Decay of the $i_{13/2}$ State in Pb^{205}

R. STOCKENDAL
Nobel Institute of Physics, Stockholm, Sweden
(Received December 21, 1959)

The L_I, L_{II}, L_{III}, M_I, M_{II}, M_{III}, M_{IV}, N_I, N_{III}, and O_I conversion lines of a 26.22±0.01-kev transition in Pb^{205} have been found from studies with electromagnetically separated samples of Bi^{205}. The transition, having $M2$ character, most probably takes place from a 4-msec $i_{13/2}$ state of 1014.0 kev to the 987.6-kev 9/2- state, thus causing the latter state to appear metastable, as has earlier been reported. This suggestion is also supported by strong evidence for the existence of a 310.5-kev $E3$ transition between the isomeric state and the 703.3-kev state. The energy 1014.0 kev of the $i_{13/2}$ state coincides with a transition energy in Pb^{205} earlier reported, and is found to fit well into the energy systematics of the $i_{13/2} \rightarrow f_{5/2}$ $M4$ transitions in the odd lead isotopes.

An isomeric $i_{13/2} \rightarrow f_{5/2}$ transition in Pb^{205} has long been sought. From a systematic study of such transitions in Pb^{197}, Pb^{199}, Pb^{201}, Pb^{203}, and Pb^{207} (Stockendal et al.[1]) an $M4$ transition was expected to exist in Pb^{205} with an energy of 980±40 kev and a half-life of 1.5±0.5 sec. However, no such transition was observed in the "milking" experiments performed with a sample of Bi^{205}. It was therefore suggested, among other alternatives, that the metastability of the $i_{13/2}$ state in Pb^{205} is destroyed by an underlying complex state of intermediate spin. This assumption was later supported by results of Schmorak et al.,[2] who made an extensive investigation of the decay of Bi^{205}. The complex level scheme proposed by them includes energy levels at 703.3 and 987.6 kev having spin and parity 7/2− or 9/2−.

Recently, Vegors and Heath[3] observed an activity of 4.8±1.5 msec half-life in the decay of Bi^{205}. The isomeric level was found to decay with the emission of 987.8-, 703.3-, and 284.4-kev gamma rays, but no other gamma rays of energy greater than 10 kev were observed in the decay of this isomer. At first one might suspect that the 987.8-kev transition is, after all, the $M4$ transition searched for in Pb^{205}. However, from a recent absolute measurement by Stockendal and Hultberg[4] of the K-conversion coefficient of the 987.8-kev transition, it must be concluded that the multipolarity is $E2$, as was already indicated in the experiments of Schmorak et al.[2] Furthermore, the half-life of 4.8 msec experimentally found is considerably shorter than expected for an $M4$ transition.

There was, however, in the experiments of Vegors and Heath[3] some evidence (L x-rays in coincidence with the 987.8-kev gamma ray) that the 988-kev level itself may not be isomeric but that it may be fed entirely by a highly converted low-energy transition ($16<E<88$ kev) from an isomeric level. The experimental evidence on this point was not conclusive.

The present investigation was undertaken in order to ascertain whether or not such a transition in Pb^{205} in the above energy region exists. The measurements were carried out in a double-focusing beta spectrometer, adjusted to give a relative half-width of about 0.35%. A window of about 20 $\mu g/cm^2$ Formvar foil was used for the G.M. tube giving a cutoff energy of (2.3±0.2) kev. The Bi^{205} source was prepared by means of electromagnetic isotope separation.

In addition to the Auger lines some very strong conversion lines were found in the energy region between 10 and 26 kev, as shown in Fig. 1. Their intensities are of the order of 1–15 times higher than the intensity of the strong K line of the 703.3-kev transition. Some of these lines (although unassigned) had been seen also earlier at this institute[2] on a photographic film. However, because of the low sensitivity of the film for low-energy electrons, these lines were very weak. On the basis of the measured energy values, the lines can be interpreted as L_I 26.22, L_{II} 26.21, L_{III} 26.22, M_I 26.22, M_{II} 26.22, M_{III} 26.23, M_{IV} 26.22, N_I 26.22, N_{III} 26.22, and O_I 26.22, thus suggesting a transition in Pb^{205} of energy 26.22 kev (adopted value). The relative intensities of the measured conversion lines are consistent only with an $M2$ assignment for this transition.

