Isomeric Level in Pb^{205} Formed in the Decay of Bi^{205}†

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An activity of 4.8-msec half-life which is assigned to Pb^{205m} has been observed in the electron capture decay of 14.5-day Bi^{205}. This isomeric level decays with the emission of 987.8, 703.3, and 284.4-kev gamma rays with relative transition intensities of 100, 10, and 10. No other gamma rays of energy greater than 10 kev were observed in the decay of this isomer. The 284.4- and 703.3-kev gamma rays are in coincidence but neither is in coincidence with the 987.8-kev transition. This evidence suggests that the 987.8-kev level de-excites directly to the ground state by the emission of a 284.4, 703.3 kev cascade with a 987.8-kev cross-over. There is some evidence (not conclusive) that the 987.8-kev level itself may not be isomeric but that it may be fed entirely by a highly converted low-energy transition (<100 kev) from an isomeric level.

I. INTRODUCTION

TWO extensive investigations have been previously made of the decay of Bi^{205}.[1,2] No gamma rays were observed to be in coincidence with the 987.8-kev gamma ray in either of these investigations. For this reason and also because of its intensity, the 987.8-kev gamma ray was assumed to be a ground-state transition, predominantly fed directly by electron capture. However, $M4$ isomeric transitions have been observed in in Pb^{197}, Pb^{199}, Pb^{201}, Pb^{203}, and Pb^{207}.[3] An analysis of the systematics of these transitions leads to the prediction that an $M4$ transition with an energy of 980 ± 40 kev and a 1.5 ± 0.5 sec half-life should exist in Pb^{205}.[4] Two experiments which attempted to detect an isomer of this half-life and energy gave negative results.[2,4] An analysis of these experiments revealed that if the half-life of the suspected isomer were shorter than the predicted value by a factor of about ten or more, then a negative result would be expected. In order to eliminate this possibility, it was decided at this laboratory to look for coincidences between the electron-capture x-rays and the 987.8-kev gamma ray. When no coincidences were observed between the Pb K x rays and the 987.8-kev gamma rays (resolving time $\tau\simeq5\times10^{-7}$ sec), this suggested the possibility that the 987.8-kev gamma ray was isomeric with a half-life much shorter than had been predicted.

II. EXPERIMENTAL PROCEDURE

Source Preparation

The source of Bi^{205} was produced by bombarding radiogenic lead[5] (approximately 85% Pb^{206}) with 20.8-Mev protons in the Oak Ridge cyclotron. The sample thicknesses were 0.010 in. and 0.011 in., respectively, in two different irradiations. The cyclotron energy and sample thicknesses were chosen to maximize the production of Bi^{205} relative to Bi^{207} and Bi^{206}.[6] This type of bombardment yielded samples in which the ratio of the 8-year Bi^{207} to 14.5-day Bi^{205} activity was $<0.2\%$ approximately four to six weeks after the bombardment. At this time the activity due to 6-day Bi^{206} was negligible.

Experiments which Demonstrate that the 987.8-kev Gamma Ray is Delayed

Several experiments were performed which demonstrated that the 987.8-kev gamma ray is isomeric. The first of these was a series of gamma-gamma and x ray–gamma coincidence studies. These data were taken with a standard "fast-slow" coincidence circuit with the "fast" portion having a resolving time of 5×10^{-7} sec. The slow part of the circuit utilized a single-channel pulse-height analyzer operated in conjunction with a 20-channel pulse-height analyzer. The window of the single-channel pulse-height selector was set on a section of the Bi^{205} gamma-ray spectrum and the data in coincidence with events in this window were recorded on the 20-channel pulse-height analyzer. The detectors used for this work were two 3-in. diameter×3-in. thick NaI(Tl) scintillation crystals. The detectors were operated at an angle of 180° with the front faces 6 cm apart and the source located at the midpoint. A "graded" backscattering shield was used to minimize scattered radiation from one detector to the other.

Figure 1 shows a plot of the singles spectrum of Bi^{205} taken on a 3-in. diameter×3-in. thick NaI crystal. The "peak" at 1 Mev is known to contain at least those gamma rays whose intensities are indicated by vertical bars. The bars for the 1002.7, 1014.1, and 1073.3-kev gamma rays[1] represent upper intensity limits. These data are summarized in Table I. The relative gamma-ray intensities are obtained by a knowledge of the K

† This work performed under the auspices of the U. S. Atomic Energy Commission.
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[1] M. Schmorak et al., Nuclear Phys. **2**, 193 (1956/57).
[2] A. R. Fritsch, University of California Radiation Laboratory Report UCRL-3452 (unpublished) and J. Inorg. and Nuclear Chem. **6**, 165 (1958).
[3] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).
[4] R. Stockendal et al., Arkiv Fysik **11**, 165 (1956).
[5] K. T. Bainbridge, *Experimental Nuclear Physics*, edited by E. Segrè (John Wiley & Sons, Inc., New York, 1953), Vol. 1, pp. 637, 638.
[6] The sample thicknesses and irradiation energies were suggested by J. L. Need of the cyclotron staff at the Oak Ridge National Laboratory.

