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SATELLITE LINES OF NEON-LIKE RESONANCE LINES, FOR 17<Z<48

S. JACQUEMOT, M. LOUIS-JACQUET, O. PEYRUSSE, M. CORNILLE*, J. DUBAU*
and P. LAUTARD**

Commissariat à l'Energie Atomique, Centre d'Etudes de Limeil-Valenton,
BP 27, F-94190 Villeneuve-Saint-Georges, France
**U.A. 812/DAMAp Observatoire de Meudon, F-92915 Meudon, France*
***Observatoire de la Côte d'Azur, F-06003 Nice Cedex, France*

Résumé

Les raies diélectroniques satellites des raies de résonance des ions néonoïdes,du type $1s^22s^22p^53d$ - $1s^22s^22p^6$,ont été observées dans des spectres produits par irradiation laser à Limeil,lors d'expériences Laser X,de plasmas collisionnels denses ($10^{20}<n_e<10^{21}cm^{-3}$,$T_e$=600eV) de Cu,Ge,Se,Mo et Ag.
Nous présentons ici les calculs théoriques des coefficients de taux de recombinaison diélectronique des ions néonoïdes vers les ions sodiumoïdes.Les paramètres atomiques nécessaires à cette étude : énergies, longueurs d'onde,probabilités radiatives et d'autoionisation sont calculées à l'aide de deux codes : SUPERSTRUCTURE et AUTOLSJ.

Abstract

The dielectronic satellite lines of the neon-like resonance lines $1s^22s^22p^53d$ - $1s^22s^22p^6$ have been observed in the spectra obtained during the Limeil X-ray Laser experiments under collisional dense plasma conditions ($10^{20}<n_e<10^{21}cm^{-3}$,$T_e$=600eV) for Cu,Ge,Se,Mo and Ag.We present here the theore--tical calculations of dielectronic recombination rate coefficients for neon-like ions to form sodium-like ions.The atomic parameters required are energy levels,wavelengths,radiative and autoionization probabilities.The quantities are calculated with two coherent codes SUPERSTRUCTURE and AUTOLSJ.

Introduction

The X-ray spectra in the range of Ne-like resonance lines emitted from a soft X-ray Laser plasma is used to make a spectroscopic diagnostic of the plasma.By computing intensity ratios of Ne-like resonance and Na-like satellite lines,we are able to obtain plasma parameters (electronic density and temperature).
This study implies the knowledge of the Z-dependance of different atomic parameters:
- wavelengths (for the resonance and satellite lines)
- autoionization and decay rates (of doubly excited states involved in the satellite lines)

or
- corresponding line factors F^*_s:

$$F^*_s = g_s/g_i \cdot A_aA_r/(A_a+A_r) \qquad \text{(see Figure 1).}$$

We used,to determine all these parameters,atomic structure and electron-ion computer codes:
- SUPERSTRUCTURE

and
- AUTOLSJ.

The calculations,including relativistic effects in a fine structure scheme,have been done on a large selection of ions,from Ar to Ag.

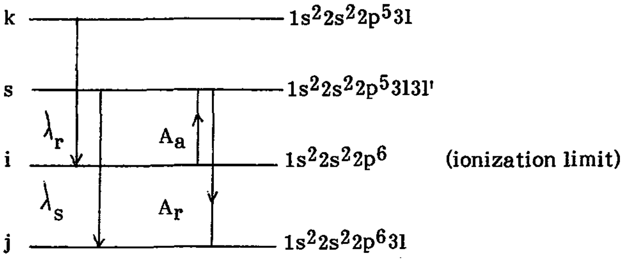


Figure 1 : Diagram of Ne- and Na-like ions,showing the resonance lines and associate satellite transitions.

