JOINT INSTITUTE FOR NUCLEAR RESEARCH

Laboratory of Nuclear Problems

P-243

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*) The paper is submitted to "Pribory i tekhnika eksperimenta".

The experimental device with a ring-shaped scatterer for investigation of neutron scattering at hundreds of Mev energies is described. A telescope of scintillation counters with aluminium converter (neutron telescope) is used as a detector of scattered neutrons. The experimental device of such a type makes it possible to carry out the measurements with neutron beams of the comparatively low intensity and can be successfully used especially in experiments on the small angle scattering.

The differential neutron-proton elastic scattering cross sections at high energies (of the order of hundreds of Mev) are usually determined by measuring the proton recoils reaching the detector placed at different angles to the neutron beam. The thickness of hydrogen scatterers (polyethylene) used in these experiments depends on the energy of scattered protons and changes from 5 g/cm^2 for the angular interval 0°-50° lab. to 0.5 g/cm^2 for angles 50°-70° lab. However, for the range of the laboratory recoil angles 70°-90° where the recoil protons have a low energy (and hence the short ranges) thinner scatterers must be used. This leads to the decrease of the useful counting rate and therefore to the deterioration of the effect-background relation. Because of the low energy of the recoil protons it was very difficult to investigate them in this angular range by scintillation counters. Gas counters could be used for this purpose but their equipment is very complicated and the resolving time is considerably deteriorated. The experiments with a hydrogen-filled diffusion chamber take a lot of time before and acceptable statistical accuracy of the results can be reached.

The defects of methods founded on the proton recoil registration in the range of small scattering angles of neutrons make one use the direct registration of scattered neutrons. The fundamental difficulty which one must overcome is the low registration efficiency of the present-day neutron detectors. One of the methods of the direct neutron registration is the method of measurements in the "intermediate geometry"I) where the efficiency rises at the expense of placing a large quantity of scatterer into a neutron beam. However, its essential defect lies in the fact that to obtain the cross section of the investigated process, the observed results must be treated mathematically what reduced the accuracy of final data.

The direct registration of scattered neutrons can be carried out by the neutron telescope2). This device has much better efficiency than the formerly used fission chamberI), it allows quite simply to set a necessary threshold energy of neutron registration. The disadvantage of the method is that in measuring at small scattering angles, the telescope is removed far away from the scatterer in order to avoid the "lighting" of the telescope by a direct neutron beam. This leads to a strong decrease of the useful effect.

The registration efficiency of neutrons can be increased by using the counter suggested in3):

However, this counter has a low nonregulating energy threshold and sensitivity practically independent of the direction of neutron flight. Because of small ranges of recoil protons it is impossible to set the counter in coincidence with a telescope at small angles of neutron scattering.

As a result of the discussion of different methods in experiments on measurement of n-p scattering cross section in the small angular region (35° to 5° c.m.s.)[4] we used a method which allowed to avoid some defects of the "intermediate geometry" and "neutron" telescope methods, and to combine their good qualities.

This method consists in the following. The annular high energy neutron beam is preliminarily formed with the help of collimators. The beam is directed to the toroidal scatterer with a central axis coinciding with the longitudinal axis of the beam. The detector of scattered neutrons made on the principal of "neutron" telescope is placed on the axis of symmetry of the device, and can move along it on rails. The ring-shaped scatterer makes it possible to put into a beam the amount of scattering matters many times exceeding that used in other experimental methods.

Experimental arrangement is given in the figure.

Neutrons produced by 680 Mev protons on the inner target of the Laboratory of Nuclear Problem synchrocyclotron were collimated by two collimators placed successively on the axis. The first was 3.6 m long, the hole being 30 cm in diameter. This collimator was located in the ambrasure of 4 meter concrete shielding placed at a distance 9.5 m from the target of the accelerator.

