INTERPRETATION OF PSEUDOCONTINUA IN THE SPECTRA OF HIGHLY IONIZED ATOMS FROM Tm TO W IN LASER PRODUCED PLASMAS

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X-ray spectra of highly ionized atoms (Tm to Pt) emitted from Laser produced plasma are characterized by the simple structure given by resonant transitions of the NiI-like ions, accompanied by the more complex pattern of satellite transitions emitted by ions in the neighbouring states of ionization. An analysis of these structures has been given recently for the satellites of the $3d^{10}-3d^9 4p$[1] and of the $3p^6 3d^{10}$ - $3p^5 3d^{10} 4s$, $4d$[2] transitions of the NiI-like ions. However, most of the radiation emitted in this spectral range [4-10Å] concentrate in a wide, rather structureless satellite feature in the long wavelength side of the $3d^{10}-3d^9 4f$ Ni-I like transition, on which some lines are superimposed. Line identification has been achieved successfully with the methods of [1], [2] and will be published separately. In this communication, we deal only with the pseudocontinuum.

THE PSEUDOCONTINUUM

a. Origin of the pseudocontinuum

The electronic temperature T_e in the plasma (> 1000 eV) is sufficient to populate noticeably configuration where one 3d and some external electrons of the n = 4 shell are excited simultaneously e.g. the configuration $3d^9 4s4p4f$ in ZnI-like that will give an observable transition to $3d^{10} 4s4p$. But as the ℓ and the number of the spectator electrons get higher, so do the complexity of the transition which degenerates into Unresolved Transitions Arrays (UTA) forming a large pseudocontinuum.

b. Computation of the mean wavelength and width of the UTA.

Computation of mean wavelength and width of UTA, assuming Gaussian shape can be performed in our case using simple formula [3]. In fig. 1 a comparison is made between ab-initio computation of the whole CuI-like $3d^9 4f4p-3d^{10} 4p$ array in Tm XLI (curve 1) and the UTA computation assuming Gaussian distribution (curve 2). As can be seen, the assumption of Gaussian distribution is wrong because the array is spin-orbit splitted into three different groups, according to the three $3d^9_j 4f_j -3d^{10}$ transitions. In this case the 4p spectator electron contributes to the width of each individual group only. Now, new formulas have been developed [4] which enable computing of mean wavelength and width of each splitted array, assuming j-j coupling. The results of these formulas are presented here for the first time. Table 1 gives the computation of the spin-orbit-splitted arrays (S.O.S.A.) of 3 transitions for four state of ionization of Tm. Curve 3 in fig. 1 shows these results for the $3d^9 4f4p-3d^{10} 4p$ case. Departure from pure j-j coupling cause a little shift in the mean wavelength of the splitted array although the width is well reproduced. To take account of the off diagonal matrix element, the mean wavelength for all the computed transition for the different ionization state has been shifted by the same amount measured in fig. 1.

c. Width of the all pseudocontinuum

The width of the pseudocontinuum is directly connected to the number of state of ionization that emits in this part of the spectrum. Indeed, for each ionization state, it has been shown [4] that the mean wavelength of each . S.O.S.A. is independent of the nature of the satellite electrons-in a central field approximation-and thus the different transitions, in the same state of ionization are blended. Moreover, it can be seen from table 2 that only for the four state of ionization CuI, ZnI, GaI and GeI do the 3d-4f transition correspond to an energy smaller than the ionization potential. The overall width of the pseudocontinuum is thus limited by the contribution of these four states of ionization.

d. Intensity

Assuming LTE the intensity ratio of the S.O.S.A. would approximately be in the proportion 10:2.5:0.01 for the $[\frac{3}{2}, \frac{5}{2}]$, $[\frac{5}{2}, \frac{7}{2}]$ and $[\frac{5}{2}, \frac{5}{2}]$ S.O.S.A. However, the laser produced plasma is optically thick for some transitions and we use here a simple model for estimating the effect of absorption [5]. Each transition probability is multiplied by a function

$$T(\tau) = \frac{1}{\tau\sqrt{\pi}} \int_{-\infty}^{+\infty} (1-e^{-\tau e^{-y^2}}) \, dy,$$

where τ is the optical thickness of the plasma for the center of the line. For large τ ($\tau \simeq 200$ for the strongest transition in our case)

$$T(\tau) \propto \frac{1}{gf}$$

and the resulting intensity is nearly independent of gf. For this reason the theoretical intensities in fig. 2 are just taken as free parameters, whereas the width and the positions of the S.O.S.A. are calculated ab-initio.

CONCLUSION:

New formulas were used for spin-orbit splitted arrays (S.O.S.A.) and applied to laser produced spectra of Tm. There is good agreement with experiment for the position and width of transition arrays, allowing doubtless identification of the pseudocontinuum.