Theoretical methods

The energy levels,wavelengths and decay rates are calculated using the SUPERSTRUCTURE computer code /1/.In a first step,this code constructs a set of non-relativistic wavefunctions of the 10-electron system by diagonalization of the non-relativistic Hamiltonian,using orbitals nl calculated in a scaled Thomas-Fermi-Dirac potential,the scaling parameters λ_l being obtained by a self-consistent energy minimization procedure of all the **terms** of the configurations $1s^22s^22p^6$,$2p^53l$ (l=s,p,d) (see Figure 2).In a second step,the code diagonalizes on this basis the Breit-Pauli Hamiltonian,including relativistic corrections in configuration mixing,to determine all the **levels** of the following configuration sets:

* $(1s^22s^2)2p^6,2p^53l,2p^54l';(1s^22s)2p^63l,2p^64l'$ (l=s,p,d;l'=s,p,d,f)
* $(1s^22s^2)2p^63l,2p^53l3l'$ (l=s,p,d;l'=s,p,d)

The autoionization probabilities and the line factors are calculated by using the AUTOLSJ code /2/,which needs as inputs , from SUPERSTRUCTURE :
* the 'term coupling coefficients' for N and N+1 electronic systems (N=10),
* the radiative de-excitation probabilities (A_r).
It determines the bound-free transition matrix elements,in a Distorted Waves approximation, and calculates the recoupling coefficients,and,afterwards,the autoionization probabilities (A_a) and the line factors (F^*_s).

Application of the histogram-construction to the satellites of Ne-like resonance lines

On Figures 4 to 10,the histograms represent (solid lines) the line factors F^*_s of the dielectronic satellites:

* $(1s^22s^2)2p^53p3d \longrightarrow 2p^63p$
* $2p^53d^2 \longrightarrow 2p^63s,3d$

normalized to their maximum (for each element) $\bar{F}^*_s$,reached at $\bar{\lambda}$(see Figure 3),and (dashed lines) the position of the corresponding resonance lines versus wavelengths:

* $(1s^22s^2)2p^53l \longrightarrow 2p^6\ {}^1S_0$

key	upper 3l level	key	upper 3l level
3G	3s $^1P_1$	3E	3d $^3P_1$
3F	3s $^3P_1$	3D	3d $^3D_1$
		3C	3d $^1P_1$

Comparisons ,for Germanium (Z=32) and Selenium (Z=34), between theoretical histograms and experimental spectra obtained during the Limeil X-ray Laser program /3/ are presented on Figures 11 and 12. We can easily identify the 3-2 resonance lines and some important satellite lines,with approximate correct relative intensities.

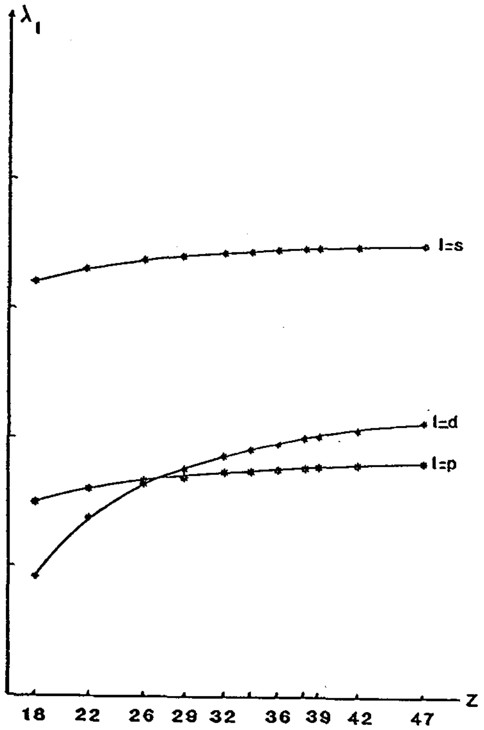


Figure 2 : Scaling parameters of a 10-electrons TFD potential versus nuclear charge.