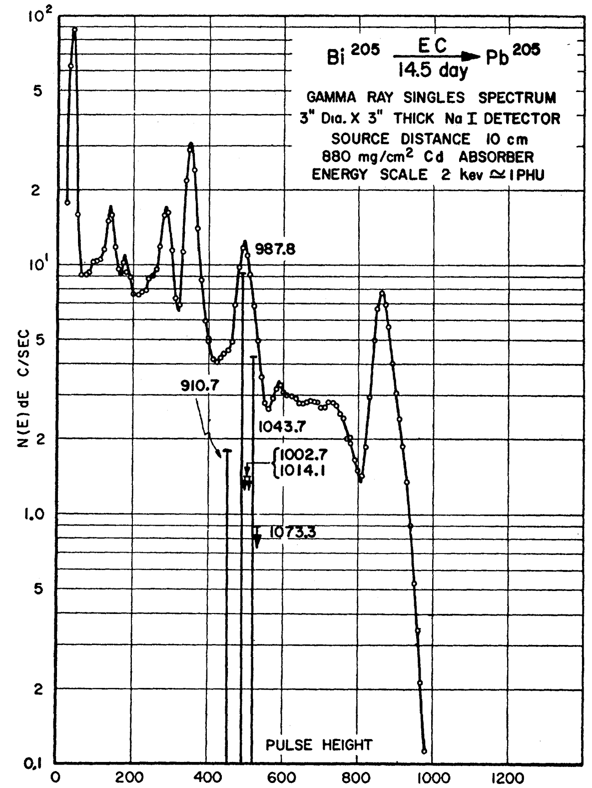

FIG. 1. Bi^{205} gamma-ray singles spectrum. The vertical bars represent the relative intensity of the gamma rays in the 1-Mev region of the spectrum. The bars for the 1002.7, 1014.1, and 1073.3-kev gamma rays represent upper intensity limits. Energy scale 2 kev≃1 pulse-height unit.

conversion coefficients and the relative electron intensities[1,7] and by consecutive unfoldings of high-energy gamma rays from the gamma-rays singles spectrum which was done at this laboratory. The results of these are compared by normalizing the values obtained for the 987.8-kev gamma ray. An average of the gamma-ray intensities obtained from these methods was used in Fig. 1. It is obvious, therefore, that a single-channel window set in the 1-Mev region will accept contributions from several of the gamma rays whose photopeaks are in this energy region as well as from the Compton distributions of gamma rays having higher energies. Therefore, in order to determine which gamma rays, if any, are in coincidence with the 987.8-kev gamma ray it is necessary to take several coincidence spectra. These must include spectra where the window of the single-channel analyzer is sitting on the maximum of the photopeak of the 987.8-kev gamma ray as well as several spectra taken on either side of this peak. Coincidence spectra were obtained with a 20-kev wide single-channel window whose lower edge was set at 840, 850, 870, 895, 910, 940, 960, 980, 1000, 1020, and 1040 kev. The results of these measurements indicated that if any gamma ray having an energy greater than 50 kev were in coincidence with the 987.8-kev gamma ray, then its intensity must be less than 10% of the intensity of the 987.8-kev gamma ray. Other coincidence runs in which the location of the window of the single-channel pulse-height analyzer was moved over the portions of the spectrum both above and below the 1-Mev region indicated that the 987.8-kev gamma ray is not in coincidence with any of these portions of the spectrum.

Since the 987.8-kev gamma ray is not in coincidence with any of the major gamma rays it must either be

TABLE I. Relative gamma-ray intensities.

	Inferred from Swedish electron intensities[a]			From analysis of author's gamma-ray spectrum
E_γ (kev)	I_e	α_K	I_γ	I_γ
910.7	9.8	0.0064	1530	960
987.8	27.5	0.0054	5100	5100
1002.7	2.1	>0.002	<1050	<800
1014.1	4.9	>0.002	<2450	<800
1043.6	32.5	0.013	2500	2550
1073.3	...	...	...	<500

[a] See reference 1.

[7] Private communication from R. Stockendal via G. Andersson.

