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Energy Levels and Transition Probabilities in Mo XIV

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Abstract

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An investigation is made of the energy levels in Mo XIV (Cu I isoelectronic sequence). Published material is combined with previously unreported measurements to obtain reasonably accurate energies for terms with $n=4$, 5, 6, 7 and 8. For the ionization limit we find the value 2 441 ± 2 kK. These data are used to calculate transition probabilities, oscillator strengths and radiative lifetimes for a large number of transitions by means of a numerical Coulomb approximation procedure.

1. Introduction

In connection with spectroscopic studies of Tokamak discharges several authors [1, 2] have observed transitions in highly ionized molybdenum, in particular the $\Delta n = 0$ resonance lines in Mo XIII, XIV, XXXI and XXXII (Zn, Cu, Mg and Na isoelectronic sequences, respectively). For diagnostic purposes it is of importance to determine the level structure and transition probabilities in these spectra.

In Mo XIV Hinnov [1] gives the wavelengths 423.5 ± 0.5 and 373.8 ± 0.5 Å for the $4s\ ^2S_{1/2}$–$4p\ ^2P_{1/2,3/2}$ doublet. These results can be combined with an earlier study in the XUV by Alexander et al. [3] who measured the wavelengths (to within ±0.005 Å) of the 4*s*–5*p*, 4*s*–6*p*, 4*p*–5*s*, 4*p*–5*d* and 4*d*–5*f* multiplets.

From refs. [1] and [3] we thus obtain the $4p\ ^2P$, $5p\ ^2P$, $6p\ ^2P$, $5s\ ^2S$ and $5d\ ^2D$ term energies. To determine the $4d\ ^2D$ and $5f\ ^2F$ energies only the $4d\ ^2D$–$5p\ ^2P$ wavelengths are needed. The spark spectrum of Mo has been recorded by one of us [4] and an extended analysis now gives the desired 4*d*–5*p* wavelengths as well as some additional 4*s*–*np*, 4*p*–*ns* and 4*f*–*ng* transition wavelengths. By combining published measurements with our own determinations, wavelengths for transitions among fourteen different excited doublet terms were obtained. These data are listed as part of Table I, denoted according to their source by *a* (ref. [1]), *b* (ref. [3]) and *c*, *d* or *e* (our own measurements, of uncertainties ±0.05, ±0.1 or ±0.2 Å respectively). These measured wavelengths were used to infer the term energies and ionization potential and to predict energies of additional terms using quantum defect expansions along various Rydberg series. The empirical set of term values so generated, although of uneven accuracy, permits the calculation of transition probabilities and oscillator strengths through the use of the Coulomb approximation with estimated uncertainties of ±10% in this relatively simple spectrum.

2. Measurements

The measurements reported here are based upon two spectrograms, one in the region 35–121 Å and the other in the region 122–184 Å, which were recorded in Uppsala in 1937 using a 5-m grazing incidence spectrograph. The plate factor ranged from 0.28 Å/mm at the shorter wavelengths to 0.54 Å/mm at the longer wavelengths. The light source was a 0.4 μF, 60 kV vacuum spark between graphite rods, one of which was filled with Mo, the other with a mixture of Mo, BeO and B_2O_3, thus providing reference lines in Be, B and O. Two exposures were made, one for 1 hour 45 minutes, the other for 20 minutes.

Twelve Mo XIV multiplets were identified, ten of which were measurable in two fine structure components. In the cases of the 4*p*–5*s* and the 4*d*–5*p* multiplets the fine structure components with longest wavelength were beyond the end of the plate. This was particularly unfortunate for the case of the 4*d*–5*p*, since it is vital to establishment of the 4*d* and 5*f* levels. It was possible to locate the weak $\Delta J = 0$ satellite line, but this identification and wavelength measurement should be verified by a subsequent search for its other component at 185.0 Å. The results of our study confirmed the measurements of Alexander et al. [3] for the 4*s*–5*p*, 4*s*–6*p*, 4*p*–5*s*, 4*p*–5*d* and 4*d*–5*f* transitions, and also included the 4*s*–7*p*, 4*p*–6*s*, 4*p*–7*s*, 4*p*–8*s*, 4*f*–5*g*, 4*f*–6*g* and 4*d*–5*p* transition wavelengths. Since these plates were not originally taken with the aim of exclusively studying Mo XIV wavelengths, some of the lines needed in the present analysis were near the ends of the plates and not bracketed by reference lines. In such cases extrapolations rather than interpolations were needed. Thus some of the accuracies are below those usually reported in high resolution spectroscopic studies. However, they should be quite sufficient for plasma-diagnostic studies as well as for the calculation of transition probabilities to within present measurement accuracies.

