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Radiative-collisional processes in electron-tungsten ions collisions: quasiclassical calculations and data

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First Research Coordination Meeting on Spectroscopic and Collisional Data for Tungsten from 1 eV to 20 keV

13-15 December 2010, IAEA Headquarters, Vienna, Austria

UNIVERSAL REPRESENTATION OF RADIATIVE-COLLISIONAL PROCESSES WITH COMPLEX TUNGSTEN IONS

Processes under consideration:

1) Bremstrahlung (Br) in a frozen atomic core:

2) Radiative recombination (RR) in the frozen core;

3) Core polarization effects for complex ions (polarization Br, RR).

4) Dielectronic recombination (DR) for core excitation without change of its principle quantum number;

Advantages: a) estimation of electron-atomic processes for complex ions by small numbers of input parameters: Z, Zi, E

b) universal scalings for atomic processes .

General approach - quasiclassical methods: V.A.Astapenko, L.A.Bureyeva, V.S.Lisitsa Review of Plasma Physics, 2003, v.23, pp.1-206.

L.A. Bureyeva et al. Phys. Rev.A, v.65032702 (2002)
V.I. Kogan, A.B. Kukushkin, V.S. Lisitsa, Phys. Rep., v.213,1 (1992)

Fast code for Bremsstrahlung + Radiative Recombination spectra (frozen core)

ESMEABRR = (Electron + Static Many-Electron Atom)

Goals:

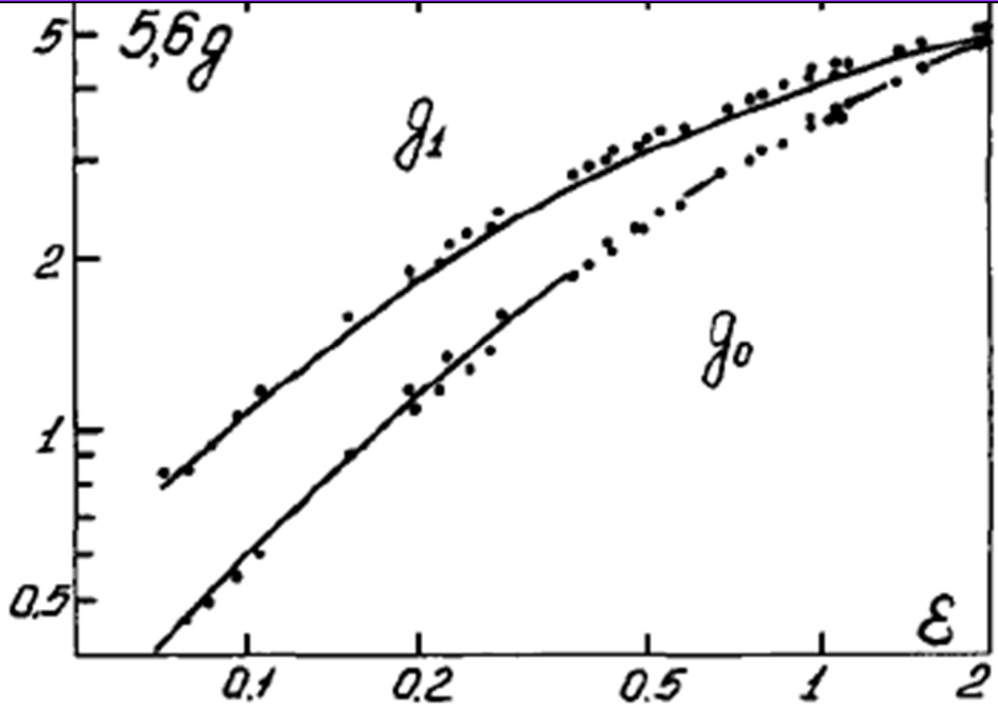
- Estimations of background radiation for Thomson scattering diagnostics in ITER.
- Estimation of contribution of impurities to continuous spectrum in divertor and edge tokamak plasmas (including ITER divertor diagnostics tasks)

Semi-analytic description of Bremsstrahlung and radiative recombination cross sections for collisions of quasiclassical electrons with a static many electron atoms and ions (from neutral atom to fully stripped).