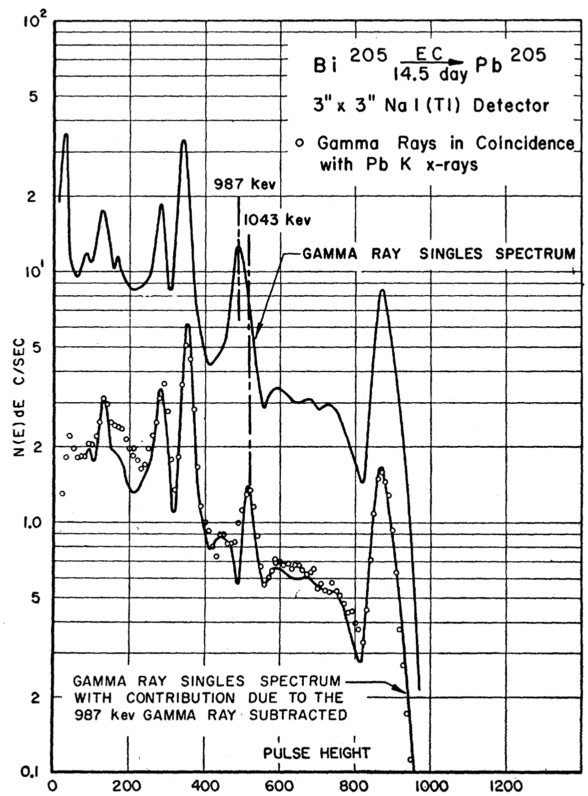

FIG. 2. The open circles indicate the spectrum of the gamma rays in coincidence with the Pb K x rays. The solid curve through these points is the result of subtracting the contribution of the 987.8-kev gamma ray from the singles spectrum (shown above for comparison) and is normalized to the experimental points in intensity only. Energy scale 2 kev≃1 pulse-height unit.

isomeric; be fed by a low-energy, highly converted isomeric gamma ray; or be fed directly by electron capture. Figure 2 shows the spectrum of those gamma rays which are in coincidence with the Pb K x rays (open circles) together with a singles spectrum for comparison. The result of subtracting the contribution of the 987.8-kev gamma ray, as determined by an analysis of the gamma-ray singles spectrum, is shown as the solid curve which passes through the data points. This solid curve has been normalized in intensity only. It may be concluded that the discrepancy between the singles curve and the spectrum of gamma rays in coincidence with the Pb K x rays is accounted for by the fact that the 987.8-kev gamma ray is not in coincidence with the Pb K x rays.

From this it follows that if one were to measure the gamma-ray spectrum of all events *not* in coincidence with the Pb K x rays, the 987.8-kev gamma ray should be enhanced. A block diagram of the experimental arrangement used to perform this measurement is shown in Fig. 3. A source of Bi^{205} was placed in the center of a $\frac{1}{4}$ in. thick by $1\frac{1}{2}$-in. diameter split NaI crystal. This small crystal is preferentially sensitive to low-energy photons, with an efficiency of $>90\%$ for the detection of the Pb K x rays. This detector was operated in an anticoincidence arrangement with the 3-in.$\times$3-in. NaI crystal. Due to the anticoincidence circuit, each time an x ray was detected by the small crystal, the multichannel pulse-height analyzer was made insensitive, thus recording only those events not in coincidence with the x rays. Because of limits imposed by the electronics, the Pb L and M x rays would not trigger the anticoincidence gate. For this value of Z, approximately 15% of the electron capture events should proceed by L_I orbital capture. Although L_I capture is the predominant mode of capture beyond the K shell, other modes, i.e., L_{II}, L_{III}, M, N $\cdots$, may add an additional 5%.[8] This, together with the fact that the split crystal is not

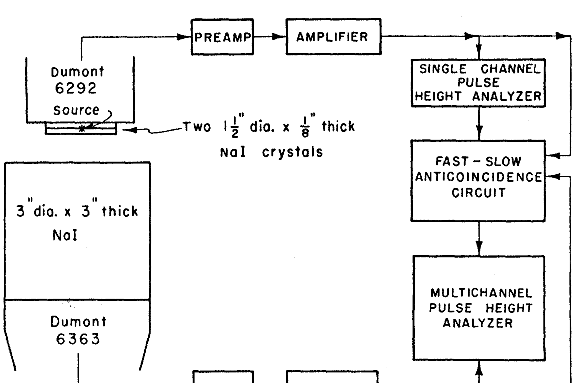

FIG. 3. Block diagram of the electronics used in the anticoincidence experiment.

[8] H. Brysk and M. E. Rose, Oak Ridge National Laboratory Report ORNL-1830 (unpublished).

