A FAST NEUTRON TIME-OF-FLIGHT SPECTROMETER

By

G. Hrehuss*, A. Neszmélyi* and K. Simonyi

Institute for Theoretical Electricity of the Polytechnic University, Budapest

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To solve many a problem of nuclear physics, it is necessary to measure the energy of neutrons producing nuclear reactions or arising in the process of it. Such problems are, among others, the energy dependence of cross-sections, especially that of the fission cross section, further the investigation of highly excited states of nuclei by means of inelastic scattering, and the measurement of energy spectra of neutron-sources. As is well-known from literature, different apparatuses have been developed for measuring neutron energy from thermal to 10 MeV [1—5]. Some of these require comparatively simple equipment as e. g. the precise emulsion-, [6—7], or telescope-technique [8] based on proton-recoil, on the other hand either their evaluation takes up much time or they possess low efficiency. Others, however, as the neutron diffractogragh or the He^3 recoil method can only be applied in a narrow energy band. The time-of-flight apparatuses which are becoming more and more current, undoubtedly possess the largest energy range; the high efficiency and a relatively good resolution counterbalances their expensiveness.

Short neutron bursts at low energy are usually produced by mechanical methods, in the fast region with electronical ones (by interrupting the charged particle beam which generates the neutrons). The energy can be determined by measuring the flight time over a given distance. The quadratic character of the time—energy function and consequently the necessity of a redoubled accuracy in measuring time are the apparent disadvantages of this system. On the other hand, with the lenghtening of a flight-path, if intensity allows, the time-of-flight method is applicable even in the 100—200 MeV energy region [9].

We shall describe a fast neutron time-of-flight spectrometer for the energy range of 0,8—14 MeV. It was developed in the Department for Atomic Physics of the Central Research Institute of Physics (Budapest), for the investigation of the reaction-mechanism of highly excited nuclei (direct interaction) by means of inelastic scattering experiments. The general arrangement of

* At the Central Research Institute of Physics, Department for Atomic Physics.

the apparatus is similar to that of CRANBERG and LEVIN [10], some details of which, however, may be of general interest.

For neutrons of energy E the flight-time over a distance L is :

$$t^{m\mu s} = \frac{72{,}3\, L^m}{\sqrt{E^{MeV}}}$$

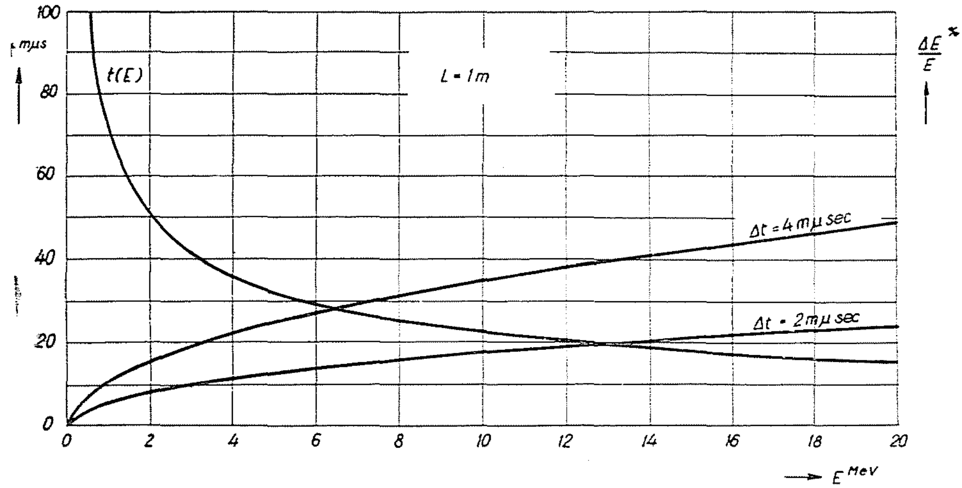

Fig. 1. Flight-time and relative energy spread as a function of neutron energy. The flight-path is 1 m

Fig. 1 shows the smallest relative errors which can be attained at different energies, if the error of the time measurement is 2 and 4 mμsec respectively. The reported values concern a flight path $L = 1\, m$. Neutrons are generated in short bursts and after having been scattered they flight the path 1,2—1,8 m, with a changed energy. At the end of this they enter a fast detector. Between the pulse given by the detector and the reference signal, appearing at another channel in the moment the deuteron bursts are produced, there is a time difference : $t +$ const. The two signals get into the fast coincidence unit, which gives an output signal only if the reference pulse is properly delayed. The delay is equal to the flight-time, which is obviously determined only to the extent of an additive constant, but it can be precisely fixed with a suitable calibration (inelastic γ rays).