If the new transition is identical with the predicted low-energy transition populating the 987.6-kev state, an isomeric state would be situated at $(26.2+987.6=1013.8)$ kev. The fact that a transition of 1014.2 [2] or 1014.0 kev[5] is known in the decay of Bi^{205} lends strong support to this suggestion. As indicated in the work of Schmorak et al.,[2] a state of this energy is suggested also from the energy relation $(1014.2+1552.3=2566.5)$ kev (see the energy level at 2566.5 kev). (However, in the quoted investigation it was not possible to decide the order of emission of the two gamma rays.) From the collected information on Pb^{205}, it seems probable that the state of 1014.0 kev (adopted mean value) is the 13/2+ state searched for in this nucleus. Especially significant is the fact that this assignment is in agreement with the multipolarities $M2$ and $E2$ proposed for the transitions of 26.22 and 987.8 kev, respectively. The

[1] R. Stockendal, J. A. McDonell, M. Schmorak, and I. Bergström, Arkiv Fysik **11**, 165 (1956).
[2] M. Schmorak, R. Stockendal, J. A. McDonell, I. Bergström, and T. R. Gerholm, Nuclear Phys. **2**, 193 (1956/57).
[3] S. H. Vegors, Jr., and R. L. Heath, Phys. Rev. **118**, 547 (1960).
[4] R. Stockendal and S. Hultberg, Arkiv Fysik **15**, 33 (1959).
[5] A. R. Fritsch and J. M. Hollander, J. Inorg. Nuclear Chem. **6**, 165 (1958).

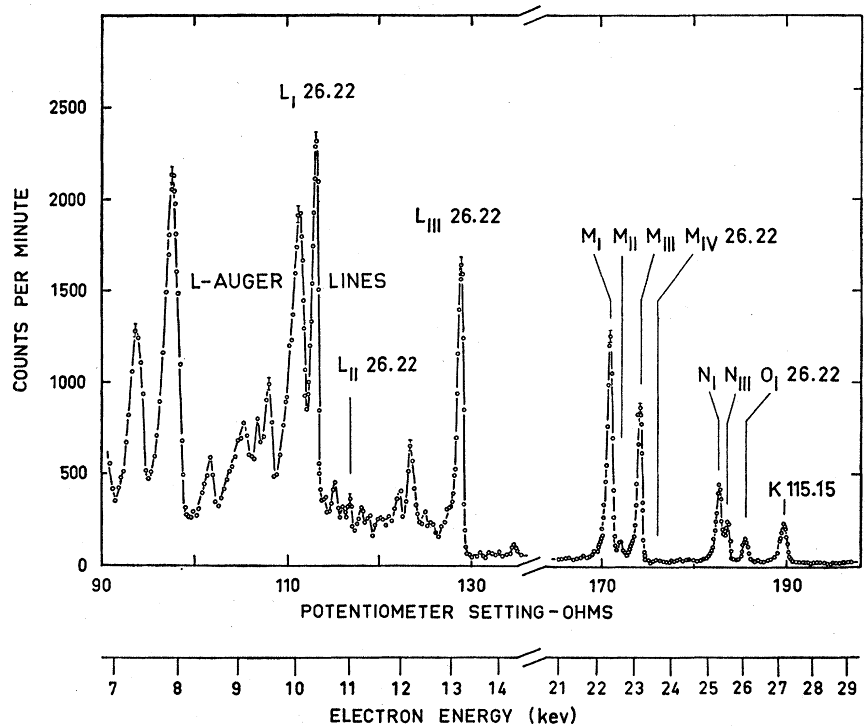

FIG. 1. Conversion lines of the 26.22-kev $M2$ transition as measured in the double-focusing spectrometer with an electromagnetically isotope-separated sample of Bi^{205}. These lines did not appear in a measurement with a Bi^{206} source.