3. Determination of the ionization potential and energy level extrapolations using quantum defect methods

The ionization potential was determined by a joint analysis of the $^2S_{1/2}$, $^2P_{1/2}$ and $^2P_{3/2}$ Rydberg series using a weighted non linear least squares minimizing parameter adjustment of the Ritz formula to the measured data. The procedure used is simple and general, and is described briefly below.

We denote the energy of a level with principal quantum number n, orbital angular momentum L and total angular momentum J by E_{nLJ}, and the uncertainty in its measurement by ΔE_{nLJ}. Our approach consists of searching for the value for E_∞, the ionization potential, which best allows the simultaneous description of all overdetermined Rydberg series by their respective Ritz formulae. For a given series the Ritz formula relates E_∞ to the measured E_{nLJ} through an expansion

$$\delta_{nLJ}(E_\infty) = a_{LJ} + b_{LJ} t_{nLJ}(E_\infty) + \ldots \quad (1)$$

in powers of t_{nLJ}, which is the term energy in units of the Rydberg energy R and the stage of ionization $\zeta - 1$

$$t_{nLJ}(E_\infty) \equiv (E_\infty - E_{nLJ})/R\zeta^2 \quad (2)$$

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Table I. *Transition probabilities, oscillator strengths and line strengths in Mo XIV*

Notation follows the definitions of ref. [18]

