parison; the general agreement is good. Slight discrepancies arise mainly because our experimental values for F_{2p} at high q^2 values are close to zero whereas an extrapolation of the Stanford form factors gives negative values. Our experiments indicate also a somewhat smaller difference between F_{2p} and F_{2n}.

The experimental data are fit equally well by the BSFV form factors or by those following from our simple core model (see Fig. 1 and the curves in the preceding Letter[4]).

According to the interpretation of BSFV, our values of q_v and q_s would imply that the resonant energy of the two-pion state is $4.0 m_\pi$ and that of the three-pion state is $2.9 m_\pi$.

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$$\frac{d\sigma}{d\Omega}=\sigma_0\left\{F_1^{\,2}+\frac{q^2}{4M^2}\left[2(F_1+F_2)^2\tan^2(\theta/2)+F_2^{\,2}\right]\right\},$$

i.e., the different proton and neutron cross sections result directly from inserting the different values of F_1 and F_2 that are given by (1). We can speak of a partial charge or a partial magnetic moment whose value is given by the value of the corresponding partial form factor at $q^2=0$, the total charge or moment being the sum of the partial charges or partial moments.

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X-RAY YIELDS IN THE K AND L SERIES OF μ-MESONIC ATOMS*

J. L. Lathrop, R. A. Lundy, V. L. Telegdi, and R. Winston
The Enrico Fermi Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois
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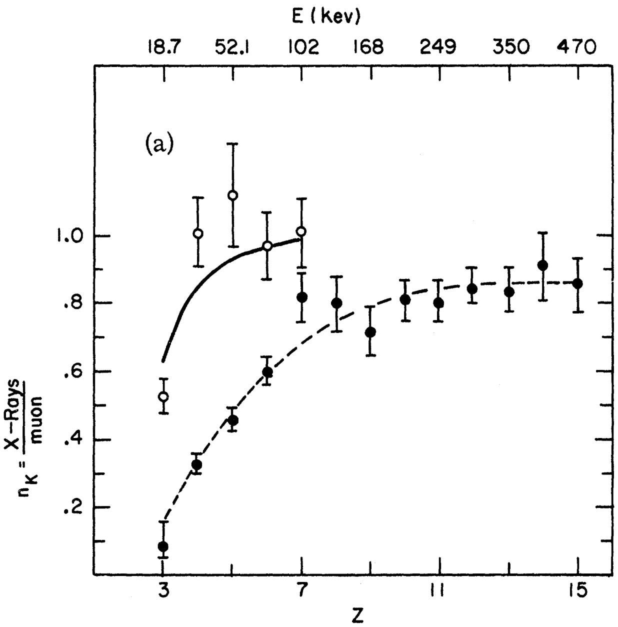
Since the experimental work of Stearns and Stearns,[1] much theoretical speculation has been presented[2-7] to account for the low yields of x-rays in the K and L series of light μ-mesonic atoms reported by these authors. Their results, reproduced in Figs. 1(a) and 1(b) (filled circles), require that the Auger rates[8] competing with radiative transitions be, respectively, ~300 times (K series) or ~30 times (L series) as fast as predicted by conventional theory, or else that one postulate some hithertofore unknown competitive transition mechanism. The situation for the yields of π-mesonic x rays of comparable energies is entirely similar,[9] but need not be discussed here.

In view of this situation, we decided to remeasure the yields in the π-mesonic K and L series, in particular for those light elements for which low (or even experimentally unobservable) yields were reported in reference 1. In view of our findings, we think it useful to present here our preliminary results. They are displayed in Figs. 1(a) and 1(b) (open circles).

The experimental arrangement used by us is shown in Fig. 2 and is essentially the same as that used by Stearns and Stearns.[1] Some relevant differences are the following: (a) use of thinner (1/16 in.) plastic scintillators, wrapped in 1-mil Al foil, just before and just behind the x ray target T, to improve the transmission of soft x rays and to decrease the background of carbon mesonic x rays; (b) use of an improved window (20 mils of Be) on the 1/16-in., 2-in.-diameter NaI detector employed for x rays up to 75 kev; (c) use of a longer effective resolving time (100 nsec vs the 50 nsec of Stearns and Stearns) for NaI-induced coincidences; (d) use of a 100-channel pulse-height analyzer (RIDL 34).

The running conditions differed more markedly from those available to earlier workers in this field, in the following respects: (a) use of a μ^- beam of low e^- content and of a Čerenkov counter (No. 3 in Fig. 2) for further electron rejection; (b) use of a good duty-cycle (~5) meson beam, obtained by means of a vibrating cyclotron target.[10] These conditions enabled us to use rather slow NaI coincidences without generating large accidental backgrounds. As is well known, hard clipping of NaI pulses of small amplitude (from, say,