To be $\Delta t = 1$—3 mμsec it is necessary that the neutrons in the bursts should start with no more than the same uncertainity. This was attained as follows : a Cockroft—Walton type generator of two hundred kilovolts with a radiofrequency-ion source [11] supplies a well-focused D^+ ion-beam of about 0,1—1,0 mA intensity. The ion-beam vertically leaving the accelerator, enters a mass and energy analyzing magnetic field, which deflects the D^+ component with 90° to the horizontal direction (Fig. 2). The D^{++} component

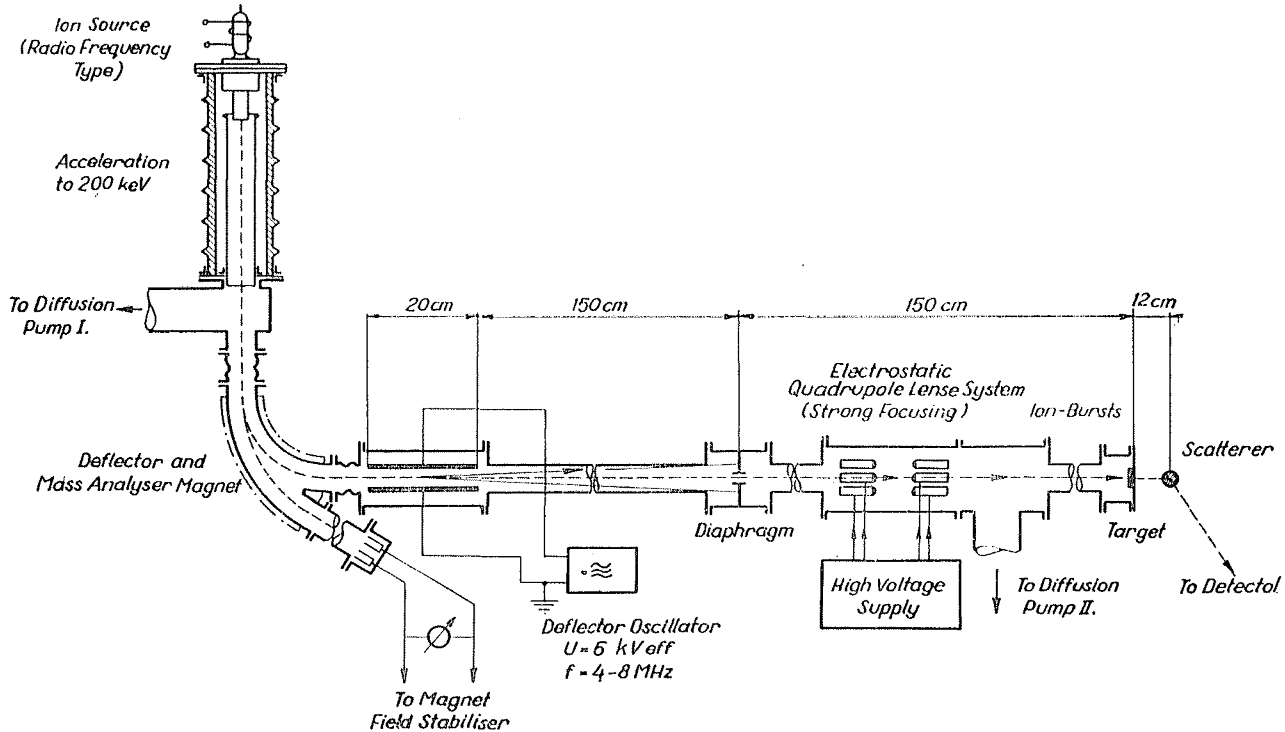

Fig. 2. Time of flight fast neutron spectrometer. General layout of the apparatus

may separately be used to stabilize the magnetic field and the accelerating voltage, respectively. The deflector magnet weights about 250 kg and at 6000 gausses it requires 6 A at 300 V. The magnet is water-cooled.

