PHYSICAL REVIEW A VOLUME 32, NUMBER 1 JULY 1985

$4p^54d^2$ configuration of Mo VI

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(Received 28 November 1984)

The internally excited $4p^54d^2$ configuration gains notoriety in the Rb isoelectronic sequence from Y III onwards for appreciably disturbing levels of the nf and np series of the one-electron spectra. We have worked out, on the basis of the spectra recorded in collaboration with J. O. Ekberg at Lund University and with the help of R. D. Cowan's computations, transitions from this configuration to the ground configuration $4p^64d$. Of the 45 levels of $4p^54d^2$, all 38 that can combine with $4p^64d$ are established. Many levels of $4p^54d^2$ are computed to be highly mixed within the configuration, as well as with levels of $5f\,^2F$, $4f\,^2F$, $6p\,^2P$, and $5p\,^2P$ in descending order of magnitude. This is evidenced experimentally by the observation of transitions connecting some $4p^54d^2$ levels with those of ns, nd (other than $4d$), and ng.

INTRODUCTION

The $4d$-$4f,5p$ transitions were already well known in the one-electron Rb-like spectra in the isoelectronic sequence up to Mo VI (Ref. 1) half a century ago. But on calculating them in the single-configuration approximation, Cowan (in 1967) found systematic departures from experiment[2] of order 8–20 Å in $4d$-$4f$ transitions for Y III–Mo VI, while an erratic situation prevailed for $4d$-$5p$ ranging from -11 Å in Y III, 31 Å in Zr IV, to 7 Å in Mo VI. Later work[3–6] revealed good agreement in the case of $4d$-$6p$, but appreciable departures in $4d$-$5f$ that increased as the series advanced (4–15 Å). On mixing levels of the $4f,5f$, and $5p,6p$ configurations with those of the internally excited $4p^54d^2$, Cowan could match the computed wavelengths of the above-mentioned transitions with experimental values within 3 Å (about 1%) in 1978.[7] This established the importance of $4p^54d^2$ levels as strong perturbers of the one-electron part of the spectrum. We have just communicated a detailed analysis of the one-electron part of Mo VI, with the kind collaboration of Edlén, elsewhere.[8] Here we are reporting our experimental analysis of the $4p^54d^2$ configuration of Mo VI, following Zr IV (Ref. 9) and Nb V (Ref. 10).

STRUCTURE

The $4p^54d^2$ configuration, formed by the excitation of one $4p$ electron from the ground state to the $4d$ orbital, has the following term structure:

$d^2(^3F)p^5$: $^4(GFD)$, $^2(GFD)$
$d^2(^3P)p^5$: $^4(DPS)$, $^2(DPS)$
$d^2(^1G)p^5$: $^2(HGF)$
$d^2(^1D)p^5$: $^2(FDP)$
$d^2(^1S)p^5$: ^2P

Theoretical calculations, as quoted above, show that the levels of these terms are so intimately mixed together within the configuration that the assigned designations (Table I) often become mere labels without much physical significance. The calculations show better overall purities in the LS formalism, varying from 86% for $J=\frac{1}{2}$ to 61% for $J=\frac{7}{2}$, than in jj. Levels designated $(^3F)^2F_{5/2,7/2}$ are computed to be largely mixed with $5f\,^2F_{5/2,7/2}$ and to some extent with $4f\,^2F_{5/2,7/2}$, whereas $(^1D)^2F_{7/2}$ has exhibited slight mixing with $4f\,^2F_{7/2}$ and $(^3P)^2D_{3/2}$ with $6p\,^2P_{3/2}$.

Levels with $J=\frac{9}{2}$ and $\frac{11}{2}$ do not combine radiatively with those of the ground configuration. In fact, the electric dipole transition rules do not permit them to combine with any level of a one-electron configuration. Their purities are calculated to be almost the same in LS and jj schemes.

EXPERIMENTAL INFORMATION

The molybdenum spectrum was recorded, for the present work, first on the 5-m grazing-incidence vacuum spectrograph of Lund University (Sweden) in 1968, then on the 3-m normal incidence vacuum spectrograph of the same institution in 1973 and 1978, using a Au-coated grating for $\lambda < 950$ Å and Al-Mg-coated one for the longer wavelengths. Our line list thus extends from 50 to 2540 Å.

