Lifetimes of the $5d^96p$ levels in Hg III

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We report measurements and theoretical calculations for the lifetimes of the $5d^96p$ levels in Hg III with $J = 0,2,3,4$. This is an extension of earlier measurements of the lifetimes of the $5d^96p$ levels in Hg III with $J = 1$, and now provides data for all 12 of the levels. The results also provide an isoelectronic comparison with earlier studies of these levels in Au II of the Pt sequence, and a homologous comparison with earlier studies of the $4d^95p$ levels in Ag II, Cd III, and In IV in the Pd sequence. [S1050-2947(99)10905-3]

I. INTRODUCTION

We have earlier made measurements [1] of the lifetimes of the three $6d^97p$ $J = 1$ levels in Hg III via transitions to the ground state $6d^{10}$. However, at that time we were unable access the $6d^97p$ $J = 0,2,3,4$ levels, which decay to the metastable $6d^97s$ levels, because of low intensity and blending problems. This is to be contrasted with our measurements [2] of 11 of the 12 corresponding levels in the iselectronic ion Au II, where the full manifold of $6d^97s-6d^97p$ transitions was accessible. We have recently developed methods which enhance the production of Hg III and permit the efficient study of $6d^97s-6d^97p$ transitions in that system. We present here lifetime data for all 12 $6d^97p$ levels in Hg III, and compare the results with theory and with the isoelectronic results for Au II and homologous results for Ag II, Cd III, and In IV.

Significant difficulties were necessary to overcome to access the $6d^97s-6d^97p$ transitions in Hg III. In our foil excitation studies of Au, our 220 keV beam gave more than 50% Au II, whereas for Hg our 250 keV beam gave only 11% Hg III (percentages from Ref. [3]). These energies represent a reasonable limit to the stable operation of an open air particle accelerator, which provides the rapid access to the ion source for reloading and adjustment that permits efficient accumulation of data. However, because of the lower charge fraction of Hg III, the lower light levels required wider spectrometer slit settings, which led to reduced spectral resolution and line blending. To overcome these problems, we developed methods that permit us to produce multiply ionized atoms in our ion source, allowing us to optimize the foil production of a given charge state without sacrificing the advantages of an open air accelerator. By producing Hg^{2+} in our ion source we are able to obtain a 500 keV beam which yields over 50% Hg III after the foil, and has permitted measurements of similar accuracy to that obtained for Au II.

II. EXPERIMENT

As described in Ref. [1], this experiment utilized the University of Toledo Heavy Ion Accelerator, and detailed descriptions of this facility are provided in reports of earlier studies [1], and instrumentation reviews [4,5]. Ions of Hg^{2+} were produced in the ion source, accelerated through 20 kV, and magnetically analyzed. After momentum and mass-to-charge ratio selection, the ions were post-accelerated to final energies of 220 keV. The ions then entered an electrostatic switchyard and were steered into the experimental station and collimated before passage through a thin carbon foil (ranging from 2.1 to 2.5 μ g/cm^2). The decay curves were measured by recording the intensity of the spectral lines as a function of distance downstream from the exciter foil. The experiment was controlled by an on-line data acquisition system.

The Hg III emission lines were analyzed with an Acton 1-m normal incidence VUV monochromator, with three sets of concave gratings and detectors: a 2400 l/mm grating blazed at 800 Å coupled with a channeltron detector; a 1200 l/mm grating blazed at 1500 Å coupled with a solar blind detector; and a 600 l/mm grating blazed at 3000 Å coupled with a bialkali detector.

Lifetimes were extracted using the nonlinear least-squares multiexponential fitting program DISCRETE [6]. As was found in our earlier studies of Au II and Hg III, cascade effects were small and tractable by curve fitting methods.

III. RESULTS

Table I presents the new results for Hg III, together with the earlier $J = 1$ measurements for Hg III [1] and the earlier Au II [2] measurements. Our theoretical calculations for these lifetimes (made using the Dirac-Fock code GRASP [7] as described in Ref. [1]) are also reported in Table I. For the $J = 0-2$ level lifetimes, the agreement between theory and

TABLE I. Lifetimes of the $5d^96p$ levels in Au II and Hg III.

