# OBSERVATION OF ATOMIC MUONIUM IN CRYSTALLINE QUARTZ

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The asymmetry coefficient (c') in the angular distribution of the positrons from the decay of mesons stopped in crystalline quartz at room temperature was measured in the meson beam of the JINR synchrocyclotron with the aid of apparatus used to observe $\mu^+$-meson spin precession in a magnetic field. The target was a set of plates of acoustical crystalline quartz, of 100 x 100 mm area and 8.28 g/cm$^2$ thickness.

Four cycles of the sinusoidal precession curve, with a frequency corresponding to the magnetic moment and spin of the $\mu^+$ meson, were traced at a magnetic field intensity 50.0 ± 0.3 Oe for ~6 μsec after the stopping of the $\mu^+$ meson in the target. The asymmetry coefficient corrected for the energy spectrum of the emitted positrons, for the counter geometry, and for the beam polarization was equal to c' = 0.065 ± 0.006 (the total number of $\mu^+$ mesons stopped in the target was $4 \times 10^6$, and the product of the solid angle by the counter efficiency was ~1/30).

At a magnetic field intensity 2.70 and 1.35 Oe (observation for ~1.5 μsec, number of stoppings in the target $1 \times 10^7$), the obtained precession corresponded to the frequency of revolution of atomic muonium with exponentially damped amplitude and with relaxation time 0.3 - 0.4 μsec. The experimental asymmetry coefficient, extrapolated to zero time, was $c_0' =$ 0.09 - 0.13 without correction for the beam polarization.

A more detailed investigation of the precession of atomic muonium was hindered by the presence of intensity modulation, connected with the fine structure of the accelerator pulse. Work on the investigation of the phenomenon is being continued.

# THE DECAYS $V \rightarrow \gamma + l^+ + l^-$ AND C-NONINVARIANCE OF ELECTROMAGNETIC INTERACTION

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In connection with the possible existence of charge-invariant electromagnetic interaction [1], several authors investigated meson decays [2)], the experimental observation and study of which could provide a check on the correctness of this hypothesis. In particular, theoretical studies were made of the radiative decays:

$$\pi^0 \to 3\gamma \ [1\text{-}4], \quad \eta \to 2\pi^0\gamma \ [6], \quad K_2^0(K^\pm) \to 2\pi\gamma \ [8], \quad \omega(\varphi) \to \rho^0\gamma,$$

$$\varphi \to \omega\gamma \ [1,\ 5], \quad f(A_1^0,\ A_2^0) \to \pi^0(\eta)\gamma, \quad \text{and } B^0 \to \omega(\rho^0)\gamma \ [9];$$

a study was also made of the conversion decay $\eta \to \pi^0 e^+e^-$ [1,6,7]. The available experimental data on the decays $\pi^0 \to 3\gamma$ [10] and $\eta \to \pi^0 e^+e^-$ [11] agree with C-parity conservation, but give only a rough upper limit of the probabilities for the decays $\varphi \to \omega(\rho^0)\gamma$ [12].

As noted by L. B. Okun' (private communication), a check on the charge-invariance of the electromagnetic interaction may be afforded by one more conversion decay, viz., $\omega \to \gamma e^+e^-$.

We consider in the present note decays of the neutral vector mesons $\omega$, $\rho^0$, and $\varphi$ (their quantum numbers $J^{PG}I^G$ are respectively [13] $1^{--}0^-$, $1^{-+}1^-$, and $1^{--}0^-$) into a gamma quantum and a lepton pair (electronic or muonic) via one virtual photon:

$$V \to \gamma + l^+ + l^-. \tag{1}$$

We note first that the decays $V \to 2\gamma$ are forbidden, since the two photons cannot be in a state with total angular momentum $J = 1$ [14], and the decays (1), which proceed via one virtual photon, are forbidden by virtue of C-parity. In the case of the proposed noninvariance of the electromagnetic interaction with respect to charge conjugation, these decays can occur and are described by a matrix element of the type

$$T = (4\pi\alpha)^{3/2}L^2(q^2)[(Vk)e_\alpha - (Ve)k_\alpha][\bar{u}(q_-)\gamma_\alpha v(q_+)], \tag{2}$$

where $\alpha = 1/137$, $L(q^2)$ a form factor with the dimension of length, $q$ the four-momentum transferred to the pair, $V$ the wave function of the vector meson, $e$ and $k$ the polarization and the four-momentum of the photon, and $q_\pm$ the four-momenta of the leptons. The differential probability of the decay (1), averaged over the spins of the V meson and summed over the photon polarization, is equal to

$$d\Gamma = \frac{\alpha^3 L^4(q^2)M_V}{6\pi^2}\frac{d^3k\ d^3q_+\ d^3q_-}{\omega\epsilon_+\epsilon_-}\,\delta^4(p - q - k)[\tfrac{1}{4}(1 - q^2/M_V^2)^2(q^2 + \mu^2) + (2 - q^2/M_V^2)(2\epsilon_+\epsilon_- - \tfrac{1}{2}q^2)], \tag{3}$$