Transition	λ (Å)	g_i	g_k	A_{ki} (10^8 sec^{-1})	f_{ik}	S (at.u.)	Transition	λ (Å)	g_i	g_k	A_{ki} (10^8 sec^{-1})	f_{ik}	S (at.u.)
4s–4p	423.6[a]	2	2	81.4	0.219	0.611	5s–7p	127.2	2	2	55.9	0.0136	0.0114
4s–4p	373.7[a]	2	4	120.	0.502	1.24	5s–7p	126.5	2	4	44.3	0.0213	0.0177
4s–5p	83.894[b]	2	2	332.	0.0350	0.0193	5p–5d	554.7	2	4	129.	1.19	4.36
4s–5p	82.970[b]	2	4	252.	0.0519	0.0284	5p–5d	598.8	4	4	21.1	0.113	0.894
4s–6p	61.201[b]	2	2	210.	0.0118	0.00475	5p–5d	590.6	4	6	132.	1.03	8.04
4s–6p	60.957[b]	2	4	168.	0.0188	0.00753	5p–6d	(186.3)	2	4	10.9	0.0114	0.0139
4s–7p	53.30[c]	2	2	129.	0.00547	0.00192	5p–6d	(191.0)	4	4	3.93	0.00215	0.00540
4s–7p	53.19[c]	2	4	104.	0.00881	0.00309	5p–6d	(190.6)	4	6	21.0	0.0171	0.0429
4p–4d	240.8	2	4	506.	0.879	1.394	5p–6s	258.0	2	2	168.	0.167	0.284
4p–4d	260.5	4	4	81.8	0.0832	0.285	5p–6s	267.1	4	2	353.	0.189	0.664
4p–4d	256.8	4	6	513.	0.761	2.57	5p–7s	153.5	2	2	85.1	0.0301	0.0304
4p–5d	88.014[b]	2	4	104.	0.0241	0.0140	5p–7s	156.7	4	2	177.	0.0326	0.0673
4p–5d	90.525	4	4	30.	0.00369	0.00440	5p–8s	123.4	2	2	46.3	0.0106	0.00858
4p–5d	90.335[b]	4	6	165.	0.0303	0.0361	5p–8s	125.5	4	2	97.9	0.0116	0.191
4p–6d	(66.99)	2	4	109.	0.0146	0.00645	5d–5f	589.1	4	6	158.	1.23	9.57
4p–6d	(68.43)	4	4	28.1	0.00197	0.00178	5d–5f	597.7	6	6	10.9	0.0582	0.687
4p–6d	(68.38)	4	6	159.	0.0167	0.0150	5d–5f	595.7	6	8	165.	1.17	13.7
4p–5s	117.134[b]	2	2	475.	0.0978	0.0754	5d–6f	(223.3)	4	6	23.0	0.0258	0.0758
4p–5s	121.623[b]	4	2	1 015.	0.113	0.180	5d–6f	(224.5)	6	6	1.81	0.00137	0.00606
4p–6s	74.43[c]	2	2	214.	0.0178	0.00871	5d–6f	(224.3)	6	8	26.2	0.0264	0.117
4p–6s	76.22[c]	4	2	453.	0.0197	0.0198	5d–6p	382.1	4	2	218.	0.239	1.20
4p–7s	62.21[c]	2	2	117.	0.00679	0.00278	5d–6p	372.8	4	4	21.3	0.0444	0.218
4p–7s	63.45[c]	4	2	248	0.00748	0.00625	5d–6p	376.0	6	4	192.	0.272	2.02
4p–8s	56.65[d]	2	2	63.7	0.00306	0.00114	5d–7p	198.4	4	2	98.6	0.0291	0.0761
4p–8s	57.61[d]	4	2	138.	0.00343	0.00260	5d–7p	196.9	4	4	9.74	0.00566	0.0147
4d–4f	(265.1)	4	6	558.	0.882	3.08	5d–7p	197.8	6	4	87.7	0.0343	0.134
4d–4f	(269.0)	6	6	38.2	0.0415	0.221	5f–5g	(2 703.)	6	8	1.26	0.184	9.80
4d–4f	(268.9)	6	8	575.	0.831	4.41	5f–5g	(2 734.)	8	8	0.0450	0.00504	0.363
4d–5f	112.287[b]	4	6	243.	0.0690	0.102	5f–5g	(2 734.)	8	10	1.26	0.176	12.7
4d–5f	112.99	6	6	18.3	0.00351	0.00783	5f–6g	(332.7)	6	8	401.	0.888	5.84
4d–5f	112.941[b]	6	8	271.	0.0691	0.154	5f–6g	(333.2)	8	8	14.9	0.0248	0.217
4d–6f	(85.57)	4	6	271.	0.0446	0.0503	5f–6g	(333.2)	8	10	417.	0.866	7.61
4d–6f	(85.98)	6	6	20.	0.00222	0.00376	5f–6d	(535.3)	6	4	83.7	0.240	2.53
4d–6f	(85.96)	6	8	296.	0.0437	0.0743	5f–6d	(531.9)	6	6	3.98	0.0169	0.177
4d–5p	185.0	4	2	526.	0.135	0.329	5f–6d	(533.0)	8	6	79.6	0.254	3.57
4d–5p	180.6[e]	4	4	50.6	0.0248	0.0589	5g–6h	(378.0)	18	22	636.	1.66	37.3
4d–5p	182.4[e]	6	4	457.	0.152	0.548	5g–6f	(414)	18	14	12.3	0.0246	0.604
4d–6p	(101.8)	4	2	210.	0.0163	0.0218	6s–6p	1 839.	2	2	7.90	0.401	4.85
4d–6p	(101.1)	4	4	20.3	0.00312	0.00415	6s–6p	1 642.	2	4	11.1	0.896	9.69
4d–6p	(101.7)	6	4	184.	0.0190	0.0381	6s–7p	337.2	2	2	22.1	0.0377	0.0836
4d–7p	81.65	4	2	110.	0.00552	0.00593	6s–7p	332.8	2	4	16.2	0.0537	0.118
4d–7p	81.39	4	4	10.7	0.00106	0.00114	6p–7s	477.1	2	2	68.7	0.235	0.737
4d–7p	81.76	6	4	96.5	0.00645	0.0104	6p–7s	492.4	4	2	144.	0.261	1.69
4f–5g	181.72[c]	6	8	1 892.	1.249	4.48	6p–8s	271.5	2	2	35.3	0.0389	0.0696
4f–5g	181.72	8	8	70.0	0.347	0.166	6p–8s	276.4	4	2	74.0	0.0424	0.154
4f–5g	181.79[c]	8	10	1 961.	1.214	5.82	6p–6d	(1 054.)	2	4	44.4	1.48	10.3
4f–6g	122.87[c]	6	8	768.	0.232	0.563	6p–6d	(1 132.)	4	4	7.35	0.141	2.10
4f–6g	122.87	8	8	28.4	0.00644	0.0208	6p–6d	(1 117.)	4	6	45.8	1.29	18.9
4f–6g	122.90[c]	8	10	796.	0.225	0.729	6d–6f	(1 097.)	4	6	56.4	1.53	22.0
4f–5d	(291.1)	6	4	135.	0.115	0.659	6d–6f	(1 111.)	6	6	3.89	0.0720	1.58
4f–5d	(289.1)	6	6	6.43	0.00806	0.0461	6d–6f	(1 107.)	6	8	59.0	1.44	31.6
4f–5d	(289.3)	8	6	129.	0.121	0.923	6d–7p	(678.7)	4	2	98.2	0.339	3.03
4f–6d	(142.8)	6	4	48.2	0.00983	0.0277	6d–7p	(661.3)	4	4	9.65	0.0633	0.551
4f–6d	(142.6)	6	6	2.29	0.000698	0.00197	6d–7p	(666.6)	6	4	86.9	0.386	5.08
4f–6d	(142.6)	8	6	45.8	0.0105	0.0394	6h–7i	(630.9)	22	26	279.	1.97	90.0
5s–5p	978.6	2	2	21.5	0.309	1.99	7s–7p	3 068.	2	2	3.51	0.495	9.99
5s–5p	866.1	2	4	31.1	0.699	3.99	7s–7p	2 741	2	4	4.89	1.10	19.9
5s–6p	183.8	2	2	76.1	0.0385	0.0466	7p–8s	792.6	2	2	24.3	0.229	1.19
5s–6p	181.6	2	4	57.7	0.0570	0.0682	7p–8s	817.8	4	2	51.4	0.258	2.77