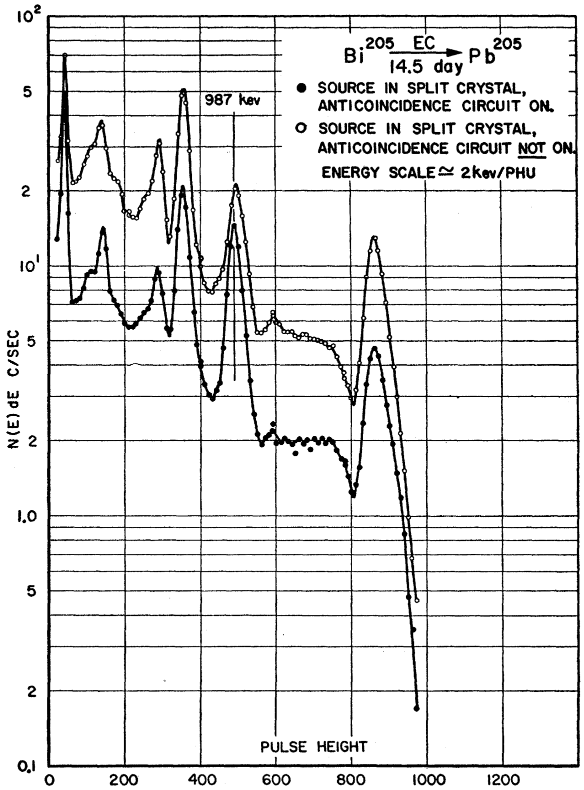

FIG. 4. Result of the anticoincidence experiment. Energy scale 2 kev$\simeq$1 pulse-height unit.

100% efficient for the Pb K x rays, would indicate that the intensity of events in coincidence with the K x rays would be reduced to roughly 30% of their original intensity in such an experiment. This estimate is in good agreement with the experimental result. Figure 4 shows the spectrum obtained with and without the anticoincidence requirement. Note that the intensity of the 987.8-kev gamma ray is not diminished, the decrease in intensity of the 1-Mev peak being due to the elimination of the 1.043-Mev gamma ray.

Additional confirmation was provided by measurements in a well-type "summation" detector. If the 987.8-kev gamma ray were not in coincidence with any other gamma rays arising from the decay of Bi^{205} or with the electron capture K x rays, then a source placed in a well crystal should show a prominent peak at 987.8 kev. The prompt gamma rays present in the spectrum will have added to their energy at least the energy of the electron capture x rays plus the energy of any coincident gamma rays which interact with the detector. The result of such a measurement is displayed in Fig. 5, which shows the spectrum for a source outside a 3-in. $\times$3-in. well crystal and inside the well crystal, both with and without an absorber to stop the K x rays. It is clear from these results that the 987.8-kev gamma ray is not in coincidence with either the K x rays or any other major gamma rays since this peak does not shift ap-

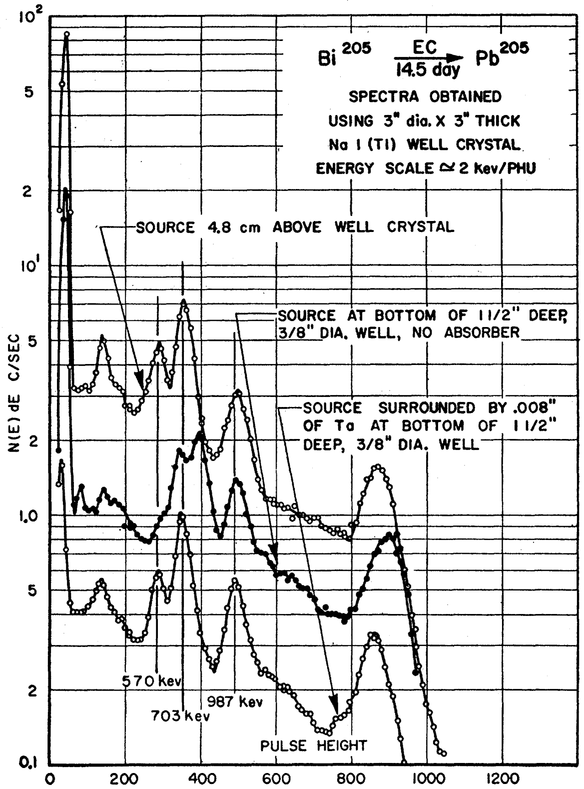

FIG. 5. Spectra obtained with the source inside and outside a 3-in. thick×3-in. diam well crystal. Energy scale 2 kev≃1 pulse-height unit.

preciably in energy as do the other major gamma rays which are fed strongly by electron capture.

III. PROPERTIES OF THE ISOMER

Half-Life

The half-life associated with the decay of Pb^{205m} was measured using delayed-coincidence techniques. The output pulses from a single-channel pulse-height analyzer whose window was set on the Pb K x ray were used to mark $t=0$. The number of output pulses from a second single-channel analyzer whose window was centered on the 987.8-kev gamma ray were then recorded as a function of time after the x-ray pulse, using a five-channel time discriminator.[9] A typical half-life is shown in Fig. 6. This measurement gives a half-life of 5.6±2 msec. The best value based on five measurements is 4.8±1.5 msec.

