THE DECAY $^{207}_{80}Hg \rightarrow ^{207}_{81}Tl$

B. Jonson
CERN-ISOLDE, CERN, Geneva, Switzerland

O.B. Nielsen
Niels Bohr Institute, Copenhagen, Denmark

L. Westgaard
Chemical Institute, University of Oslo, Norway

J. Żylicz
Institute of Experimental Physics, University of Warsaw, Poland

The ISOLDE Collaboration

Abstract

^{207}Hg was produced in a secondary (n,2p) reaction on ^{208}Pb. The decay scheme was studied by means of a plastic scintillator and Ge(Li) detectors. Fourteen excited levels in ^{207}Tl are discussed in terms of proton hole states coupled to the core excitations of ^{208}Pb.

1. Introduction

An investigation of the decay scheme of ^{207}Hg is of considerable interest since it might add to our knowledge of the levels in ^{207}Tl, which can be considered as a hole in a ^{208}Pb core. Until now, ^{207}Hg has, however, not been reported in the literature, probably because it has one neutron more than any convenient target material, which makes it difficult to produce in charged-particle reactions. It turned out, however, that it was produced in the ISOLDE facility by a secondary (n,2p) reaction on ^{208}Pb together with the lighter mercury isotopes, which were formed in the primary reactions Pb(p,3pxn)Hg.

2. Production of ^{207}Hg

As the production of a radioisotope in a secondary reaction is somewhat untraditional, the experimental conditions shall be briefly outlined. The ISOLDE targets used for the production of mercury isotopes consist of molten natural lead of an effective thickness ∿ 15 cm or 170 g/cm^2 [1]. This is not much less than a radiation length, and a large fraction of the 600 MeV protons give rise to spallation reactions in which protons and neutrons are emitted with energies that are sufficient for secondary reactions. Protons of 600 MeV cause, on the average, the ejection of 2-3 neutrons with an energy above 50 MeV, which is enough for the (n,2p) reaction. The target size also allows a considerable part of these neutrons to react with the ^{208}Pb part of the lead, resulting in a yield of ^{207}Hg that is 2-3 orders of magnitude lower than that of the ^{206}Hg formed in the primary ^{208}Pb(p,3p) reaction.

As could be expected, the (n,2p) reaction was enhanced in targets having dimensions larger than those of the standard ISOLDE type, and the final version contained more than 500 g of lead. With a proton beam of ∿ 2×10^{12} particles/s, the yield of ^{207}Hg was about 10^5atoms/s or a few μCi (Fig. 1).

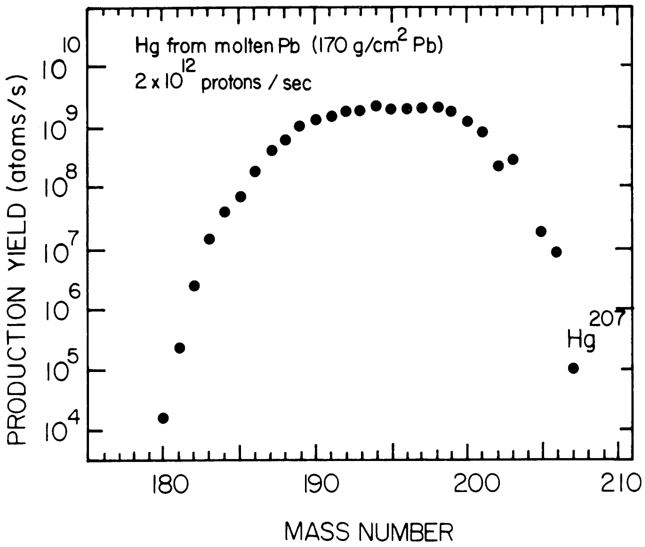

Fig. 1 Production yield in the ISOLDE facility of the mercury isotopes, including ^{206}Hg and ^{207}Hg.

3. The detector system

The ^{207}Hg was collected inside the separator vacuum on a metallized mylar tape, and was moved via an automated transport system[2] to a position inside a plastic scintillator, which had a narrow slit cut through the middle. The β-particles were accordingly detected with almost 100% efficiency. A Ge(Li) detector, of either 63 or 40 cm^3, was placed outside the vacuum, close to the scintillator, and the γ-rays could be recorded in coincidence with the β-particles as well as in the singles mode.

