ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E-2494

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ЛАБОРАТОРИЯ ЯДЕРНЫХ ПРОБЛЕМ

1965

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Submitted to PTE

INTRODUCTION

One of the most important features of a beta-spectrometer is the background of its detecting system. The low background of the beta-spectrometer is essentially important for studying low intensity lines of conversion electrons and weak positron radiation for sufficiently large halflives of radioactive isotopes.

Usually one counter was used for detecting electrons in a beta-spectrometer. In this case background is due mainly to the counter volume: it is 10-20 counts/min for Geiger counters; 1 count/min/1/ is possible with small volume plastic scintillators. The background of the detecting system can be considerably reduced if counters sufficiently remoted from each other and connected to the coincidence circuit are used. In this case the detection of electrons, scattered inside the spectrometer and those arising in the interactions of gamma-rays with matter surrounding the counter, is partially excluded. Coincidences due to cosmic radiation detection are also hardly probable. Thus, when two counters placed in a series behind the spectrometer focus and connected to the coincidence circuit are used, it is possible to reduce the background down to 2 counts/min/2/.

The beta-spectrometer background is considerably reduced by double-focusing. This principle was suggested and developed by B.S.Dzhelepov et al/3,4/. For instance, the background was reduced down to 1-2 coinc./hour by using triple focusing at the angle 180° in a homogeneous magnetic field and three counters connected to the coincidence circuit.

However, comparatively small solid angles: 0.06% with a 1% resolution/5/, are used in the spectrometers of such a type. Some ways of developing the method of multiple focusing/6,7,8,9/ were suggested. They implied the use of more effective methods of electron focusing which allowed to obtain greater luminosity and better resolving power of the device. In our opinion, a beta-spectrometer with double focusing at the angle $\pi\sqrt{2}$ suggested by B.S.Dzhelepov and S.A.Shestopalova/6/ is the best possibility.

The beta-spectrometer with double focusing at the angle $\pi\sqrt{2}$ constructed at the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research is described in the present paper.

2. Magnetic Field of the Spectrometer

In our spectrometer use is made of the Pavinsky type field/10/:

$$H(\rho) = H_0\left(1-\frac{1}{2}\rho + \frac{1}{8}\rho^2 + \frac{1}{16}\rho^3 + \dots\right)$$

where $\rho \equiv \frac{r - r_0}{r_0}$.

H_0 is the value of the magnetic field strength at the equilibrium orbit,

r_0 – the equilibrium orbit radius.

The equations of motion for an electron in such a field were solved in the third approximation by Listengarten/11/.

In the spectrometer with double focusing at the angle $\pi\sqrt{2}$ the source can be placed above (or below) the symmetry plane of the magnetic field. For such a location of the source it follows from the Listengarten formula that the image in the first focus has a curved shape and in the second focus it is nearly straight and narrow, but since dispersion in the second focus is zero, the spectrometer resolution is entirely dependent on the image width in the first focus, the slit width, the diaphragm shape and the width of the source.

The equations for electron trajectories were used for calculating the shape of the slit and the diaphragms.

To produce the required magnetic field of the spectrometer use was made of the CП - 10 electromagnet. The data on the shape of pole pieces were kindly given by S.A.Shestopalova. The value of the air gap in the centre of the magnet is 142 mm. The resistance of two magnet windings connected in series is 1.3 Ohm, the inductance is 1.25 Henry.

The theoretical and experimental shape of the magnetic field is shown in Fig.1. The deviation of the experimental values of the magnetic field strength from the theoretical ones in the working region is not larger than 0.1%. No axial asymmetry was found for magnetic fields from 30 to 1500 Oe (measurement accuracy was 0.02%).

3. Magnet supply

For standard operation of the magnetic spectrometers with the resolution 0.1% the magnetic field is required to be stable within about 10^{-3}% for several hours. A semiconductor stabilization method for the electromagnet current which assures current stability to an accuracy of 2.10^{-5} /12/ was developed at our laboratory. Experience with this circuit has shown that it can ensure continuous operation of the spectrometer during several months.