Preliminary measurements made at the University of Illinois,[10] using the technique developed there for measuring short-lived isomeric states,[9,11] indicate that an activity with a half-life of several milliseconds is present when radiogenic lead is bombarded with gamma rays. The Pb^{205m} is formed by the reaction $Pb^{206}(\gamma,n)Pb^{205m}$. A 0.9-Mev gamma ray which decays with a half-life of 6.5±0.5 msec has also been observed when Tl is bombarded with 20-Mev protons.[12] In the light of the present work it seems quite possible that the activity observed was due to $Tl^{205}(p,n)Pb^{205m}$.

Delayed Gamma-Ray Spectrum

A spectrum of the gamma rays which de-excite the isomeric level was recorded. In this measurement the source was inserted in a $\frac{3}{8}$-in. diameter, $1\frac{1}{2}$-in. deep well in a 3-in. diameter×3-in. thick NaI crystal. Only those events were recorded which occurred in a time interval between 100 μsec and 2100 μsec following an output pulse from a single-channel pulse-height analyzer whose window was set on the Pb K x ray. The x ray was used to mark the formation of the isomeric level, which then de-excited (in approximately 20% of the cases) during the time in which the equipment was sensitive. In order to reduce the effect of chance correlations in time, it was necessary to use very weak sources. Strengths of approximately 20 K x rays per second were found to be satisfactory.

The result of this measurement is shown in Fig. 7. The 987.8-kev gamma ray is clearly enhanced. The result of subtracting the background from this curve is shown in Fig. 8 as the open circles. The statistical deviations are also indicated. The three solid curves

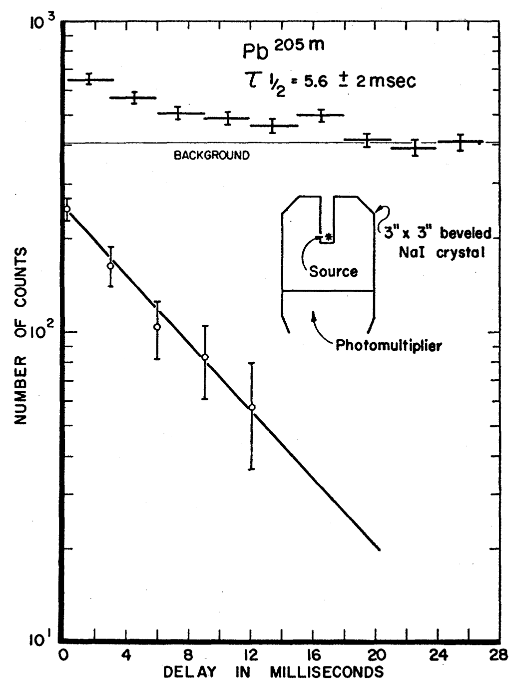

FIG. 6. Pb^{205m} half-life. This measurement gives $\tau_{\frac{1}{2}}=5.6\pm2$ msec. Best value based on five measurements is 4.8±1.5 msec.

[9] R. B. Duffield and S. H. Vegors, Jr., Phys. Rev. **112**, 1958 (1958).
[10] P. Weston and P. Axel (private communication).
[11] S. H. Vegors, Jr., and Peter Axel, Phys. Rev. **101**, 1067 (1956).
[12] O. I. Leipunskii, V. V. Miller, A. M. Morozov, and P. A. Iampol'skii, Doklady Akad. Nauk S.S.S.R. **109**, 935 (1956) [translation: Soviet Phys. Doklady **1**, 505 (1956)].

marked 987.8, 703.3, and 284.4 indicate the expected relative intensities of the 987.8, 703.3, and 284.4-kev gamma rays if the decay of the 987.8-kev level in Pb^{205} is not in coincidence with the electron capture events. In the calculation of these relative intensities, account was taken of the fact that the 284.4- and 703.3-kev gamma rays are in coincidence and hence "sum" to 987.8 in a large fraction of the decays. The relative intensities of the 987.8- and 284.4-kev transitions were obtained from K-conversion electron intensities and values of α_K[1,7] and from an analysis of the gamma-ray singles spectrum. The two techniques yielded values of 0.11 and 0.09 for the ratio of the number of 284.4-kev transitions to 987.8-kev transitions. A value of 0.10 was used in the above calculations. The values of ϵ, the crystal efficiency for detecting the gamma rays, were obtained by doubling the efficiency of a $1\frac{1}{2}$ in. thick by 3-in. diameter crystal with a source 0.001 cm above the face.[13] Thus the correction which is necessary for the well itself was neglected. It may be seen that the intensity sum of the 987.8, 703.3, and 284.4-kev gamma rays (dashed line) is in agreement with the experimental result to within the statistical uncertainty. The composite spectrum is normalized in intensity only to the observed intensity of the 987.8-kev gamma ray. It is clear that it is difficult from these data to say anything about the delayed-coincidence spectrum except that the 987.8-kev gamma ray is present and is by far the dominant feature.