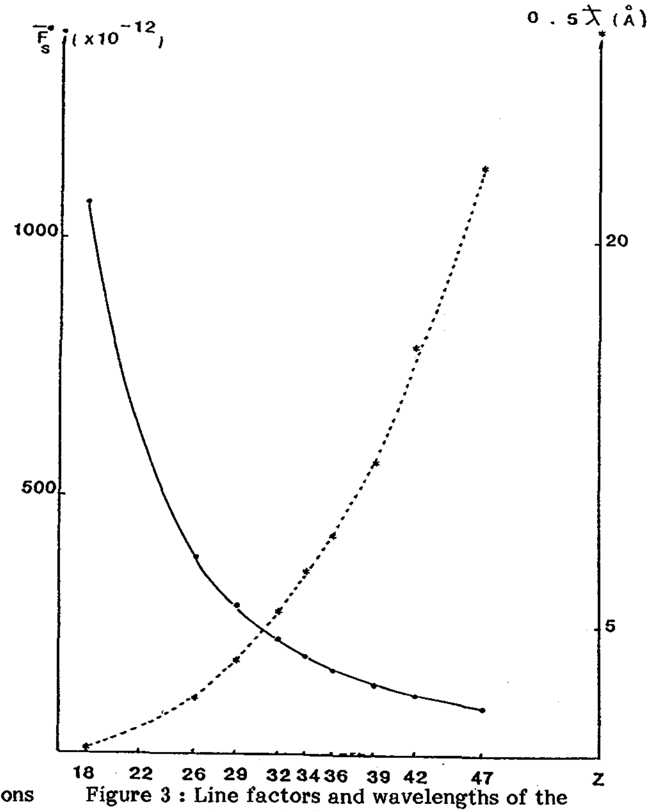


Figure 3 : Line factors and wavelengths of the strongest dielectronic satellite line $((1s^2 2s^2 2p^5)3d^2\ {}^2F_{7/2} - 2p3d\ {}^2D_{5/2})$ versus nuclear charge.

Determination of the dielectronic recombination rate coefficients

All these calculations allow us to determine the dielectronic recombination rate coefficient $\alpha_d(j)$

* from the Ne-like ground state $i=1s^2 2s^2 2p^6\ {}^1S_0$

* to the Na-like ground state or one of the n=3 singly excited states $j=1s^2 2s^2 2p^6 3l$ (l=s,p,d)

* via the chosen set of doubly excited states $s=1s^2 2s^2 2p^5 3l3l'$ (l=l'=s,p,d)

which can be written,if T_e is the electronic temperature of the plasma (in eV) :

$$\alpha_d(j)=1.65\ 10^{-22}\ F^*(j)\ T_e^{-3/2}\ \exp(-E^*(j)/T_e) \qquad \text{(see Figure 13)}$$

The partial n=3 total dielectronic rate coefficient $\alpha_d^{tot} = \sum_{j=2p^6 3l} \alpha_d(j)$ is then approximated by :

$$\alpha_d^{tot}=A\exp(-\ Z^2/T_e)(T_e/Z^2)^{-3/2} \qquad \text{(see Figure 14).}$$

References

/1/ W. Eissner,M. Jones,H. Nussbaumer Comput.Phys.Comm.**8**,270(1974)
/2/ J. Dubau,M. Loulergue J.Phys.**B15**,1007 (1981)
/3/ O. Peyrusse and co-workers to be published in J.of Appl.Physics

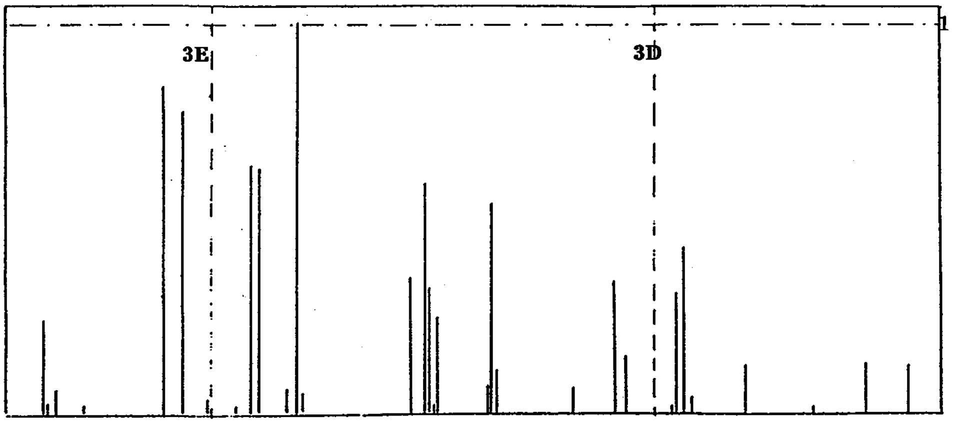


Figure 4 : Argon (Z=18)