As source, a condensed spark setup[11] was used both in its open and sliding versions. Additional inductance in steps of 1, 2, 4, 10, and 15 turns of a copper wire was introduced in the discharge circuit to vary the excitation conditions. The resulting systematic variation in the intensity of the recorded spectral lines enabled us to assign their ion affiliation. For example, for a set of spectra recorded with the gold grating illuminated by sliding sparks, the lines of Mo VI showed almost constant intensity all along, while those of Mo VII declined and those of Mo V increased noticeably at 15 turns.

The spectrograms were measured at Aligarh; adopted mean wavelengths can admit errors up to 0.015 Å in general, and 0.03 Å in cases of very faint lines observed in traces. Lines of carbon, oxygen, and aluminum are used as references.

TABLE I. Observed energy levels of $4s^24p^54d^2$ in Mo VI.

Desig.	E (cm^{-1})	Observed minus calculated	Percentage composition[a]
$(^3F)^4D_{1/2}$	289 337	-428	$-86-13(^3P)^4D$
$(^3F)^4D_{3/2}$	290 959	$+228$	$-79-16(^3P)^4D+3(^3F)^4F$
$(^3F)^4D_{5/2}$	291 557	-800	$-68-22(^3P)^4D+6(^3F)^4F+3(^3P)^4P$
$(^3F)^4D_{7/2}$	293 902	-1108	$58+32(^3P)^4D-8(^3F)^4F$
$(^3P)^4P_{5/2}$	302 680	-868	$-86+5(^3F)^4F-3(^3F)^4D$
$(^3F)^4G_{7/2}$	302 871	-1500	$68-19(^3F)^4F+4(^3F)^2G-4(^3F)^2F$
$(^3F)^4G_{5/2}$	303 004	-2666	$40-20(^3F)^4F-14(^3F)^2F+9(^1G)^2F-7(^3P)^4P-4(^1D)^2D$
$(^3P)^4P_{3/2}$	306 909	$+164$	$-85-3(^3F)^4D+3(^1D)^2P$
$(^3P)^4P_{1/2}$	309 280	-571	$88-5(^3P)^2S-4(^1D)^2P$
$(^1D)^2D_{3/2}$	309 788	$+430$	$-30-43(^3F)^4F+12(^3F)^2D+7(^1D)^2P+3(^3P)^4P$
$(^1D)^2D_{5/2}$	310 540	-1049	$52-15(^3F)^2D+9(^3F)^4G-7(^3F)^2F+6(^1G)^2F+5(^3F)^4F-4(^1D)^2F$
$(^3F)^4F_{7/2}$	312 200	-1718	$-42-29(^3F)^2G-11(^3F)^4G-7(^3F)^2F+6(^1G)^2F$