With the much higher production rate for the lighter mercury isotopes, the problems arising from cross-contamination in the isotope separator, and general room background had to be considered. However, unlike ^{207}Hg, none of the likely impurities emit high-energy β-particles in coincidence with high-energy γ-rays. The transitions originating in ^{207}Tl could therefore be easily identified in the γ-ray spectra measured in coincidence with β-particles above a certain energy.

The γ-γ coincidence measurements were performed with two Ge(Li) detectors placed in a 90° geometry. The experimental conditions allowed the establishment of only a limited number of coincidence relations.

4. Half-life and decay energy of ^{207}Hg

The half-life was determined by two different selective methods of counting, performed by means of the above detector system. Firstly, gross coincidences between high-energy β's and high-energy γ's were recorded as a function of time. Secondly, the decay of one of the strong lines in the γ-spectrum was followed. The result in both cases was a half-life of 2.9 ± 0.2 min.

The continuous β-ray spectrum was investigated in the plastic scintillator, using a technique described elsewhere[3]. In the present case, only β-particles in coincidence with high-energy γ-rays were recorded. The subsequent analysis of the decay scheme shows that the β-groups of highest energy populate four levels with energies between 2912 and 3143 keV. The measured maximum energy of 1800 keV was a weighted average for these groups, and the total decay energy is estimated, with a modest accuracy, as 4775 ± 150 keV.

The half-life and the Q-value of ^{207}Hg are almost identical to those of ^{208}Tl: 3.05 min and 4992 keV.

5. Preliminary considerations on the levels of ^{207}Tl

Before the experimental facts are discussed, we shall briefly outline some main features of the level structure of ^{207}Tl as suggested from our knowledge of the neighbouring nuclei around ^{208}Pb. Figure 2 shows the proton hole states as found in charged-particle reactions[4], the assignments being relatively unambiguous. To the right are indicated the lowest states of ^{208}Pb, which are core excitations, i.e. a rather collective two-particle excitation. The level scheme of ^{207}Tl is expected to arise from the coupling of the proton hole states to these core excitations. Below 2600 keV, the level scheme should accordingly be simple, but above that energy a considerable number of negative-parity states can occur. Above ∿ 3500 keV, the level density is likely to be so high that an interpretation of individual levels will be difficult.

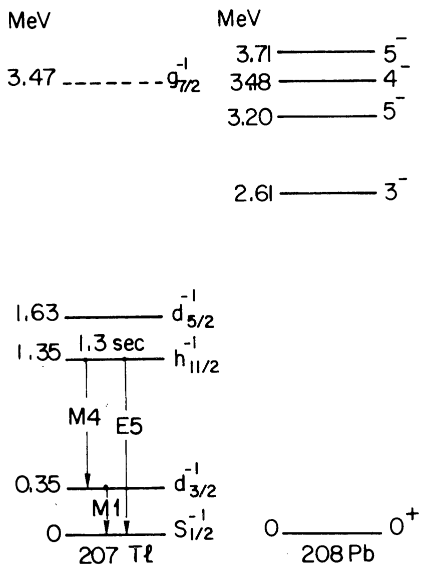

Fig. 2 Single-particle hole states of ^{207}Tl and core states of ^{208}Pb

In addition to the states of the above configurations, a level corresponding to the ground state of ^{206}Hg coupled to a $h_{9/2}$ proton is expected. Blomqvist[5] has estimated its position as being at 2963 keV.

6. The decay scheme

The following discussion of the levels in ^{207}Tl is based upon the γ-ray and γ-γ coincidence measurements performed with the Ge(Li) detectors. We have no information about conversion lines, angular correlations, etc., and all assignments of spins and multipole orders are based on systematics. Most of the experimentally determined levels of Fig. 3 are proposed on the basis of energy fits better than 0.3 keV. The γ-γ coincidence relations are decisive in some cases, and the whole scheme is supported by a satisfactory intensity balance.

6.1 The $h_{11/2}$ and $d_{3/2}$ states

The isotope ^{207}Hg has 127 neutrons, and the odd particle is thus the first outside the closed shell and is assigned as $g_{9/2}$. This neutron can decay to the $h_{11/2}$ state of Fig. 2, but the transition is expected to be weak[5]. Owing to the 1.3 s half-life of the $h_{11/2}$ state, such a β-group could not be singled out by coincidence measurements, but we are able to conclude that only a small fraction of the population of the level might be the result of direct β-feeding. Beta-decay to the other single-particle states of Fig. 2 are highly forbidden and were not observed.

