TWO-FLAT CRYSTAL DIFFRACTION SPECTROMETER FOR STUDY OF MESIC ATOMS AT MOSCOW MESON FACILITY

K. E. Kiryanov, A. V. Kravtsov, V. I. Marushenko, A. F. Mezentsev, A. A. Petrunin, Yu. V. Filatov[1)], P. A. Pavlov[1)]

[1)] *St.Petersburg Electrotechnical University*

The most accurate measurements of the energies and line widths of pionic X-ray transitions in the energy region $E_x \leq 150$ keV were performed with crystal diffraction spectrometers. The LNPI-SIN collaboration has carried out a precision measurement of energies of $3d$-$2p$ transitions and widths of $2p$-levels in light pionic atoms [1]. The more accurate measurement of the pion mass allowed one to lower the upper limit for the mass of a muon neutrino from $m_{\nu_\mu} \leq 2.7$ MeV in 1967 [2] to $m_{\nu_\mu} \leq 0.26$ MeV now.

All these experiments were performed with transmission type bent-crystal spectrometers so measured energies were restricted by $E_x \geq 18$ keV due to high X-ray absorption in a crystal. To measure mesic X-rays with the energy lower than 18 keV it is necessary to use the reflecting geometry. It looks more reasonable to apply for this purpose a spectrometer with flat crystals, since a bent-crystal one has considerable aberrations in this energy region.

Basing on these considerations we have constructed a spectrometer with two flat crystals. The instrument can be used as a reflection-type device for $2.5 \leq E_x \leq 20$ keV and as a transmission-type one for $E_x \geq 20$ keV. The angular position of both crystals is measured by circular laser goniometers which allow us to determine angles with the accuracy 0.1 arcsec in the region 0°–360°. Each of the two crystals is a quartz slab with the surface of 280 cm^2, reflecting plane — (110). The characteristics of the spectrometer were investigated with X ray lines of Cu, Mo and Ag in the energy interval 8–22 keV. The apparatus is planned to be installed at the Moscow Meson Facility in 1995 (Fig.1). The measurements will be carried out using the co-called Gatchina source technique [3]. A water cooled pion production target made of 2 cm thick tantalum plate will be situated at a 30 μA, 600 MeV proton beam.

At the first step we plan to measure the hyperfine structure (h.f.s.) of the $3d$-$2p$ transition in the pionic ^{10}B atom and then in pionic ^{11}B, ^{9}Be, ^{6}Li and ^{7}Li. The aim is to determine a contribution of spin dependent strong pion-nucleon interaction into hyperfine splitting of the $2p$-level. This interaction manifests itself for the nl-levels of pionic atoms with $l \neq 0$ as an additional shift of the F-components caused by the spin dependent part of the πN-scattering amplitude [4]:

$$f_{\pi N}(\vec{s}) = 2i[d_0 + d_1(\vec{t} \cdot \vec{\tau})](\vec{s} \cdot [\vec{k'} \times \vec{k}]),$$

here d_0, d_1 are the corresponding isoscalar and isovector πN scattering volumes; $\vec{t}, \tau$ are the pion and nucleon isospins; $\vec{s}$ is the nucleon spin; $\vec{k}$, $\vec{k'}$ are initial and final pion momenta.

We have performed calculations of the h.f.s. of the $2p$-levels in pionic atoms with $3 \leq Z \leq 8$ ($6 \leq A \leq 17$) [5]. An important result of the calculations is that in pionic atoms with $Z \leq 5$ the total splitting exceeds a natural width of the h.f.s. components, so that the structure of $2p$-levels is physically resolved (Fig.2). Comparing the amplitudes d_0 and d_1 obtained from the pionic atoms with those from the experiments on the pion-nucleon scattering one can study the renormalization of the spin dependent πN-interaction in nuclear matter. One should note that various models of the pion-nucleus interaction give different predictions on

this renormalization, so the measurement of d_0 and d_1 in pionic atoms may be a test for these models.