[a] Hinnov [1]. The wavelength uncertainty is ±0.5 Å.
[b] Alexander et al. [3] ±0.005 Å.
[c] This work ±0.05 Å.
[d] This work ±0.1 Å.
[e] This work ±0.2 Å.

and δ_{nLJ} is the quantum defect

$$\delta_{nLJ}(E_\infty) \equiv n - [t_{nLJ}(E_\infty)]^{-1/2} \tag{3}$$

In our study we have neglected terms of order higher than linear in t_{nLJ} in eq. (1), and assumed that $b_{LJ}=0$ for $L \geqslant 4$ and that $a_{LJ}=0$ for $L \geqslant 5$. The uncertainties in δ_{nLJ}, denoted $\Delta\delta_{nLJ}$, can be written as

$$\Delta\delta_{nLJ}(E_\infty) = \Delta E_{nLJ}/2R_\zeta^2[t_{nLJ}(E_\infty)]^{3/2} \tag{4}$$

For each Rydberg series in which the number of measured terms exceeds the number of unknown parameters in its appropriate Ritz formula, it is possible to determine the Ritz coefficients (a_{LJ}, b_{LJ}, etc.) and, E_∞, and test the goodness of fit by the chi-square criterion, all by minimizing the quantity χ^2_{LJ}, defined as

$$\chi^2_{LJ} \equiv \sum_n \left[\frac{\delta_{nLJ}(E_\infty) - a_{LJ} - b_{LJ}\, t_{nLJ}(E_\infty)}{\Delta\delta_{nLJ}(E_\infty)}\right]^2 \tag{5}$$

This nonlinear fit can be efficiently accomplished by assigning a trial value to E_∞ and performing a standard (multiple) linear regression, yielding a value $\chi^2_{LJ}(E_\infty)$. A search for the value of E_∞ which minimizes $\chi^2_{LJ}(E_\infty)$ gives the best weighted least squares estimate of E_∞ for that series. The value of E_∞ for which the sum of $\chi^2_{LJ}(E_\infty)$, taken over all overdetermined Rydberg series, gives the best joint least squares estimate of the ionization limit for all included series.

