muons observed, 1.5 accidental counts were expected. The contribution to the counting rate due to the radiative decay has been calculated,[7] but since there are no previous experimental data the result is not considered reliable to better than a factor of two. An absolute lower limit to the expected number of counts from these decays is then 1.4 counts.

On the basis of four events, the analysis of the data with the background as discussed above yields a branching ratio $R(\mu\rightarrow e+\gamma)/\mathrm{R}(\mu\rightarrow e+\nu+\bar{\nu})$ which is probably less than 0.7×10^{-6}. The systematic error in the efficiency for detecting the $\mu\rightarrow e+\gamma$ decays is estimated to be not more than 30%, and the branching ratio is then found to be less than 2×10^{-6} with a 90% confidence level.

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[2]G. Feinberg, Phys. Rev. 110, 1482 (1958).

[3]S. Lokanathan and J. Steinberger, Phys. Rev. 98, 240 (A) (1955).

[4]Berley, Lee, and Bardon, Post-Deadline Paper, American Physical Society Meeting, New York, January, 1959.

[5]Davis, Roberts, and Zipf, Phys. Rev. Lett. 5, 211 (1959).

[6]Lithium hydride was chosen over other hydrogenous materials (polystyrene, polyethylene, water), in which we also found a substantial number of π^- captures by hydrogen, because the low conversion probability in the lithium made this substance more favorable for efficiency measurements.

[7]The transition probability for the radiative decay was computed from the formulas derived by Behrends, Finkelstein, and Sirlin [Phys. Rev. 101, 866 (1956)], by assuming a $V-A$ interaction. An analysis of the data obtained is now in progress and a further communication on the subject of the muon decay with inner bremsstrahlung will follow.

CORRECTIONS TO THE 3D-2P TRANSITIONS IN μ-MESONIC PHOSPHORUS AND THE MASS OF THE MUON

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The recent precise determination of the muon magnetic moment[1] has raised the question as to whether the lower limit for the μ-meson mass can be trusted with enough precision to demonstrate a clear discrepancy between the experimental value for the muon moment and its value predicted by standard quantum electrodynamics. Actually, by using the best lower limit known up to now,[2] the inequality

$$g_\mu > 2(1.00158\pm0.00022), \qquad (1)$$

obtains, whereas quantum electrodynamics predicts[3]

$$g_\mu = 2(1.001165). \qquad (2)$$

The discrepancy of a few parts in 10^4 requires a precise knowledge of the precision to which the lower limit of the muon mass can be trusted. Crowe's best value for that limit involves a tentative limit of error of 2×10^{-4}, although some corrections were only guessed and some others were not yet evaluated. Owing to the real importance of having the most precise value of the limit, this paper is devoted to a very careful examination of the corrections in order to reduce considerably the limit of error. A summary of the corrections we have been considering is listed in Table I.

The fine structure splits the 3D-2P transition into a triplet, the components of which have the following energies in electron-volts:

$$3D_{3/2}-2P_{3/2}\text{: [1] } (425.42)m_\mu/m_e; \qquad (3)$$

$$3D_{5/2}-2P_{3/2}\text{: [9] } (425.65)m_\mu/m_e; \qquad (4)$$

$$3D_{3/2}-2P_{1/2}\text{: [5] } (427.75)m_\mu/m_e. \qquad (5)$$

The numbers in square brackets are the relative intensities.

Fitch, Rainwater, and Koslov[4] have shown that the 3D-2P transition energy falls above the Pb K-edge energy and below the Bi K-edge. Therefore the Pb K-edge energy will provide a lower limit to m_μ/m_e. Using the very probable value[5] of (88 015 ± 5) ev for the Pb K-edge energy, one gets, using (4), the inequality

$$m_\mu/m_e > 206.78 \pm 0.01. \qquad (6)$$

Using (3), one would get a still higher lower limit. However, owing to its weakness, it is very likely that one cannot decide whether or not this energy is absorbed by the Pb filter.