4. Spectrometer Chamber and the Vacuum System

The spectrometer chamber is made of duralumin and has the following dimensions: 468 mm in diameter, 400 mm in internal diameter and 135 mm high. Two counter chambers with Geiger-Muller counters are inside it. In order to have a possibility of placing a probe of the magnetic field strength at any distance from the centre of the magnet a pocket not connected with the vacuum system is inserted into the chamber. The source is put at the equilibrium orbit with a vacuum lock without violating the chamber vacuum. A vacuum set BA-011 and a fore pump are used to produce vacuum. The chamber pressure is about 5.10^{-5} mm Hg.

5. Measurement of the Magnetic Field

To measure the magnetic field strength a method is used based on the nutation of the total proton magnetic moment. This method was suggested for the first time by Zhernovoy et al /13/. Fig.2 shows the scheme of the device for measuring the magnetic field strength. Its parameters are: 1) the intensity of the polarizing magnetic field of the magnet M_1 is 11000 Oe; 2) the volume of water contained in the gap of the magnet M_1 is 20 cm^3; 3) Nutation probe (6) has 20 turns of 0.2 mm wire wound on a glass tube 5 mm in diameter; it is placed in the magnetic field of the beta-spectrometer magnet; 4) the length of the connecting tubes is 2 m (1 m from the magnet M_1 to the magnet M_2 and 1 m from M_2 to M_3). The inner diameter of the tubes is 5 mm; 5) water consumption is 1.5 litre per minute; 6) R.F. oscillations from the generator of the GSS -6 type (1) are supplied to the nutation probes. The frequency is determined precisely with the help of a frequency-meter ChZ - 3 (2). When measuring magnetic field strengths higher than 230 Oe between the generator and the frequency-meter an additional frequency divider made on semiconductor triodes is switched on. The frequency-meter gives the values with an accuracy ± 1 Hz while with an addition of the frequency divider it is ± 10 Hz; 7) A magnetic induction meter IMI-2 detects nuclear absorption signals; 8) Magnetic fields from 30 Oe to 1500 Oe are measured (this corresponds to electron energies from 15 to 6000 KeV). The magnetic field strength is determined with the accuracy of ± 0.005%.

6. Detection System

Three Geiger-Muller counters connected in a triple coincidence circuit ("Yablonya") are used to detect electrons. The 0.6 mm slit is in the first focus. It is made in a 1 mm thick tantalum plate. The second and the third Geiger-Muller counters are in the second focus. The entrance window width of the second counter is 8 mm. The windows of counter chambers are covered with a 5 micron thick lavsan film. There is a collodium film sprayed with bismuth between the second and the third counters. Argon with alcohol vapour in the ratio 4: 1 at the total pressure 10 cm Hg is used as a working mixture. The employment of a ballast tank connected to the counters allows to work for about 100 days with one filling of the counters. Fig. 3 shows the dependence of the efficiency of triple (1c + 2c + 3c, curve 1) and double (1c + 2c , curve 2) coincidences upon the energy of the detected beta-emission. The dependence was obtained by measuring the beta^{+} - spectra of Pr^{140}.

7. The System of Automatic Measurement

Measurements with the beta-spectrometer are automatized [14]. The block-diagram of the electromagnet current stabilization and automatic control is given in Fig. 4. Before a cycle of measurements the operator sets the initial value of the current in the magnet winding with a decade divider and thus determines a) the direction of current change; b) the number of current change steps (16, 32, 64, 128 or 256); c) the value of the current changes at each stage ($\frac{\Delta I_M}{I_M} = 0.04\%$; 0.03%, 0.02% or 0.01%); d) the duration of the detection of coincidence counting for given current values (from 1 to 3599 sec).

After the detection cycle is over the readings of the scalar are written down automatically on the tape.