The horizontal ion beam passes between two deflector plates, the applied r. f. voltage is max. 7 kV eff. at 4—8 MHz. The ion-beam deviates from the horizontal plane with a corresponding frequency. A diaphragm (with an

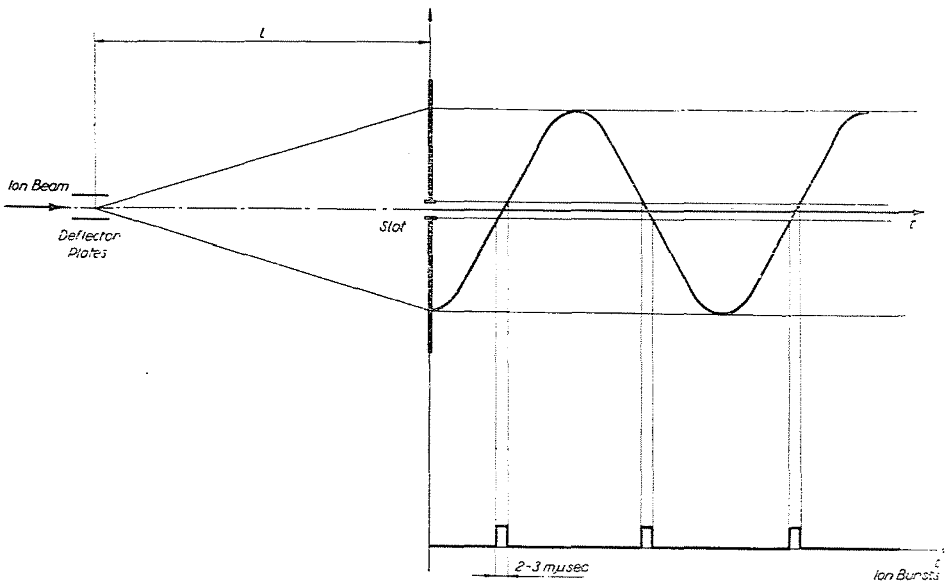

Fig. 3. Production of very short ion-bursts

opening of 1,5 cm, placed at a distance of 1,5 m) bars the continuing route of the ions coming to the diaphragm beyond the time interval: $T/2 - \tau$, $T/2 + \tau$. (Fig. 3.) At a given geometrical arrangement and frequency, adequately short bombarding deuteron bursts can be obtained by a suitable voltage amplitude. The ions going through the diaphragm and passing through an electrostatical quadrupole lens system are focused on the target containing tritium or deuterium. This quadrupole lens system is of strong focusing and does not take part in the accelerating process. The lens requires two independent and regulated voltages in the range of 0—5 kV.

The vacuum system is about 7 m long (its volume being 100 l) and a pressure of $0{,}8$—$2 \cdot 10^{-5}$ torr is maintained by two vacuum pumps located at different parts of the system and having a speed of 1750 μl/sec. The external rate of gas enter of the whole system is negligible compared to the 10 ncm$^3/h$ D_2 gas getting into the system through the ion-source. Along the ion-path three vacuum-meters are placed, one of the ionization-, and two of the Penning-type.

The intensity of the pulsed ion-beam bombarding the target is about 1 μA and the resulting neutron yield is 10^6—10^7 neutrons/sec from the reactions D/d, n/He^3, T/d, n/He^4, respectively. The secondary electron current is suppressed by a reverse electric field, resulting in a less then one-percent error for determining the ion-current. The tritium targets are imported from abroad, while the deuterium-targets are produced at the Department [12].

