Attenuation of Solar Neutrons in the Air Determined by an Accelerator Experiment

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Abstract

The attenuation of neutrons in the atmosphere was investigated experimentally by bombarding neutron beam onto a target of carbon. Since carbon has nearly the same atomic composition as the atmosphere, it is suitable to use a carbon target as a simulator of the atmosphere. The dimension of the target was designed according to a simulation study. The thickness of the target was changed from 0 g/cm^2 to 540 g/cm^2. The attenuation of neutrons in the carbon target was measured as a function of thickness at three different energies of neutrons, 100 MeV, 200 MeV, and 300 MeV, at the Research Center for Nuclear Physics, Osaka University. The results obtained by the experiment were consistent with our simulation.

1 Introduction:

It is very important to study neutrons in association with solar flares, because they propagate from the Sun to the Earth without influence from the interplanetary magnetic field. Therefore neutrons keep information on their production time, or the acceleration time of ions, if the energy of the neutron is identified. This is essential in understanding the acceleration mechanism of ions at the solar surface. The construction of a world-wide network of new types of solar neutron detectors, with capabilities of measuring neutron energies, was completed in 1998 (Matsubara et al. 1999).

In order to interpret neutron signals associated with solar flares correctly, it is required to know the detection efficiency of neutrons, and the propagation of neutrons in the atmosphere. There were discrepancies among simulations on the propagation of neutrons in the atmosphere (Shibata, 1994; Debrunner, Flückiger, and Stein, 1989). Both the detection efficiency of the neutron detectors and the attenuation of neutrons in the atmosphere were measured at the Research Center for Nuclear Study (RCNP), Osaka University, using neutron beams with well defined energies. The results of the detection efficiencies of these new detectors for neutrons are presented in Tsuchiya et al. (1999). The attenuation of neutrons in the atmosphere determined by this accelerator experiment, is presented here, together with details of the experiment.

2 Carbon Target:

The mass number of carbon is quite similar to that of nitrogen and oxygen, the major constituents of air. There are, however, three points which have to be considered in designing the carbon target to be as close a simulator of the atmosphere as possible. At first, we considered the density distribution of the carbon target. As is well known, the density of the atmosphere is not uniform from the top to the ground level. However, a carbon target has a uniform density. The second is the lateral size of the target. In cosmic ray experiments, the atmosphere can be regarded to have infinite size in comparison with neutron detectors. However, it is impossible to realize a target with infinite size inside the beam tunnel of neutrons (N0 course) at RCNP, and the effect of the finite size has to be considered. The third problem is an existence of gaps in the target. The attenuation of neutrons must be measured by changing the number of carbon blocks, and it is unavoidable to have small gaps between adjacent blocks. We calculated the attenuation of neutrons in the carbon target using a Monte Carlo simulation taking into account above mentioned problems. The model of the simulation is the same as used in the Shibata model (1994).

2.1 Difference between real atmosphere and uniform atmosphere:

The attenuation of neutrons in the atmosphere was examined for two cases. One is for neutrons passing through the real atmosphere. A "U.S. standard atmosphere 1975" model was used to represent the real atmosphere. The other is for neutrons passing through a uniform density atmosphere. We found no difference between both models when the attenuation of neutrons was represented by the column density.

2.2 Size limit of the carbon target: We have calculated the expected attenuation length of neutrons for various cases by changing the lateral size of the carbon target and of the scintillator behind the target. The cross section of the scintillator is taken to be the same as that of the target, and the threshold of the energy deposited in the scintillator was 40 MeV. The attenuation length calculated varies with the cross section of the carbon target, and it is desirable to make the lateral size of the target as large as possible. However, due to a limit towards the lateral direction, one must correct for systematic differences among lateral sizes of the target after measurement.

2.3 Structure of the carbon target: In order to examine the effect of extra space inside the target, the attenuation of neutrons in two types of target was simulated. One of the targets simulated has extra gaps in parallel with the neutron beams. The other has gaps only perpendicular to the beam line. The results of the simulation show that even a 1mm gap in parallel with the neutron beam gives more than a 10% difference in the attenuation length, whereas a 1mm gap perpendicular to the beam affects less than 1%. It is therefore essential to prepare the carbon target without a gap which is parallel to the direction of the neutron beam.