The spread in the values of current change stages does not exceed ± 2% of the stage value. In automatic operation the current in the electromagnet winging varies monotonously (14). Fig. 5 shows the variation of the magnetic field in the centre of the magnet (H_C) versus the current in the electromagnet I_M ($\frac{\Delta I_M}{I_M} = 0.04\%$). It is seen from Fig.5 that within measurement errors this dependence is linear, which allows to measure the magnetic field only at the initial and final point of the cycle without reducing the measurement accuracy.

8. Energy Calibration

In order to calibrate the device with respect to energies, the electron conversion lines of Th $(B + C + C'')$ whose energies are known to a high accuracy(15) were measured. The obtained calibration curve is shown in Fig. 6 from which it is seen that the calibration coefficient $\frac{r_0 H_0}{H_0}$ is constant to an accuracy of 0.03%.

The errors shown in the Figure include the uncertainty in the energy values of calibration lines, the error of magnetic field measurements and the inaccuracy in determining the position of the line maximum. The application of the obtained calibration coefficient made it possible to determine conversion electron energies to an accuracy better than 0.08%. If the radioactive sample under study and the calibration source Th$(B+C+C'')$ are deposited on one backing, the accuracy of determining the conversion electron energy is improved to 0.04%.

9. Adjustment

Along with the 0.6 mm slit in the first focus there are two diaphragms defining the beam at the angles $\frac{\pi\sqrt{2}}{2}$ and $\frac{5\pi}{12}$ in the spectrometer. The optimum parameters of the device were determined experimentally. Before the slit was installed the focus position had been defined for successive shifts of the source with respect to ρ and ϕ by taking pictures of beam images in the focusing region.

The source was finally adjusted according to the maximal number of triple coincidences on a certain conversion line and the smallest half-width with the best shape of the line F Th$(B+C+C'')$ and the K-line of the 1275 keV γ-transition in Er^{166}. The best conditions were found to correspond to a $+5^{o}$ increase of the focusing angle for $r_o = 140$ mm. The centre of the source is shifted with respect to the symmetry plane by 31 mm, the source length is 15 mm. For conversion electrons of the 1275 keV transition in Er^{166} the line intensity is two times larger in the first counter than the intensity obtained with three counters connected to the coincidence circuit. The relative half-width of the line is -0.21%. The geometrical solid angle is 0.25% with this resolution for the first focus. The experimental solid angle was not determined.

The background of triple random coincidences above the conversion electron boundary was measured for 15 hours. No pulses were detected during this time.

The authors take the opportunity to express their gratitude to B.S.Dzhelepov and Zh.Zhelev for helpful discussions in constructing the spectrometer, to

S.A.Shestopalova and I.Uchevatkin for information on the shape of the magnet piece poles, and exchange of experiences, to M.A.Listengarten for sending us the results of trajectory calculation, to V.P.Dzhelepov for constant interest in the construction of the spectrometer. The authors are deeply grateful to P.T. Shishlyanikov, S.A.Ivashkevich, V.I.Prilipko for great help in designing and constructing the stabilized source for the electromagnet supply, the system of frequency measuring and the system for automatic spectra measuring, V.I.Sobolev and the workers of the experimental shops of the Laboratory of Nuclear Problems for performing all mechanical operations.

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Received by Publishing Department
on 13 December, 1965.

