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Observation of excited states in ^{206}Hg†

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We investigated ^{206}Hg, the missing link for particle-vibration coupling studies around ^{208}Pb. In ^{18,17}O induced reactions on ^{204}Hg we identified γ rays from states at 1.068 and 2.102 MeV in ^{206}Hg. Relying on theoretical arguments we propose spins 2^+ and 4^+, respectively.

[NUCLEAR REACTIONS ^{204}Hg(^{18}O, ^{16}O), (^{17}O, ^{16}O), E(^{18}O)=75 and 81 MeV, E(^{17}O) =81 MeV. Measured particle-γ and γ-γ coin., deduced ^{206}Hg level energies (and spins). Enriched targets.]

I. INTRODUCTION

In recent years the nuclei in the vicinity of ^{208}Pb have served as testing grounds for refinements of the shell model. In particular, the nuclei differing from the doubly closed shell by two particles or holes have been the subject of many theoretical studies in order to probe the power of more elaborate calculations which make use of effective two particle (hole) interactions.[1,2] One notable gap in the corresponding experimental data exists in the case of ^{206}Hg which lacks two protons in the closed shell. This constitutes a particularly serious drawback since any weak coupling description[3] of states with a ^{206}Hg core needs knowledge of the low-lying spectrum of this nucleus. In this paper we report on the experimental observation of two low-lying excited states in ^{206}Hg.

We have measured particle-γ and γ-γ coincidences following ^{17}O and ^{18}O induced transfer reactions on ^{204}Hg at energies near the Coulomb barrier. The (^{18}O, ^{16}O) reaction is expected to populate low-lying excited states in ^{206}Hg because of optimum transfer conditions.[4] Compared to this reaction [and the reaction ^{204}Hg(t,p)], all other two-neutron transfer reactions on ^{204}Hg or two-proton pickup reactions on ^{208}Pb are probably unfeasible because of orbit mismatching.

II. EXPERIMENTAL DETAILS AND RESULTS

Beams of ^{18}O at 75 and 81 MeV and ^{17}O at 81 MeV from the Munich MP tandem accelerator have been used to bombard thick isotopically enriched targets (96% ^{204}Hg) which consisted of a drop of liquid mercury[5] covered with 30 μg/cm^2 Formvar.

In the particle-γ experiments we recorded coincidences between a 60 cm^3 Ge(Li) detector at 90° to the beam axis and an annular surface barrier detector (60 μm thick, accepting particles with scattering angles from 168° to 176°). The particle spectra were calibrated with ^{18}O$^{7+,8+}$ ions using thin targets of bismuth on gold.

At bombarding energies around the Coulomb barrier transfer reactions occur only near the surface of the target thus leading to a relatively small effective target thickness (about 4 mg/cm^2 for ^{18}O at 81 MeV). Therefore, the maximum energy of the particle spectra in coincidence with the γ lines permits identification of the different reactions taking place [see Figs. 1(b)–1(e)]. In this way we could clearly identify transitions in the Hg isotopes because all competing transfers involving the stripping of protons have negative Q values and the low-lying spectrum of the corresponding residual nuclei is well known whereas transfers involving the pickup of protons should proceed with very small cross sections because they are strongly mismatched (see Table I).

Problems arose in the identification of inelastic scattering and neutron transfers because there are not sufficient experimental data available on the γ decay of excited states of the heavier mercury isotopes. Therefore we looked also for ^{17}O induced reactions on ^{204}Hg. In this case the two-neutron transfer is strongly mismatched ($Q_{g.s.}$ = – 7.4 MeV) whereas the one-neutron transfer is kinematically more favored than for the ^{18}O projectile.