Users:

- ITER Divertor Thomson Scattering diagnostics, E.Mukhin et al. (Ioffe, Russia)
- ITER Edge Physics and Plasma-Wall Interactions Section (ITER).

Gaunt factor *g* for electron Bremsstrahlung on neutral atoms (frozen core)



Statistical Thomas-Fermi model

Z – nucleus charge

E- incident electron energy

$$\varepsilon = 0.885 \cdot \hbar^2 E / (m_e e^4 Z^{4/3})$$

$$\Omega = 0.589 \cdot (\hbar^3 \omega / m_e e^4 Z)$$

$$g_0(\varepsilon) \equiv g_{at}(0, \varepsilon)$$

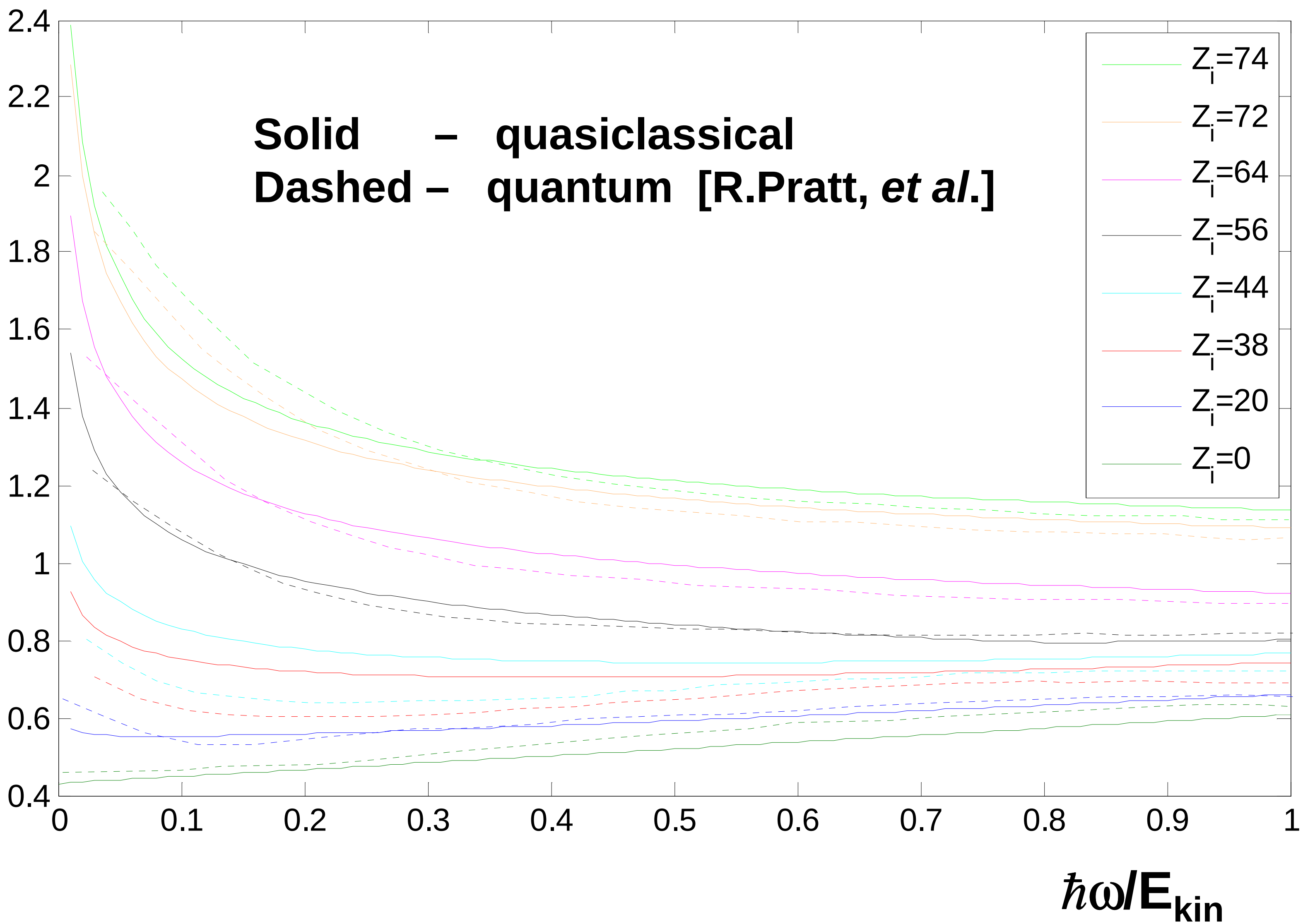
$$g_1(\varepsilon) \equiv g_{rot}(2\varepsilon, \varepsilon)$$