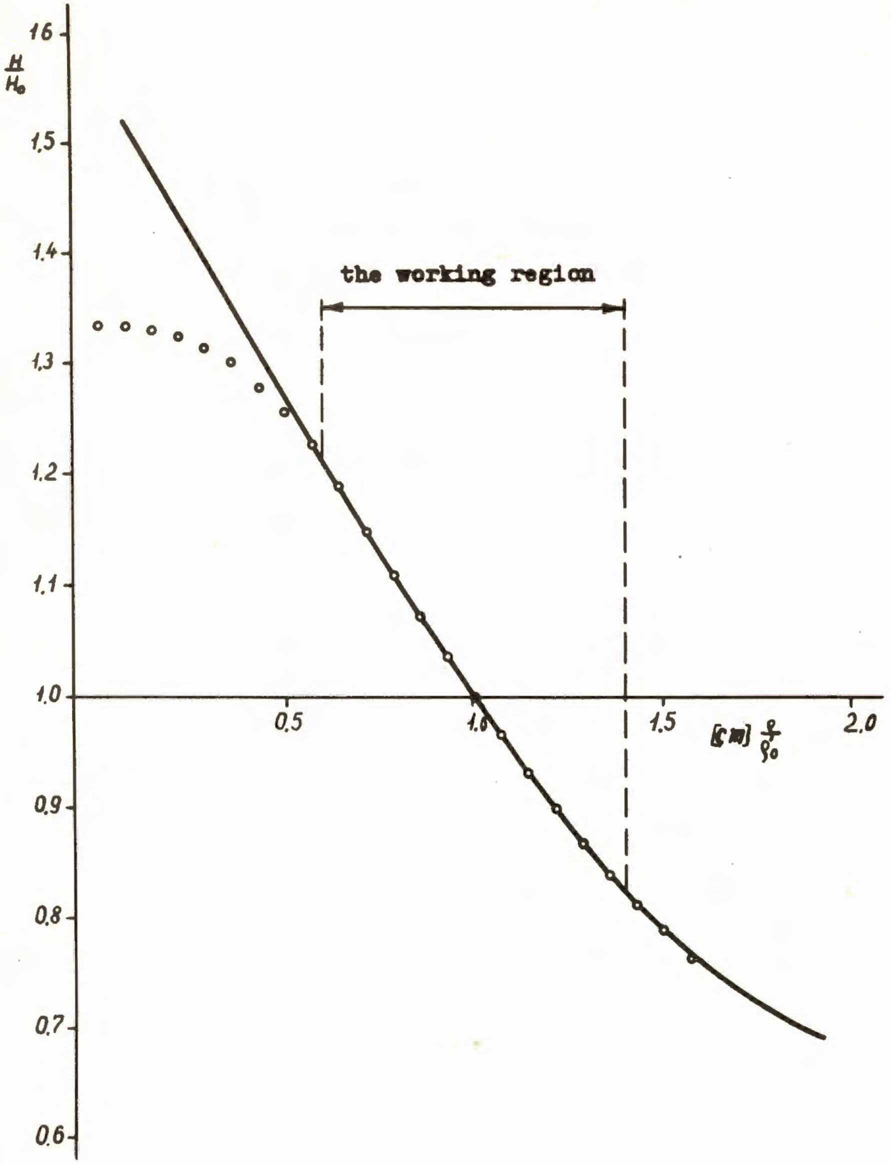

Fig. 1. Experimental and theoretical shapes of the magnetic field of the beta-spectrometer (solid curve-theory, circles-experiment).

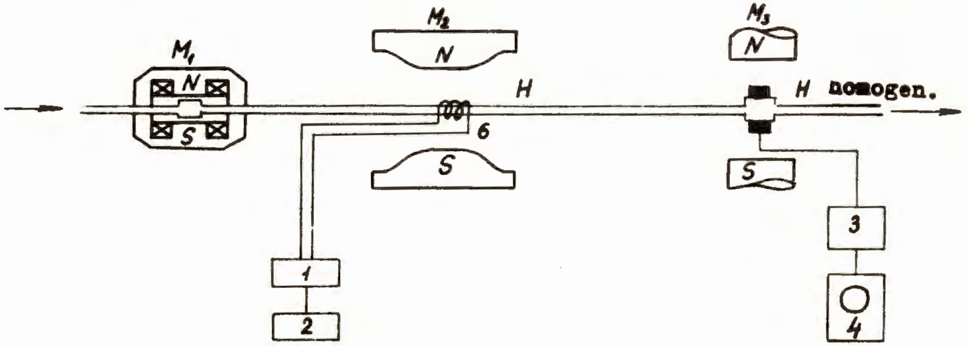

Fig. 2. The device for measuring the magnetic field strength. M_1 is the magnet producing the polarizing magnetic field; M_2 the magnet of the beta-spectrometer; M_3 the constant magnet with a homogeneous field. 1 is a r.f. oscillation generator GSS-6; 2 is the frequency meter; 3 – the magnetometer IMI – 2; 4 – the oscilloscope; 5 – the nuclear magnetic resonance probe; 6 – the nutation probe.