Individual and joint fits were made for the $^2P_{1/2}$ ($n=4$–7), $^2P_{3/2}$ ($n=4$–7) and $^2S_{1/2}$ ($n=5$–8) Rydberg series. The joint fit yielded $E_\infty = 2\,441.0 \pm 0.3$ kK (1 kK $= 10^3$ cm^{-1}) while the individual fits differed from that value by less than 0.5 kK. To test the reliability of this approach we made a similar calculation for Zn II, using the energies for the same terms as in the Mo XIV case. However, since the Zn II term energies are more accurately known [5] we introduced randomly generated simulated errors with relative magnitudes comparable to those in Mo XIV. The resulting value for the ionization potential for Zn II was 144.840 kK, 0.035% below the accepted value of 144.8906 kK [5], with the largest deviation obtained from a single Rydberg series lying 0.076% below that. Thus we estimate that our Mo XIV determination should be accurate to within 0.08%, and have adopted the value E_∞(Mo XIV) $= 2\,441 \pm 2$ kK which is in reasonable agreement with the result $2\,450 \pm 5$ kK reported in ref. [3] (using only the $5p$ and $6p$ term values and the assumption of a constant quantum defect). The agreement is also good with the calculations of Rosén [6] and Cowan [7] which yielded 2 435 and 2 437 kK, respectively. However, our value differs significantly from earlier estimates [8, 9].

The value of E_∞ deduced from these measurements was used to predict term values and energies for additional levels. Thus by combining our value for E_∞ with the measured $4f$–$5g$ and $4f$–$6g$ wavelengths and assuming a constant quantum defect for the ^2G terms we obtained term values for the $5g\ ^2G$ and $6g\ ^2G$ levels. This in turn fixed the $4f\ ^2F$ term values (assuming a negligible fine structure separation for the ^2G levels), which, together with the measured $5f\ ^2F$ values were used to predict the $6f\ ^2F$ energies. Zero quantum defects were used to place the yrast levels $6h$ and $7i$. Thus all $n=4$, $n=5$ and $n=6$ terms, as well as the $7s$, $8s$, $7p$ and $7i$ levels were located, with varying degrees of accuracy. The term system is displayed in Fig. 1.

The set of semi-empirical term energies so generated is given in Table II. Here the energies for $4p\ ^2P$, determined in ref. [1], have been adjusted about their mean to match the more accurate value for their fine structure separation given in ref. [3]. The uncertainties associated with the various combined experiments are listed for the measured term values, while term energies extrapolated using quantum defect assumptions are given in parentheses. Notice that for purposes of transition probability calculations Table II contains a complete subset of levels, i.e. for each term listed all terms below it to which dipole transitions can occur are also listed.

4. Calculation of meanlives and transition probabilities using the numerical Coulomb approximation

The numerical Coulomb approximation [10] is a semi-empirical method using energy levels and ionization potentials as the only input parameters. It distinguishes itself from the traditional Bates–Damgaard method [11] by its calculation of wave functions and its unique way of determining a cutoff radius for the wave function. The wave function for a specific state is calculated using an inward integration of the radial Schrödinger equation

