the introduction of donor impurities have produced negative results.

In conclusion the authors must thank Academician A. A. Lebedev for his interest and valuable suggestions. The authors are also grateful to G. V. Anan'eva and A. I. Kuznetsov for their assistance.

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Energy Distribution of Neutrons Emitted from Beryllium Bombarded by 680 Mev Protons

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The neutron energy spectra were measured at angles of 0 and 18° in the laboratory system. A peak not observed at lower primary-proton energies was detected in the 100–400 Mev region. The existence of this peak is explained by π-meson production processes.

THE PRESENT NOTE is to describe one of the experiments carried out to investigate the main characteristics of the fast neutron beams formed when beryllium targets are bombarded by 680-Mev protons.

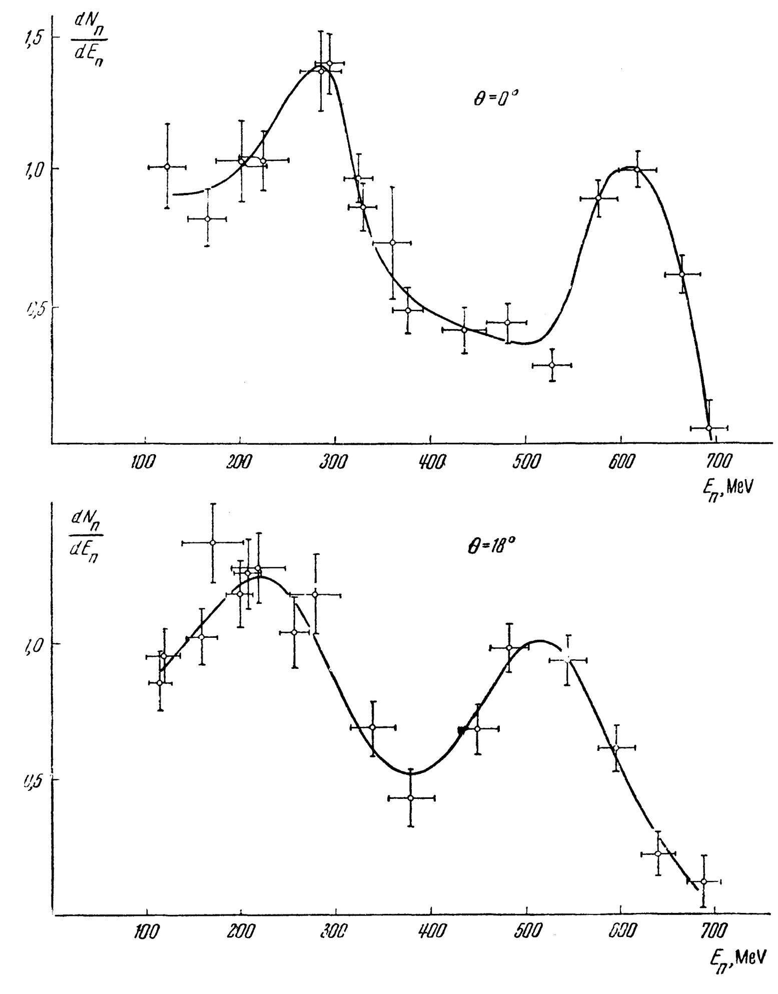
In the present experiment the target was placed inside the synchro-cyclotron chamber and was 2.5 cm thick. The experiment was performed at angles $\theta = 0°$ and $\theta = 18°$ between the neutron beam and the direction of the velocity of the protons impinging on the target. The neutron energy distribution was investigated by determining the energy spectra of the recoil protons, emitted at a 30° laboratory angle, as a result of elastic $n-p$ scattering. For this purpose, paraffin or graphite scatterers were placed in the path of the neutron beam; the effect due to hydrogen was determined from the difference between the effects of these two scatterers.

The measurements were performed principally by the differential method. In this case the detector, a telescope with four scintillation counters (three were connected for coincidence, the fourth for anticoincidence), was used to measure the intensity of the recoil proton current in some relatively narrow energy interval. The width of this interval and its position on the energy scale were fixed by means of copper and tungsten filters, placed between the third and fourth and between the second and third counters, respectively. A system of controlling experiments made it possible to make all the necessary corrections, in particular to take into account the loss of protons in filters, their scattering in the scintillators, etc.