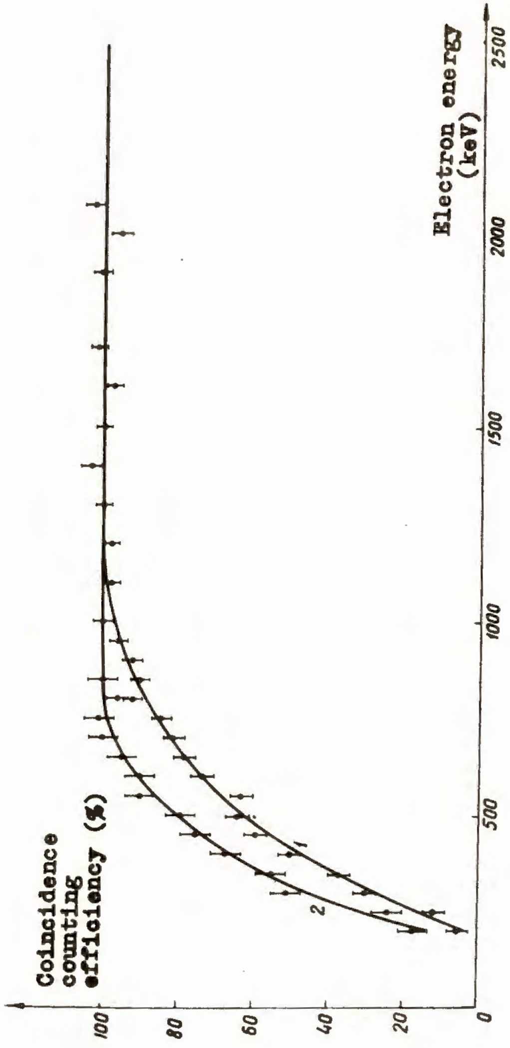

Fig. 3. Variation of the triple (curve 1) and double (curve 2) coincidences with detected beta-radiation energy.