The question is raised then whether one can without ambiguity decide, by analyzing the experimental curves,[6] if both the transitions $3D_{5/2}$-$2P_{3/2}$ and $3D_{3/2}$-$2P_{1/2}$ are absorbed by the Pb filter, or if only the $3D_{3/2}$-$2P_{1/2}$ energy is absorbed. In the latter case, the numerical value (6) would become an upper limit, whereas the energy of the $3D_{3/2}$-$2P_{1/2}$ transition would provide the lower limit:

$$m_\mu/m_e > 205.76 \pm 0.01. \qquad (7)$$

The inequality (6), precise now to 5×10^{-5}, confirms the discrepancy between the experimental and theoretical values for the magnetic moment of the muon. However, if it would turn out that in fact the Pb edge splits the two transitions (4) and (5) of the triplet, the inequality (7) would no longer lead to a contradiction between theory and experiment[7]. But an improvement in this situation is also complicated by a thickness effect of the lead foil.[8] The authors do not feel competent to discuss this point any further.

In conclusion, if one accepts the results as stated above, the two possible explanations of the discrepancy between (1)[9] and (2) are as follows:

(a) Either the Pb K-edge actually splits the $3D_{5/2}$-$2P_{3/2}$ and $3D_{3/2}$-$2P_{1/2}$ lines of the $3D$-$2P$ transition in μ-mesonic phosphorus.

(b) Or the μ-meson behaves slightly differently from a simple heavy electron; the discrepancy would thus be the first sign of such a difference.

The authors are gratefully indebted to Professor L. Lederman for very instructive discussions on that matter.[10]

Table I. Corrections to the $3D_{5/2}-2P_{3/2}$ transition in μ-mesonic phosphorus ($Z=15$, $A=31$), not including reduced mass correction. ($m_\mu/m_e = 206.75$ has been used.)

Effect	Contribution in ev (1 ry_∞ = 13.605 ev)
Second order vacuum polarization, corrected for reduced mass[a]	329.23
Fourth order vacuum polarization	2.19
Coulomb Green's function correction for vacuum polarization[b]	0.33
Finite-size effect on Coulomb potential[c]	-3.20±1.0
Shielding by atomic electrons	1.32
Lamb shift	-0.49
$(Z\alpha)^2$ correction to the Pauli approximation	0.16
Hyperfine structure (outer components: $f=2\rightarrow1$)	0.03
Finite-size correction to the vacuum polarization potential[d]	negligible
Finite-size corrections to the wave functions for vacuum polarization	...
Coulomb wave function corrections for second order vacuum polarization: not evaluated	±1.00
Corrections for finite mass of the nucleus (recoil) (Notice that the $2P$ level has 4.3 ev natural width)	negligible
Total	329.57±2.00

[a]A. Galanin and I. Pomeranchuk, Doklady Akad. Nauk S.S.S.R. 86, 251 (1952); L. Foldy and E. Eriksen, Phys. Rev. 95, 1048 (1954); A. Mickelwait and H. Corben, Phys. Rev. 96, 1145 (1954); S. Koslov, Nevis Report No. 19, 1956 (unpublished).

[b]E. Wichmann and N. Kroll, Phys. Rev. 96, 232 (1954).

[c]Using a spherical uniform charge density of radius $R=1.3A^{1/3}\times10^{-13}$ cm. We are grateful to R. Hofstadter for a discussion on this point.

[d]R. Rockmore (unpublished).

[1]Garwin, Hutchison, Penman, and Shapiro (to be published).

[2]K. Crowe, Nuovo cimento 5, 541 (1957); Cohen, Crowe, and DuMond, Fundamental Constants of Physics (Interscience Publishers, Inc., New York, 1957).

[3]C. Sommerfield, Phys. Rev. 107, 328 (1957); A. Petermann, Helv. Phys. Acta 30, 407 (1957); H. Suura and K. Wichmann, Phys. Rev. 105, 1930 (1957).

[4]Koslov, Fitch, and Rainwater, Phys. Rev. 95, 291 625 (1954).

[5]A. Sandström, Handbuch der Physik (Springer Verlag, Berlin, 1957), Vol. 30; Y. Cauchois and H. Hulubei, Tables de Constantes Sélectionnées. Longueurs d'Onde des Emissions X et des Discontinuités d'Absorption X. (Hermann et Cie, Paris, 1947). The uncertainty of 5 ev in the energy of the K-edge is taken for granted by the optimistic quotations of experts in this field. We thank Professor L. G. Parratt for private communication on the structure of the edge.