One more important problem which can be solved with the same technique is electron screening in mesic atoms. Energy of a mesic atom transition depends on the K-shell electron population (the dependence on the other shells is negligible). An experimental diffraction line shape is formed by a sum of the lines, corresponding to definite K-shell population. Relative intensities of the components are proportional to probabilities of the K-shell population to be equal to 2, 1 or zero. It is impossible to calculate these probabilities and hence to calculate the experimental line centre of gravity shift. The uncertainty of the electron screening effect is the source of the main experimental error in case of the precision measurement of the mesic atoms transition energies. The high resolution of the spectrometer (Fig.3) will allow us to separate the lines which correspond to the presence of 2, 1 or zero electrons in the K-shell. At present this is the only way to study such an important problem of mesic atom physics.

As the next step we plan to measure the strong interaction shift ϵ_{1s} and broadening Γ_{1s} of the $1s$-level in pionic hydrogen. These quantities together with the Panofsky ratio allow one to determine the πN scattering lengths a_1 (isospin 1/2) and a_3 (isospin 3/2) through the Deser formula [6]:

$$\epsilon_{1s} = -\frac{4 \cdot E_{1s}}{3 \cdot r_B}(2a_1 + a_3),$$

$$\Gamma_{1s} = -\frac{16 \cdot Q}{9 \cdot r_B} E_{1s}(1 + 1/P)(a_1 - a_3)^2,$$

here E_{1s} is the $\pi^- H$-atom $1s$-level binding energy, r_B is the corresponding Bohr radius, Q is a reduced mass factor and P — the Panofsky ratio.

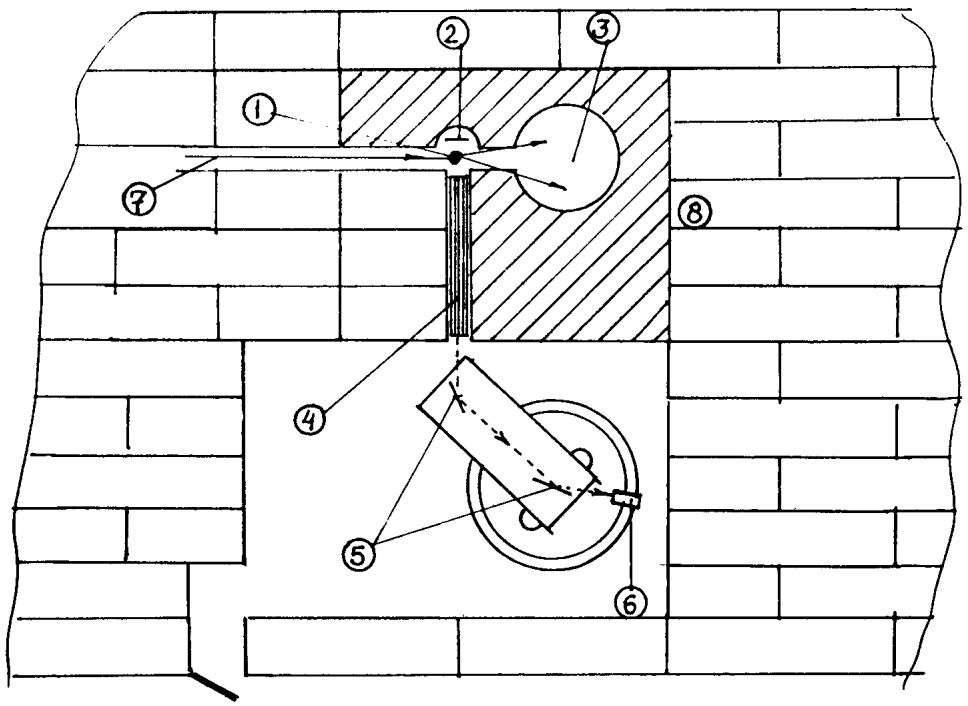

Fig.1. Schematical layout: 1 — pion-production target; 2 — X-ray target; 3 — beam dump; 4 — multi-slit collimator; 5 — crystals; 6 — detector; 7 — proton beam; 8 — shielding