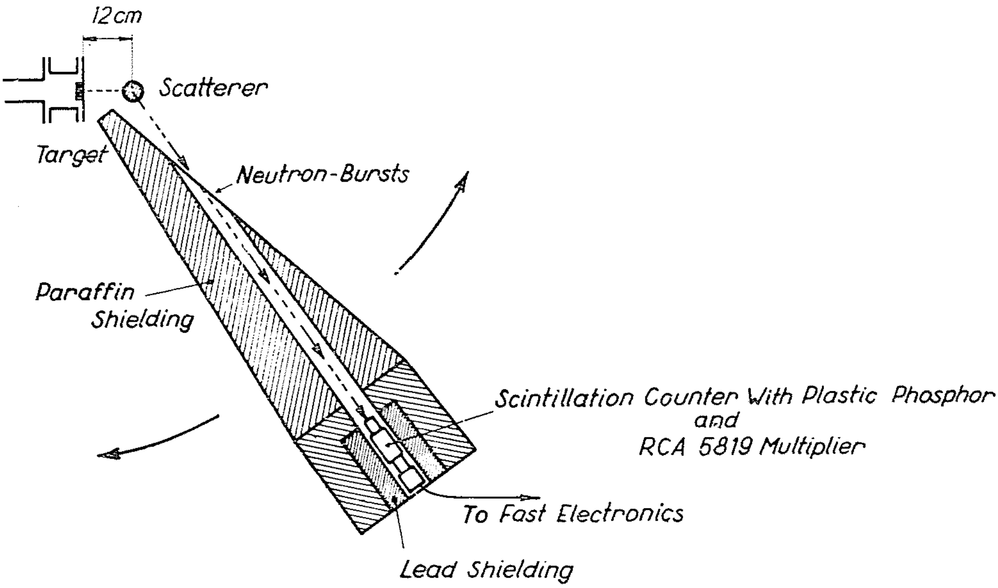

Fig. 4. Physical arrangement of detector, shield and target

The scattered neutrons enter the detector through a paraffin collimator (Fig. 4) which prevents the direct target-neutrons being counted. The neutron detector is a plastic scintillator (1,5" in diameter and 2" long, having a decay time constant of 2,5 mμsec), which is covered, together with the RCA 5819 type multiplier, by a lead shield of 5 cm thickness. The detector and collimator can be rotated from 0—90° around the scattering axis to ensure the possibility for the investigation of the angular dependence of scattering (See Fig. 5 and Fig. 6).

In the design of fast electronics it was necessary to insure maximum speed (Fig. 1 shows that at high energies the required frequency-band extends up to 2—300 MHz). A fast time-analyzer was developed consisting of the usual elements of the millimicrosecond technique. The time-measuring system is of the one-channel type. Instead of measuring the time intervals directly, we detect coincidences between the reference-pips and the neutron signals, the former being delayed in a known and variable manner. The block diagram of the electronic arrangement is shown in Fig. 7. The neutron signal at the

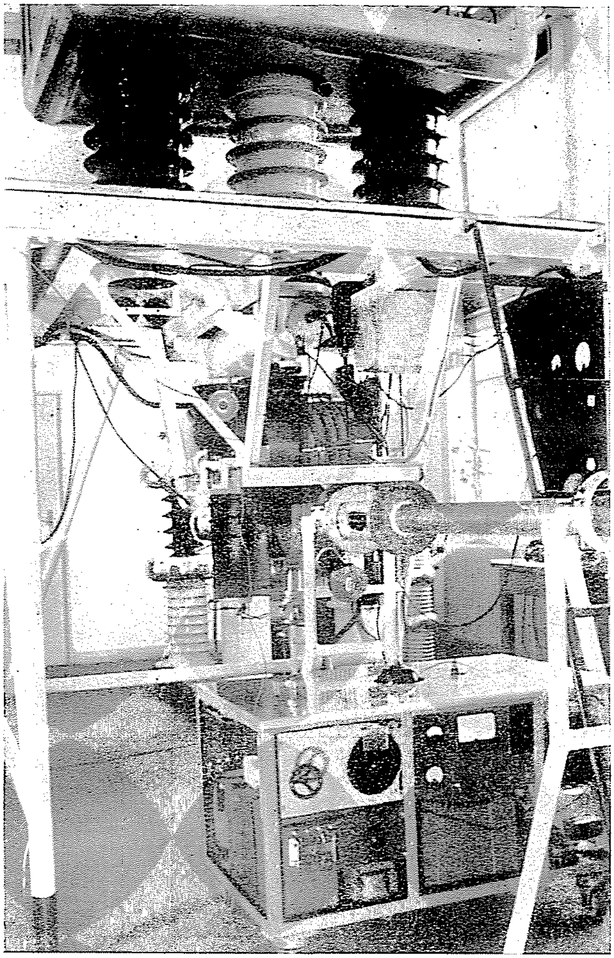

Fig. 5. View of the 200 keV accelerator, deflector magnet and high frequency oscillator

anode of the multiplier has an amplitude of about 0,1 V and a rise-time of 1—3 mμs. After clipping with a shortened line it is amplified by a distributed amplifier. The characteristic data of the amplifier are the following ; frequency band : 10 kHz—170 MHz, gain : 25 dB at a matched output, input impedance : 150 ohms, tubes employed : 11 pieces of the EF 80 type [13].