Having passed the distance of I4 meters from the first collimator, neutrons went into the second collimator which shaped the beam into a ring form and directed it to the scatterer. This collimator was mounted in the 2 m concrete wall and consisted of a tube 2m long by 66 cm diameter and a massive brass core 46 cm in diameter and 2.5 m long, placed inside the tube. Coaxiness of collimators was carefully checked with the help of theodolite. At the exit of the second collimator where the ring-shaped scatterer was placed, the beam intensity was about 3×10^3 neutrons/cm^{2}sec. The energy distribution of neutrons in the beam was determined in [5]. Preliminary investigation of the neutron beam showed that in the beam there are considerable number of slow charged particles and gamma-rays[+]. To protect one from them the lead 2.5cm thick was placed at the exit of the first collimator. Collapsible lead shield of a cylindrical form 50 cm in diameter and 60 cm long was made for protecting from a background of neutrons scattered by the exit end of the ring-shaped collimator. Mounted 3 m away from the ring collimator it will completely shield the converter when measuring the scattering at angles ⩾3.5°. In a neutron beam before the brass core of the second collimator the monitor was

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[+] The authors are grateful to Yu.S.Krestnikov (Teplotehnich.lab) who performed this investigation.

placed consisting of the air ionization chamber of 5 litres volume and the integrating device of the DIGD dosimetre type.

The scattering on hydrogen was determined from the difference in counting rate of the detector when polyethylene and graphite ring-shaped scatterers were placed into the beam. Polyethylene scatterer weighting 5490.7 g was gummed together in a multangular form from I8 identical cylindrical pieces, 62 cm in diameter each. The weight of the graphite scatterer equal to 470I.5 g is taken from the equality of the number of carbon nuclei in it to the number of those in polyethylene scatterer. The latter consists of II cylindrical pieces of 62 mm diameters, arranged uniformly in a circle 64 cm in diametre. The scatterers were placed beyond the additional lead shield on the side where the measuring telescope was situated coaxially with a neutron beam and a telescope, and were mounted by means of thin penopolystyrene bars (0.03 g/cm^3 density) on the back surface of the shield.

In a condition of the given geometry the scattering angle of a neutron θ lab. is given by a distance between a scatterer and a converter and determined from the relation

$$\theta_{lab} = \mathrm{arctg}\left(\frac{R}{X}\right) + \varphi , \qquad (I)$$

where R is the average radius of a ring-shaped scatterer; X is the distance along the beam axis from the plane of the central scatterer circle to the centre of the converter; φ is the angle of divergence of a neutron beam (φ =0.5°).

Neutrons scattered by a ring-shaped scatterer are detected by a neutron telescope consisting of five scintillation counters and a converter. "Charge exchange" protons produced in the converter are registered by counters I,2,3,and 4 placed beyond the converter and set in coincidence (CCI).

To exclude the possibility of the telescope detection of charged particles emitted from the scatterer and which are not the result of "charge exchange" of neutrons in the converter, the additional counter 5 set in coincidence with counters 2,3, and 4 (CC2) was placed before the converter. This circuit is set in anticoincidence with CCI.

The converter is an aluminium cylinder 4 cm in diameter and 6 cm high. With the help of selsyns it can be moved off from the telescope and replaced in front of detecting counters on the neutron beam axis.

Geometrical dimentions of scatterers and the converter indicated above give the angular resolution shown in Table I.

Table I

Measuring angle θ lab.	I5°	I0°	5°	3.5°	2°
Resolution Δ θ lab.	±2°	±I.5	±0.7°	±0.5°	±0.25°

Counters 5,I,2,3,4 have liquid scintillation volumes in a form of disks I06,60,70,I00 and I06 mm in diameters, respectively, and I0 mm thick. The scintillator's diameter of counter 5 is chosen so that each particle going from the scatterer's side into the telescope should pass through counter 5.

As a scintillator in all the counters a solution of 3.5 g/litre p-therphenyl in phenyl-cyclogexan was taken, poured into plexiglass containers which were in optical contact with photocathodes of photomultiplier FEU-I9 M.