The $^{11}/_{2}^{-}$ state was strongly populated by γ-transitions from higher levels (Fig. 3). The de-excitation was mainly by an intense 997.1 keV line to the 351.0 keV $^{3}/_{2}^{+}$ level, but the cross-over transition of 1348.1 keV was seen in the γ-spectrum with

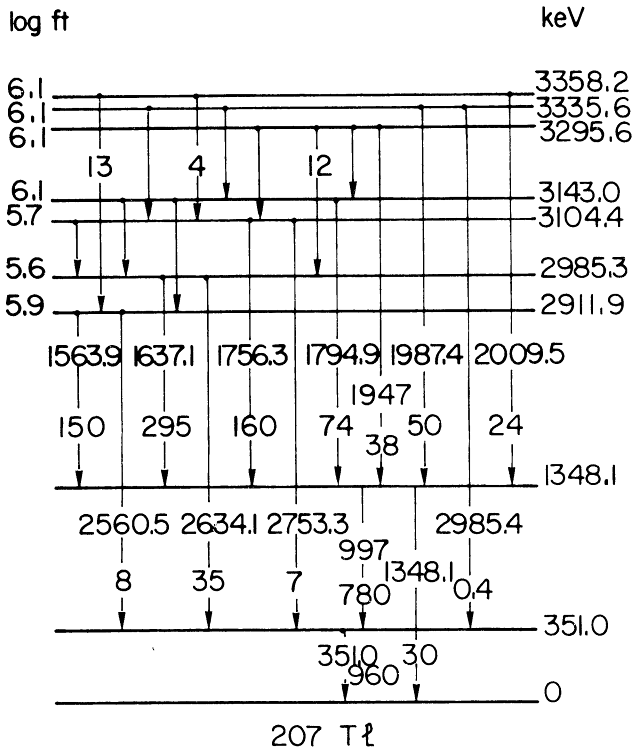

Fig. 3 Part of the decay scheme ^{207}Hg → ^{207}Tl. The γ-transitions are indicated by their energy and intensity in units of one per mille of all decays. Corrections for internal conversion are made when possible.

an intensity which could not be explained by summing in the Ge(Li) detector. The summing contribution was estimated by the measurement of spectra with different distances from source to counter. After correction, the intensity of the 1348.1 keV γ-ray was found to be (4 ± 1)% of the 997 keV line. It must be interpreted as an E5 transition, which is able to compete with a predominantly M4 transition of 997 keV. An E5 transition between corresponding levels in ^{206}Tl has been observed earlier[6].

6.2 The strongly excited levels

More than 80% of all β-decays proceed to seven levels in ^{207}Tl between 2912 and 3358 keV. They decay predominantly to the $11/2^-$ state; in four cases, weak cross-overs to the $3/2^+$ state at 351 keV were also observed. The cross-overs were all seen in coincidence with the 351 keV γ-ray, whereas for natural reasons the transitions to the long-lived $11/2^-$ state were missing in the coincident spectrum.

The ^{207}Hg with spin $9/2^+$ can decay to levels of spin $7/2$, $9/2$, and $11/2$ with allowed or first-forbidden β-transitions. Most of the β-decays of ^{208}Tl to ^{208}Pb excite the 5^- and 4^- levels by transitions with log ft values 5.6 and 5.7. Similar transition rates are expected in the decay of ^{207}Hg to states corresponding to the same core excitations in ^{207}Tl. Blomqvist[5] has estimated that the coupling of $s_{1/2}^{-1}$ to the 5^- and 4^- states and of $d_{3/2}^{-1}$ to 3^-, 5^-, and 4^- gives rise to nine states of spin $7/2^-$, $9/2^-$, and $11/2^-$ between 2900 and 3500 keV. In addition, the ^{206}Hg $h_{9/2}$ state is predicted in the same energy region. Most of these states will be strongly admixed, but even if it is not possible to give unambiguous assignments to the experimental levels of Fig. 3, the main features of the β-decay of ^{207}Hg are well explained by the model outlined above. For example, the "β-strength functions" are almost identical for the ^{208}Tl → ^{208}Pb and ^{207}Hg → ^{207}Tl decays.

Negative-parity assignments for the strongly excited levels imply that the γ-transitions to the $11/2^-$ state are M1 or E2. The cross-overs to the $3/2^+$ state are then E3. The 3^- state of ^{208}Pb is connected to an enhanced E3 transition strength, which apparently also in ^{207}Tl can compete with M1 and E2 transitions of lower energy.

6.3 Some weakly populated levels

The γ-ray measurements further revealed the four levels in Fig. 4. They are only weakly excited and must partly be fed by unidentified β-groups and γ-rays from higher-lying levels.