$(^1G)^2F_{5/2}$	314 952	-2219	$-21-29(^3F)^4F+18(^3F)^2F+12(^1D)^2D-9(^3P)^4D+4(^3F)^4G$
$(^1G)^2F_{7/2}$	316 473	-2176	$-25+26(^3F)^2F-22(^3P)^4D-16(^3F)^4F+5(^1G)^2G$
$(^3F)^4F_{3/2}$	316 835	-4	$45+21(^1D)^2P-15(^1D)^2D-7(^3P)^2P+4(^3P)^4P+3(^1S)^2P$
$(^3F)^4F_{5/2}$	317 375	-2080	$28+44(^3F)^4G-12(^1G)^2F+8(^3F)^2F-3(^1D)^2D$
$(^1D)^2P_{1/2}$	318 301	-488	$-69+19(^3P)^2P-6(^3P)^4P-4(^1S)^2P$
$(^1D)^2F_{7/2}$	320 087	-2373	$90-4(4f)^2F$
$(^3F)^2G_{7/2}$	327 540	-2390	$-60+17(^3F)^4G+9(^3F)^4F-5(^1G)^2F+5(^3F)^2F$
$(^3P)^4D_{5/2}$	328 253	-2588	$52-25(^3F)^4D+13(^3P)^2D-7(^3F)^4F$
$(^1D)^2P_{3/2}$	328 933	$+149$	$-19-25(^1D)^2D+12(^3P)^2P-12(^1S)^2P+10(^3F)^2D$ $+8(^3F)^4F-5(^3P)^2D+3(^3P)^4S+3(^3F)^4D$
$(^3P)^4D_{7/2}$	329 371	-2526	$-42+38(^3F)^4D+6(^3F)^4F+6(^1G)^2F-3(^3F)^2F$
$(^3P)^4D_{3/2}$	332 779	$+261$	$49+24(^3F)^2D-11(^3F)^4D-6(^1D)^2P-6(^1D)^2D$
$(^3P)^4D_{1/2}$	336 327	-811	$-83-12(^3F)^4D-3(^1D)^2P$
$(^1D)^2F_{5/2}$	337 067	-1085	$-82-5(^3P)^2D+5(^3F)^2D-3(^1D)^2D$
$(^3P)^2D_{3/2}$	343 373	-164	$-51+23(^3P)^4D-12(^3P)^4S+4(^3F)^2D+3(^1D)^2D+3(6p)^2P$
$(^3P)^2S_{1/2}$	345 325	-1114	$-92-6(^3P)^4P$
$(^3P)^4S_{3/2}$	346 535	-206	$77-7(^3P)^2D+5(^3P)^4P+4(^1S)^2P+3(^3P)^4D$
$(^1G)^2G_{7/2}$	346 887	-1868	$85-7(^3F)^2F-5(^3F)^2G$
$(^3P)^2D_{5/2}$	348 283	-1190	$66-13(^3P)^4D-6(^1D)^2F-6(^1D)^2D-6(^3F)^2D$
$(^1S)^2P_{3/2}$	355 397	-525	$71-25(^1D)^2P$
$(^1S)^2P_{1/2}$	369 227	-711	$-79+12(^1D)^2P+7(^3P)^2P$
$(^3F)^2F_{5/2}$	400 360	-758	$-29+36(5f)^2F-30(^1G)^2F+3(4f)^2F$
$(^3F)^2F_{7/2}$	405 696	-1243	$38+31(^1G)^2F-27(5f)^2F-3(4f)^2F$
$(^3P)^2P_{1/2}$	409 020	-963	$71+16(^1S)^2P+12(^1D)^2P$
$(^3P)^2P_{3/2}$	413 276	-958	$75+17(^1D)^2P+7(^1S)^2P$
$(^3F)^2D_{3/2}$	418 057	-2849	$-72-17(^1D)^2D-10(^3P)^2D$
$(^3F)^2D_{5/2}$	418 661	-1914	$-70-16(^1D)^2D-12(^3P)^2D$