3E=42.743 Å 3D=42.180 Å

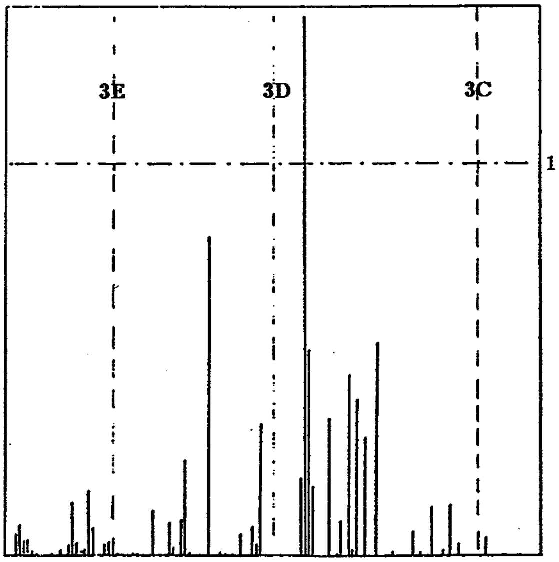


Figure 5 : Iron (Z=26)

3E=15.443 Å 3D=15.243 Å
3C=14.981 Å

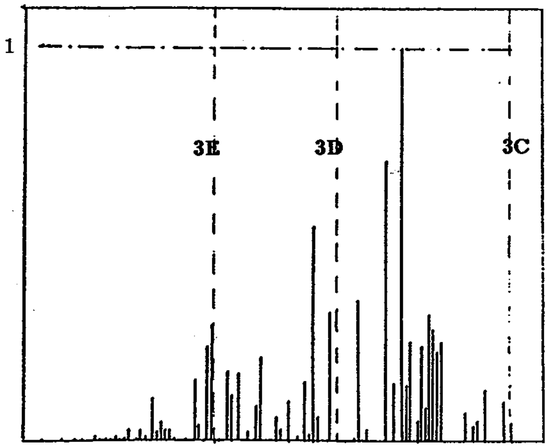


Figure 6 : Copper (Z=29)

3E=11.716 Å 3D=11.566 Å
3C=11.348 Å

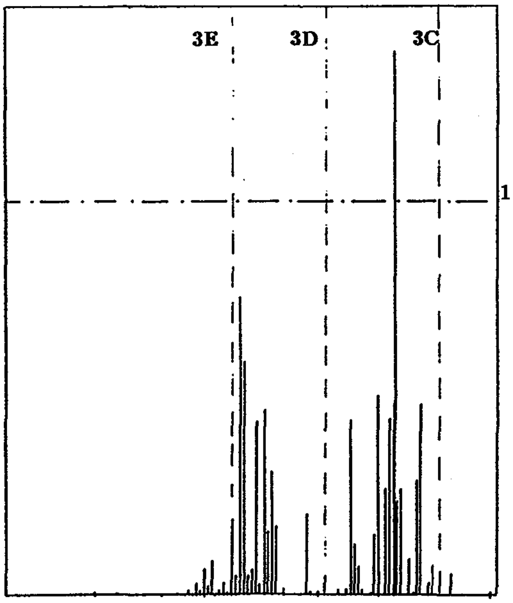


Figure 7 : Krypton (Z=36)

3E=6.927 Å 3D=6.842 Å
3C=6.666 Å

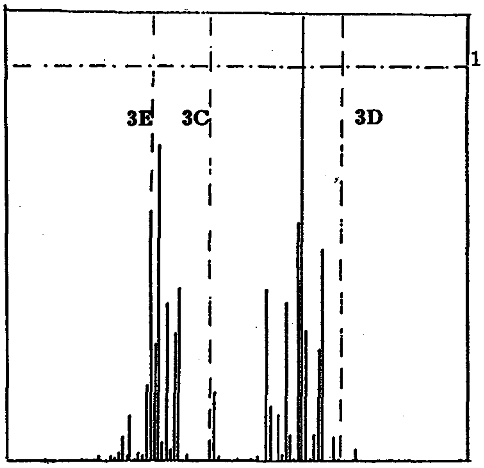


Figure 9 : Molybdenum (Z=42)