The coincidence unit was of the crystal diode-bridge type similar to that described by Minton [14]. The resolution curve of the distributed amplifier — coincidence circuit system had a half-width of $3 \cdot 10^{-9}$ sec at half-maximum, and an efficiency of 60%. It was checked by direct experiments, (see Fig. 8) that the resolution time was not increased by the rise-time limitation of the amplifier. The delay of the reference-pip was obtained by

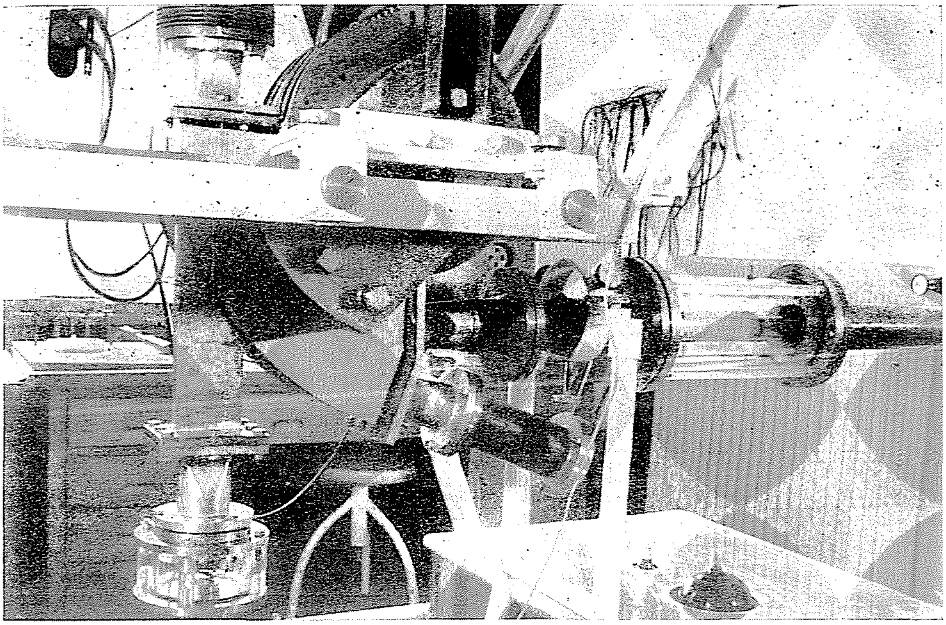

Fig. 6. Deflector magnet, electrical deflector plates

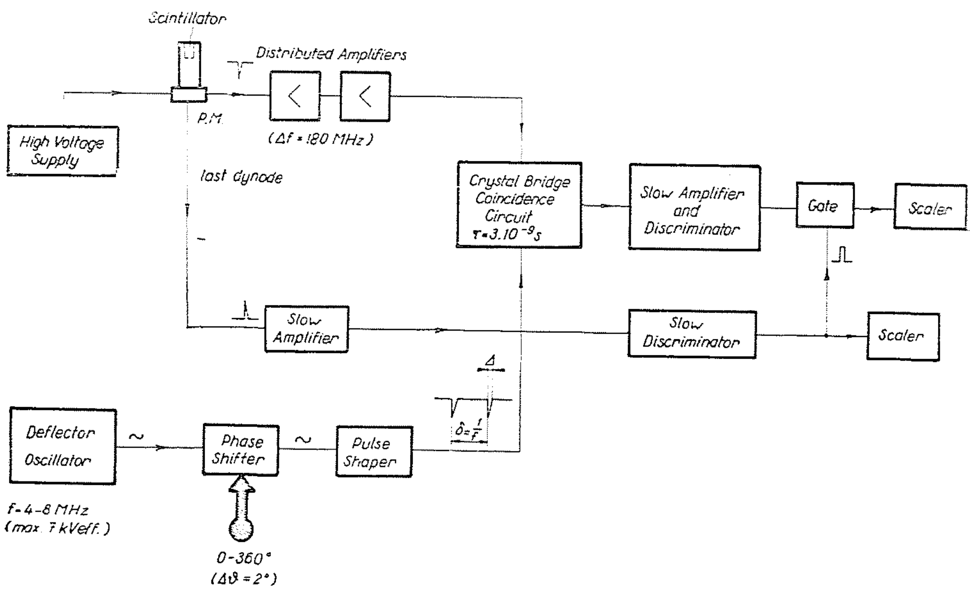

Fig. 7. Instrumentation diagram for fast neutron time-of-flight experiment

a precision wide-band phase shifter circuit, the input signal of which was derived directly from the deflector coil of the r. f. oscillator. In the 4—8 MHz band the error of the phase shifter was less than 2°. The phase of the output signal could be varied continuously in the 0—360° range. The null-comparation was carried out by a symmetrically driven squaring circuit consisting of two difference-amplifier stages. After clipping with a shortened line and further amplification the resulting signal had a half-width of 3—4 mμsec.