The universal classical functions $g_0(\varepsilon)$ and $g_1(e)$ (curves) compared with the corresponding (replotted) results of the numerical quantum calculations [Lee C.M., Kissel L., Pratt R.H., Tseng H.K. Phys.Rev., 1976]

V.I. Kogan, A.B. Kukushkin, V.S. Lisitsa, Phys. Rep., 213 (1992) 1.

Bremsstrahlung, W ion (charge Z_i) + electron (E_{kin} = 5 keV)

Gaunt factor (defined with respect to Z =Znucleus=74)

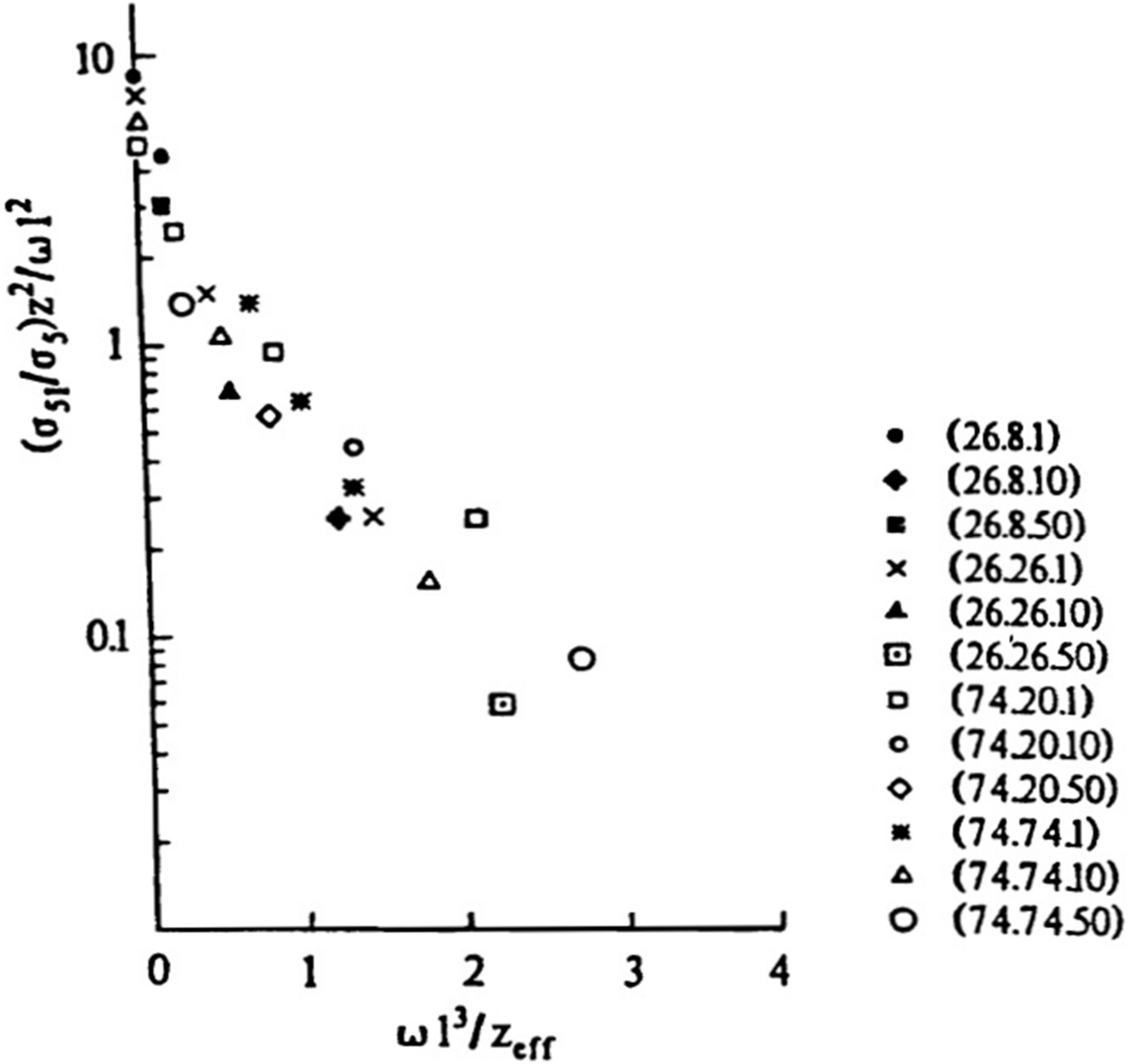


Quantum (L.Kim,R. Pratt,1987) vs quasiclassical data for RR

Table 2.2: Recombination coefficient $\alpha = < v\sigma^{tot} >$ (in $10^{-12}\text{cm}^3\text{s}^{-1}$) [48]