1014.0-kev transition to the $5/2-$ ground state of Pb^{205} should then be an $M4$ transition. As shown in Fig. 2, the energy fits very well into the energy systematics of the $i_{13/2} \rightarrow f_{5/2}$ transitions in the odd lead isotopes.

If a $13/2+$ state exists at 1014.0 kev, a transition of energy 310.7 kev should take place to the $9/2-$ (or $7/2-$) state of 703.3 kev. An examination of the conversion line spectra previously obtained at this institute[2] was therefore made, and three weak Bi^{205} lines with positions corresponding to (1) K 310.5, (2) L_I 311.1 or L_{II} 310.4, and (3) M_I 311.0 or M_{II} 310.7 were found (a possible L_{III} line would not be resolved from the Bi^{206} lines K 386.0 and L_I 313.6). The first line, K 310.5, was earlier assigned L_{III} 235.9, but from a consideration of L-subshell ratios one must definitely conclude that this line is wholly or partly due to another transition. The second line was earlier supposed to be the K line of a 383.2-kev transition, other conversion lines of which were not observed. No assignment was previously made for the third line.

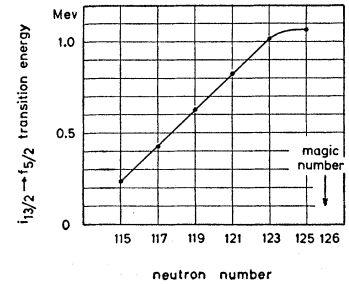

FIG. 2. Level spacing $i_{13/2} \rightarrow f_{5/2}$ in the odd-mass isotopes Pb^{197}–Pb^{207}.

The above examination thus suggests a transition of the expected energy. A rough estimate of the $K/(L_I+L_{II})$ ratio (about 1) favors an $E3$ assignment for this transition in agreement with the fact that, according to the measured conversion energies, conversion takes place rather in the L_{II} and M_{II} shells than in the L_I and M_I shells.

Figure 3 shows the decay scheme proposed for the isomer Pb^{205m}. The half-life given, 4.1 ± 0.2 msec, is the result of the most recent measurements.[6] The branching ratio given for the $M2$ transition was calculated from

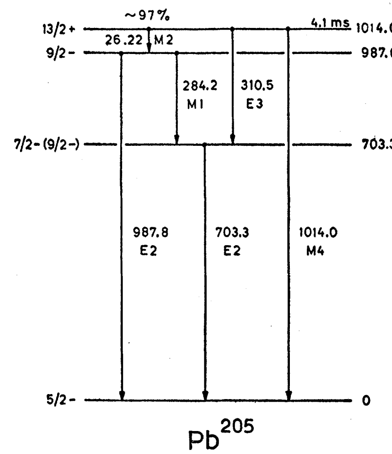

FIG. 3. Decay of 4.1-msec $i_{13/2}$ state in Pb^{205}.

[6] I. Bergström, E. C. O. Bonacalza, A. Jech, M. Perez, and P. Thieberger, Nuclear Instr. (to be published).

the measured conversion line intensities of the isomeric transitions, using the theoretical conversion coefficients for the multipolarities proposed above. It should be pointed out that also the gamma-transition probabilities calculated for the isomeric transitions speak in favor of the multipolarity assignments made. However, in the case of the 1014.2-kev transition, the gamma-transition probability seems to indicate that only part of the radiation is due to the $M4$ transition.

The $E3$ assignment of the 310.5-kev transition suggests that the 703.3-kev state has spin and parity $7/2-$. This is in agreement with the theoretical predictions by Pryce[7] and True.[8] Because of the $E2$ character of the 703.3-kev transition[2,4] $9/2-$ previously appeared more probable.

It should also be mentioned that the present results indicate that only about 65% of the feeding to the 987.6-kev level takes place via the 26.22-kev $M2$ transition.

The investigation of this isomeric decay is being continued. It is hoped that decisive information will be gained from the planned coincidence measurements. Details of experiments and results will appear in Arkiv för Fysik.

