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OBSERVED ISOTROPY IN PIONIC ARGON X-RAY ANGULAR DISTRIBUTION*

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ABSTRACT

A measurement of the angular distribution of x rays from pionic Ar indicated that the emission was isotropic. Our results show $\alpha = 0.007 \pm 0.089$ where α is defined by $P(\theta) = 1 + (\alpha/2)\sin^2\theta$ and θ is the polar angle with respect to the incident pion beam.

According to G. Ya. Korenman[1] the angular distribution of x-ray emission from mesonic atoms can have a significant anisotropy related to the direction of the meson beam incident on the target. Anisotropy would imply that the mesons were captured into atomic states before their momenta became so low that, by scattering, the original direction was lost. If the momentum were sufficiently large at the instant of capture, the axis of rotation of the mesonic atom would tend to be in a plane perpendicular to the meson beam. Korenman claimed that the original orientation of the orbital angular momentum of the system could be preserved during deexcitation. Auger and electric dipole transitions would not necessarily randomize the mesonic atom spin axes. The angular distribution of the radiation would be given by

$$P(\theta) = 1 + (\alpha/2)\ \sin^2\theta \qquad (1)$$

where θ is the polar angle and α is the coefficient of anisotropy.

Korenman suggested that the target element should have a high ionization potential so that atomic capture would compete with ionization processes at the highest meson energy. He expected that the largest anisotropy would come from heavy inert gases. Gaseous targets cause experimental complications because of their inefficiency to stop mesons. Therefore, we compromised and used a target of liquid Ar.

X-ray anisotropy would give valuable information on the mechanism of mesonic atom formation. The meson energy at the instant of atomic capture influences the distribution in angular momentum states ℓ and the population of energy levels n. Any additional details of mesonic atom processes could help in understanding how the atoms' electronic configuration can influence the capture or cascade and lead to the observed Z-dependence of x-ray intensities.[2]

In the experiment to look for the anisotropy, we used the low momentum beam at the Bevatron tuned for negative pions of 170 MeV/c. This beam has two stages of electrostatic separation that effectively suppressed electron and muon contamination. The apparatus consisted of conventional scintillation counters for determining the stopped pions, two semiconductor detectors of Ge 3 cm in diam by 1 cm thick, and a target of liquid Ar. Ar has intense pionic x-ray lines at energies near to those of maximum efficiency of our x-ray spectrometer. A diagram of the arrangement is shown in Fig. 1. The target was a cylinder with its axis perpendicular to the plane in which the angular distribution was measured, a geometry that minimized changes in self absorption at various measurement angles. Distance from the center of the target to the detectors was R = 20 cm.

The number $Y(\theta)$ of x rays per stopped pion counted in a given spectral line depends upon the number emitted I, detector efficiency η, solid angle subtended by the detector $\Delta\Omega$, and the x-ray transmission T of the target.

$$Y(\theta) = I\eta\frac{\Delta\Omega}{4\pi} T \tag{2}$$

For a given line η does not vary with the angle of measurement θ whereas I, $\Delta\Omega$, and T could be a function of θ. If $\Delta\Omega$ and T are to be independent of θ, the distribution of stopped pions within the target must be equivalent to all the pions stopping on the axis of the cylinder; the centroid of the distribution must be on the axis. For example, a uniform distribution throughout the cylindrical target would be acceptable. We tried to avoid false anisotropies by using a target that was smaller than the extent of the beam of stopping pions and thinner than the spread in pion range due to momentum uncertainty and straggling. This arrangement tended to immerse the target in a uniform field of stopping pions. The vertical thickness of the beam was about 2 cm and all measurements were confined to a plane that contained the in-coming beam.

It is essential that the livetime of the counting system be nearly 100% when it is used to accurately compare intensities under conditions where the ambient background radiation changes as the detector is moved with respect to a beam or other source. We monitored livetime by inducing a constant charge on the detector from a pulse generator that was triggered by every one-thousandth stopped pion. The number of stopped pions was registered by a counter telescope and recorded for each run. Livetime was given by the ratio of the number of pulses found in the pulse generator peak to the number of triggers. The equivalent energy of the pulse generator was set near the upper limit of the amplifier system so that it did not interfere with the x-ray spectra. Average livetime was 0.94. Six percent of the events were lost by electronic rejection of those events that occurred within about 20μ sec of each other.

Angles from 40° to 90° and from 270° to 320° were accessible for measuring the anisotropy coefficient α defined by Eq. (1). Counters and the collimator occupied the region from 100° to 220°. In the forward direction we could not place the detectors in the beam of pions that missed the target.

