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Communications

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New mass values for ^{206}Bi and secondary masses*

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The Q value for the reaction ^{204}Pb(α, d)^{206}Bi has been measured as $Q_0 = -15\,798 \pm 11.6$ keV. This leads to a ^{206}Bi mass excess of $-20\,019 \pm 13$ keV which differs by 107 keV from the previously accepted value. Previously adopted mass values for ^{210}At, ^{214}Fr, ^{218}Ac, and ^{222}Pa are also directly affected by a change in the ^{206}Bi mass.

[NUCLEAR REACTIONS ^{204}Pb(α, d), E =48 MeV, measured Q value relative to ^{206,208}Pb(α, d). Deduced ^{206}Bi g.s. mass.]

The isotopes ^{206}Bi, ^{210}At, ^{214}Fr, ^{218}Ac, and ^{222}Pa are linked to the mass of ^{206}Bi by rather precisely measured α-decay energies.[1] They all have a common (≈ 26 keV) quoted uncertainty in their mass excess. The link to stable and well-known isotopes seems to have been made using β-decay energies for ^{206}Bi and ^{210}At.[1] These measurements are difficult: The ^{206}Bi$\to^{206}$Pb and ^{210}At$\to^{210}$Po ground state β^+ transitions are highly forbidden. The dominant β^+ decay branches go to highly excited states in the daughter nucleus and compete with electron capture. Published results for ^{206}Bi scatter[2,3] and may be subject to errors considerably in excess of 26 keV. Similarly, the empirical value for the ^{210}Po-^{210}At mass difference[4] is not very precise. Doubt in the currently adopted ^{206}Bi mass value[1] should be heightened by a recent indirect deduction of the ^{206}Bi mass from electron capture ratios[5] which differs from the mass table value by 99 ± 22 keV.

In our recent^{204,206,208}Pb(α,d) spectrograph data[6] taken at Princeton with $E_\alpha = 48.2$ MeV we have a very direct comparison of the ^{206}Bi, ^{208}Bi, and ^{210}Bi masses through the (α,d) Q values. The calibration of the Princeton quadrupole-dipole-dipole-dipole spectrograph with its focal plane detector was checked and fine-adjusted by measurement of the well-known ^{210}Bi spectrum. This calibration predicted the position of the 2 MeV more energetic ^{208}Bi ground state deuteron group to within 6 keV with respect to the commonly accepted Q value of $-15\,613(\pm 11)$ keV. As the ^{204}Pb(α,d) and ^{206}Pb(α,d) Q values are very close, we measured both spectra at the same angles and at identical magnetic field setting. For six of seven measurements at $10° \le \theta_{lab} \le 40°$ the ^{204}Pb(α,d)^{206}Bi measurements immediately preceded or followed the ^{206}Pb(α,d)^{208}Bi measurement with only the thin self-supporting targets having been exchanged. Figure 1 shows a direct comparison of the ^{206}Bi and ^{208}Bi ground state slices of the spectra for $\theta_{lab} = 35°$. The ^{208}Bi(5^+) ground state is relatively strong. In ^{206}Bi the ground state and first excited (60 keV) states are expected to be extremely weak in (α,d) for nuclear structure reasons.[6] The ^{206}Bi ground state is not visible above background in Fig. 1; however, the well established 83 keV (5^+) and the 140 keV (7^+) states[7,8] are quite strong, as expected, with the 163, 200, and 523 keV states less visible.

Measured excitation energies for strong—generally high spin—^{208}Bi levels are shown in the top spectrum of Fig. 1. Differences between these levels and corresponding known levels for ^{208}Bi are below ± 4 keV. We estimate our calibration error for excitation energies as $\Delta E^* \approx \pm 0.004 E^*$ for resolved states. This leads to a detector scale error of ± 1.5 keV near $Q = -16$ MeV. The correction for the difference in the measured thickness of the self-supporting ^{204}Pb and ^{206}Pb targets was 3 ± 0.5 keV. Uncertainty in the excitation energy of the relevant 140 keV level in ^{206}Bi is $\lesssim 1$ keV. The standard deviation of six separate measurements of $Q[^{204}\text{Pb}(\alpha,d)^{206}\text{Bi}(140\text{ keV})]$—primarily due to statistics—was 3 keV. Hence the total experimental error for the relative Q_0 value mea-