[a] Cowan (Ref. 7); contributions less than 3% are omitted. Algebraic signs are those of eigenvector components, using the phase conventions in Ref. 12.

TRANSITIONS TO THE GROUND CONFIGURATION

Out of the total of 45 $4p^54d^2$ levels, 38 can combine with $4d\,^2D_{3/2,5/2}$ through 60 allowed transitions. All of them have been observed; gf values as calculated by Cowan are reproduced in Table II. Observed intensities are in fair agreement with calculations. Experimentally determined level values are reported in Table I along with departures from theoretical estimates. For each level, the calculated percentage composition is given up to 3%. The observed level structure is plotted in Fig. 1 with the interacting $4f,5f,6f$, and $6p,7p$ levels of the one-electron part of the spectrum. Calculated positions of the remaining seven $4p^54d^2$ levels ($J=\frac{9}{2},\frac{11}{2}$) are indicated by dashed lines.

TABLE II. Classified lines of Mo VI.

Wavelength λ (Å)	Intensity I	Wave number σ (cm^{-1})	gf[a]	Classification $4p^6 4d$-$4p^5 4d^2$
238.857	64	418 661	0.545	$^2D_{3/2}$-$(^3F)^2D_{5/2}$
239.205	52	418 051	10.880	$^2D_{3/2}$-$(^3F)^2D_{3/2}$
240.34[b]	33	416 077	17.295	$^2D_{5/2}$-$(^3F)^2D_{5/2}$
240.686	34	415 479	1.100	$^2D_{5/2}$-$(^3F)^2D_{3/2}$
241.969	55	413 276	0.900	$^2D_{3/2}$-$(^3P)^2P_{3/2}$
243.492	28	410 691	8.915	$^2D_{5/2}$-$(^3P)^2P_{3/2}$
244.487	45	409 020	4.870	$^2D_{3/2}$-$(^3P)^2P_{1/2}$
248.070	70	403 112	17.194	$^2D_{5/2}$-$(^3F)^2F_{7/2}$
249.774	40	400 368	11.785	$^2D_{3/2}$-$(^3F)^2F_{5/2}$
251.403	28	397 767	0.255	$^2D_{5/2}$-$(^3F)^2F_{5/2}$
270.836	19	369 227	0.028	$^2D_{3/2}$-$(^1S)^2P_{1/2}$
281.375	34	355 398	0.014	$^2D_{3/2}$-$(^1S)^2P_{3/2}$
283.438	28	352 811		$^2D_{5/2}$-$(^1S)^2P_{3/2}$
287.123	22	348 283	0.065	$^2D_{3/2}$-$(^3P)^2D_{5/2}$
288.576	13	346 529		$^2D_{3/2}$-$(^3P)^4S_{3/2}$
289.255	10	345 716		$^2D_{5/2}$-$(^3P)^2D_{5/2}$
289.582	22	345 325	0.008	$^2D_{3/2}$-$(^3P)^2S_{1/2}$
290.442	34	344 303	0.220	$^2D_{5/2}$-$(^1G)^2G_{7/2}$
290.734	19	343 957	0.038	$^2D_{5/2}$-$(^3P)^4S_{3/2}$
291.226	34	343 376	0.010	$^2D_{3/2}$-$(^3P)^2D_{3/2}$
293.439	13	340 786	0.069	$^2D_{5/2}$-$(^3P)^2D_{3/2}$
296.661	40	337 068	0.262	$^2D_{3/2}$-$(^1D)^2F_{5/2}$
297.330	22	336 327	0.025	$^2D_{3/2}$-$(^3P)^4D_{1/2}$
298.970	28	334 482	0.085	$^2D_{5/2}$-$(^1D)^2F_{5/2}$
300.502	25	332 776	0.029	$^2D_{3/2}$-$(^3P)^4D_{3/2}$
302.848	8	330 199	0.012	$^2D_{5/2}$-$(^3P)^4D_{3/2}$
304.015	4	328 931		$^2D_{3/2}$-$(^1D)^2P_{3/2}$
304.639	22	328 257	0.012	$^2D_{3/2}$-$(^3P)^4D_{5/2}$
306.010	28	326 784	0.077	$^2D_{5/2}$-$(^3P)^4D_{7/2}$
306.418	5	326 352		$^2D_{5/2}$-$(^1D)^2P_{3/2}$
307.064	10	325 665	0.061	$^2D_{5/2}$-$(^3P)^4D_{5/2}$
307.734	22	324 956	0.008	$^2D_{5/2}$-$(^3F)^2G_{7/2}$
314.168	16	318 301	0.009	$^2D_{3/2}$-$(^1D)^2P_{1/2}$
314.958	61	317 503	0.701	$^2D_{5/2}$-$(^1D)^2F_{7/2}$
315.085	19	317 375	0.078	$^2D_{3/2}$-$(^3F)^4F_{5/2}$
315.620	19	316 837	0.009	$^2D_{3/2}$-$(^3F)^4F_{3/2}$
317.508	49	314 953	0.208	$^2D_{3/2}$-$(^1G)^2F_{5/2}$
317.670	16	314 792		$^2D_{5/2}$-$(^3F)^4F_{5/2}$
318.219	2	314 249	0.015	$^2D_{5/2}$-$(^3F)^4F_{3/2}$
318.584	49	313 889	0.044	$^2D_{5/2}$-$(^1G)^2F_{7/2}$
320.136	34	312 367	0.043	$^2D_{5/2}$-$(^1G)^2F_{5/2}$
322.020	23	310 540		$^2D_{3/2}$-$(^1D)^2D_{5/2}$
322.808	13	309 782	0.023	$^2D_{3/2}$-$(^1D)^2D_{3/2}$
322.981	40	309 616	0.010	$^2D_{5/2}$-$(^3F)^4F_{7/2}$
323.332	7	309 280		$^2D_{3/2}$-$(^3P)^4P_{1/2}$
324.721	8	307 957		$^2D_{5/2}$-$(^1D)^2D_{5/2}$
325.510	7	307 210		$^2D_{5/2}$-$(^1D)^2D_{3/2}$
325.832	28	306 907		$^2D_{3/2}$-$(^3P)^4P_{3/2}$
328.593	22	304 328		$^2D_{5/2}$-$(^3P)^4P_{3/2}$
330.027	16	303 006	0.022	$^2D_{3/2}$-$(^3F)^4G_{5/2}$

TABLE II. (*Continued*).