The main source of error in our experiment could have been the admixture of charged particles emitted from the following reactions in the scatterer:

$$n + p \rightarrow \pi^0 + (n + p); \quad n + p \rightarrow \pi^- + p + p;$$
$$n + p \rightarrow \pi^+ + n + n.$$

The corrections related to meson production processes included only in the high energy part of the neutron spectrum ($E_n > 450$ Mev), for which Kazarinov and Simonov, in a special experiment[1], have measured the integral $\pi^{\pm}$-meson yield from these reactions. Unfortunately, there are no experimental data on the energy spectrum of $\pi^{\pm}$-mesons formed in $n-p$ collisions. These corrections have therefore been calculated on the assumption that the energy distribution of the $\pi^{\pm}$-mesons corresponding to different incident neutron energies has a form similar to the spectra of $\pi^{\pm}$-mesons from the



Neutron energy spectra.

reaction $p + p \rightarrow p + n + \pi^+$, spectra which have been studied for 657 and 556 Mev protons. The same calculations indicate that the admixture of charged particles from the above-mentioned reactions constitutes, in the part of the spectrum with $E_n < 450$ Mev, an average of $\sim 5\%$ of the number of the protons emitted in elastic $n-p$ scattering.

The neutron energy distributions determined from the experiments are shown in the figure. The errors are statistical errors due only to the present measurements. One can see from the figure that for $\theta = 0°$ the maximum in the high energy region (600 Mev) is $\sim$ 80 Mev lower than the upper limit of the spectrum. This decrease of the neutron energy with respect to the maximum energy of the protons impinging on the target is mainly related to the proton energy spread. The latter is due mostly to the radical oscillation of the synchro-cyclotron beam[3] and to the loss of energy by ionization during multiple passage of the protons through the target. The mean value of the energy lost by such processes constitutes 20 to 25 Mev. The angular spread of the beam due to multiple scattering and the angular spread of the proton incidence on the target are too small to affect this value. The additional energy losses should therefore be attributed to the proton-beryllium interaction process itself.

It is interesting to note that, in the impulse approximating, owing to the energy and momentum conservation laws, the pair collision of protons with nuclear neutrons should give for the neutrons emitted at an angle $\theta = 0°$ a spectrum identical to the spectrum of the primary protons. In this case, however, because of the exchange character of the $p-n$ interaction, the nucleus is left out with a low energy proton instead of a neutron. The probability of such a process should decrease considerably because of the Pauli principle. It is possible that a considerable role is played by multiple collisions and also by collisions in which part of the energy is carried away by a third particle. In this case, the restriction made by the Pauli principle can be removed and the energy of the neutrons coming out of the nucleus must then be considerably different from the primary proton energy; the neutron spectrum will then be strongly smeared out. Quantitative calculations of all these processes are difficult at the present time, and our remarks have only a qualitative character.

A new fact observed when changing the primary proton energy from 480 Mev[5] to 680 Mev is the presence of a second maximum in the neutron energy spectrum, located in the 100–400 Mev region. The presence of this peak is mainly due to neutrons emitted in the reactions with π-meson production on beryllium nuclei:

$$p + p \rightarrow \pi^+ + n + p; \quad p + n \rightarrow \pi^0 + n + p;$$
$$p + n \rightarrow \pi^+ + n + n.$$

The proposed explanation is confirmed by the following facts:

1. The total cross section for neutron yield (calculated per nucleon) from the mentioned reactions is close to the total elastic $p-n$ scattering cross-section.

2. The position and the shape of the second maximum of the neutron energy spectrum for $\theta = 0°$ coincides within experimental accuracy with the position and shape of the maximum of the spectrum of the protons emitted in the elementary process $p + p \rightarrow \pi^+ + n + p$ at an angle close to 0°. This follows from the comparison of our data with the proton spectrum from the above-mentioned reaction, which was carefully measured[4] for an emission angle of 7°.

3. As the angle is changed to $\theta = 18°$, the second maximum shifts towards lower energies; the part of the neutrons in the low-energy region of the spectrum (from 100 to 400 Mev) decreases considerably with respect to the part of the neutrons in the high-energy region (from 400 to 680 Mev); this is in qualitative agreement with the proposed explanation for the nature of these neutrons.

4. For a proton energy of 480 Mev, when the cross section for π-meson production in nucleon-nucleon collision is not large, an analogous (second) maximum is not observed (within experimental accuracy)[5].

These data also permit to say that the mechanism of nuclear emission in π-meson production on nucleons bound in the nucleus retain in a definite way the character of free nucleon-nucleon collisions.

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