The strongest γ line whose coincident particle spectrum is energetically compatible with a $2n$ transfer and which is absent in the ^{17}O run has an energy of (1.068 ± 0.001) MeV [see Fig. 1(b)].[6]

As the next step we measured γ-γ coincidences

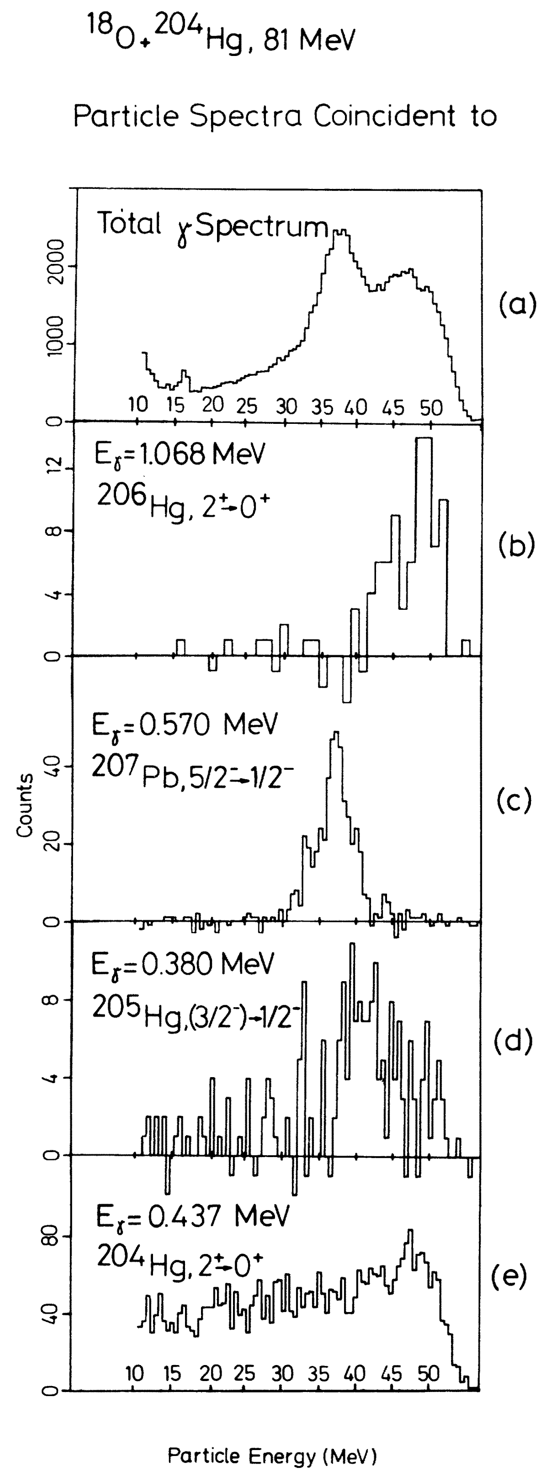

FIG. 1. (a) Total particle spectrum observed at 175° in coincidence with γ rays from the bombardment of a thick ^{204}Hg target with 81 MeV ^{18}O. (b)–(e) The particle spectra coincident to particular γ transitions in the residual nuclei.

TABLE I. Ground-state Q values ($Q_{g.s.}$) and optimum excitation energies $E^*_{opt} = Q_{g.s.} - Q_{opt}$, $Q_{opt} = E_{c.m.}\{(Z_3 Z_4/Z_1 Z_2) - 1\}$ (Ref. 4), for some ^{18}O and ^{17}O induced reactions on ^{204}Hg at $E_{lab} = 75$ MeV. Only pure p and n transfers are given. The $(p+n)$ transfers show the same trend as the corresponding pure p transfers.

Reaction	$Q_{g.s.}$ (MeV)	E^*_{opt} (MeV)
^{204}Hg(^{18}O, ^{19}F)^{203}Au	−1.2	−8.8
^{204}Hg(^{18}O, ^{20}Ne)^{202}Pt	4.0 [a]	−11.1
^{204}Hg(^{18}O, ^{21}Na)^{201}Ir	−3.5 [a]	−25.8
^{204}Hg(^{18}O, ^{17}N)^{205}Tl	−9.5	−1.6
^{204}Hg(^{18}O, ^{16}C)^{206}Pb	−15.4	0.6
^{204}Hg(^{18}O, ^{15}B)^{207}Bi	−34.8	−10.6
^{204}Hg(^{18}O, ^{18}O)^{204}Hg	0	...
^{204}Hg(^{18}O, ^{17}O)^{205}Hg	−2.4	−2.4
^{204}Hg(^{18}O, ^{16}O)^{206}Hg	0.2	0.2 [b]
^{204}Hg(^{17}O, ^{16}O)^{205}Hg	1.5	1.5
^{204}Hg(^{17}O, ^{15}O)^{206}Hg	−7.4	−7.4

[a] Calculated from the mass excess of the residual nucleus as given in Ref. 8.