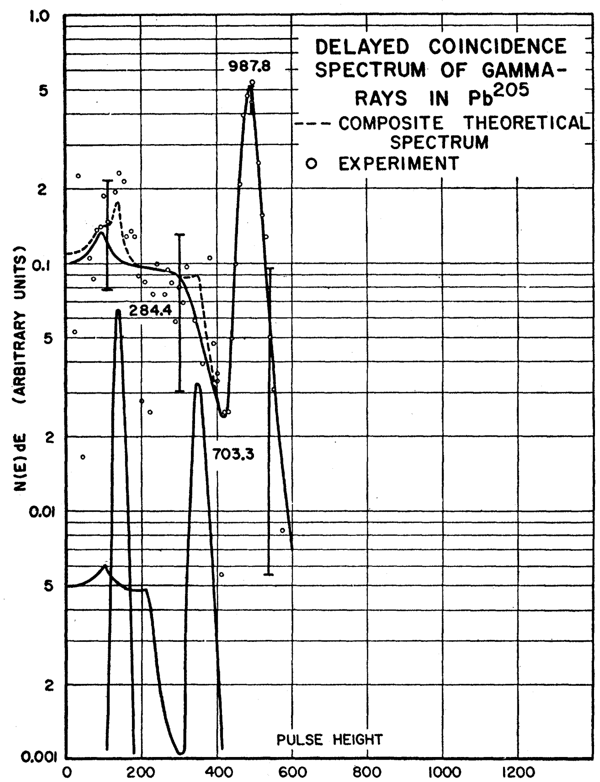

FIG. 8. The spectral shapes and computed intensities of the 284.4, 703.3, and 987.8 kev gamma rays from the decay of the isomer are shown as solid lines. The sum of the intensities of these three gamma rays is shown as the dashed curve. Experimental data are indicated as open circles. Energy scale 2 kev≃1 pulse-height unit.

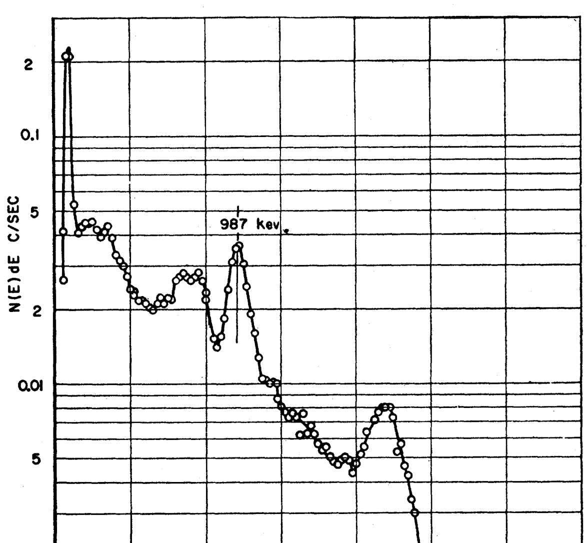

FIG. 7. Delayed coincidence spectrum of Pb^{205m}. The open circles show the total number of counts/sec in a time interval from 100 to 2100 μsec after each K x ray. Energy scale 2 kev≃1 pulse-height unit.

Measurement of α_K

Although the values of α_K for the 284.4, 703.3, and 987.8-kev gamma rays have been previously measured,[1,7] it was felt that a check of these values should be made. This was accomplished by measuring the absolute intensity of the electrons and gamma rays, respectively, on a $1\frac{1}{2}$-in. diameter$\times\frac{1}{2}$-in. thick anthracene crystal and a 3-in. diameter$\times$3-in. thick NaI crystal. The method was checked by measuring the conversion coefficients for the 662-kev Cs^{137}, 570-kev Bi^{207}, and 1064-kev Bi^{207} transitions. The results obtained for α_T were: 0.104 (Cs^{137}, 662 kev), 0.03 (Bi^{207}, 570 kev), and 0.109 (Bi^{207}, 1064 kev). Recent values from the literature are 0.111, 0.024, and 0.12, respectively. Values for α_T were then obtained for the 703.3- and 1766.6-kev transitions in Bi^{205}. In these measurements, the small contribution from the conversion lines of the 745, 758.3, 761, 1777.4, and 1863.3 kev[1] transitions was neglected. The results were $\alpha_T=0.015$ (Bi^{205}, 703.3 kev) and 0.0041 (Bi^{205}, 1766.6 kev) which imply $\alpha_K=0.012$ and 0.0035, respectively, when corrected by previously measured K/L

[13] S. H. Vegors, Jr., L. L. Marsden, and R. L. Heath. Atomic Energy Commission Report IDO-16370, September, 1958 (unpublished).

ratios.[1,7] These results are accurate to better than 20% and are in agreement with the Swedish[1,7] results of $\alpha_K = 0.01$ (Bi^{205}, 703.3 kev) and 0.004 (Bi^{205}, 1766.6 kev).