The threshold of neutron detection was taken from the "charge exchange" proton energy with the help of a copper filter placed between counters I,2,3 and 4. It was shown experimentally$^{6)}$ that the mean energy loss at "charge exchange" process for Al is equal to 30% and does not depend upon E_n^{kin} in the neutron energy region of interest.

The filter thickness was chosen by taking acoount of such loss of energy.

Block-diagram of radio-technical part of the device is also given in the figure.

The positive impulses with the amplitude of about I.5 v are taken off from the exits of preamplifiers placed in blocks of photomultipliers FEU-I9 M. These impulses are fed into the entrance of coincidence circuits where the impulses are formed with the help of pieces of cables RK-50 I m long each, short-circuited at their ends by the resistances of 30 ohm. The coincidence circuits are identical and assembled on diodes D2V.

The impulses from the exit of CC2 are discriminated and delayed up to 3.5×10^{-7} sec, amplified and leveled in amplitude. The impulses with CCI are also discriminated, amplified and delayed up to 1.4×10^{-7} sec with the help of delay line. Then both groups of impulses are fed into the anticoincidence circuit assembled on the lamp 6ZH2. After additional amplification the impulses from the anticoincidence circuit are fed into scalar PS-64. The resolving time of the coincidence circuit was 1×10^{-8}sec.

As it was stated, the discribed arrangement was used to determine the differential n-p scattering cross section in the region of small scattering angles. In these conditions the advantages of aplication of the device with a ring-shaped scatterer over other methods are clearly seen. Only relative values of cross sections were measured. This made it possible to exclude the necessity of determining the absolute value of the flux of neutrons and the probability of their "charge exchange" in the converter.

The ratio of differential cross section of the elastic n-p scattering at the angles ϑ_1 and ϑ_2 in the c.m.system was determined by the formula:

$$\frac{\sigma(\vartheta_1)}{\sigma(\vartheta_2)}=\frac{[N_K^{CH_2}(\theta_1)-N_0^{CH_2}(\theta_1)]-[N_K^{C}(\theta_1)-N_0^{C}(\theta_1)]}{[N_K^{CH_2}(\theta_2)-N_0^{CH_2}(\theta_2)]-[N_K^{C}(\theta_2)-N_0^{C}(\theta_2)]}\;\frac{\Omega(\theta_2)}{\Omega(\theta_1)}\;\frac{\eta(\theta_2)}{\eta(\theta_1)}\;\frac{W(\theta_2)}{W(\theta_1)}\,B$$

where θ is the scattering angle in the laboratory system, ϑ is the scattering angle in c.m.s; N^{CH} is the counting rate of neutrons scattered on the polyethylene scatterer; N^{C} is the counting rate of neutrons scattered by a graphite scatterer; Ω is the effective solid angle subtanded by converter; η is the portion of charge exchange protons covered by the solid angle subtanded by counters I-4:, the index "K" indicates that the converter is placed into the working position;, the index "O" shows that the converter is removed from the telescope; $B(\vartheta_1, \vartheta_2, \theta_1, \theta_2)$ is the scaling coefficient of the ratio of cross sections measured in the laboratory system to the ratio of cross sections in c.m.system.

The ratio $\eta(\theta)/\eta(\theta)$ depends not only upon the scattering angles of neutrons but upon the angular distribution of "charge exchange" protons. This ratio was found by graphic integration of the measured by us angular distribution of "charge exchange" protons on aluminium over the solid angle subtanded by counters I,2,3 and 4. The ratio of "charge exchange" probability $W(\theta_2)/W(\theta_I)$ under our conditions is very close to I, as the energies of scattered neutrons at the edges of angular region under investigation differ by no more than I0%, and $W(\theta)$ at high energies depends only slightly upon the energy$^{6)}$.

It should be noted that at the intensity of neutron beam incident on the scatterer equal to only $3 \times I0^3$ n/cm^{2}sec it was not difficult to perform our measurements.

The method described makes it possible to measure the effect at low intensities at least up to $5 \times I0^2$ particles/cm^{2}sec.