[b] The discrepancy between the calculated value and the measured value of $E^*_{opt} \gtrsim 3$ MeV can be removed by the inclusion of the effects of recoil and nuclear forces in the theoretical calculation. For pickup reactions the same effect leads to even more negative value of E^*_{opt}.

between two Ge(Li) detectors at 0° and 90°, using ^{18}O as the projectile. During these experiments the target had no Formvar cover and was cooled to solid CO_2 temperatures. This allowed us to use beam currents up to 3–4 particle nA without getting an excessive γ-ray intensity from light elements. In coincidence with the 1.068 MeV transition we clearly observed one other line at 1.034 MeV [Fig. 2(b)] which from the particle-γ experiment is known to have about one-fourth of the intensity of the 1.068 MeV transition. Further coincident transitions could not be reliably identified since their intensity is smaller by at least another factor of 5 which is the detection limit. If we exclude some rather unlikely situations, viz. that the strong transition of 1.068 MeV feeds a lower state from the decay of which we observe only the weak branch of 1.034 MeV and miss all the other deexcitation γ rays, we also know that the 1.034 MeV transition is preceding the one at 1.068 MeV. Furthermore, the latter should lead to the ground state since we expect the first excited state to be near 1 MeV, in analogy with ^{206}Pb.

Because of the low intensity of the two γ transitions we were not able to determine the multipolarities in an angular correlation experiment. In order to obtain some idea about the spins of these states we therefore had to rely on theoreti-

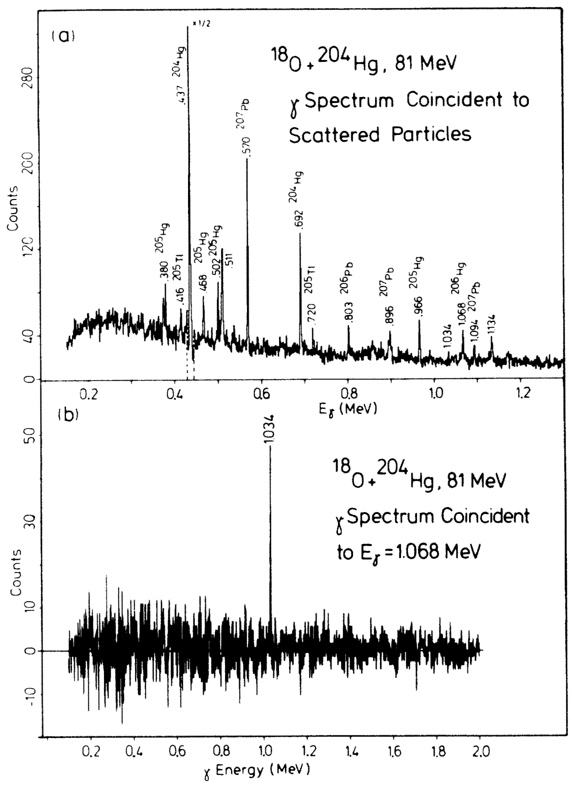

FIG. 2. (a) γ spectrum observed in a Ge(Li) diode at 90° in coincidence with backscattered particles of energies larger than 30 MeV detected in an annular surface barrier detector. (b) γ spectrum coincident with the 1.068 MeV transition as observed in the γ-γ experiment at 81 MeV.