2.4 Design of the carbon target: According to the simulation results, the carbon target was to be composed of a uniform block. The size of one block of the carbon target is 50cm$\times$50cm$\times$10cm. The carbon target was installed perpendicularly to the beam as shown in Figure 1. The density of the carbon block is 1.8g/cm^3, and 30 blocks of the same size were prepared. Therefore it is possible to vary the total thickness of the carbon target from 0 g/cm^2 to 540 g/cm^2 at intervals of 18 g/cm^2.

3 Experiment:

The experiments were performed in 1998 at N0 concourse, the neutron time-of-flight facility (Sakai et al. 1992), at RCNP. Protons from the RING cyclotron bombarded into a ^{7}Li target with a thickness of 2.617mm. The beam intensity was continuously monitored with a Faraday cup and a beam line polarimeter. The latter method uses the $^1H(\vec{p},p)^1H$ reaction. The typical beam current used was 10 nA∼14 nA with the Faraday cup.

Neutrons from the (p, n) reaction at the ^{7}Li target were detected by a plastic scintillator with a size of 30cm×30cm×40cm, which is the same type as used in Bolivia (Matsubara et al. 1993). The detector was located at 63m away from the ^{7}Li target during the experiment. The carbon target was put just in front of the detector, and the number of carbon blocks was changed from 0 to 30, which corresponded to 0 g/cm^2 to 540 g/cm^2. The energy of protons bombarded into the ^{7}Li target was fixed in each experiment, and we performed four experiments in 1998 with different energies of protons, 100 MeV, 200 MeV (twice), and 300MeV. The experimental setup is shown in Figure 1.

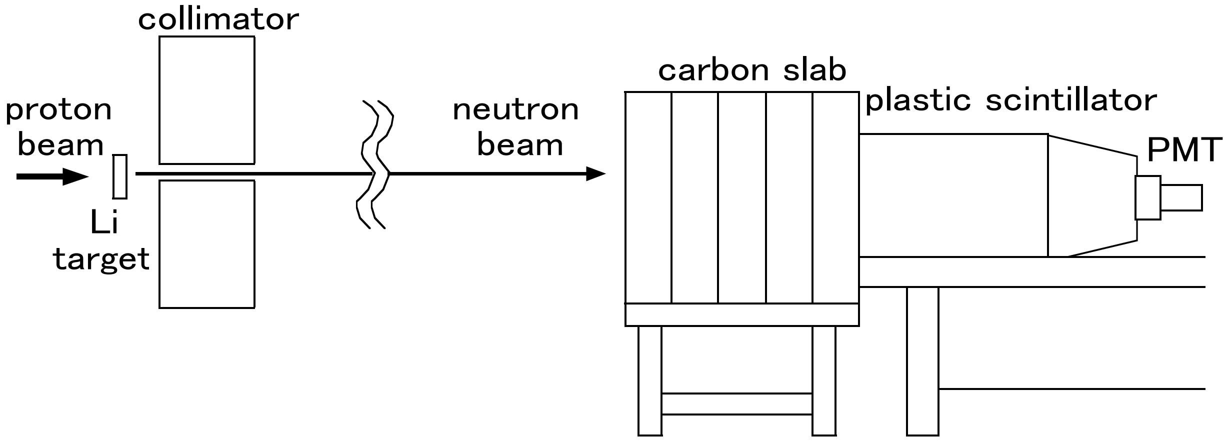

Figure 1: The experimental setup at RCNP to measure the attenuation of neutrons in the atmosphere.

There are two different types of (p, n) reactions at the ^{7}Li target. One is elastic by which neutrons obtain the same energy as of protons. The other is inelastic by which the energy of neutrons distributes almost uniformly below the energy of protons. The ratio of the elastic to the inelastic reaction is almost 1:1. In order to select neutrons obtained only by the elastic reaction, the energy of neutrons incident on the detector was selected by using the time-of-flight method.

