New measurement of the π^--meson mass

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We measured the energies of the π-mesic-atom $4f$-$3d$ transitions in Ti and Ca, equal respectively to 87 649.2 ± 1.9 and 72 347.0 ± 1.1 eV. The normal value was taken to be the $K_{\alpha 1}$W energy from the β decay of ^{182}Ta: 59 318.77 ± 0.21 eV. Using the conversion factors given in [1], we found for the rest mass of the π^- meson the value $M_{\pi^-}c^2 = 139\ 565.7 \pm 1.7$ keV.

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The most accurate value of the pion mass was obtained in[1-3]. The results of[1,2] were obtained with a crystal diffraction spectrometer in the Du Mond geometry, and the data of[3] with a semiconductor spectrometer. The accuracy limits in the case of the semiconductor spectrometer are imposed by purely metrological difficulties. The crystal diffraction spectrometer make possible measurements with relative accuracy to 10^{-6}.[4] However, owing to their small transmission, such an accuracy can be realized if the investigated radiation is intense enough. Usually the target was placed in the extracted beam of slow pions[2,3] of intensity up to 10^6 sec^{-1}, and the corresponding counting rate at the maximum of the diffraction mesic-x-ray line was ≈ 3 hr^{-1}.[2] Progress in this

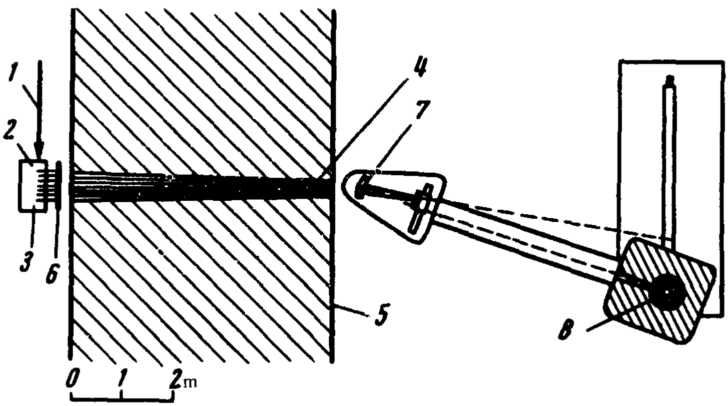

FIG. 1. Diagram of setup.

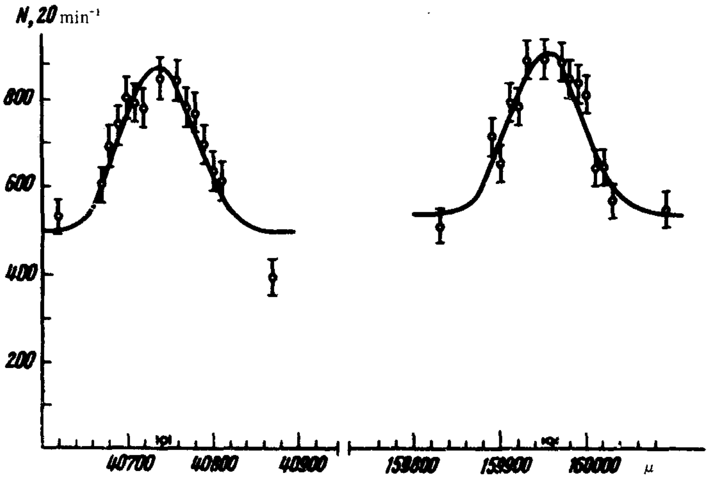

FIG. 2. Diffraction $4f$—$3d$ lines of Ti in the left-hand and right-hand positions of the instrument. The abscissas are the angle positions of the crystal in microns (1 μ corresponds to 0.2 second), and the ordinates are the counts in 20 minutes.

field depends on the development of strong-current accelerators (meson factories).