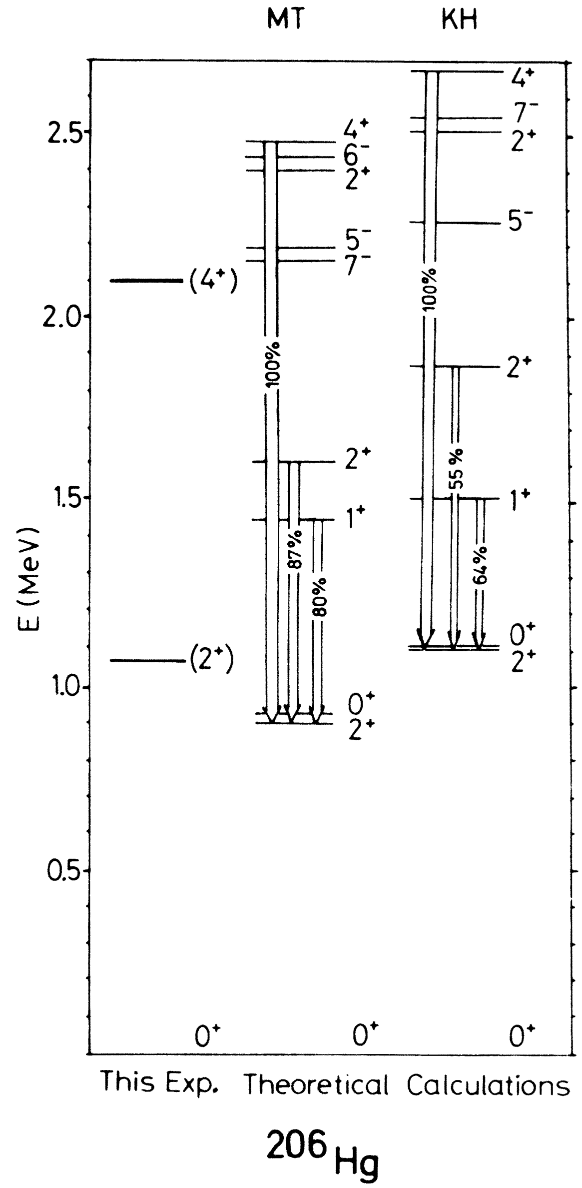

FIG. 3. The results of our experiment in comparison with the theoretical predictions of Refs. 1 (MT) and 2 (KH).

cal arguments and retreat to a somewhat biased analysis: Calculations[7] of the γ decay of the low-lying levels in ^{206}Hg with the wave functions of Herling and Kuo[2] and Ma and True[1] show that most of the γ intensity is collected by the first 2^+ state and the first 4^+ state decays completely to this level (Fig. 3). In fact, if the 2.102 MeV level has spin 4 it is probably the lowest state with spin greater than 2 and therefore collects a large fraction of the γ decay of the higher states. The calculated lowest 5^- and 7^- states lie also near this energy, but we reject this possibility because we observe the 1.034 MeV transition promptly ($\tau < 10$ ns) whereas the Weisskopf estimate for an $E3$ transition of 1 MeV is about 1 μs. We therefore favor an assignment of the observed transitions to the decay ^{206}Hg(4^+, 2.102 MeV) $\rightarrow$ ^{206}Hg(2^+, 1.068 MeV) $\rightarrow$ ^{206}Hg(0^+, g.s.).

We know from the coincident particle spectra at 75 MeV (where the ring counter sees the grazing angle of the reaction) that the initial excitation energy of ^{206}Hg has a lower limit around 4 MeV. This means that the range of excitation extends up to at least 6 MeV unless the Q window of the reaction is unexpectedly narrow. Therefore, it remains to be understood why we observe only two strong deexcitation γ rays. In particular, we looked for signs of an $E1$ decay of the 3^- state, which should lie near 2.6 MeV, to the lowest 2^+ state. We detected no γ ray strong enough to be explained even tentatively as such a transition.

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[6]We exclude the case that this γ ray originates from the transition 2^-(5.517 MeV) → 1^-(4.449 MeV) in ^{18}O because none of the consecutive deexcitation γ rays is seen in our spectra.

[7]We thank O. Häusser for allowing us to use his computer program.

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