nucleons in the nucleus, where the spin-orbital term is particularly significant.

[1] H. Hellman, Acta Phys.-Chim. URSS 4, 225 (1936)

[2] D. Ivanenko and V. Rodichev, Dokl. Akad. Nauk SSSR 70, 605 (1950)

[3] P. Gombash, Uspekhi Fiz. Nauk 49, 385 (1953)

[4] L. Rapoport and V. Filimonov, J. Exper. Theoret. Phys. USSR 27, 243 (1954)

Translated by E. Rabkin
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Total Cross Sections of Nuclei of Certain Elements for Neutrons with Energies of 590 mev

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USING the synchrocyclotron of the Institute of Nuclear Problems we performed experiments for the purpose of determining the total cross section of protons, deuterons and more complex nuclei for neutrons with average effective energies of 590 mev. The neutrons were obtained as a result of "charge exchange" in beryllium of protons accelerated to energies of 680 mev. The above cross sections were measured on the basis of the loss of neutrons from the beam.

The general experimental scheme is shown in Fig. 1. The absorbers of materials under investigation were placed immediately in front of the steel collimator (diameter of the aperture: 3cm) which was placed within the protective wall. The neutrons, having traversed the absorber and the collimator were detected by the telescope T_1, composed of three scintillation counters (with tolane crystals) which registered the recoil protons emitted at an angle of 20 degrees from a polyethylene scatterer placed in the beam. The experiments were performed under conditions of good geometry. The neutrons scattered in the sample at an angle greater than 15 minutes could not strike the scatterer and consequently were not detected by the telescope. The intensity of the neutron beam was continuously controlled by means of a similar telescope T_2. The resolving time of coincident events of the telescopes was 6×10^{-8} sec.

The energy threshold of the detector for neutrons was 470 mev, determined by the thickness of tungsten filters placed between the second and third counters. The neutron energy distribution in the beam was determined in our laboratory by Fliagin[1]. The results of these measurements are shown in Fig. 2. With the energy threshold of the detector set to the above indicated value, the average effective energy of the neutrons for which we determined the cross sections, $E^{eff}_{n,\,average} = 590$ mev. The cross sections were determined on the basis of the formula:

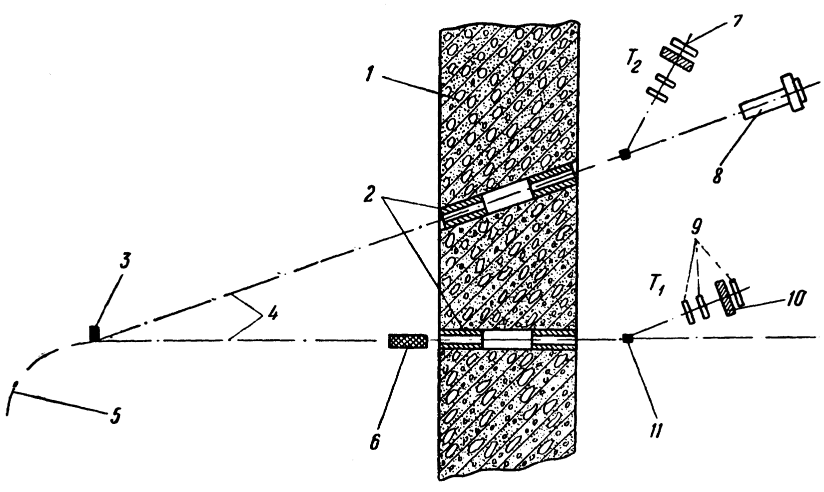

FIG. 1. Experimental Arrangement. *1* – Concrete shield; *2* – Collimators; *3* – Target (Be); *4* – Neutrons; *5* – Protons ($E_p = 580$ mev); *6* – Sample; *7* – Telescope; *8* – Bi- Chamber; *9* – Detecting telescope; *10* – Filter; *11* – Scatterer

$$\sigma_t = \frac{1}{nx} \ln \frac{N_0}{N_n},$$

where: N_0 and N_n are relative neutron intensities, corrected for the background and measured in the presence of the sample in the beam, and without it. n = number of nuclei per cubic centimeter of sample material, and x = thickness of the sample in centimeters.