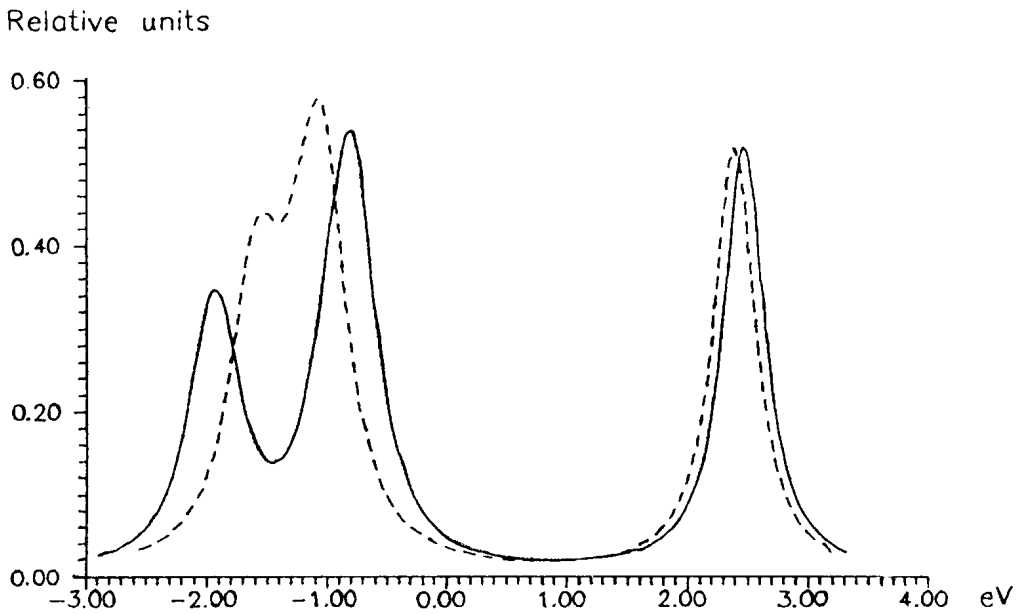

Fig.2. Hyperfine splitting for $3d$-$2p$ transition in $^{10}B_5$ pi-atom (theory). Dashed line — without spin forces. Solid line — spin forces included

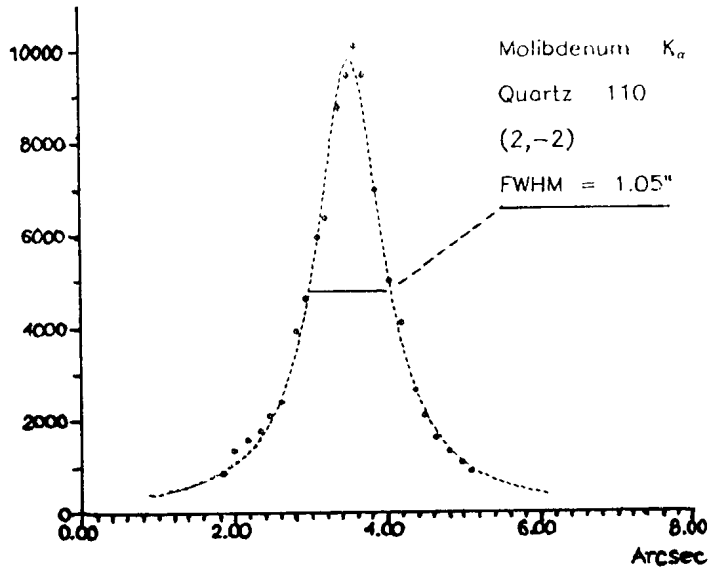

Fig.3. The (2,–2) rocking curve for the Mo K_α with quartz (110) crystals. The FWHM (Full Width at Half Maximum) is 1.05 sec

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