where $R_{du} \equiv (m_d + m_u)/(m_d - m_u)$, $R_{su} = (m_s + m_u)/(m_s - m_u)$. In the $m_u = 0$ model, one obtains $\mu(\delta^+) \approx 5.9\mu(\pi^+) = 800$ MeV, to be compared with the measured value $\mu(\delta^+)_{\rm expt} = 970$ MeV. Given the approximate nature of the calculation, we regard this as remarkably good agreement.

We conclude that the value $m_u = 0$, $\delta = 0.036$ is not unreasonable. Thus if the axion is not found or a suitable theoretical alternative worked out, we see little reason from within the framework of current algebra to reject the possibility that $m_u = 0$. On the other hand, we do not believe that the arguments presented here are sufficiently exact to enable one to extract a reliable value for m_u/m_d, although $m_u/m_d < \frac{1}{2}$ seems to be favored. If m_u/m_d *is* zero (or small), the result (16) for the δ-meson mass is a curiously accurate current-algebra prediction that is interesting in its own right.

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Isomeric States in ^{212}Bi

P. A. Baisden, R. E. Leber, M. Nurmia, J. M. Nitschke, M. Michel, and A. Ghiorso
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
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Two new alpha activities with half-lives of 25 and 9 min have been observed in reaction of heavy ions with a variety of heavy targets. The 25-min activity was found by combined radiochemical methods and mass separations to be an isomer in ^{212}Bi; the 9-min activity is also likely to be an isomer in ^{212}Bi.

During a search for superheavy elements via the reaction of ^{48}Ca with ^{248}Cm, we observed several alpha lines around 10 MeV.[1] In addition a rather intense line at 11.66 MeV was observed and attributed to the known isomer in ^{212}Po.[2] A closer investigation of the 11.66-MeV peak through analysis of its decay curve revealed a longer-lived component of 9± 1 min, in addition to the expected 45-sec half-life. The half-life of the group of lines at 10 MeV was determined to be 25± 1 min. We eliminated the possibility that these activities could be associated with the decay of superheavy elements when these activities were found in a bombardment of ^{208}Pb with ^{40}Ar ions.

After preliminary experiments showed that the activities were coprecipitated with CuS from an acidic solution and taking into account the high energy associated with their decay, these activities were presumed to be nuclides in the lead re-

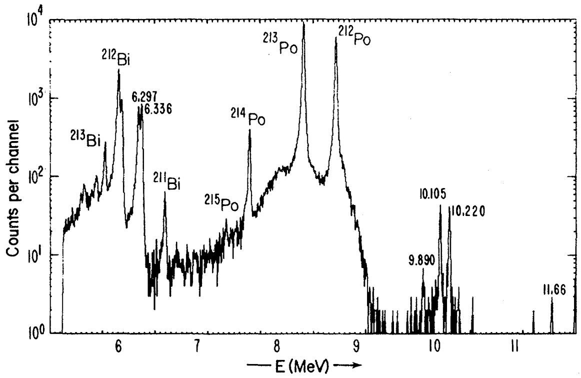

FIG. 1. Alpha spectrum of the Bi, Po, and At fraction from $^{48}Ca + ^{238}U$. Geometry 20%, resolution, full width at half-maximum = 25 keV.

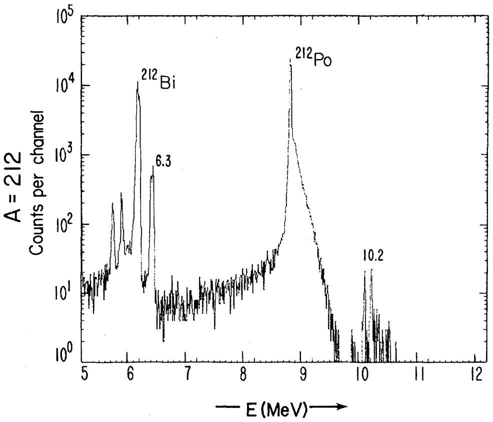

FIG. 2. Alpha spectrum of the mass-separated sample from the reaction of $^{40}Ar + ^{238}U$. Geometry 25%, resolutions, full width at half-maximum = 40 keV.

gion. Further studies revealed that both activities could be produced by the bombardment of ^{238}U targets by a variety of heavy ions such as ^{40}Ar, ^{48}Ca, and ^{136}Xe. The reaction of ^{40}Ar with ^{238}U was used in most of subsequent work because of the availability of intense beams and target material.