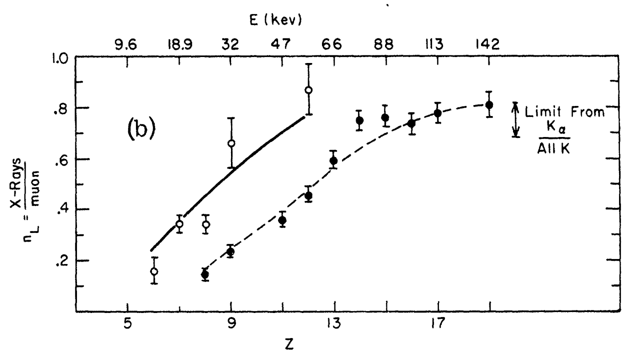


FIG. 1. (a) Observed μ K-series yields: open circles, this experiment; filled circles, reference 1. Curves are fits to $n_K = \text{const}\ Z^4/(Z^4+C_1)$. For this experiment, const = 1.00, $C_1 = 45$, while const = 0.86, $C_1 = 450$ for reference 1. With the same assumptions as used in reference 1, present data require an Auger transition probability about 30 × theoretical. Note that the sole evidence for fall of K yield with low Z rests on the Li K point. (b) Observed μ L-series yields: open circles, this experiment; filled circles, reference 1. Curves are fits to $n_L = \text{const}\ Z^4/(Z^4+C_2)$. For this experiment, const = 0.80, $C_2 = 3\times10^3$, while const = 0.97, $C_2 = 2\times10^4$ for reference 1. With the same assumptions as used in reference 1, present data require an Auger transition probability about 4 × theoretical.

25-kev photons) can easily lead to large time jitters and hence appreciable coincidence losses. The limiter (see Fig. 2) used by us was well cut off by 12-kev x rays from a Hg^{203} source under the operating conditions of the NaI detector; further, during actual runs a good plateau (< 2% slope/100 v at 2100 v photomultiplier voltage) was obtained with Li K x rays (19 kev).

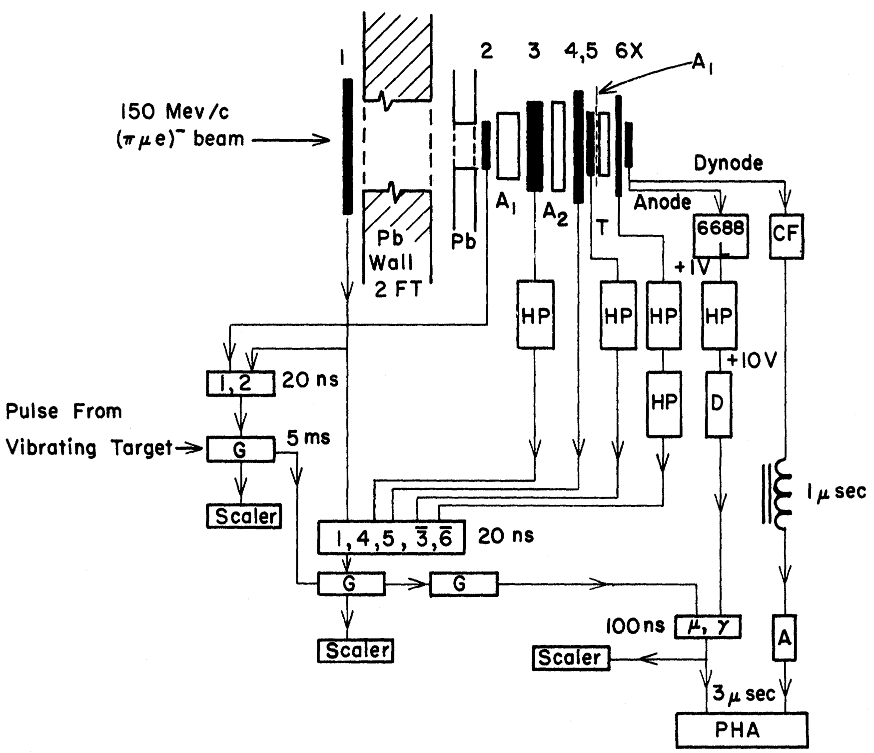


FIG. 2. Experimental arrangement: 1, 2, 4, 5, and 6 are plastic scintillators, viz., 1 = 6 × 6 × 3/8 in., 2 = 3 × 3 × 1/4 in., 4 = 5 × 5 × 1/8 in., 5 = 3 × 3 × 1/16 in., 6 = 4.5 × 4.5 × 1/16 in., 4 = 4 × 4 × 1 in. H_2O–Čerenkov counter, X = 2-in.-diam × 1/16-in. NaI crystal, connected by logarithmic light pipe to a 5-in.-diameter photomultiplier (10-stage EMI). A_1, A_2, A_3 absorbers; A_1 = 2 in. graphite, A_2 = 0.75 in. Cu, A_3 = 0.008 in. brass (shield for x rays from counter 5); T, target (in Table I; L = limiter; CF = cathode follower; HP = distributed amplifier, gain 10; D = fast discriminator; G = 5-msec gates; A = linear amplifier; PHA = 100-channel analyzer. (1,2), (145$\bar{3}\bar{6}$), and ($\mu\gamma$) are coincidence circuits with the indicated resolutions.

Table I. Experimental data used for yield evaluation.