3E=4.823 Å 3C=4.765 Å
3D=4.602 Å

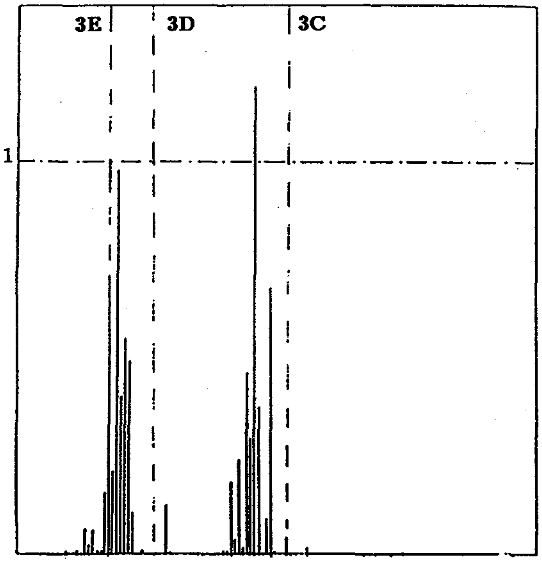


Figure 8 : Ittrium (Z=39)

3E=5.735 Å 3D=5.664 Å
3C=5.496 Å

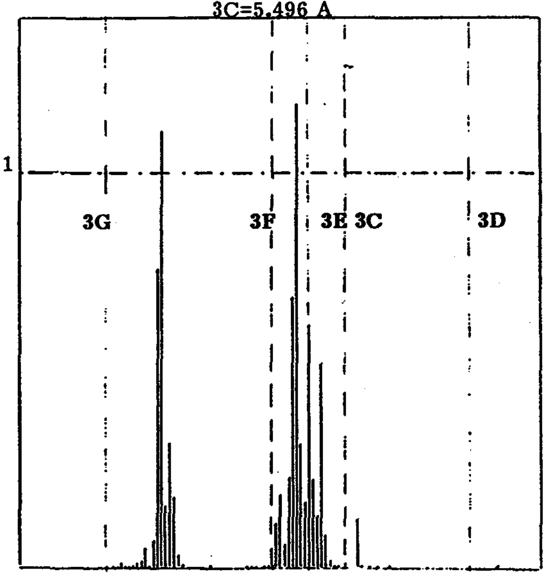


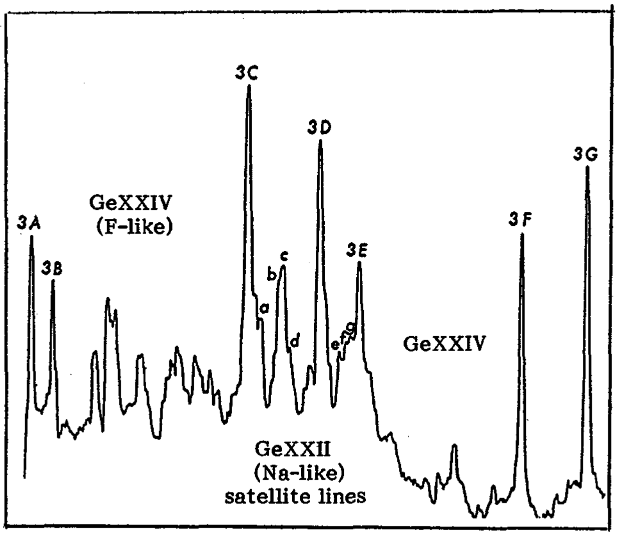
Figure 10 : Silver (Z=47)

3G=3.970 Å 3F=3.769 Å 3E=3.720 Å
3C=3.675 Å 3D=3.520 Å

Figure 11 : Germanium (Z=32)