Wavelength λ (Å)	Intensity I	Wave number σ (cm^{-1})	gf^a	Classification $4p^64d$-$4p^54d^2$
330.381	19	302 681		$^2D_{3/2}$-$(^3P)^4P_{5/2}$
332.871	6	300 417		$^2D_{5/2}$-$(^3F)^4G_{5/2}$
333.015	31	300 287		$^2D_{5/2}$-$(^3F)^4G_{7/2}$
333.229	8	300 094		$^2D_{5/2}$-$(^3P)^4P_{5/2}$
342.985	22	291 558		$^2D_{3/2}$-$(^3F)^4D_{5/2}$
343.268	22	291 318		$^2D_{5/2}$-$(^3F)^4D_{7/2}$
343.687	16	290 962		$^2D_{3/2}$-$(^3F)^4D_{3/2}$
345.618	16	289 337		$^2D_{3/2}$-$(^3F)^4D_{1/2}$
346.072	19	288 972		$^2D_{5/2}$-$(^3F)^4D_{5/2}$
346.774	2	288 372		$^2D_{5/2}$-$(^3F)^4D_{3/2}$
				$4p^65s$-$4p^54d^2$
447.130	6	223 649		$^2S_{1/2}$-$(^3P)^2D_{3/2}$
477.982	13	209 213		$^2S_{1/2}$-$(^1D)^2P_{3/2}$
534.265	13	187 173		$^2S_{1/2}$-$(^3P)^4P_{3/2}$
				$4p^65d$-$4p^54d^2$
736.220	6	135 829		$^2D_{3/2}$-$(^3F)^2D_{5/2}$
792.475	8	126 187		$^2D_{3/2}$-$(^3P)^2P_{1/2}$
819.131	16	122 081		$^2D_{5/2}$-$(^3F)^2F_{7/2}$
850.799	8	117 537		$^2D_{3/2}$-$(^3F)^2F_{5/2}$
1392.86	5	71 794.7		$^2D_{5/2}$-$(^1S)^2P_{3/2}$
1527.96	9	65 446.7		$^2D_{3/2}$-$(^3P)^2D_{5/2}$
1569.70	2	63 706.4		$^2D_{3/2}$-$(^3P)^4S_{3/2}$
1589.34	4	62 919.2		$^2D_{5/2}$-$(^3P)^4S_{3/2}$
1600.14	3	62 494.5		$^2D_{3/2}$-$(^3P)^2S_{1/2}$
1651.73	1	60 542.6		$^2D_{3/2}$-$(^3P)^2D_{3/2}$
1673.43	2	59 757.5		$^2D_{5/2}$-$(^3P)^2D_{3/2}$
1869.03	5	53 503.7		$^2D_{3/2}$-$(^3P)^4D_{1/2}$
				$4p^54d^2$-$4p^66d$
1079.41	2	92 643.2		$(^3F)^4D_{7/2}$-$^2D_{5/2}$
1195.03	2	83 679.9		$(^3F)^4G_{7/2}$-$^2D_{5/2}$
1196.90	2	83 549.2		$(^3F)^4G_{5/2}$-$^2D_{5/2}$
1197.79	1	83 487.1		$(^3P)^4P_{5/2}$-$^2D_{3/2}$
1202.39	4	83 167.7		$(^3F)^4G_{5/2}$-$^2D_{3/2}$
1255.58	2	79 644.5		$(^3P)^4P_{3/2}$-$^2D_{5/2}$
1315.54	2	76 014.4		$(^1D)^2D_{5/2}$-$^2D_{5/2}$
1344.92	24	74 353.9		$(^3F)^4F_{7/2}$-$^2D_{5/2}$
1426.85	16	70 084.5		$(^1G)^2F_{7/2}$-$^2D_{5/2}$
1453.57	4	68 796.1		$(^3F)^4F_{5/2}$-$^2D_{3/2}$
1504.57	2	66 464.2		$(^1D)^2F_{7/2}$-$^2D_{5/2}$
1749.01	17	57 175.2		$(^3P)^4D_{7/2}$-$^2D_{5/2}$
1872.92	2	53 392.6		$(^3P)^4D_{3/2}$-$^2D_{3/2}$
2004.48	2	49 844.7		$(^3P)^4D_{1/2}$-$^2D_{3/2}$
2316.01	13	43 177.7		$(^3P)^2D_{3/2}$-$^2D_{5/2}$
2520.90	16	39 668.4		$(^1G)^2G_{7/2}$-$^2D_{5/2}$

TABLE II. (*Continued*).