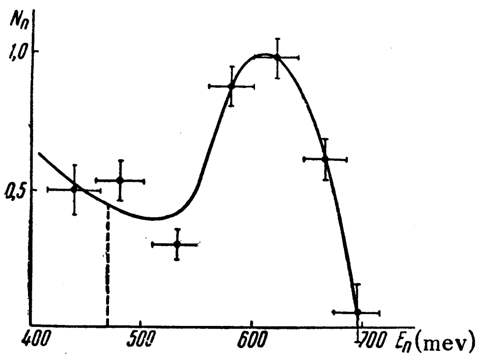

FIG. 2. Neutrons Energy Spectrum

The results of control experiments, performed with Al and Cu absorbers of various thicknesses, showed that the semi-logarithmic plot of the decrease of the neutron beam is, indeed, linear with respect to the absorber thickness.

The total cross section for neutron scattering in hydrogen was determined on the basis of the difference of the cross sections of carefully purified polyethylene and graphite. The cross section of oxygen was determined on the basis of data obtained for total cross sections for neutron interactions with water and hydrogen; the cross section of deuterium was determined on the basis of the difference of the cross sections of heavy water (D_2O) and oxygen.

The results of the measurements are shown in the following Table (third column). The limits of accuracy of the magnitudes of the cross sections, indicated in the Table, represent the average quadratic errors, determined by the differences of the results of a large number (30-40) of separate measurements of cross sections, from the arithmetical average .

The analysis of the data obtained and their comparison with the results of measurements performed at lower neutron energies permits the following conclusions:

1. The total cross section for the interaction of neutrons with protons, practically does not change in the neutron energy interval from 270 to 590 mev. The magnitude of this cross section obtained at 590 mev, and also the fact, that according to references 2 and 3 total cross sections for the production of neutral and charged π-mesons in $(n-p)$ collisions at that energy represent $\sim 6 \times 10^{-27}\text{cm}^2$ and $(3-4) \times 10^{-27}\text{cm}^2$ respectively, permit the conclusion that the total cross section of the elastic $(n-p)$ scattering, $\sigma_t^{elast}(n-p)$, at this energy, equals $\sim$ (26-28) $\times 10^{-27}\text{cm}^2$. Considering that at 270 mev, $\sigma_t^{elast} \times (n-p)$ is $35 \times 10^{-27}\text{cm}^2$ [4], then the observed

Substance	Geometrical cross section* of the nucleus πR^2 in 10^{-27} cm^2	σ_t in 10^{-27} cm^2 E_n=590 mev	Transparence of the nucleus $\eta = 1 - \sigma_t/2\pi R^2$
H	—	36±2	—
D	—	72±2,5	—
D—H	—	36±2	—
Be	255	261±4	0.49
C	310	319±2	0.48
O	375	407±5	0.46
Al	515	631±9	0.39
Cu	945	1250±40	0.34
Sn	1430	1980±40	0.31
W	1900	2780±60	0.27
Pb	2060	2920±70	0.29
U	2260	3290±70	0.27

* The geometrical cross sections of the nuclei are determined on the basis of nuclear radii $R = 1.37 \times A^{1/3} \times 10^{-13}$cm, determined from known data on total nuclear cross sections for neutrons with energies of 15-20 mev when the nuclei can be assumed to be non-transparent.

decrease of this cross section is about 20% when the energy of the neutrons is raised from 270 to 590 mev. Since the total cross section of the elastic $(n-p)$ scattering represents the sum of interactions of nucleons in states with isotopic spins $T=0$ and $T=1$, and since, on the basis of available data [5,6], the cross section for elastic $(p-p)$ scattering (cross section of interaction in state with $T=0$) remains constant in the indicated energy range, then the observed decrease of $\sigma_t^{elast}(n-p)$ is determined by the decrease with energy of the cross section of interaction of nucleons in a state of isotopic spin T equal to zero. This deduction, among others, indicating the difference in nucleon interaction in states with $T=0$ and $T=1$, was made by us previously[7], where the problem of $(n-p)$ interactions at high energies was studied in more detail.