[6]S. Koslov, footnote a of Table I.

[7]G. Shapiro (private communication) has independently considered this possibility.

[8]J. W. M. DuMond (private communication). We are grateful to Professor DuMond for having called our attention to this very important feature.

[9]The uncertainty of 0.00022 being now reduced to 0.00005.

[10]G. Shapiro, at Columbia University also evaluated with D. Tycko the second-order vacuum polarization contribution on the IBM 650 computer, with the same result as we quote on the first line of the table.

THREE-BODY DECAYS OF K_2^0 AND K_1^0*

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In the course of our associated-production experiment using the Berkeley 10-inch liquid hydrogen bubble chamber, we have seen nine "anomalous" K^0 decays. Within their limited statistical accuracy these events (a) are consistent with equal leptonic decay rates for K_1^0 and K_2^0, (b) are in good agreement with decay rates predicted[1] by the "extended" $\Delta I = \frac{1}{2}$ rule, and (c) yield a new value for the K_2^0 lifetime.

In the entire experiment we find[2] 497 decays of the type $K_1^0 \to \pi^+ + \pi^-$ (that is, $N_{+-} = 497$), from K^0 produced via $\pi^- + p \to \Lambda + K^0$ or $\Sigma^0 + K^0$. The production and decay points are required to lie within a well-defined fiducial volume in the chamber. Of the nine K^0 decays which fail to fit $\pi^+\pi^-$ decay, one (previously reported[2]) fits $\pi^+\pi^-\pi^0$ decay ($N_\tau = 1$) and eight fit leptonic decay into $\pi^\pm\mu^\mp\nu$ and $\pi^\pm e^\mp\nu$ ($L = 8$). The incident π^- momentum is known precisely.[3] Therefore the K^0 momentum is known from its production angle. (There are actually four possibilities, corresponding to Λ and Σ^0 production, and to forward and backward c.m. production.) For given rest-mass assignments to the two charged decay fragments, and from their measured momenta, we can determine the missing energy and momentum, and therefore the rest mass of the neutral decay fragment. The errors are such that it is fairly easy to distinguish between the $\pi^+\pi^-\pi^0$ decays (135-Mev neutral rest mass) and the leptonic decays (zero neutral rest mass) and to eliminate all but one possible K^0 momentum. However, the four leptonic modes are not easily distinguishable among themselves, since the total energies of the charged decay fragments are determined largely by the momenta rather than by the rest masses. With a larger sample of data, a statistical separation would be possible.

A leptonic K^0 decay can escape detection by simulating a $\pi^+\pi^-$ decay. From the available phase space and known measurement errors, we estimate that less than 10% of the three-body decays are thus masked. No corresponding correction was made to L.

The events are listed in Table I and a photograph of one of the decays is shown in Fig. 1.

The "true" number of K^0 produced in the experiment is 2020 ± 100.[2] According to CPT invariance, half of these (K_1^0) should be short-lived ($N_1 = 1010$) and half (K_2^0) long-lived ($N_2 = 1010$).[4] Gell-Mann[5] has shown that if CP invariance holds, and if the weak interactions are not such as to allow $\Sigma^+ \to n + e^+ + \nu$, then K_1^0 and K_2^0 should undergo leptonic decay at the same rate,

$$\Gamma_{1L} = \Gamma_{2L}. \quad (1)$$

(The oscillatory interference terms between K_1^0 and K_2^0 disappear in the sum over both signs of electric charge of the decay products.)

There are two ways in which we can check the prediction (1). The first is to look at the time

Table I. K^0 three-body decays. T is the K^0 proper potential time and t the proper lifetime.

Event	p_K (Mev/c)	T (10^{-10} sec)	t (10^{-10} sec)
203 999	615	2.60	1.29
235 805	760	1.20	0.56
288 517	670	2.87	1.54
359 058	680	3.60	1.21
385 627	684	2.87	0.67
416 759	656	3.79	1.63
448 646[a]	298	4.89	2.32
499 237	240	9.16	3.81
501 242	120	13.22	0.20

[a]Decays into $\pi^+\pi^-\pi^0$. (The remaining eight decays are leptonic.)