[7] M. H. L. Pryce, Nuclear Phys. **2**, 226 (1956/57).
[8] W. W. True, Princeton University (private communication).

PHYSICAL REVIEW VOLUME 118, NUMBER 4 MAY 15, 1960

Isomeric Transition in Pb^{205}†

DAVID E. ALBURGER
Brookhaven National Laboratory, Upton, New York
(Received December 30, 1959)

A (26±1)-kev transition in Pb^{205} occurring in the electron capture decay of Bi^{205} has been identified from its L, M, and N internal conversion electrons measured in an intermediate-image beta-ray spectrometer. By using NaI scintillation detectors behind the source in the spectrometer the M and N lines of the 26-kev transition are found to be not in coincidence with electron-capture K x rays but they are in coincidence with a principal gamma ray of 1 Mev and weak components of ~0.7 and ~0.3 Mev. Since the Bi^{205} gamma rays of 987.8 and 284.2 kev and a fraction of the 703.3-kev gamma rays have been shown by Vegors and Heath to be delayed with respect to electron-capture K x rays with a half-life of 4.8 msec, the present coincidence results indicate that the delayed radiation is associated with the 26-kev transition originating from an isomeric state in Pb^{205} at 1013.8 kev. The 26-kev transition is probably a quadrupole and a possible assignment is $M2$ if the spin-parity assignment of the 987.8-kev level is $9/2-$ and if the 1013.8-kev level is the $13/2+$ state predicted at 1.1 Mev by Pryce. The possibility that all or part of the known 1014.2-kev gamma radiation constitutes the "missing" $M4$ transition in Pb^{205} is discussed.

INTRODUCTION

OF the many gamma rays occurring in the electron-capture decay of 14.5-day Bi^{205} it had been found[1,2] that the strong 987.8-kev transition is not in coincidence with any other gamma ray in the spectrum. Vegors and Heath[3] recently extended the coincidence work and showed that this gamma ray is also not in coincidence with electron-capture K x rays, thus requiring that an isomeric state exist in Pb^{205}. It was then discovered by Vegors and Heath that an activity of 4.8-msec half-life follows the decay of Bi^{205} and that the spectrum of gamma rays in delayed coincidence with electron-capture K x rays exhibits the 987.8-kev transition and the 284.4–703.3 kev cascade transitions, the latter with a relative intensity of about 10%. They suggested that the 987.8-kev level itself may not be isomeric but that it may be fed by a highly converted low-energy transition.

In the conversion-electron spectrum of Bi^{205}, low-energy lines at about 25 kev have been reported[1,2] which have been assigned variously as the K lines of 112.2- or 115.2-kev transitions. Vegors and Heath[4] reinvestigated the low-energy region with a beta-ray spectrograph and they tentatively assigned the three most intense lines in the neighborhood of 25 kev as the L_{I}, L_{II}, and L_{III} internal conversion electrons of a 38.8-kev transition. Since this seemed to be the most likely candidate for the 4.8-msec isomeric transition the same energy region has been studied here in order to check the transition energy assignment, to see if the transition is delayed with respect to electron capture and to measure the spectrum of gamma rays in coincidence with the low-energy internal conversion lines.

EXPERIMENTAL METHODS AND RESULTS

The Bi^{205} activity was made at Oak Ridge by bombardment of radiogenic lead with 20.8-Mev protons according to the procedures described by Vegors and Heath.[3] Carrier-free separation[5] of the bismuth was carried out about 2 months after the bombardment and

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. Schmorak, R. Stockendal, J. A. McDonell, I. Bergström, and T. R. Gerholm, Nuclear Phys. **2**, 193 (1956/57).
[2] A. R. Fritsch and J. M. Hollander, J. Inorg. & Nuclear Chem. **6**, 165 (1958).
[3] S. H. Vegors and R. L. Heath, Phys. Rev. **118**, 547 (1960).
[4] S. H. Vegors (private communication).
[5] D. E. Alburger and G. Friedlander, Phys. Rev. **81**, 523 (1951).