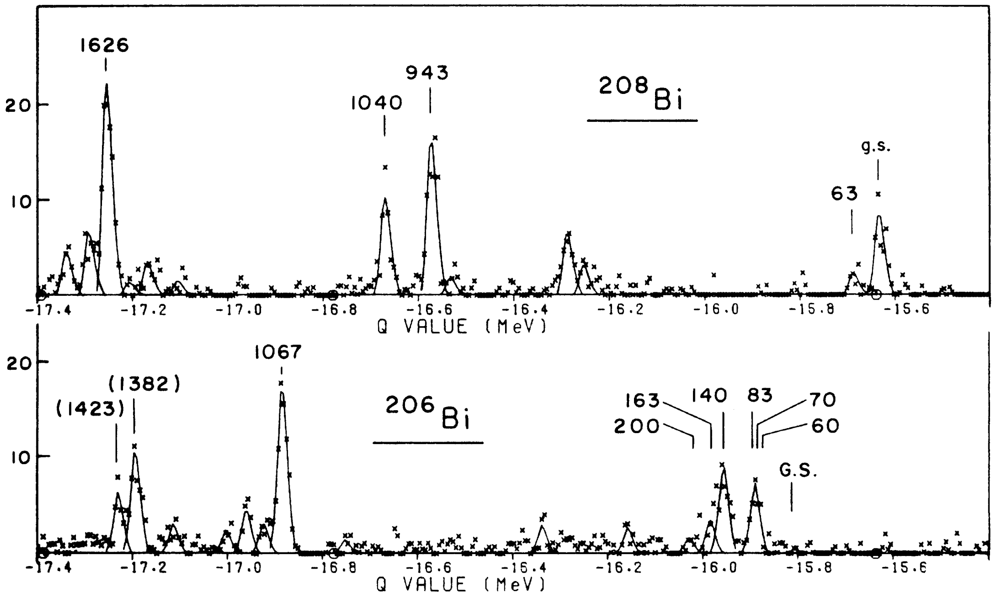

FIG. 1. Typical comparison of $^{206}Pb(\alpha, d)^{208}Bi$ and $^{204}Pb(\alpha, d)^{206}Bi$ spectra taken in sequence under nearly identical conditions. The spectrum shown was taken at $\theta_{lab} = 35°$, $E_\alpha = 48.2$ MeV. The solid lines show fits with the analysis program AUTOFIT. The Q value is derived from the fits to the ^{208}Bi ground state and the ^{206}Bi 140 keV state, as the third height position of the latter is not affected by other levels. Other peak fits are shown to demonstrate consistency with known levels.

surement is ± 3.5 keV if errors are added in quadrature. This is small compared to the 11 keV uncertainty in $Q_0[^{206}Pb(\alpha, d)^{208}Bi]$.

On the basis of our six best measurements relative to ^{208}Bi with $Q_0[^{206}Pb(\alpha, d)] = -15\,613 \pm 11$ keV we obtain

$$Q_0[^{204}Pb(\alpha, d)^{206}Bi] = -15\,798 \pm 11.6 \text{ keV}.$$

This value differs by 107 keV or four standard deviations from the previously accepted value (− 15 691 ± 26 keV).

Including an uncertainty of ± 6 keV for the ^{204}Pb mass the deduced ^{206}Bi mass excess is ME(^{206}Bi) = − 20 019 ± 13 keV, provided our identification of the low-lying ^{206}Bi states is correct. This value is in agreement with the value deduced in Ref. 5 but in considerable disagreement with the result of Ref. 2. It should be emphasized that a reassignment of the ^{206}Bi mass excess directly affects the derived (secondary) mass values of ^{210}At, ^{214}Fr, ^{218}Ac, and ^{222}Pa, and possibly others which were derived or extrapolated[9] on the basis of the ^{206}Bi mass. Using the currently accepted α-decay energies for the $^{222}Pa \rightarrow {}^{206}Bi$ chain[7,10-12] we suggest the following improved mass excess values: ME(^{210}At) = − 11 963 ± 14 keV, ME(^{214}Fr) = − 950 ± 15 keV, ME(^{218}Ac) = + 10 852 ± 18 keV, and ME(^{222}Pa) = + 21 974 ± 35 keV.

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