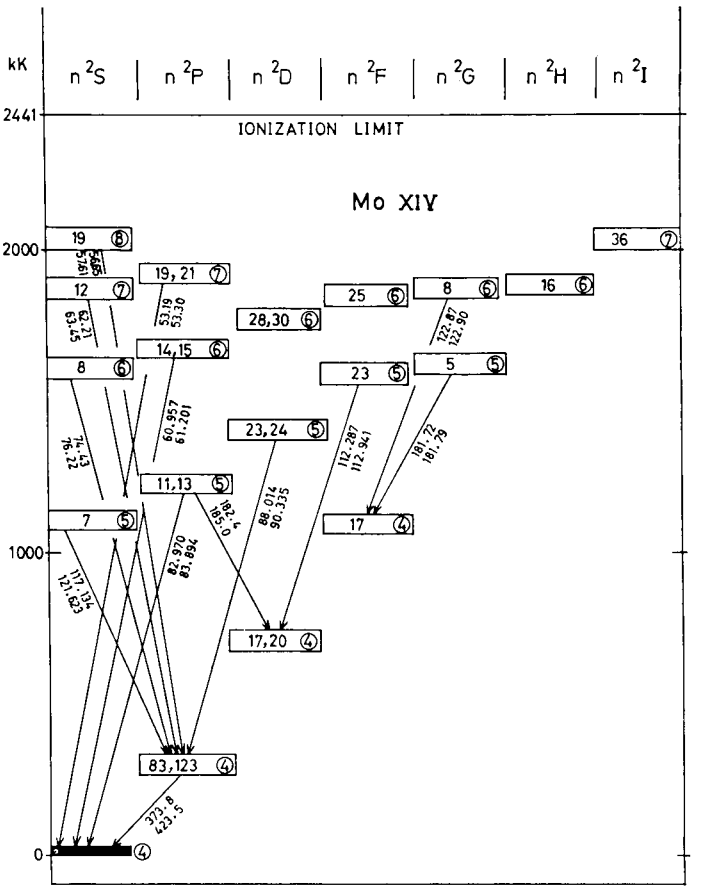

Fig. 1. Energy level diagram for Mo XIV. Boxes designate the 18 excited energy levels which were determined using the 13 doublet transition wavelengths indicated. The numbers within the boxes denote the calculated level lifetimes and (circled) the principal quantum numbers. (Transition probabilities, oscillator strengths and line strengths for all significant dipole-allowed transitions among these levels are given in Table I.)

to the origin. This causes the wave function to diverge for all states except S-states. The wave function is then chosen equal to the limiting form r^{L+1} between a cutoff radius which gives a reasonable value for the mean radial distance $\langle r \rangle$ and the mean inverse radial distance $\langle 1/r \rangle$. Hydrogenic formulae for $\langle r \rangle$ and $\langle 1/r \rangle$ suggest a requirement for the wave function of the form

$$\langle r \rangle = 3(2\langle 1/r \rangle)^{-1} - L(L+1)/2 \qquad (3)$$

This procedure has been shown to give accurate lifetimes in the Ga I and In I atoms [12], systems for which other semi-empirical methods are difficult to apply [13]. The numerical approximation has been shown to give very accurate results for one-electron systems such as Li I and its isoelectronic sequence [14] both for the neutral end and the highly ionized species. The method is particularly well suited for the examination of systematic trends, since it permits rapid computation of a large number of wave functions and matrix elements automatically.

Values for the level lifetimes, calculated by this technique, are listed in Table II. The wavelengths, transition probabilities, absorption oscillator strengths and line strengths are given in Table I. The wavelengths which have been obtained by extrapolation are given in parentheses. In all cases we have assumed LS coupling. The Coulomb approximation calculation used here is basically non-relativistic but the relativistic effects are nevertheless accounted for to some extent, via the experimental wavelengths and quantum defects. The analyses of the Cu I sequence by Froese Fischer [15] and Weiss [16] also show that for Mo XIV

Table II. *Mean lifetimes (in ps) and excitation energies in Mo XIV*

Level	Meanlife (ps)	Energy (kK)[a]
$4s\ ^2S_{1/2}$	∞	0
$4p\ ^2P_{1/2}$	123	236.07±0.28
$4p\ ^2P_{3/2}$	83.4	267.58±0.36
$4d\ ^2D_{3/2}$	17.0	651.44±0.61
$4d\ ^2D_{5/2}$	19.5	657.01±0.61
$4f\ ^2F_{5/2}$	16.8	(1 028.71)[a]
$4f\ ^2F_{7/2}$	17.4	(1 028.92)
$5s\ ^2S_{1/2}$	6.7	1 089.79±0.22
$5p\ ^2P_{1/2}$	11.4	1 191.98±0.07
$5p\ ^2P_{3/2}$	12.6	1 205.25±0.07
$5d\ ^2D_{3/2}$	23.8	1 372.25±0.28
$5d\ ^2D_{5/2}$	23.1	1 374.57±0.36
$5f\ ^2F_{5/2}$	23.2	1 542.02±0.61
$5f\ ^2F_{7/2}$	23.0	1 543.43±0.61
$5g$	5.1	(1 579.01)
$6s\ ^2S_{1/2}$	8.4	1 579.59±0.66
$6p\ ^2P_{1/2}$	13.9	1 633.96±0.13
$6p\ ^2P_{3/2}$	15.3	1 640.51±0.13
$6d\ ^2D_{3/2}$	29.8	(1 728.84)
$6d\ ^2D_{5/2}$	28.0	(1 730.04)
$6f\ ^2F_{5/2}$	26.6	(1 820.03)
$6f\ ^2F_{7/2}$	25.4	(1 820.36)
$6g$	8.2	(1 842.59)
$6h$	15.7	(1 843.54)
$7s\ ^2S_{1/2}$	11.9	1 843.58±0.92
$7p\ ^2P_{1/2}$	19.3	1 876.17±1.76
$7p\ ^2P_{3/2}$	21.3	1 880.05±1.77
$7i$	35.8	(2 002.05)
$8s\ ^2S_{1/2}$	18.9	2 002.34±2.18
Limit		2 441.0±2.0

[a] Parentheses denote quantum defect extrapolations. (1 kK = 10^3 cm^{-1}.)

transition rates the relativistic effects are rather small, even in the case of the 4*s*–4*p* lines.