We are grateful to I.G.Dragunov and V.S.Turchenev for help in constructing the apparatus.

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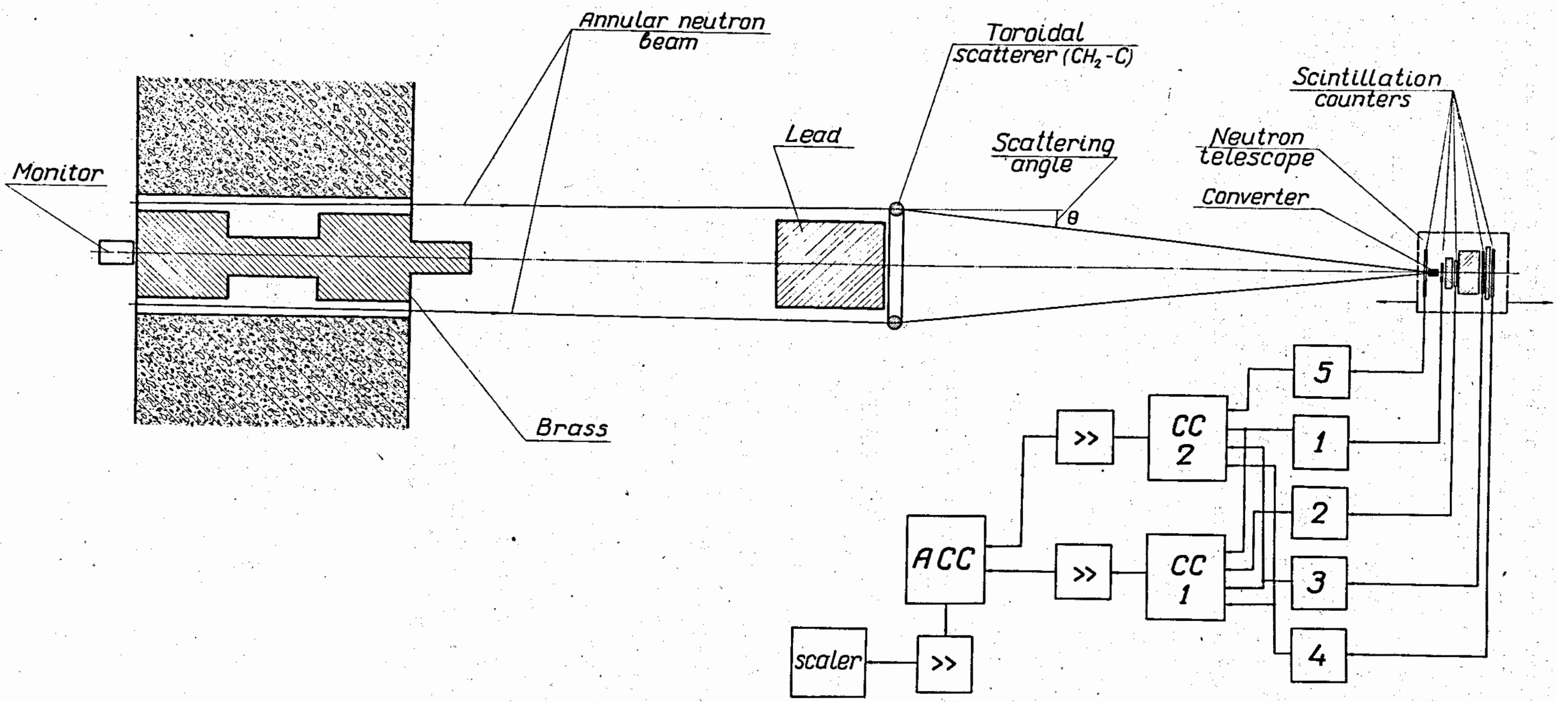
This article was received by Publishing Department
in October, 7 I958.



Experimental arrangement used in mesurements of cross section for (np)-scattering at small angles.