The positive signal from the last dynode was used for amplitude selection, the fast coincidence output being gated by a slow system (0,08 μsec rise-time) consisting of a slow amplifier, integral discriminator and scaler. This is necessary to prevent the counting of neutrons from previous bursts and random coincidence pulses. The output of the slow system was used as a monitor.

For the measurement of neutron energy spectra we must determine the gated coincidence rate as the function of the phase-shift (i. e. constant time delay) which can be directly read off on the phase shifter. As our detector

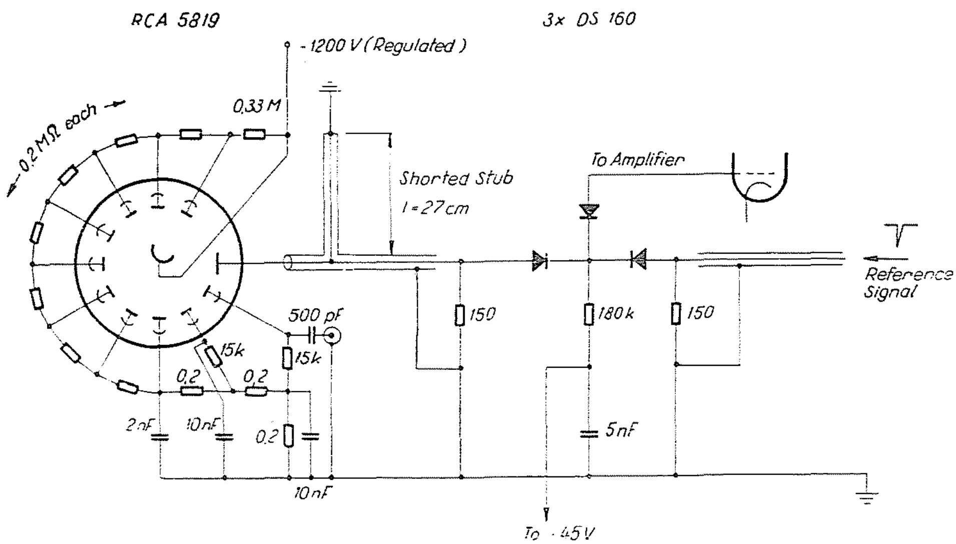

Fig. 8. Fast coincidence circuit

has a non-negligible efficiency for γ rays, the physical zero can be measured as an intense group in the neutron spectra caused by inelastic γ rays.

To prove the whole system, we measured the direct target spectrum of a zirconium-target (Fig. 9). The double representation was introduced for control purposes : it is a direct consequence of the fact that neutron bursts are produced at each null transition of the r. f. signal, i. e. at a double rate