Element	Target thickness (g/cm^2)	Series, K_α (L_α) (kev)	Stopped[b] Muons $\times 10^3$ (corrected)	Calibration source	Counting[c] efficiency correction	Detected[d] x rays	K_α / all K (%)	Series yield[e] / Muon
Li	Metal, 1.2	K, 18.7	35.1	18 kev, Am^{241}	0.091	1.700	0.70	0.53 ±0.05
Be	Metal, 1.5	K, 33.3	76.3	32 kev, Cs^{137}	0.078	6.061	0.82	1.01 ±0.10
C	Graphite, 1.2	K, 75.0	18.9	73 kev, Hg^{203}	0.086	1.592	0.71	0.97 ±0.10
C	Graphite, 0.48	L, 13.9	44.6	12 kev, Hg^{203}	0.067	0.475	0.63	0.16 ±0.05
B	Powder, 1.9[a]	K, 52.1	52.0	52 kev, Tm^{170}	0.093	5.475	0.77	1.12 ±0.17
N	95% $(NH_2)_n$	K, 102	29.9	60 kev, Am^{241}	0.16	4.836	0.69	1.01 ±0.10
	+5% H_2O, 1.0[a]	L, 18.9	34.6	18 kev, Am^{241}	0.077	0.889	0.63	0.34 ±0.03
O	Ice, 1.0	L, 25	32.7	32 kev, Cs^{137}	0.088	0.964	0.68	0.32 ±0.03
F	LiF, 1.0[a]	L, 32	23.2	32 kev, Cs^{137}	0.087	1.334	0.81	0.66 ±0.10
Mg	Metal, 2.0	L, 56	36.6	60 kev, Am^{241}	0.091	2.892	0.75	0.87 ±0.04

[a]Contained in 3-inch diameter × 1/16-inch wall bakelite cylinder with 0.02-inch Lucite end windows.
[b]Fraction of muon stops in other than target material was measured.
[c]Includes empirically determined target, ac counter, and NaI casing attenuation, in- and out-scattering, and NaI efficiency (escape correction theoretical for Be K).
[d]All runs with 2-inch diameter × 1/16-inch NaI detector except N K with 3-inch diameter × 1/4-inch NaI detector; C K background was measured independently, C L background from counter No. 5 was filtered out with 0.008 inch brass.
[e]Indicated errors are increased over statistical to include error in analyzing spectra for background and error in absolute calibration with sources.

Table I summarizes the experimental data leading to the yields plotted in Figs. 1(a) and 1(b). The targets were in general 3-in. diameter cylinders, matched in surface density for roughly equal attenuation (~10%) of the mesonic x rays under study, rather than for equal stopping power,[1] and subtending approximately equal solid angles at the detector; the number of stopped particles was determined experimentally. The targets were calibrated in situ with uniform extended radioactive sources of calibrated intensity[11] yielding photons of energies close to those of the mesonic x rays of interest. Further calibrations, mainly for in- and out-scattering, were performed in the laboratory by displacing extended sources through appropriately subdivided targets. The important escape correction (~35%) for the Be K radiation (33 kev) had to be taken from theory[12] because no radioactive sources yielding photons as close to the iodine K edge (33.2 kev) were available. Dead-time corrections to the data stored in the pulse-height analyzer were negligible (10 analyses/sec, 100-μsec analysis time).

As is evident from Figs. 1(a) and 1(b), our results do not appear to bear out those of reference 1. Assuming that the mesons have a statistical distribution of $2l+1$ in the $n=14$ level, their results require an Auger rate of 5.85×10^{13} sec^{-1} (~300× "theoretical") for the K series and an Auger rate of 2.68×10^{14} sec^{-1} (~30×"theoretical") for the L series. In both cases the remaining "discrepancy" is an order of magnitude less serious than suggested by reference 1. By making different, but not unreasonable assumptions about the initial populations,[13] one can hope to reduce the extant "discrepancy" even further.

It has occasionally been suggested that the results of Stearns and Stearns[1] could be attributed to a thin "dead layer" on the front face of their NaI(Tl) crystal, or of such crystals in general. This hypothesis is not only at variance with general experience with NaI(Tl) detectors, but also fails to provide a satisfactory explanation. The effect of such a "dead layer" should be quite different for x ray energies just below, and just above, the iodine K edge, i.e., for Be K_α (33.3 kev) and F L_α (32 kev). The yields of reference 1 show no great variation between these two x rays.

Another suggestion frequently advanced is that the muon may be "trapped" in some high-n orbit. We briefly investigated this possibility by delaying the μ input to the μ-γ coincidence circut (see Fig. 2) by 100 nsec and looking for Li K x rays, the ones for which we find the lowest K yield. Not more than (1.0 ± 0.5)% "delayed" x rays were found in this way. This observation is most naturally interpreted in terms of some residual jitter of the NaI pulse, but can clearly not preclude the existence of a long-lived delayed component. In the case of the π^- mesons, recent work at CERN[13] suggests, however, negligible trapping in Be.

A repetition of the present μ-mesonic yield measurements with a proportional counter is in progress, and an extension to pions is contemplated.

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