties. The effect of omitting the N* contribution is shown for C and Pb. The effects of regeneration from ref. [2] are several times as large.

$$\frac{d}{dz}\phi_\alpha(b,z) = \tag{2}$$

$$= \frac{1}{2ik_\alpha}\sum_\beta U_{\alpha\beta}(b,z)\exp\{i(k_\beta - k_\alpha)z\}\,\phi_\beta(b,z)$$

The optical potentials are given by

$$U_{\alpha\beta}(r) = -4\pi f_{\alpha\beta}(0)A\rho(r) \tag{3}$$

In the above equations, q is the three-momentum transfer and $f_{\alpha\beta}(0)$ is the diffractive amplitude for particle α producting particle β on a nucleon in the forward direction. Particle 1 is the incident neutron. The quantity $\rho(r)$ is the single particle nucleon density assumed the same for neutrons and protons. To allow for the difference between proton and neutron amplitudes, one takes the weighted mean for $f_{\alpha\beta}(0)$. We have taken the nuclear shape to be Woods-Saxon in form with parameters as given by Ting et al. [5]. Our two-body parameters are given in the table 1. We have taken the ratio of real to imaginary parts of forward p-p and n-p- scattering, α, to be equal. We have also assumed the same phase for the diffractive production amplitudes.

The results of our calculations are shown in fig. 2. The measurements and calculations agree very well. The effects of regeneration as included here are small as shown in fig. 2. We note now uncertainty in nuclear radius, the small but non-negligible experimental errors in nucleon-nucleon total cross-sections and α (which could change our results by ± 1 to 2%) and the neglect of nuclear correlations (+1 to 2% for short range correlations, 0 to 2% for deformation effects). Given all of this, it is not completely clear that the effect of N* is manifest at present energies. However, for the heaviest nuclei, as seen in fig. 2, regeneration contributes in an energy dependent way to improve the energy dependence of the calculations when compared with experiment. The fact that the weakening of the nuclear shadow in the heavy nuclei increases appreciably with energy follows from longitudinal momentum transfer considerations. The only important regeneration amplitude comes from diagram c) of fig. 1 and interferes destructively with the "direct" Glauber scattering amplitude [6].

The authors of ref. [2] include virtually the whole missing mass spectrum as contributions to the regenerative amplitude. The forward differential cross-section from this spectrum is about half the forward elastic differential cross-section. The fact that the regenerative amplitude is not nearly so strong as suggested in ref. [2] could be the result of the following.

a) There are many diffractive amplitudes but with different phases and therefore much cancellation.

Table 1

Nucleon lab. momentum (GeV/c)	σ_{pp} (mb)	σ_{np} (mb)	α
5	41.0	40.5	-0.35
8	40.3	39.7	-0.33
14	39.4	38.7	-0.27
21	39.0	38.5	-0.20

σ_{pp} and α from ref. [10];
σ_{np} from refs. [11] and [12].

b) The non-resonant background included in the work of ref. [2] is largely non-diffractive.

c) Non-resonant diffraction products spread too much before travelling a distance of the order of inter-nucleon spacing to regenerate a nucleon. Much spreading is expected from the laws of transverse momentum distributions [7].

In connection with these possibilities, a careful study of incoherent scattering of nucleons from deuteron targets is of interest [8, 9]. Incoherent regeneration on the deuteron can still be expected to be rather strong if the weakness of coherent regeneration results from effects a) and/or b) above. It will be weak if effect c) is responsible for the weakness of coherent regeneration, since the two nucleons in the deuteron are relatively far apart (≈ 2 fm). At the moment the data are not quite good enough to be definitive.

We point out, as a final remark, that the question of whether or not one has only to couple resonances and not background in high energy coherent processes in nuclei is an interesting one. If in fact this is the case, then one can expect to get a good deal of new information about higher unstable resonances from coherent production studies [3] at Serphukov and NAL energies.

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