

ON THE ANGULAR AND ENERGY DISTRIBUTION OF SOLAR
NEUTRONS GENERATED IN P-P REACTIONS

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U S S R

Problem of high energy neutron generation in P-P reactions in the solar atmosphere is reconsidered. It is shown that the angular distribution of emitted neutrons is anisotropic and the energy spectrum of neutrons depends on the angle of neutron emission.

Solar neutrons have been detected for two flares June 21 1980 and June 3 1982 in direct experiments on board of the SMM satellite [1,2]. P.Evenson et al. [3] have observed fluxes of energetic protons in interplanetary space which they interpret as the decay products of neutrons generated in a solar flare on June 3 1982. High energy neutrons from this flare have been observed by high mountain neutron monitors at Jungranjoch (Switzerland) and Lomnitsky Stit (Czechoslovakia) and by ground-based station in Roma [4-7].

The problem of neutrons generation and their escape from the solar atmosphere have been considered by R.Lingenfelter et al. [8]. They assumed that an angular distribution of the neutrons is isotropic and the probability of neutron generation in proton-nucleus collisions does not depend on energy. However this assumption for the energies higher than 100 MeV is not valid for P-P and p-He collisions. For example, generated in p-p reactions neutrons with a kinetic energy 500 MeV are concentrated in apex angle of cone of 30° . As at the experiments solar neutrons are registered up to 1000 MeV we reconsider a problem of neutron generation taking into account available data on the differential cross sections of corresponding nuclear reactions. Here we consider only the results of the calculations for P-P interaction with

one pion generation. Neutron escape from solar atmosphere was calculated using Monte-Carlo method. Total and differential cross-sections for elastic and inelastic P-P-interactions were approximated by polynoms based on the available data. Details of calculations are given in [9]. Results of calculations are shown in Fig.1 and 2.

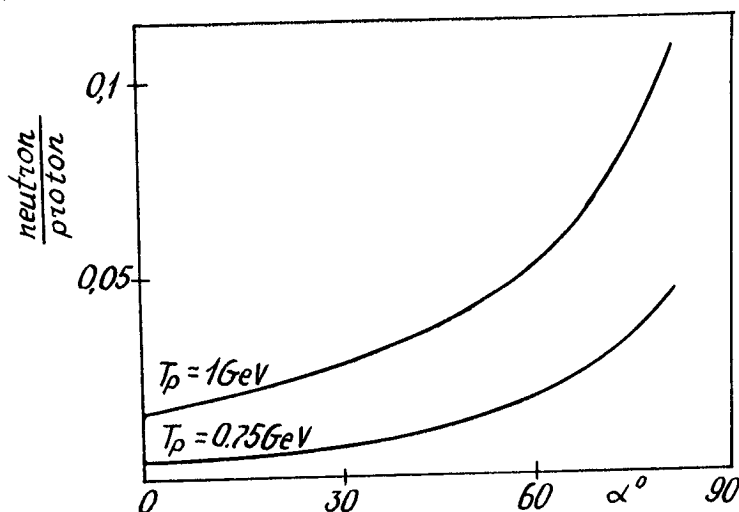


Fig.1. Dependence of neutron yield from the Sun (for energy interval 1-350 MeV) on angle of incidence α -is the angle between the Sun outward and proton velocity direction). T_p -is kinetic energy of protons.

It is seen that neutron emission is anisotropic and their energy spectrum depends on neutron emission angle. Neutrons with energy ≥ 100 MeV are emitted only at angles 60° and more. It is natural that only neutrons generated by protons with high α can escape the solar atmosphere without collision or with one or two collisions.

Based on the obtained data one can show that very few neutrons emit at the angles $\Delta\theta = 0^\circ - 15^\circ$ to solar normal and there is no neutrons with the energies ≥ 100 MeV. This fact helps to clarify that the neutrons were discovered in the flares with high heliolongitudes. The protons moving to the upper hemisphere practically have not ionization losses and the products of their reactions do not interact. Neutrons yield in this case depends on the thickness of the matter

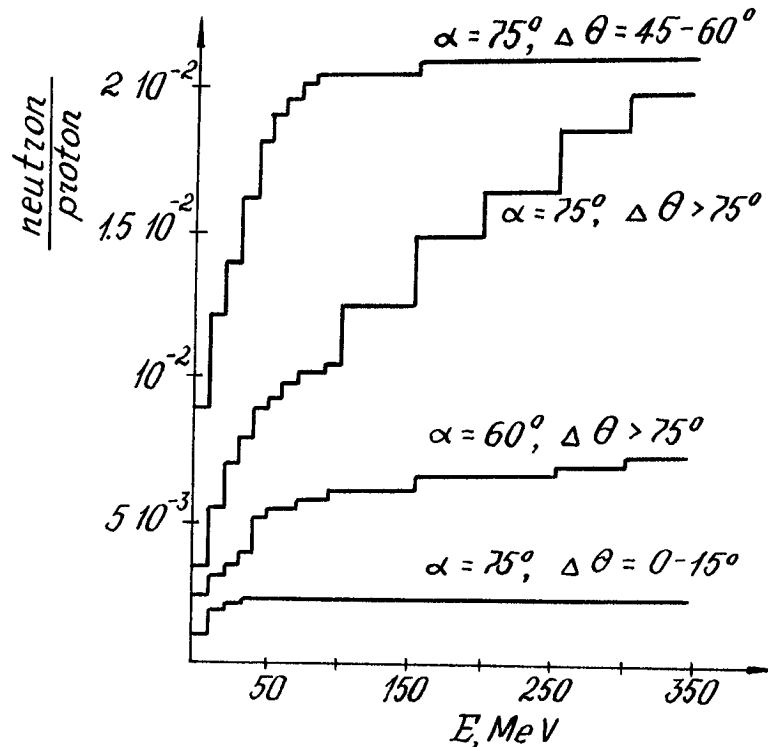


Fig.2. Energy spectrum of neutrons escaping into interplanetary medium(normalized to one proton). $T_p=1$ GeV and for the given point of observation on angular distribution of neutrons. The difference of neutron fluxes from the protons moving at 0° to solar surface and at large angle to it, will be mainly connected with different path of protons in the outer atmosphere of the Sun. Considering in first approximation that passing thickness of matter $\sim 1/\cos \alpha$ we obtain that for protons moving at the angle 72° , the neutron flux should be 3.2 times higher than for the protons at the angle 0° . Protons with the angles up to $15-20^\circ$ take part in generation of neutron flux for disc flare (0°), and for the flare E72 $^\circ$ -protons with angles less 72° are the main source of neutrons. So the difference in neutron fluxes from two such type of flares is not substantial (although, spectrum for the flare E72 will be more rigid). But the possibilities of observation of neutrons generated by protons moving to the lower hemisphere are substantially different for consi-

sphere are substantially different for considered two flares. Based on these facts, one may conclude that in flare 3.06.82(E72) the neutrons are generated by protons moving to the lower hemisphere. If in the acceleration region number density is 10^{12}cm^{-3} , the relative yield of neutrons for 72° in the case of thin target will be 10^{-2} - 10^{-3} from the yield for the thick target.

We can conclude also (not taking into consideration magnetic field), that in the flare of 3.06.82, accelerated particles did not form sufficiently narrow beam, directed bottom at the angles 0 - 30° .

The fact that the fluxes of neutrons with the energies > 100 MeV and the energy spectra depend on the direction of motion of accelerated particles allow to obtain the information on angular distribution of accelerated high energy particles by the registration of high energy neutrons.

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