These values for α_K are in agreement with the $E2$ assignment for the 987.8- and 703.3-kev gamma rays as proposed in reference (1). This suggests the possibility that the 987.8-kev level may not be isomeric but may be fed by a low-energy gamma ray which originates from an isomeric level.

Search for a Low-Energy Gamma Ray in Coincidence with 987.8-kev Transition

A series of gamma-gamma coincidence runs was made to see if a low-energy gamma ray might be in coincidence with the 987.8-kev gamma ray. For this purpose, the single-channel pulse-height analyzer base line was set (with a 20-kev window) at 900, 920, 940, 960, 980, 1000, and 1020 kev. Spectra of the low-energy gamma rays in coincidence with those gamma rays falling in the window of the single-channel pulse-height analyzer were recorded in a 20-channel pulse-height analyzer which covered the energy range from 10 to 100 kev. The results of these measurements indicated that no gamma ray (including the Pb K and L x rays) in this energy range, having an intensity as large as 20% of the intensity of the 987.8-kev gamma ray, was in coincidence with the 987.8-kev gamma ray. However, by comparing the relative intensity of the Pb L x rays as a function of the energy setting of the base line of the single-channel pulse-height analyzer, it was noted that the intensity of the L x ray increased when the single-channel window was centered on the 987.8-kev gamma ray. The effect was not very pronounced. In order to study this further, the single channel was set on the L x ray and spectra were taken of the gamma rays in coincidence with the L x ray. Bi^{205} decays approximately 15% of the time by L capture.[8] The ratio of L and K capture is approximately independent of the decay energy for energies somewhat in excess of the K binding energy, 88 kev. Therefore, if the 987.8-kev level is isomeric, one would expect that the 987.8-kev gamma ray would not be in coincidence with the Pb L x ray, whereas all the other gamma rays in the decay of Bi^{205} would be present in nearly the same ratio of intensities as they have in a singles spectrum. However, it was found that the 987.8-kev gamma ray is not missing in the spectrum of gamma rays in coincidence with the L x ray. On the other hand, its intensity relative to the other gamma rays is almost identical to that in a gamma ray singles spectrum. When a 90 mg/cm² Cu absorber was placed in front of the ½-in. thick, 3-in. diameter NaI crystal, used to detect the L x rays, this coincidence rate decreased by a factor of 10 or more. A singles spectrum taken of the 5 to 200-kev region showed that the 90-mg/cm² Cu absorber reduced the Pb L x-ray intensity by more than a factor of 10 while the intensity of the Pb K x ray (72 kev) changed less than 5%.

The results of these measurements would suggest that the 987.8-kev level itself may not be isomeric. Instead this level may be fed from an isomeric level which lies very close to the 987.8-kev level, close enough so that the gamma ray from the isomeric level to the 987.8-kev level is highly converted in the L and higher electron shells.

IV. CONCLUSIONS

The experimental results obtained at this laboratory indicate that a gamma ray of 990 ± 10 kev is not in prompt coincidence with the electron capture decay of Bi^{205}. Since no other strong gamma rays are in this energy region, it is concluded that the 987.8-kev gamma ray in Pb^{205} follows the decay of an isomeric level. Evidence[1,2] from other features of the decay of Bi^{205} suggests that the 987.8-kev transition is a ground-state transition and is paralleled by a 284.4, 703.3 kev cascade with the 284.4-kev transition on top. The fact that the 987.8-kev gamma ray is delayed is supported by the work of references 10 and 12.

If the 987.8-kev level is isomeric, then a half-life of 4.8 msec indicates that its multipolarity would be either $M3$ or $E3$.[14] Since the 284.4-kev transition competes with the 987.8-kev transition, it would also have to be isomeric. Its partial half-life of 48 msec (it is 10% as intense as the 987.8-kev transition) indicates that it should probably be either an $E3$ or $M3$ transition, however neither of these is in very good agreement with the systematics.[14] The experimental values of α_K for the 284.4- and 987.8-kev transitions are 0.45 and 0.005, respectively, and are accurate to $\pm 20\%$.[8] The theoretical values of α_K for 284-kev $M1$, $M2$, $M3$, or $E1$, $E2$, and $E3$ transitions are 0.41, 1.5, 5.2, or 0.29, 0.77, and 2.1,[15] respectively. The theoretical values of α_K for a 987-kev $M2$, $M3$, $M4$, or $E2$, $E3$, or $E4$ transition are, respectively 0.036, 0.069, 0.125, or 0.0055, 0.012, and 0.24. It is clear that a 284-kev $E3$ or $M3$ or a 987-kev $E3$ or $M3$ transition is not in agreement with the experimental values of α_K, whereas a 284-kev $M1$ and a 987-kev $E2$ assignment are in good agreement. If the 987.8-kev level is the isomeric level, then either there is considerable error in the experimental values for α_K or this is a case of an extremely slow $E2$ transition in competition with a still slower $M1$ transition. Neither of these two possibilities is very likely. One other possibility could be that the level at 987.8 kev is fed entirely from an isomeric level. The experimental evidence shows that the 987.8-kev gamma ray is not in coincidence with the Pb K x ray and that only approximately 15% of the transitions are fed by the Pb L x ray. This would imply that the isomeric level is very close to the 987.8-kev level, lying

[14] M. Goldhaber and A. W. Sunyar, *Beta and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North Holland Publishing Company, Amsterdam, 1955), Chap. XVI.