Intense sources containing both activities were produced by irradiating thick targets of depleted uranium (^{238}U) with 288–340-MeV ^{40}Ar ions from the SuperHILAC or the 88-in. cyclotron. The targets were electrolytically dissolved down to the maximum recoil range in a mixture of nitric and hydrochloric acids. The target solution was heated to remove the nitric acid before adjusting the *p*H to 2.5 ± 0.5 with NaOH. To this solution 0.5 ml of 0.1% solution of diphenylthiocarbazone (DTZ) in CCl_4 was added and the phases were equilibrated for 1–2 min using a vortex mixer. Under these conditions, Bi, Po, and At were extracted into the organic phase and a separation of the order of 95% from Pb was achieved. After centrifugation the DTZ solution was evaporated onto a platinum disk which was gently flamed. This procedure yielded weightless alpha sources of total activity several times 10^5 decays per minute consisting mostly of ^{212}Bi-^{212}Po, ^{213}Bi-^{213}Po, ^{214}Bi-^{214}Po, and the new activities. A spectrum obtained by using this procedure in a ^{48}Ca bombardment is shown in Fig. 1. An intense doublet at 6.30 and 6.34 MeV was noted to decay with a 25-min half-life and is believed to be associated with the group of lines at 10 MeV. All other lines in the spectrum could be explained in terms of known activities.

The chemical identification of the 25-min activity was accomplished through the technique of residue adsorption or chemisorption.[3] This method is based on the self-deposition of certain elements on noble-metal surfaces followed by selective desorption by an appropriate solvent. The alpha spectra of the various fractions separated by chemisorption proved unequivocally that this activity follows the chemistry of Bi. Because of the 11.66-MeV activity and its short half-life, this activity was not chemically identified by this procedure.

Three successful isotope-separation experiments were performed with the Lawrence Berkeley Laboratory isotope separator on samples obtained from $^{40}Ar + ^{238}U$ bombardments with the DTZ extraction. The results showed that both the intense doublet and the group of lines at 10 MeV are associated with the mass number 212. Again because of the short half-life and low yield, the 11.66-MeV activity was not identified as to its mass number. The alpha spectrum of a mass-separated sample is shown in Fig. 2.

The chemical separation together with the mass separation indicate that at least the 25-min activity can be associated with an isomeric state in ^{212}Bi. Our studies further indicate that the 25-min isomeric state, ^{212m}Bi, decays both by alpha emission to ^{208}Tl and by beta emission to excited levels of ^{212}Po followed by the emission of "long-range" alpha particles to the ground state of ^{208}Pb.

The assignment of the 25-min activity is supported by a comparison with the ground-state decay of ^{212}Bi. The ground state of $^{212}Bi(1^-)$ is known to alpha decay to the ground and first excited state of ^{208}Tl yielding two alpha lines separated by 40 keV.[4] Beta decay also occurs from this state to the ground state of ^{212}Po followed by the emission of alpha particles to the ground state of ^{208}Pb. In addition a small beta-decay branch to low-spin excited states of ^{212}Po exists followed by the emission of "long-range" alphas. The 25-min activity exhibits similar behavior in that two alpha lines are observed which are separated, within experimental error, by 40 keV. If it is assumed that the 6.34-MeV line results from a transition to the ground state of ^{208}Tl, the energy of the isomeric state would be 250 keV. Our interpretation of the 10-MeV group as "long-range" alphas emitted from levels of ^{212}Po following the beta decay of ^{212m}Bi is supported by the shape of the alpha lines in spectra taken at high geometry. The slope of the high-energy side of the 10.2-MeV line indicates that a beta particle was emitted simulataneously with the emission of the alpha particle within the resolving time of the equipment. This effect is visible in both the ^{212}Po ground-state transition and the 10.2-MeV line in the spectrum of the mass-separated sample, Fig. 2.

The fact that an isomeric state should exist in ^{212}Bi is suggested by analogy with the 9^- isomeric state in ^{210}Bi.[5-8] The configuration of ^{212}Bi, $(\pi h_{9/2})(\nu g_{9/2})^3$, differs from that of ^{210}Bi, $(\pi h_{9/2})$-$(\nu g_{9/2})$, in that ^{212}Bi has two additional $g_{9/2}$ neutrons. Shell-model studies have been carried out on the ground-state and low-lying states of the configuration $(\pi h_{9/2})(\nu g_{9/2})$ of ^{210}Bi by Kim and Rasmussen.[9] Their calculations which are in excellent agreement with the experimental observations of Motz *et al.*[10] indicate the level responsible for the isomeric state is a 9^- state located at 268 keV. Although no such shell-model calculations have been reported in the literature for ^{212}Bi, we do not believe that the addition of two neutrons coupled to zero should change considerably the corresponding level structure in ^{212}Bi. Therefore we suggest an analogous 9^- spin for the isomeric state in ^{212m}Bi.

Detailed shell-model calculations of the excited levels of ^{212}Po have been made by several authors. In one such calculation Glendenning and Harada allowing for configuration mixing, predicted a state with $J^\pi = 18^+$ to explain the 45-sec ^{212m}Po.[11] Their results also indicate the possibility of another isomeric state $J = 10-12$ at an excitation energy of 1.2 MeV. On the other hand, calculations assuming no configuration mixing by Auerbach and Talmi indicate a spin of 16 for ^{212m}Po.[12] Likewise, their calculations also suggest a second isomeric state, however, of lower spin, around $J = 8-10$.