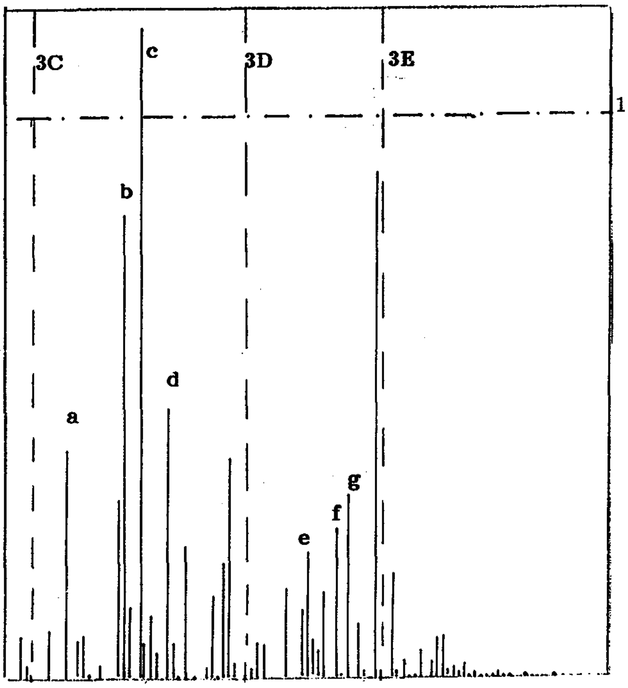
<ins>Target :</ins>
500 Å Ge deposited on 500 Å CH

<ins>Laser :</ins>
non gaussian pulse
1 ns,2×5 10^{13}W/cm^3
ω_0



a	ΣF^*_s=114.3	λ=8.915-8.92
b	=316.9	=8.96 -8.97
c	=323.2	=8.98 -8.985
d	=134.0	=9.00 -9.10
e	=79.6	=9.13 -9.14
f	=74.64	=9.15 -9.16
g	=79.93	=9.165-9.175

(all the satellite lines are blended)
(F^*_s is in 10^{12} unit)

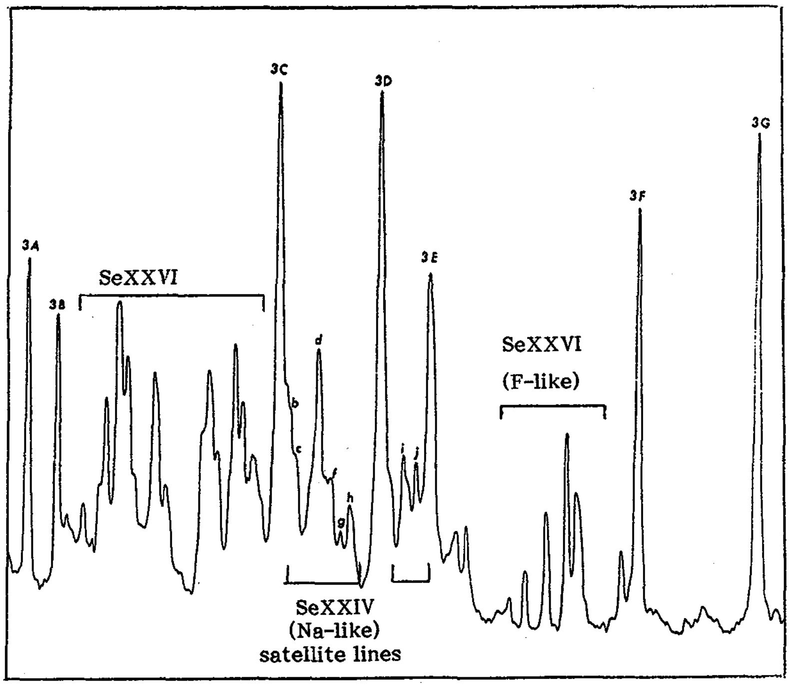


3C=8.885 A 3D=9.079 A
3E=9.196 A

Figure 12 : Selenium (Z=34)