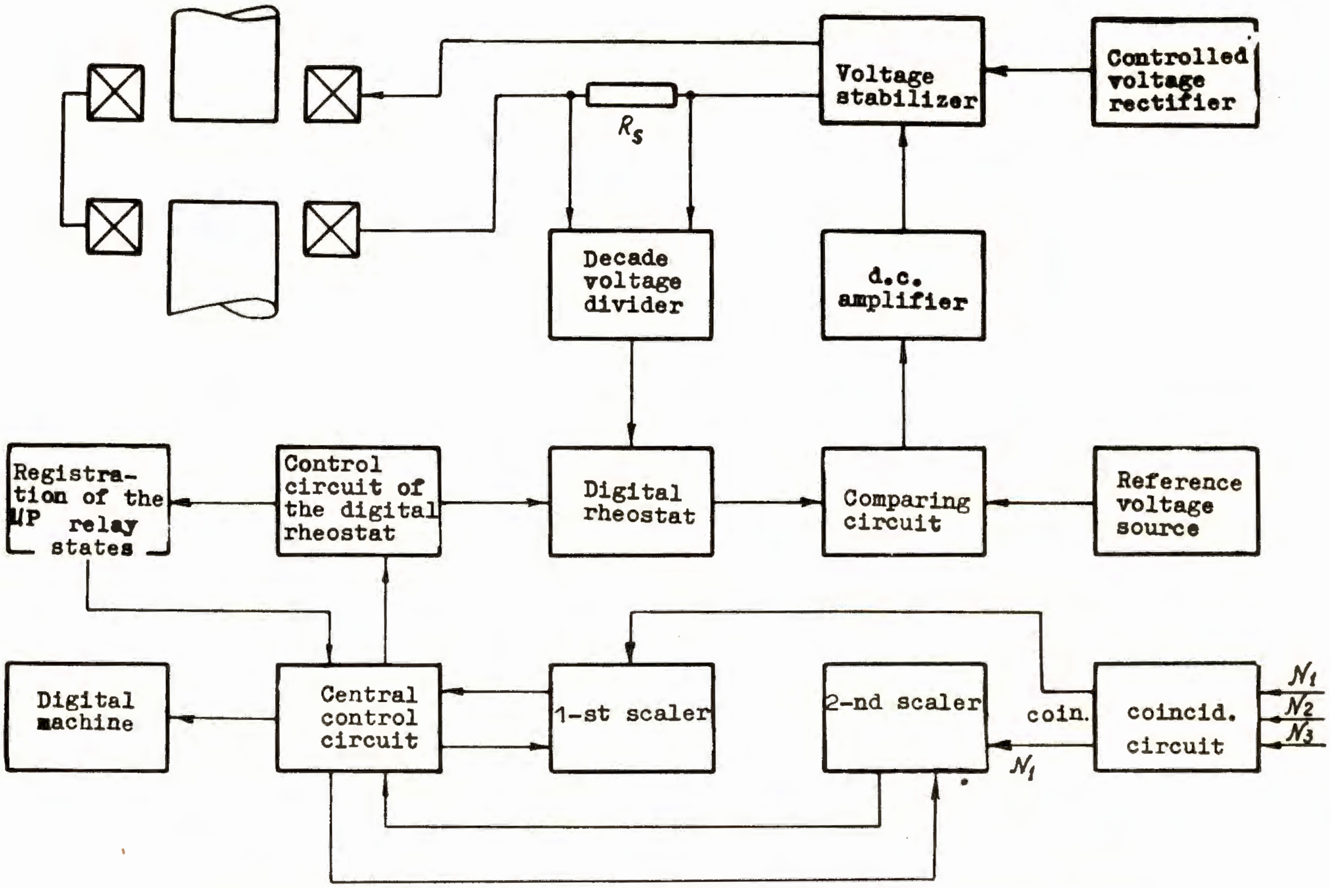

Fig. 4. The block-diagram of current stabilization of the magnet and the system for automatic measuring of conversion electron spectra.