Z	T[keV]	Nucleus		Ne-like			Ar-like		
		KrED	Coul. Z_i	KrED	Coul. Z_i	Coul. Z_{eff}	KrED	Coul. Z_i	Coul. Z_{eff}
26	1	7.5	8.1	1.4	0.71	1.5	0.57	0.062	0.64
Fe	3	3.1	3.5	0.42	0.2	0.45	0.14	0.016	0.19
	10	1.1	1.2	0.10	0.036	0.11	0.038	0.003	0.039
	30	0.37	0.40	0.027	0.0085	0.025	0.009	0.0007	0.008
42	1	24	26	7.4	5.3	7.8	4.5	2.0	4.9
Mo	3	11	12	2.6	1.8	2.8	1.5	0.62	1.6
	10	4.1	4.5	0.72	0.50	1.1	0.39	0.15	0.42
	30	1.5	1.7	0.19	0.13	0.21	0.097	0.038	0.11
74	1	94	100	40	35	43	31	23	33
W	3	44	48	16	14	17	12	8.2	12
	19	18	20	4.9	4.3	5.2	3.5	2.5	3.9
	30	7.3	8.2	1.4	1.3	1.6	1.0	0.72	1.1

SCALINGS FOR RADIATIVE RECOMBINATION (frozen core)