4 Results and Discussions:

The neutron detector is sensitive to neutrons with energies >40 MeV. The number of neutrons produced at the ^{7}Li target was calculated by using the cross section of the ^{7}Li(p,n)^{7}Be reaction by which neutrons are emitted in the direction of incident protons. We used 27.0±0.8 mb/sr for this cross section at the center-of-mass system (Tadeucci et al. 1990), and the number of protons incident on the ^{7}Li target was given by the Faraday cup.

The detection efficiency to neutrons was plotted as a function of the thickness of the carbon target in each energy of protons. The attenuation length of neutrons, λ, in the carbon target was derived by fitting this plot to a function of exp(-x/λ), where x is the thickness of the carbon target. The attenuation lengths thus derived are plotted in Figure 2 together with the simulated results.

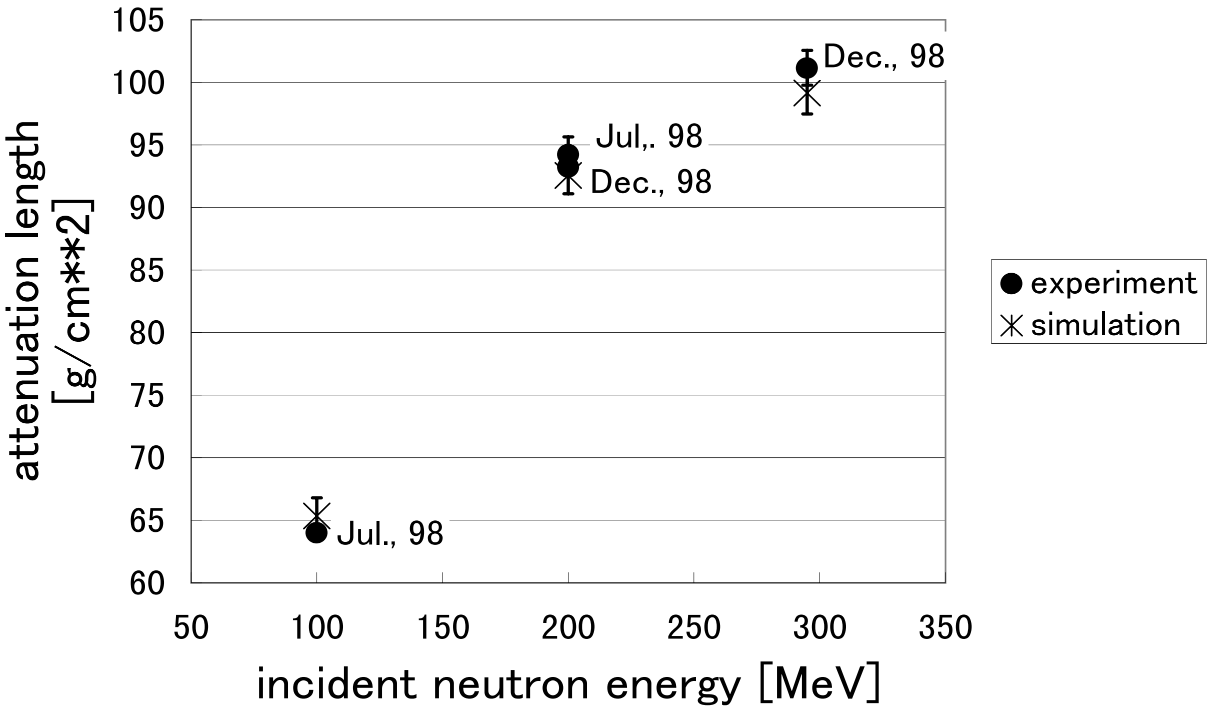

Figure 2: The attenuation length of neutrons in the carbon target. The results obtained by the experiments are consistent with the simulation.

The attenuation lengths of neutrons in the carbon target obtained by the experiments are consistent with the results obtained by our simulation. As was explained before, these values were converted to the attenuation lengths in the atmosphere which has infinite spread in the lateral direction. The attenuation length in the atmosphere thus derived is 100 g/cm^2, 135 g/cm^2, and 145 g/cm^2 for neutrons with the energy of 100 MeV, 200 MeV, and 300 MeV respectively.

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