J	Au II E (cm^{-1})[a]	λ (Å)	τ (ns) Expt.[c]	τ (ns) Theory[c]	Hg III E (cm^{-1})[b]	λ(Å)	τ (ns) Expt.	τ (ns) Theory
0	82613.0				130702.4	1383.2	1.30±0.08[d]	1.14[d]
1	73404.051	1793.3	2.3±0.4	1.5	118607.4	843.11	1.20±0.15[e]	1.00[e]
1	81660.052	1224.6	1.4±0.3	0.5	126556.3	790.17	0.52±0.15[e]	0.28[e]
1	85707.785	1783.2	2.5±0.4	1.6	134998.7	740.75	0.90±0.15[e]	0.70[e]
2	63053.499	2082.1	3.8±0.5	2.5	103549.4	1647.5	2.18±0.08[d]	2.05[d]
2	73178.509	1800.6	2.6±0.5	1.6	118548.0	1321.0	1.58±0.06[d]	1.42[d]
2	76659.912	1694.3	2.5±0.4	2.2	120927.8	1599.4	1.53±0.08[d]	1.47[d]
2	86565.879	1756.1	2.4±0.4	1.6	136479.0	1280.8	≤1.38[f]	1.01[d]
3	65003.802	2000.8	3.5±0.5	2.2	105627.8	1677.9	2.12±0.08[d]	2.02[d]
3	74791.686	1749.7	2.4±0.4	1.4	121602.0	1323.2	1.29±0.07[d]	1.00[d]
3	85700.424	1783.2	2.5±0.4	1.6	134588.0	1360.5	1.35±0.06[d]	1.07[d]
4	72495.348	1740.4	2.4±0.3	1.4	117994.5	1330.8	1.37±0.05[d]	1.03[d]

[a]Ehrhardt and Davis, Ref. [8], except for $J=0$, which is from Platt and Sawyer, Ref. [9].
[b]Moore, Ref. [10].
[c]Beideck et al., Ref. [2].
[d]This work.
[e]Beideck et al., Ref. [1].
[f]Blended with a branch of the 120 927.8 cm^{-1} level decay.

experiment is very good except for one $J=1$ level, whereas for $J=3,4$ the experimental lifetimes are approximately 25% (four standard deviations) longer than the theoretical predictions. The measured lifetime for the shortest-lived $J=1$ level in Hg III is about two times (1.6 standard deviations) longer than predicted, which is closer than the corresponding case in Au II, where the difference was a factor of 3 (three standard deviations). A similar discrepancy was noted in Ag II (see Table II) for the $^1P_1$ level.

The FWHM of the lines under the conditions of measurement was typically 0.8–1.0 Å, which permitted separation of the 1330.8 Å line from the Hg II line at 1331.74 Å and the 1360.5 Å line from the Hg II lines at 1361.05 and 1361.27 Å. However, the 1280.8 Å region contained lines originating from the 120 927.8 and 136 479.0 cm^{-1} $J=2$ upper levels in Hg III that were separated by only 0.07 Å. Thus the lifetime estimate of 1.38 ns for the 136 479.0 cm^{-1} level is only an upper limit because of its blending with a 1.53 ns lifetime of the 120 927.8 level.

The trends of these lifetime values as functions of both J and the excitation energy are very similar to those observed in the homologous $4d^95p$ levels in the Pd sequence. Since these homologous sequences differ only by a filled f shell and an unfilled g shell in the Pt-like core, similar effects from configuration interaction might be expected in the theoretical specification of these complex systems. For comparison, Table II collects the values of earlier lifetime measurements for these levels in Ag II [11], Cd III [12], and In IV [13]. In the case of Ag II, beam-laser measurements have recently been made [14] which are in general agreement, although

there is a tendency for these cascade-free measurements to be slightly shorter in lifetime, indicating the possiblilty of some small residual cascade effects in the beam-foil measurements. Theoretical calculations are also available for the

TABLE II. Lifetimes of the $4d^95p$ levels in Ag II, Cd III, and In IV.

Level	Ag II[a]	Ag II[b]	Cd III[c]	In IV[d]
$^3P_0$	2.6±0.6	3.38±0.16	1.99±0.22	1.58±0.18
$^3P_1$	3.4±0.6	2.90±0.14	1.63±0.13	1.29±0.14
$^1P_1$	1.2±0.4		0.41±0.07	0.26±0.05
$^3D_1$	2.9±0.6		1.08±0.14	0.71±0.13
$^3P_2$	4.2±0.7	3.36±0.16	2.47±0.21	1.67±0.19
$^3D_2$	3.7±0.6	2.80±0.10	1.71±0.17	1.18±0.18
$^3F_2$	3.8±0.6	3.12±0.10	2.30±0.39	1.67±0.17
$^1D_2$	3.3±0.7	2.55±0.10	1.93±0.21	1.46±0.15
$^3F_3$	4.1±0.5	3.29±0.09	2.48±0.28	1.78±0.15
$^3D_3$	3.4±0.6	2.36±0.07	1.71±0.21	1.19±0.13
$^1F_3$	3.4±0.7	2.82±0.10	1.66±0.19	1.30±0.19
$^3F_4$	3.3±0.4	2.56±0.08	1.99±0.18	1.36±0.14

[a]Irving et al., beam-foil, Ref. [11].
[b]Biémont et al., beam-laser, Ref. [14].
[c]Henderson et al., beam-foil, Ref. [12].
[d]Henderson et al., beam-foil, Ref. [13].

Ag II [14,15], Cd III [16,17], and In IV [17].

The regularity of both the isoelectronic and homologous trends of this base of lifetime data provides a good testing ground for theoretical calculations of these heavy and complex systems.

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