Four series of measurements of $Y(\theta)$ were made: three at 40°, 90°, 270°, and 320° and one at 50°, 90°, 270°, and 310°. Although the beam was well centered on the target, as evidenced by the equality of $Y(90°)$ and $Y(270°)$, we used the ratio $[Y(90°) + Y(270°)]/[Y(40°) + Y(320°)]$ to calculate α. Taking this average cancels effects due to the centroid of stopped pions being off center if the centroid lies on the 90° or 270° radial and if the target radius is small compared to the distance from target center to detector (0.064 in our experiment). To establish the centroid in the center of the target we adjusted the energy degrader and the last horizontal-bending magnet to give the maximum number of stopped pions per unit of incident beam. In addition a second detector B was used to measure Y(230°)/Y(310°) = 1, confirming that the source was at the center. During the run detector B was used to continuously monitor Y(230°) and Y(310°) while detector A measured Y of 40°, 90°, 270°, and 320°. The distance y of the effective source from the center of the target (positive upstream along the beam axis) can be calculated by Eq. (3).

$$\frac{Y(230^\circ)}{Y(310^\circ)} = \frac{(R + y\cos 230^\circ)^{-2}\exp(-\mu\, y\cos 230^\circ)}{(R + y\cos 310^\circ)^{-2}\exp(-\mu\, y\cos 310^\circ)} \tag{3}$$

where μ is the x-ray absorption coefficient for the energy of the line under consideration and $y \ll R$. The first factors on the right hand side give the corrected solid angle and the second factors give the corrected transmission of x rays out of the target. For the entire experiment the average of y was (-0.01 ± 0.03) cm.

Knowing y and having measured Y(θ), we can solve for α in Eq. (4).

$$\frac{Y(90^\circ) + Y(270^\circ)}{Y(40^\circ) + Y(320^\circ)} = \frac{[1 + (\alpha/2)\sin^2 90^\circ](R + y\cos 90^\circ)^{-2}\exp(-\mu\, y\cos 90^\circ)}{[1 + (\alpha/2)\sin^2 40^\circ](R + y\cos 40^\circ)^{-2}\exp(-\mu\, y\cos 40^\circ)} \tag{4}$$

Table I presents the results of the experiment. Values for the four series of measurements are given in order to indicate the consistency of the numbers. Errors are on counting statistics only.

The lack of significant anisotropy (α = 0.007 ± 0.089) in the distribution of pionic x rays from liquid Ar implies that the mesons' directions with respect to the beam were randomized by the time atomic capture occurred or that the alignment of the orbital angular momenta was scrambled during the mesonic cascade.

We are grateful to R. Seki for helpful discussions, to the Nuclear Instrumentation Group for improvements in semiconductor detector technique, and to the Bevatron Operations Group for supplying the beam.

TABLE I. Results of the anisotropy measurements. $Y(\theta)$ is the number of observed x rays per stopped pion measured at the angle θ. The distance from the target center to the apparent centroid of the stopped pion distribution is given in column 4. Column 6 gives α the anisotropy coefficient in $P(\theta) = 1 + (\alpha/2)\sin^2\theta$. Errors are counting statistics only.

Run No.	Transition n_i	n_f	$\frac{Y(230°)}{Y(310°)}$	$(y \pm \Delta y)$ cm	$\frac{Y(90°) + Y(270°)}{Y(40°) + Y(320°)}$	$\alpha \pm \Delta\alpha$
1	3	2	0.926 ± 0.079	−0.216 ± 0.238	0.897 ± 0.050	−0.199 ± 0.221
2	3	2	1.012 ± 0.106	0.032 ± 0.293	0.983 ± 0.067	−0.078 ± 0.296
3	3	2	0.933 ± 0.080	−0.195 ± 0.242	0.973 ± 0.051	0.050 ± 0.260
4*	3	2	1.135 ± 0.111	0.356 ± 0.273	1.118 ± 0.063	0.258 ± 0.435
Average						−0.055 ± 0.139
1	4	3	0.912 ± 0.055	−0.102 ± 0.066	1.050 ± 0.048	0.402 ± 0.258
2	4	3	0.938 ± 0.067	−0.071 ± 0.079	0.983 ± 0.054	0.073 ± 0.250
3	4	3	1.043 ± 0.060	0.047 ± 0.063	0.975 ± 0.044	−0.162 ± 0.171
4*	4	3	1.058 ± 0.066	0.062 ± 0.069	1.074 ± 0.052	0.229 ± 0.332
Average						0.050 ± 0.116
Final average						0.007 ± 0.089

* Run number 4 was made at 50° and 310° instead of 40° and 320° (column 5).

FOOTNOTE and REFERENCES

*Work supported by the United States Energy Research and Development Administration.