Wavelength λ (Å)	Intensity I	Wave number σ (cm^{-1})	gf^a	Classification $4p^54d^2$-$4p^6ng$
807.446	8	123 847		$(^1D)^2F_{7/2}$-$6g\,^2G$
1331.62	13	75 096.5		$(^1D)^2F_{7/2}$-$5g\,^2G$
1368.54	2	73 070.6		$(^3F)^2F_{5/2}$-$7g\,^2G_{7/2}$
1476.52	6	67 726.8		$(^3F)^2F_{7/2}$-$7g\,^2G$

[a] R. D. Cowan (Ref. 7); values less than 0.008 are omitted.

[b] Resolved in the second order.

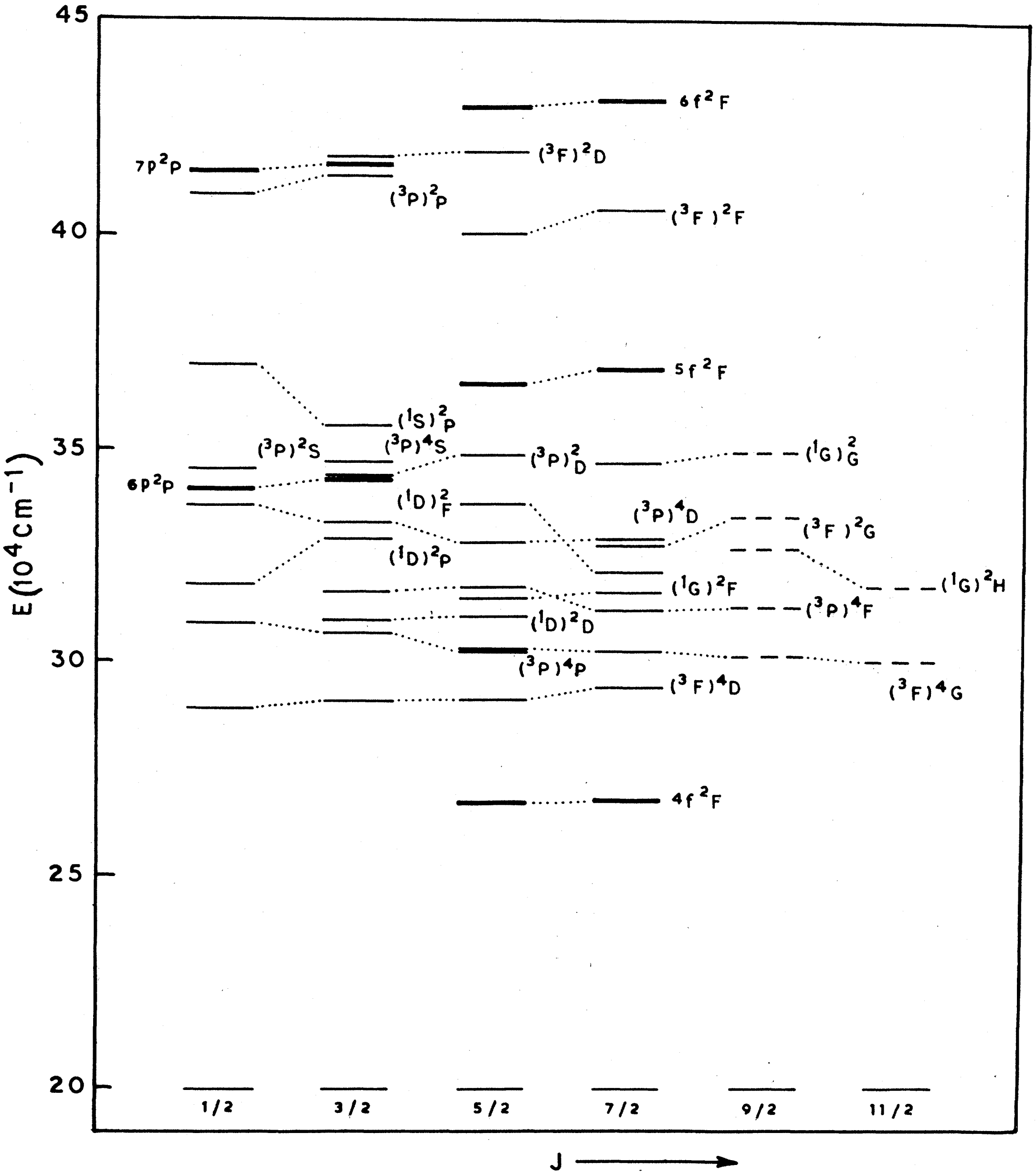

FIG. 1. Level structure of the $4p^54d^2$ configuration of Mo VI. The superposing $4f,5f,6f$ and $6p,7p$ levels are shown by bold lines and theoretical estimates of the unobserved levels by dashed lines.