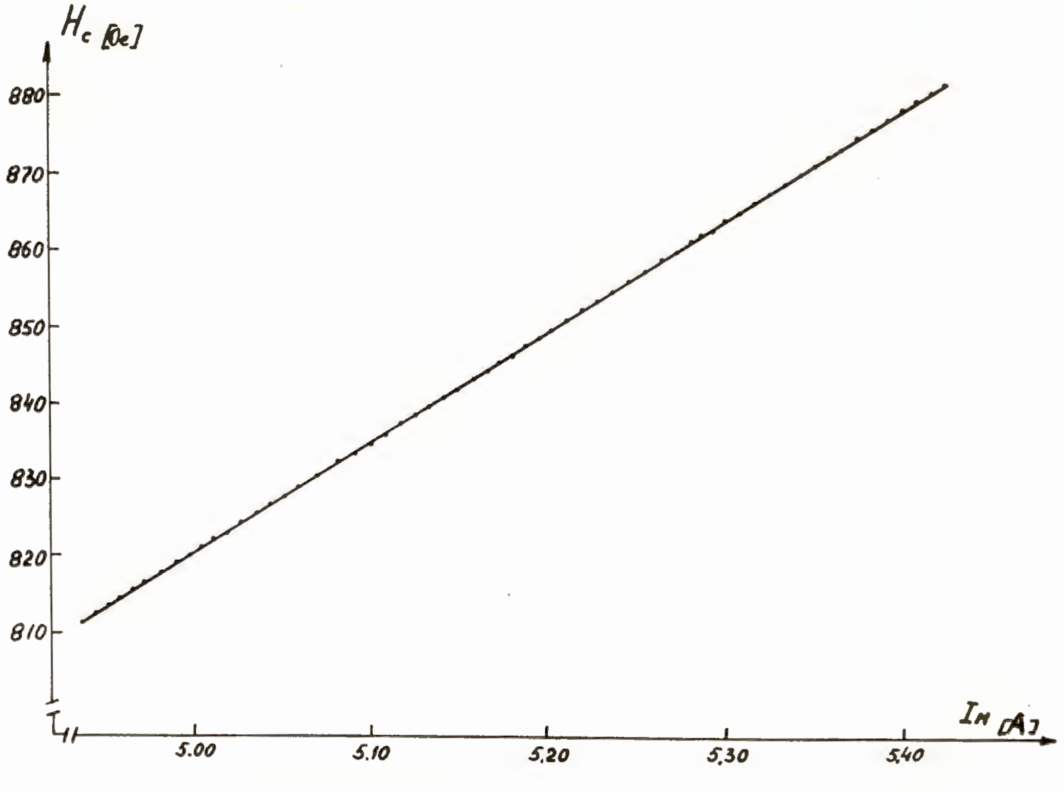

Fig. 5. Dependences of the magnetic field strength upon magnet current (within 256 stages of magnet current variations).

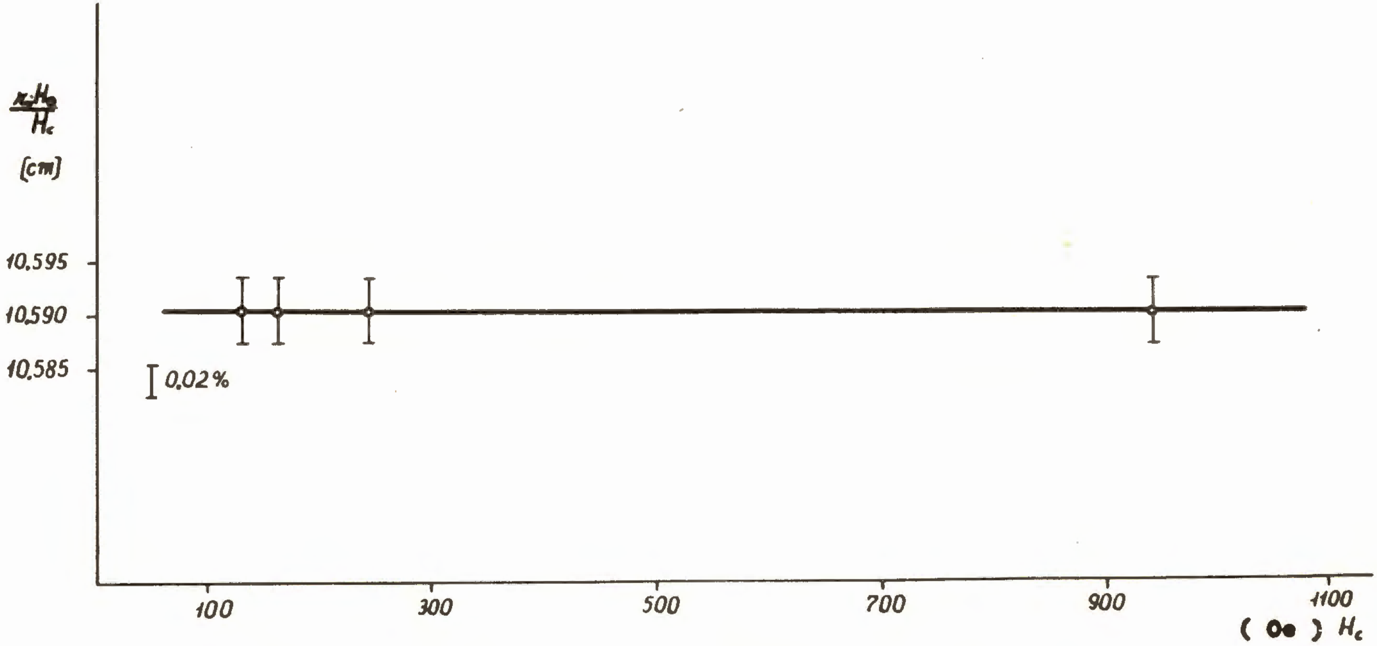

Fig. 6. Calibration curve for determining conversion electron energy.