where $M_V$ and $p$ are the mass and the four-momentum of the V meson, $\epsilon_\pm$ and $\mu$ are the energies and the mass of the leptons, and $\omega$ is the photon energy. Integrating (3), we obtain the distribution with respect to $q^2$ (the square of the invariant mass of the two leptons):

$$\Gamma_{\omega\to\gamma l^+l^-} = (1/18)\alpha^3L^4(q^2)M_V^5N, \tag{4}$$

$$N = \int\frac{dq^2}{M_V^2}\sqrt{(1 - 4)\mu^2/q^2}\ (1 + 2\mu^2/q^2)(1 + q^2/M_V^2)(1 - q^2/M_V^2)^3, \quad 4\mu^2 \le q^2 \le M_V^2, \tag{5}$$

or the photon spectrum ($\kappa = \omega/M_V$, $\epsilon = 4\mu^2/M_V^2$):

$$N = 2^5\int d\kappa\sqrt{1 - \epsilon/(1 - 2\kappa)}\ [1 + \epsilon/2(1 - 2\kappa)](1 - \kappa)\kappa^3. \tag{6}$$

Calculation of the integral N yields

$$N \approx \sqrt{1-\epsilon}\,(0.30 - 1.35\epsilon + 0.14\epsilon^2 + \dots) + \ln(4/\epsilon)(0.75\epsilon^2 + \dots), \quad (7)$$

which leads in the case of an electronic or muonic pair to the values

$$N_{e^+e^-} \approx 0.30, \qquad N_{\mu^+\mu^-} \approx 0.21. \quad (8)$$

In calculating the total decay probability by means of formula (4), we can assume that $L(q^2) \sim M_V^{-1}$; this yields

$$\Gamma_{\omega\to\gamma e^+e^-} \approx 4 \text{ eV}. \quad (9)$$

For comparison we note that calculation of the probability of the decay $\omega \to e^+e^-$ [15] leads to a value

$$\Gamma_{\omega\to e^+e^-} \approx 221 \text{ eV}, \quad (10)$$

if the dimensionless decay constant is estimated by perturbation theory. If we use for $L(q^2)$ the rough perturbation-theory estimate, then $\Gamma_{\omega\to\gamma e^+e^-}$ will be 3 - 4 orders of magnitude smaller than in (9). We note in conclusion that the decays $V \to e^+e^-$ were apparently not observed experimentally; experiment merely yields for their probability an upper limit [16-18]

$$\Gamma_{V\to e^+e^-} \lesssim (10^{-3} - 10^{-4})\Gamma_V, \quad (12)$$

where $\Gamma_V$ is the total width of the V meson.

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2) The fraction of these decays due to virtual electromagnetic interaction was investigated in connection with the possible CP-noninvariance of strong interactions [2 - 7].

## USE OF A POLARIZED PROTON TARGET TO DETERMINE ISOBAR PARITY

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To determine isobar parity by the method proposed here, there is no need to measure the polarization of the baryon produced as a result of the isobar decay. Our method may therefore prove to be most convenient in the case when this baryon is a nucleon.

The proposed method is based on the relations between the polarization effects in parity-conserving processes. For processes in which spin-1/2 particles participate, these relations are discussed in detail in the review [1]. In [2] is indicated a method of obtaining all the relations between the polarization effects in processes of the type $a + b \to c + d$, in which parity is conserved and particle spin is arbitrary.

Relations of this type have served as the basis for previously proposed methods for determining the parity of hyperons using a polarized proton target [1,3,4].

In [5] it is proposed to use a polarized target to determine the spin and parity of the isobar, but it is also necessary to measure the polarization of the baryon produced as a result of the isobar decay. However, as shown by Byers and Fenster [6], it is sufficient for this purpose to measure the polarization of the baryon with the target unpolarized.

Let us consider the process

$$\Pi_1 + p \to \Pi_2 + N^*, \qquad (1)$$

where $\Pi_1$ and $\Pi_2$ are pseudoscalar mesons, p a proton, and $N^*$ an isobar with spin $j \geq 3/2$.

The polarization moments $T_L^M$ of the isobar are expressed in terms of the polarization moments $t_l^m$ of the proton by means of the formula

$$\sum_{L,M}{}' \frac{2L+1}{2j+1} C^{j\lambda}_{\lambda';LM} T_L^M = \frac{1}{F} \sum_{\substack{l,m,\\ \mu,\mu'}} f_{\lambda\mu}(\vartheta)\, f^*_{\lambda'\mu'}(\vartheta)\, \frac{2l+1}{2}\, C^{(1/2)\mu}_{(1/2)\mu';lm}\, t_l^m, \qquad (2)$$

where