Our transition probabilities for the 4*s*–4*p* resonance lines (Table I) can be compared with the results of two recent theoretical calculations. The Hartree Fock calculations of Cowan [7] which also take into account relativistic effects yield decay probabilities of 124 and 86.3 (in units of 10^8 s^{-1}) for the $4p\ ^2P_{3/2}$ and $^2P_{1/2}$ levels of Mo XIV. The agreement with our values (Table I), 120 and 81.4 is thus quite good. In her recent theoretical analysis of the Cu I sequence Froese Fischer [15] gives several *f*-values for the 4*s*–4*p* multiplet in Mo XIV. The most accurate of these should be $f=0.706$ which is based on the multi-configuration Hartree Fock method with relativistic effects included. This value is in good accord with our value $f=0.721$ (0.219 + 0.502, cf. Table I).

5. Conclusions

An attempt has been made to present as much information as possible about energy levels and lifetimes in Mo XIV. Clearly some of the level energies given here have comparatively large uncertainties, and the present results are intended to serve as a guide until a complete term analysis, based on accurate data in a large wavelength interval, has been completed. However, even the quantum defect extrapolations which have led to the largest uncertainties in this analysis could be useful in identifying lines observed in Tokamak plasmas. We thus note that Hinnov [1] has also observed weak lines at 377 and 416 Å which are tentatively ascribed to Mo XIV. Table I shows that the former line may be due to 5*d*–6*p* or 5*g*–6*h* transitions, but it contains no suitable Mo XIV candidates for the line at 416 Å.

The reliability of our *f*-values can to some extent be judged from the above-mentioned comparisons with more elaborate theoretical approaches. Our values should thus be helpful in connection with plasma diagnostics. Accurate experimental lifetimes can in principle be obtained by the beam-foil method but it is far from an easy task to produce an accelerator beam of 30–50 MeV Mo ions which will be needed in order to obtain an appreciable fraction of Mo^{13+} after the foil. The lifetimes presented here could be useful in analyzing future beam-foil data; it is already known that very severe growing-in processes due to cascade effects complicate the analyses of decay curves for levels in highly ionized single valence electron systems [17].

In addition to the Mo XIV data Alexander et al. [3] also report the 4*s*–5*p*, 4*p*–5*d* and 4*p*–5*s* wavelengths for Y XI, Zr XII and Nb XIII. For Zr XII and Nb XIII the 4*d*–5*f* and for Nb XIII the 4*s*–6*p* wavelengths are also given. The 4*s*–5*p*, 4*p*–5*d*, 4*p*–5*s* and 4*d*–5*f* transitions in Pd XVIII, Ag XIX, Cd XX and In XXI have earlier been traced in a published spectrogram [4] which we have recently reanalyzed. We are presently combining these measurements with isoelectronic extrapolations and interpolations as well as with semi-empirical calculations to obtain term energies, fine structure separations and transition probabilities for the systems Y XI through Sn XXII in the Cu I isoelectronic sequence.

Note added in proof

More accurate wavelengths (±0.005 Å) for the Mo XIV 4*s*–4*p* (373.647, 423.576 Å) and 4*p*–5*s* (117.149, 121.647 Å) doublets have recently become available [J. Reader and N. Acquista, Phys. Rev. Lett. **39**, 184 (1977)]. Using these values it is possible to deduce energies for the 4*p*, 5*s* and 5*d* levels of higher precision than those listed in our Table II. However inclusion of these results does not improve our estimate of the ionization potential, since neglected quadratic contributions to the Ritz formula limit the usable accuracies in the lowest lying energy values in the formulation described in Section 3 above. Since these new measurements are consistent with those which we have used to within our quoted uncertainties, they do not affect our calculations of transition probabilities.

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