[15] A. L. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57 ICC K1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].

between 16 kev and ~88 kev above this level. The experimental evidence on this point is not conclusive. Because of the limitations in equipment it was not possible to look for coincidences between the Pb M x-ray and the 987.8-kev gamma ray. This experiment should be done before any final conclusions are made.

Theoretical calculations by True,[16] using $\frac{3}{4}$ singlet-even forces plus weak coupling, indicate that a $13/2^+$ level would be expected at approximately 1050 kev. These calculations also predict a $7/2^-$ level at 930 kev and a $9/2^-$ level at 940 kev. These are interpreted by True as the 987.8-kev and the 1002.7- or 1014.2-kev levels, respectively, in Pb^{205}. If the $9/2^-$ level were interpreted as the 987.8-kev level and the $7/2^-$ level were interpreted as either the 1002.7- or 1014.2-kev level then it would be possible for the $13/2^+$ level at approximately 1050 kev to feed the $9/2^-$ level at 987.8 kev. If this were the case, the 1050-kev level would decay by an $M2$ transition. For an $M2$ transition of 60 kev, the expected half-life is 220 msec.[14] Although this is not in good agreement with the measured value of the 4.8 msec the disagreement is not so severe as to eliminate this possibility. Because of experimental limitations this low-energy gamma ray was not seen. A search for it should be made using more sensitive techniques.

[16] W. W. True (private communication).

ACKNOWLEDGMENTS

The authors wish to acknowledge the help of E. C. Yates, D. G. Proctor, E. H. Turk, R. P. Schuman, G. O. English, and W. Hammer in performing the experimental work. Discussions with W. W. True and G. Andersson proved to be both stimulating and enlightening.

Note added in proof.—Electron conversion lines in the decay of Bi^{205} corresponding to a transition energy of approximately 26 kev have been observed by D. E. Alburger (private communication). R. Stockendal (private communication) has also observed electron conversion lines corresponding to a transition energy of 26.2 kev. Electron-gamma coincidence measurements by Alburger have confirmed that this transition is in coincidence with a strong gamma ray of 1 Mev (presumably the 987.8-kev gamma ray). This evidence, together with that presented in this paper, has led to the conclusion that the 987.8-kev level is not isomeric but rather is fed entirely by the 26.2-kev transition. This implies that the isomeric level is at $987.8+26.2=1014.0$ kev.

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Interaction of K^+ Mesons with Protons*

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The total K^+-p cross section was measured at the three K^+-meson energies 175 ± 25, 225 ± 25, and 275 ± 25 Mev, and the differential scattering cross section was measured at 225 Mev. The K^+-p nuclear force was shown to be repulsive, from the observed constructive interference with Coulomb scattering. The differential cross section was otherwise isotropic and could arise from either pure S-wave or pure P-wave scattering.

Subtracted dispersion relations were applied to these data and the rest of the available K-proton scattering data. The statistical errors in the data were found to be too large to determine the K-hyperon relative parity. On the assumption that the $K\Lambda$ and $K\Sigma$ relative parities are the same, then for scalar coupling, $g^2/4\pi$ would be less than 0.6; for pseudoscalar coupling, it would be less than 10.

I. INTRODUCTION

INFORMATION on the scattering of K^+ mesons on protons is of the greatest importance, in that it may allow us to determine the nature of the K-meson-nucleon forces. Data at low energies have come mostly from the rare scattering of K^+ mesons on hydrogen nuclei in emulsion. A compilation of the world total of 75 events was reported at the 1958 High-Energy Physics Conference at CERN.[1] The angular distributions in the three energy intervals 20 to 100 Mev, 100 to 200 Mev, and 200 to 300 Mev, considering the large uncertainties, were not inconsistent with isotropy.

From a more recent compilation of data,[2] total cross sections have been obtained as shown in Table I.

Table I. Results from experiments with nuclear emulsions.

Energy (Mev)	Total K^+-p cross sections (mb)
20–100	13.5 ± 2.8
100–200	14.2 ± 2.6
200–300	18.0 ± 3.5

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[1] M. F. Kaplon, *1958 Annual International Conference on High-Energy Physics at CERN*, edited by B. Ferretti (CERN Scientific Information Service, Geneva, 1958).

[2] D. H. Stork and D. J. Prowse, University of California (private communication).