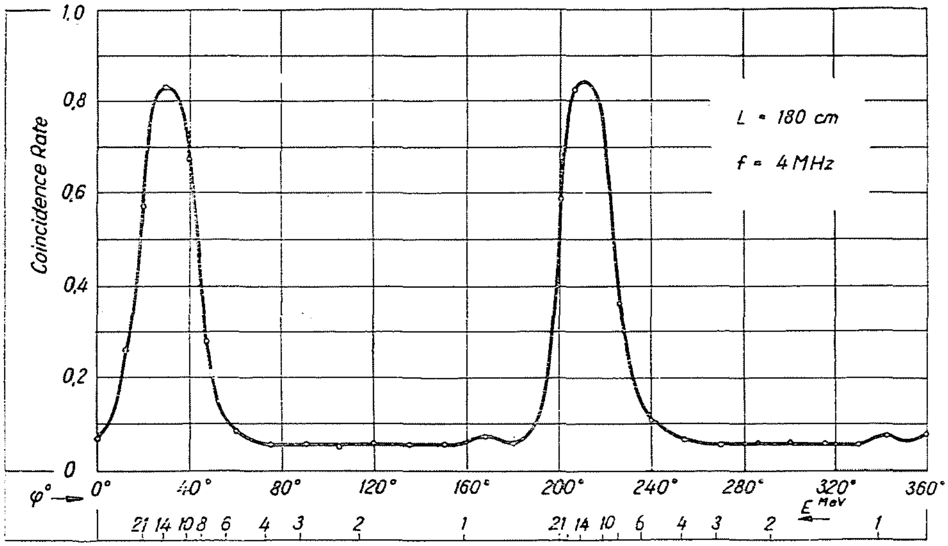

Fig. 9. Direct target spectrum of neutrons from T/d, n/He^4 reaction

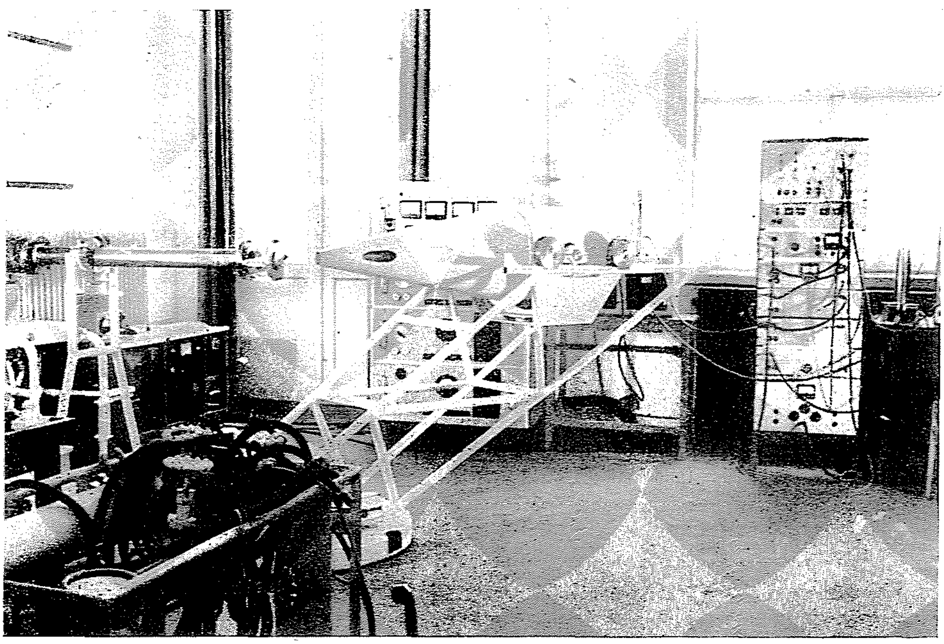

Fig. 10. Target, collimator system and fast electronics

as to the reference signal. From Fig. 9 it can be seen that the spectrometer is able to investigate neutron spectra in the desired energy range, improvements of the resolution curve and background effects, however, are necessary and are in progress.

The physical arrangement of the target, collimator and fast electronics is shown in Fig. 10.

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Summary

A fast neutron spectrometer is described, which was developed for the measurement of inelastic neutron spectra in the energy range of 0,8—14 MeV. The fast neutron bursts are produced by electronic means deflecting the 200 keV beam of a Cockroft-Walton type accelator. The neutron detector is a plastic scintillator; the neutron signals are analysed by a fast time analyzer of the single-channel type. The duration of neutron bursts is 1—3 mμsec, the time resolution is about 5 mμsec.

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Prof. K. SIMONYI, Budapest, Budafoki út 8., Hungary