COMBINATION WITH OTHER CONFIGURATIONS

It is mentioned above that the $4p^54d^2$ levels $(^3F)^2F_{5/2,7/2}$ are highly mixed with $5f$ levels and to a lesser extent with those of $4f$. These three-electron spectrum levels behave, therefore, as one-electron f levels and are observed to combine radiatively, within the spectral region covered, with those of $5d$ and $7g$ (Table II). Transitions from the $5g$, $6g$, and $6d$ levels are also observed to $4p^54d^2(^1D)^2F_{7/2}$, which is computed to be slightly mixed with $4f\,^2F_{7/2}$. The level $(^3P)^2D_{3/2}$, highly mixed within the configuration and slightly with $6p\,^2P_{3/2}$, is found connected with $5s\,^2S_{1/2}$, $5d\,^2D_{3/2,5/2}$, and $6d\,^2D_{5/2}$.

In addition to the above, we are reporting 22 faint transitions from levels of $5d$,$6d$ and two from $5s\,^2S_{1/2}$ to 21 other levels of $4p^54d^2$, not computed to be noticeably mixed with a $4f$,$5f$ or $5p$,$6p$ level. Some of these levels may be mixed with those of $6f$ or $7p$, but we think that these transitions mainly arise because the intimate mixing of the $4p^54d^2$ levels within configuration is responsible for a larger transfer of oscillator strengths than theoretically estimated. Scaling of R^k functions[12] may be adjusted to take these observations into account.

It should be noted that of the 16 $J=\frac{1}{2}$ and $\frac{7}{2}$ levels of $4p^54d^2$ that can combine with only one level of $4p^64d$, 11 levels could be substantiated by transitions with levels of other configurations (Table II). The remaining five levels, namely $(^3F)^4D_{1/2}$, $(^3P)^4P_{1/2}$, $(^1D)^2P_{1/2}$, $(^1S)^2P_{1/2}$, and $(^3F)^2G_{7/2}$, are established through a single observed transition. These latter transitions are assigned on the basis that the levels with same J value have almost a regular departure from the theory. There are a few unclassified lines that could provide alternatives to these levels, hence they are subject to further confirmation.

ACKNOWLEDGMENTS

We are very thankful for the hospitality of Lund University and the collaboration of Dr. J. O. Ekberg for recording the spectra. Dr. R. D. Cowan's generous gift of *HX* and *HF* calculations is gratefully acknowledged. This work was financially supported by the Department of Atomic Energy (DAE), India.

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[1] C. E. Moore, *Atomic Energy Levels*, Natl. Bur. Stand. (U.S.) Circ. No. 467 (U.S. GPO, Washington, D.C., 1952 and 1958), Vols. II and III, respectively.

[2] R. D. Cowan, Phys. Rev. **163**, 54 (1967); J. Opt. Soc. Am. **58**, 924 (1968); (private communication).

[3] G. L. Epstein and J. Reader, J. Opt. Soc. Am. **65**, 310 (1975).

[4] N. Acquista and J. Reader, J. Opt. Soc. Am. **70**, 789 (1980).

[5] D. T. Kagan, J. G. Conway, and E. Meinders, J. Opt. Soc. Am. **71**, 1193 (1981).

[6] N. P. Romanov and A. R. Striganov, Opt. Spekt. **XXVII**, 17 (1969).

[7] R. D. Cowan (private communication).

[8] B. Edlén, K. Rahimullah, A. Tauheed, and M. S. Z. Chaghtai (unpublished).

[9] K. Rahimullah, Z. A. Khan, and M. S. Z. Chaghtai, Phys. Scr. **22**, 493 (1980).

[10] Q. Shujauddin, A. Mushtaq, and M. S. Z. Chaghtai, Phys. Scr. **25**, 924 (1982).

[11] L. Å. Svensson and J. O. Ekberg, Ark. Fys. **40**, 145 (1969).

[12] R. D. Cowan, *The Theory of Atomic Structure and Spectra* (University of California, Berkeley and Los Angeles, 1981), p. 578.