2. The cross section of $(n-p)$ interaction when the energy was raised from 270 mev to 590 mev, increased by about 25%. The difference of total cross sections of $(n-d)$ and $(n-p)$ interactions for this energy interval increased by more than 60%. A comparison showed that within experimental errors the difference of cross sections $\sigma_t(n-d)-\sigma_t(n-p)$ found at $E_n = 590$ mev coincides in magnitude with the cross section for $(p-p)$ interaction determined in reference 8 for protons with the same energy. The latter fact, in the light of conditions of charge symmetry of nuclear forces, the existence of which is confirmed for high energy of nucleons[9], shows that interference effects at 590 mev introduce a small contribution to the cross section of $(n-d)$ interaction. In such case the observed increase of this cross section in the 270-590 mev energy interval is explained by the increase of the cross section of the interaction of neutrons with neutrons, depending as in the case of two protons interaction on the increase of the probability of inelastic $(n-n)$ resonances.

3. The total cross sections of complex nuclei when the energy is varied from the interval 200-400 mev, where they are practically constant, to 590 mev vary differently, depending on the atomic weight. Thus, the cross sections of light nuclei, such as Be, C, O increase by 10-15%. The cross sections of nuclei of heavy elements remain unchanged within experimental errors. The transparency of nuclei of elements of low A is ~ 0.5 (see Table); for elements with high A it is equal to ~ 0.3.

The observed increase of the total cross sections of light nuclei when the neutron energy is raised from 400 to 590 mev is explainable by the growth of cross sections of elementary nucleon-nucleon interactions [particularly the cross section for $(n-n)$ interactions] in the energy range under consideration. The cause of the invariability, for these energies, of the total nuclear cross sections of elements with high A, is at present unclear. The quantitative analysis (for example on the basis of the optical model of the nucleus) of such behavior of these cross sections, could be considerably helped by data on the energy dependance of total cross sections for inelastic and diffraction scattering of neutrons by nuclei in the energy range under study.

[1] V. B. Fliagin, Report Inst. Nuclear Problems, Acad. Sci., USSR, 1954

[2] V. P. Dzhelepov, V. B. Fliagin and K. O. Oganesian, Report Inst. Nuclear Problems, Acad. Sci., USSR, 1954

[3] I. M. Kazarinov and I. N. Simonov, Report Inst. Nuclear Problems, Acad. Sci., USSR, 1954

[4] E. Kelly, C. Leith, E. Segre and C. Wiegand, Phys. Rev. **79**, 96 (1950)

[5] O. Chamberlain, E. Segre and C. Weigand, Phys. Rev. **83**, 923 (1951)

[6] M. G. Meshcheriakov, N. P. Bogachev, B. C. Neganov and E. V. Piskarev, Dokl. Akad. Nauk SSSR **99**, 955 (1954); N. P. Bogachov and I. K. Vzorov, Dokl. Akad. Nauk SSSR **99**, 931 (1954)

[7] V. P. Dzhelepov, I. M. Kazarinov, B. M. Golovin, V. B. Fliagin and V. I. Satarov, Izv. Akad. Nauk SSSR, Ser. Fiz. **19**, 5 (1955)

[8] A. Shaprio, C. Leavitt and F. Cheu, Bull. Am. Phys. Soc. **29**, 4, 75 (1954)

[9] V. P. Dzhelepov, B. M. Golovin and V. I. Satarov, Dokl. Akad. Nauk SSSR **99**, 943 (1954)

Translated by M. Ter-Pogossian
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Neutron Spectrometry Based on the Measurement of the Decelerating Time of Neutrons

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THE process of the deceleration of neutrons in a medium possesses a property which permits us to develop a new method of neutron spectrometry. This property is the gradual monochromatization of neutrons resulting, essentially, from the fact that, of the neutrons introduced into the medium, the fastest neutrons collide relatively more frequently with the nuclei of the decelerator. If the mass of the nuclei of the decelerator M (the mass of the