REFERENCES

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Table I. S.O.S.A. calculations for 3d-4f transitions in Tm XLI - Tm XXXVIII (Results in Å)

I.S.	Transition	(3/2-5/2)		(5/2-7/2)		(5/2-5/2)	
		$\bar{\lambda}$	$\Delta\lambda$	$\bar{\lambda}$	$\Delta\lambda$	$\bar{\lambda}$	$\Delta\lambda$
Cu I	$3d^{9}4s4f - 3d^{10}4s$	6.969	0.007	7.117	0.008	7.231	0.019
	$3d^{9}4p4f - 3d^{10}4p$		0.020		0.017		0.036
	$3d^{9}4d4f - 3d^{10}4d$		0.035		0.045		0.073
Zn I	$3d^{9}4s4p4f-3d^{10}4s4p$	7.017	0.021	7.166	0.021	7.280	0.041
	$3d^{9}4s4d4f-3d^{10}4s4d$		0.036		0.046		0.076
	$3d^{9}4p^{2}4f-3d^{10}4p^{2}$		0.026		0.025		0.045
Ga I	$3d^{9}4s^{2}4p4f-3d^{10}4s^{2}4p$	7.065	0.020	7.217	0.020	7.329	0.036
	$3d^{9}4s^{2}4d4f-3d^{10}4s^{2}4d$		0.036		0.045		0.074
	$3d^{9}4s4p^{2}4f-3d^{10}4s4p^{2}$		0.027		0.027		0.050
Ge I	$3d^{9}4s^{2}4p^{2}4f-3d^{10}4s^{2}4p^{2}$	7.114	0.026	7.272	0.026	7.379	0.053
	$3d^{9}4s^{2}4p4d4f-3d^{10}4s^{2}4p4d$		0.041		0.050		0.083
	$3d^{9}4s4p^{3}4f-3d^{10}4s4p^{3}$		0.028		0.028		0.053

Table 2. Ionization potential vs. 3d-4f mean energy (a.u.)

I.S.	Ionization pot.	3d-4f mean energy
CuI	71.469	63.779
ZnI	69.446	63.317
GaI	64.715	62.888
GeI	62.672	62.484
AsI	58.471	62.060

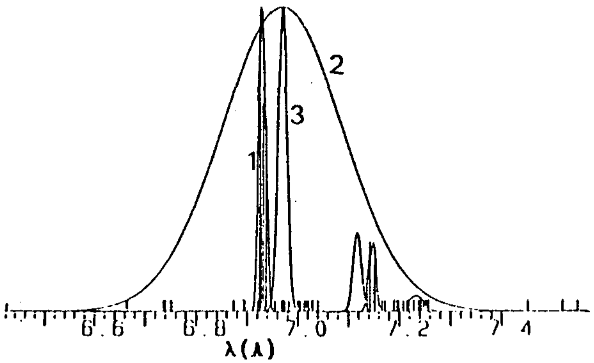

Fig.I.3d^{9}4f4p-3d^{IO}4p transition in TmXLI

I.ab-initio relativistic full calculation

2:U.T.A. calculation assuming gaussian shape

3.S.O.S.A. calculation

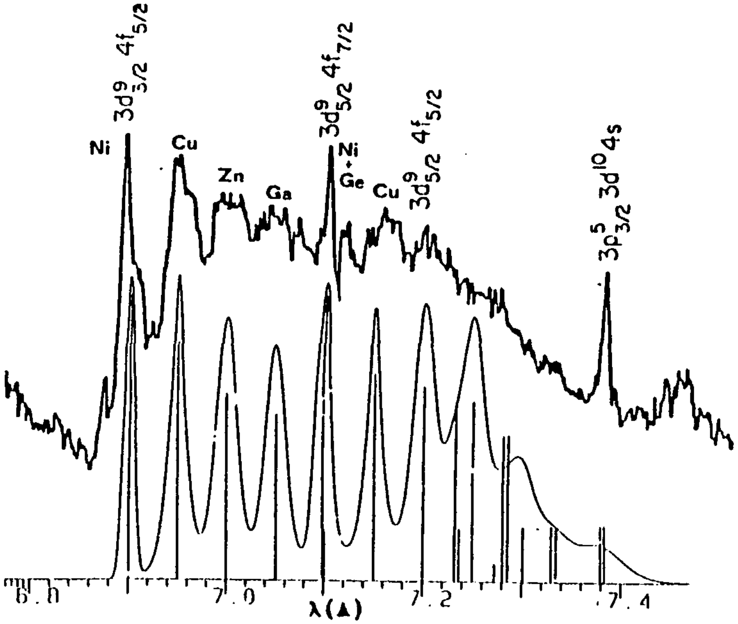

Fig.2. 3d-4f spectrum of Tm