It is shown in this paper that even with an ordinary accelerator (proton beam intensity $\approx 10^{12}$ sec^{-1}, energy 1 GeV) it is possible to increase the counting rate, by at least two orders of magnitude, by using the crystal diffraction spectrometer more effectively. We have constructed a 5-meter diffraction spectrometer with a bent crystal after Cauchois. The construction of the instrument is shown schematically in Fig. 1. A proton beam (1) is incident on a meson target (2) constituting a set of 25 copper disks 2 mm thick and 20 mm diameter, placed in the shadow of the plates of a multislit collimator (4) placed in turn in the shielding wall (5). The meson target is half-surrounded by a target of the investigated substance—x-ray target (3). The mesons produced in the meson target form mesic atoms in the x-ray target.[1)] The main difference between our setup and those of[2,3] is that the x-ray target is placed in the immediate vicinity of the pion-producing target. The density of the number of stopped pions per unit target weight is increased in this variant by at least two orders of magnitude. The main problem in our case is the large background, since it is practically impossible to register a stopped pion in the x-ray target. The crystal diffraction spectrometer of the Cauchois type turns out to be noticeably preferable under these conditions to the Du Mond variant, as shown in[5]. The mesic x rays pass through the multislit collimator and are incident on a bent quartz crystal (7) 4.7 mm thick (reflecting plane 1340). The working aperture of the crystal is 80×90 mm, and the half-width of the quasi-mosaic[6] is ≈ 17 seconds of angle, and the line width at half-height is ≈ 20 seconds. The diffraction angle was measured with the setup described in[7]. The detector was a Ge(Li) spectrometer (8) of height ≈ 100 mm, width and depth ≈ 5 mm, and resolution 2.2 keV for the 100-keV γ line. The width of the detector receiving slit was ≈ 0.5 mm. The linearity of the instrument was calibrated and checked against the $K_{\alpha 1}$W and γ lines accompanying the β decay of ^{182}Ta. The references were the $K_{\alpha 1}$W energy 59318.77 ± 0.21 eV and the γ line energies 67749.32 ± 0.32 and 100105.54 ± 0.44 eV. These energies are given in a system in which the $K_{\alpha 1}$W energy is calculated as the weighted mean of the values of[4] and [8], with the data of [9,10] taken into account in the latter. During the time of the calibration measurements, the ^{182}Ta source (6) with activity ≈ 10 Ci was placed between the multislit collimator and the targets, and then taken out of the field of view of the instrument. The relative accuracy of the instrument in the 50—100 keV range, determined with the aid of the calibration γ lines, was not worse than 5×10^{-6}. The first objects of the investigation were chosen to be $4f$—$3d$ π-mesic atom transitions in metallic Ti and Ca of natural isotopic composition. Figure 2 show the diffraction mesic x-ray lines of Ti in the left-hand and right-hand positions of the instrument for one of the series of the measurements. The time to accumulate the statistics was ≈ 10 hr. At a proton beam intensity $\approx 8\times10^{11}$ sec^{-1} the number of counts at the maximum of the diffraction line of Ti was ≈ 1200 hr^{-1} at a background 1500 hr^{-1}. Four series of measurements were made on Ti, and three series on Ca. They yielded the following 45—3d transition energies: 87649.2 ± 1.9 (1.0) eV (Ti) and 72347.0 ± 1.1(1.0) eV (Ca). The cited errors include the calibration errors and the errors in the references, while the parentheses contain the external errors. From these values, using the conversion factors given in[11] we obtained for the π^--meson mass the values 139.563.7 ± 3.0 eV (Ti) and 139.566.7 ± 2.1 eV (Ca), the weighted mean value being 139.565.7 ± 1.7 eV. The uncertainty $\approx 10^{-5}$ in the calculation of the conversion factors is not included in the cited errors. In the system where a value 59 319.18 ± 0.36 eV is used for the KW energy,[8] the mass of the π^--meson is 139 566.7 ± 1.7 eV.

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[1)]The measurements can be made in a regime in which the meson target serves simultaneously as the x-ray target.

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