Target :
750 Å Se deposited on
1500 Å CH

Laser :
gaussian pulse
600 ps,2x5 10^{13}W/cm^3
2 ω_0

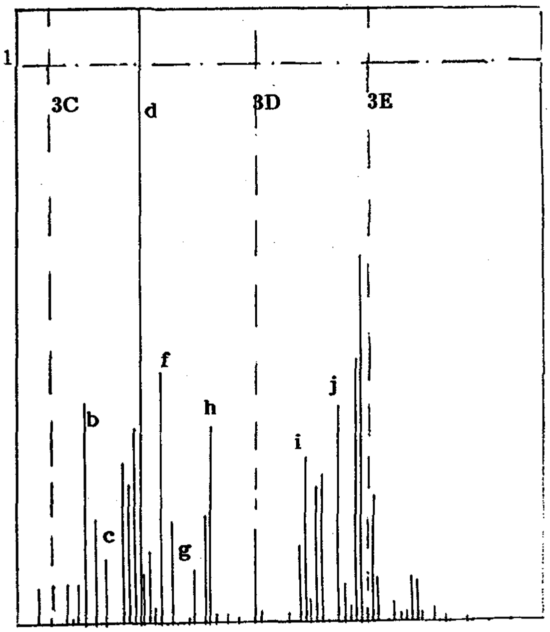


b	ΣF^*_s=165.6	λ=7.686-7.69
c	=67.9	=7.695-7.70
d	=215.5	=7.725-7.735
e	=80.5	= 7.74 -7.75
f	=172.9	= 7.75 -7.76
g	=38.6	= 7.78 -7.79
h	=198.3	= 7.79 -7.805
i	=157.8	= 7.88-7.89
j	=164.3	= 7.91 -7.92

(all the satellite lines are blended)

(F^*_s is in 10^{12} unit)

3C=7.659 A 3D=7.842 A
3E=7.942 A



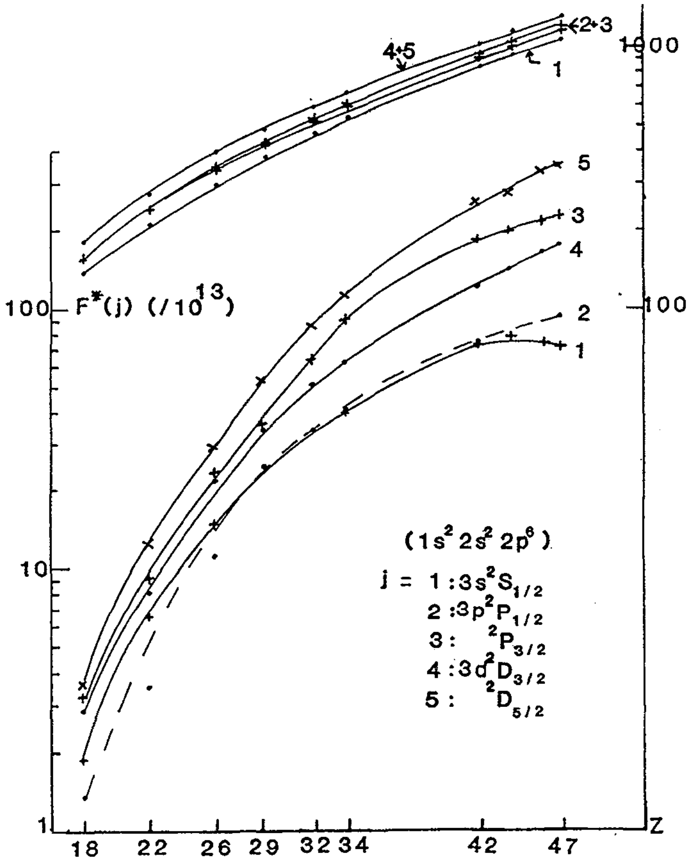


Figure 13 : Total line factors and averaged energies versus nuclear charge.

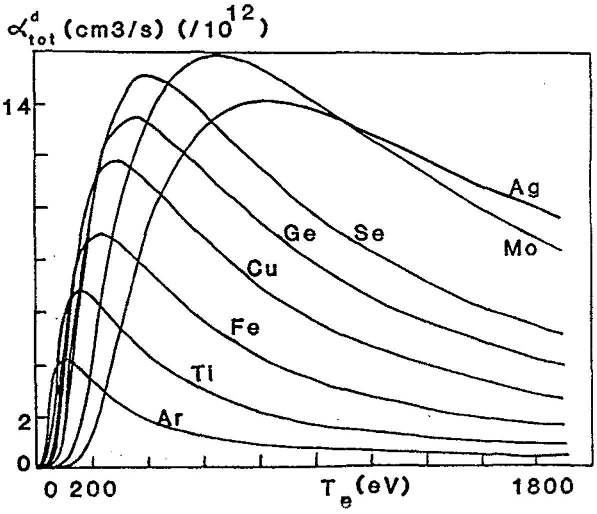


Figure 14 : Partial n=3 total dielectronic recombination rate coefficient versus electronic temperature for Na-like ions.