1. G. Ya. Korenman, Sov. J. Nucl. Phys. 21, 398 (1975).

2. C. E. Wiegand and G. L. Godfrey, Phys. Rev. A9, 2282 (1974).

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FIGURE CAPTION

Fig. 1. Schematic plan view of the apparatus. Scintillation counter S_1 was 4.9 m upstream at the first mass separation slit. S_1, S_2 were used in a time-of-flight circuit. S_3 was 0.16 cm thick and defined the beam incident on the target. $\check{C}$ and S_4 were operated in anticoincidence.

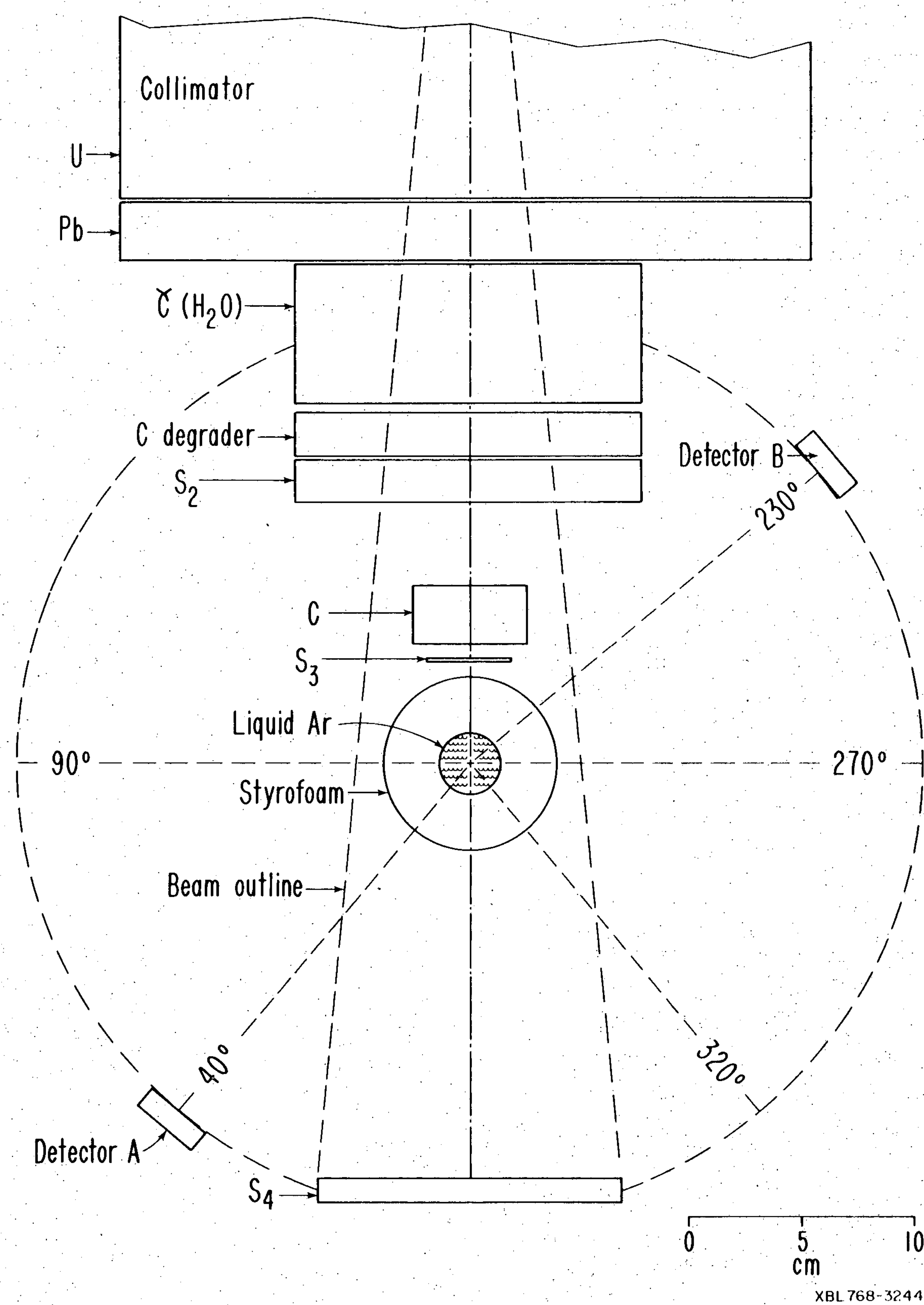
Collimator
U
Pb
Č (H2O)
C degrader
S2
Detector B
230°
C
S3
Liquid Ar
90°
270°
Styrofoam
Beam outline
40°
320°
Detector A
S4
0
5
10
cm
XBL 768-3244

Fig. 1

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