It is reasonable to assume that since the first excited state of ^{208}Pb is 2.6 MeV above the ground state, the 10-MeV group decays to the ground state of ^{208}Pb. This would place the levels in ^{212}Po responsible for the 10-MeV transitions at an excitation energy of 1.1 to 1.5 MeV. These levels are consistent with either of the shell-model calculations mentioned.

As a test for the assumption of a 9^- isomeric level in ^{212}Bi, one would expect a $\log ft$ value of 6–9 (first-forbidden transition) for a beta decay from a 9^- to either an 8^+ or 10^+ state in ^{212}Po. In view of the possibility of gamma decay the ratio of alpha transitions from the 9^- state yields a lower limit of 7% for the beta branch to ^{212}Po. The resulting upper limit of 6.8 for the $\log ft$ value is then compatible with the spin assignment of 9^- for ^{212m}Bi. Because of the small amount of activity we were unable to determine definitively the possiblity of gamma decay from the 1.46-MeV level in ^{212}Po in the gamma ray single spectrum of the chemically separated sample.

Turning now to the 9-min activity, our results on $^{248}Cm + ^{48}Ca$ proved that it is genetically a parent of the 45-sec ^{212m}Po. Since it was coprecipitated with CuS from an acidic solution, it could in principle be an isomer in ^{212}At, ^{212}Po, or ^{212}Bi. The first possibility was eliminated when we observed that we could volatilize the ^{211}At-^{211}Po activity away from our sources while the 9-min and 25-min activities remained.

In their discovery work on ^{212m}Po, Perlman *et al.*[2] irradiated a lead oxide target with 116-MeV ^{11}B ions and separated a Po fraction by a combination of volatilization and cation exchange. They found that ratio of the ^{211}Po and ^{212m}Po activities was not changed by the chemical procedure if the latter was assumed to have a half-life of 45 sec; this apparently rules out the possibility that the 9-min activity is another isomer in ^{212}Po feeding the 45-sec state. It is also difficult to postulate a second isomer in ^{212}Po that would decay into the known ^{212m}Po and yet have the required long half-life against alpha decay.

The remaining possibility, that the 9-min activity is another isomeric state in ^{212}Bi which beta decays into ^{212m}Po, appears quite plausible. If one breaks the pair of $g_{9/2}$ neutrons in ^{212}Bi and recouples the four particles outside the ^{208}Pb core to maximum spin, a 15^- state is obtained.[13] We consider this state in ^{212}Bi the most likely explanation of the 9-min activity; a consequence of this assignment would be that the spin of ^{212m}Po

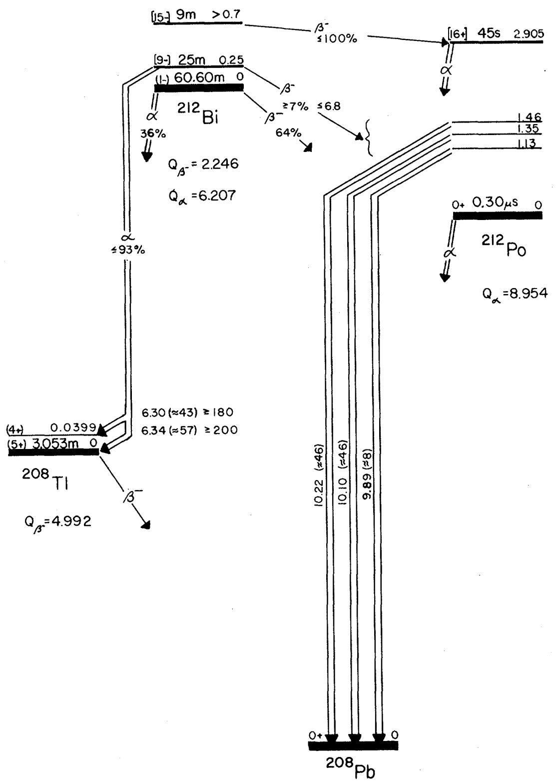

FIG. 3. Tentative decay scheme for isomeric states in ^{212}Bi. Relative alpha intensities are given in parentheses after the alpha energies. Other pertinent information shown which was not explicitly determined in this work was taken from Ref. 4.

would be 16 as suggested by Auerbach and Talmi.[12] A decay scheme of the two isomers is shown in Fig. 3.

In conclusion we have shown evidence for the existence of two isomeric states in ^{212}Bi. Since these isomers are made in a variety of heavy reactions with heavy targets, the high-energy alpha particles associated with their decay may be present in experiments aimed at the synthesis of superheavy elements. The possibility is accentuated by the fact that Bi is a homolog of element 115 and will follow the chemistry of the eka-Pb group of the superheavy elements.

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