The excitation of the $d_{5/2}^{-1}$ state at 1682.7 keV is indicated by the ground-state transition and the 1331.2 keV γ-ray, which is seen in coincidence with 351 keV. Since the feeding of this state is of considerable interest, time was invested in the measurement of the coincident γ-ray spectrum gated by the 1331 keV line. With the low intensity the experiment was marginal, but the line of 1590.3 was clearly shown to be coincident, establishing a level at 3273 keV.

Hamamoto[7] has pointed out that a γ-ray from the 2675.2 keV level (see below) might have a high transition strength to the $d_{5/2}$ state. Its energy, ∿ 992.5 keV, made it impossible to observe it in the single γ-ray spectrum, as it is situated in the tail of the 997 keV line (about 100 times stronger) from the $11/2^-$ state, but this line was strongly suppressed in the coincident spectrum, and there was a clear indication of an ∿ 993 keV line of the intensity given in Fig. 4.

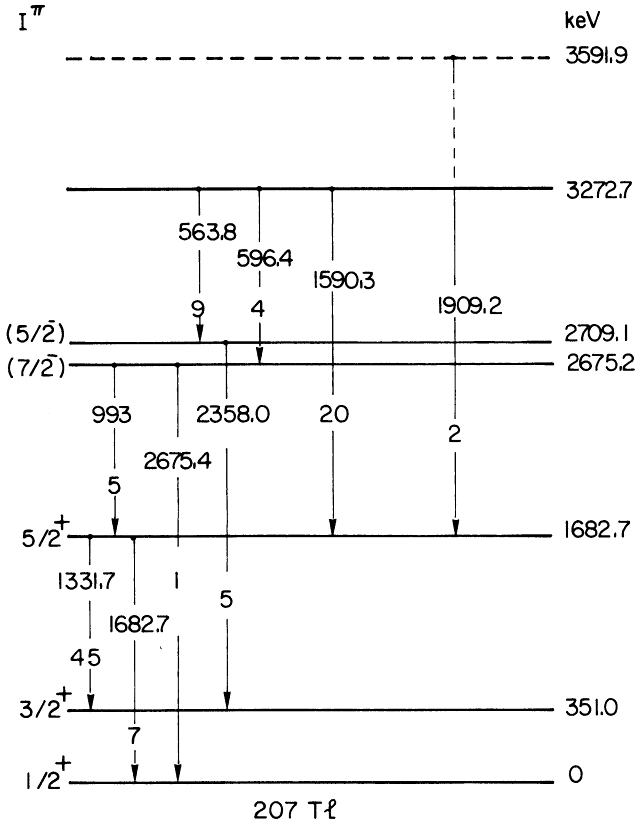

Fig. 4 The weakly excited levels discussed in Section 6.3

Two levels at 2675.2 and 2709.1 keV are interpreted as the $7/2^-$ and $5/2^-$ states of the $s_{1/2}$ 3^- configuration. The experimental evidence for the lowest level is a 2675.2 keV γ-line, which is probably not coincident with 351 keV, although its weakness made this conclusion marginal. As mentioned, there is also a strong indication of a transition to the 1682.7 keV state, and a weak line of 596.4 keV fits in energetically as a transition from the 3273 keV level. The 2709.7 keV level decays with the 2358 keV γ-ray, which is coincident with 351 keV. Like the 2675 keV state, it seems to be partly excited from the 3273 keV level.

This de-excitation can be understood by assuming that the state assigned as $7/2^-$ decays by an E3 transition to the $s_{1/2}^{-1}$ ground state, whereas the $5/2^-$ state can reach the 351 keV state by an E1 transition.

The decay mode of the 3273 keV state is so different from that of the negative-parity states in the same energy region that another structure is indicated and may be of positive parity. It is most likely populated by a weak β-group, but some feeding from higher-lying levels is not excluded.

Finally, a level at 3592.7 keV is suggested. A weak, unassigned γ-line of 1909.2 keV showed up in coincidence with the 1331 keV transition. The level is shown dotted, however, as the evidence consisted of only three coincidences observed on a negligible background.

6.4 Unassigned transitions

In addition to the γ-transitions placed in the decay scheme, a considerable number of low-energy lines could be fitted in energetically between the high-energy levels, several of them in more than one position (Fig. 3). Two γ-lines, which probably go to the $^{11}/_{2}^{-}$ level, might indicate states at 3633 and 3644 keV; and as usual in this type of decay scheme work, a number of weak, unassigned lines are left over.

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