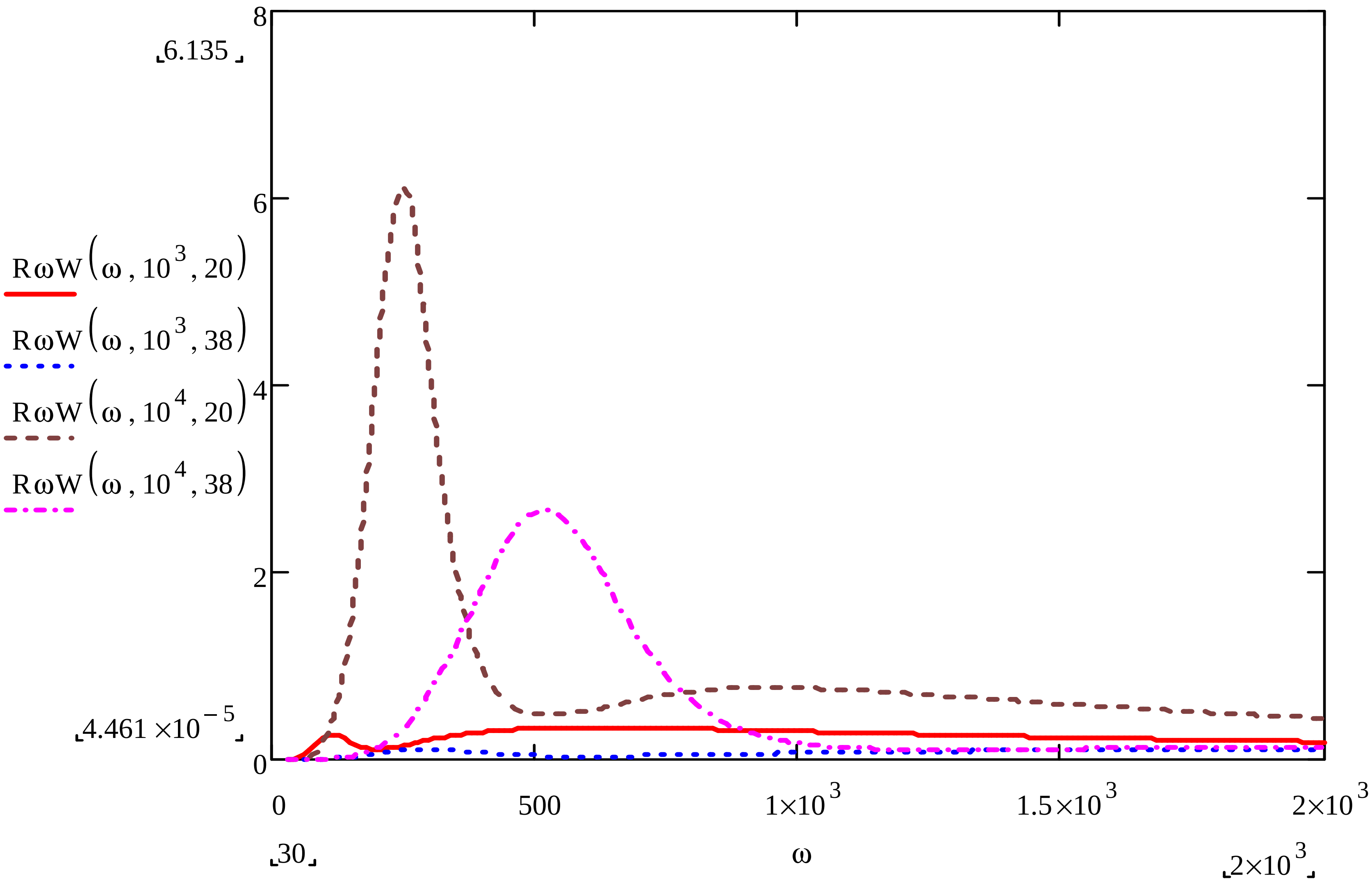


for many-electron ions with core polarization effects

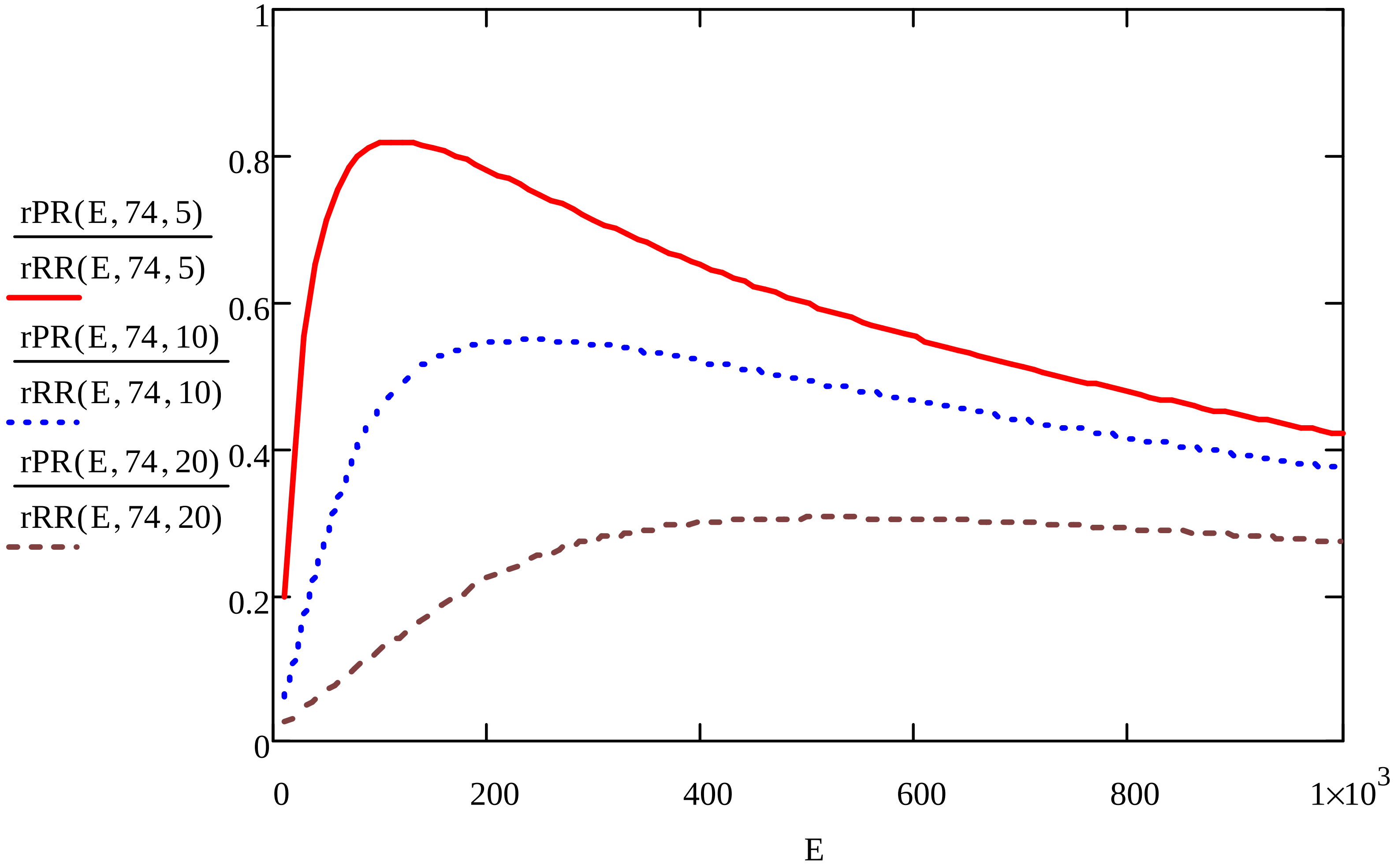
Goal: recombination rates of electrons in collision with complex ions
Applications: ionization balance in divertor and edge plasmas , Plasma continuum spectra

V.A.Astapenko, L.A.Bureyeva, V.S.Lisitsa Review of Plasma Physics, 2003, v.23, pp.1-206.
L.A. Bureyeva et al. Phys. Rev.A, v.65032702 (2002)

Ratio R(w)=Kpl(w)/Kst(w) for tungsten ions charges Zi=20,38 and electron energies 1and 10 keV

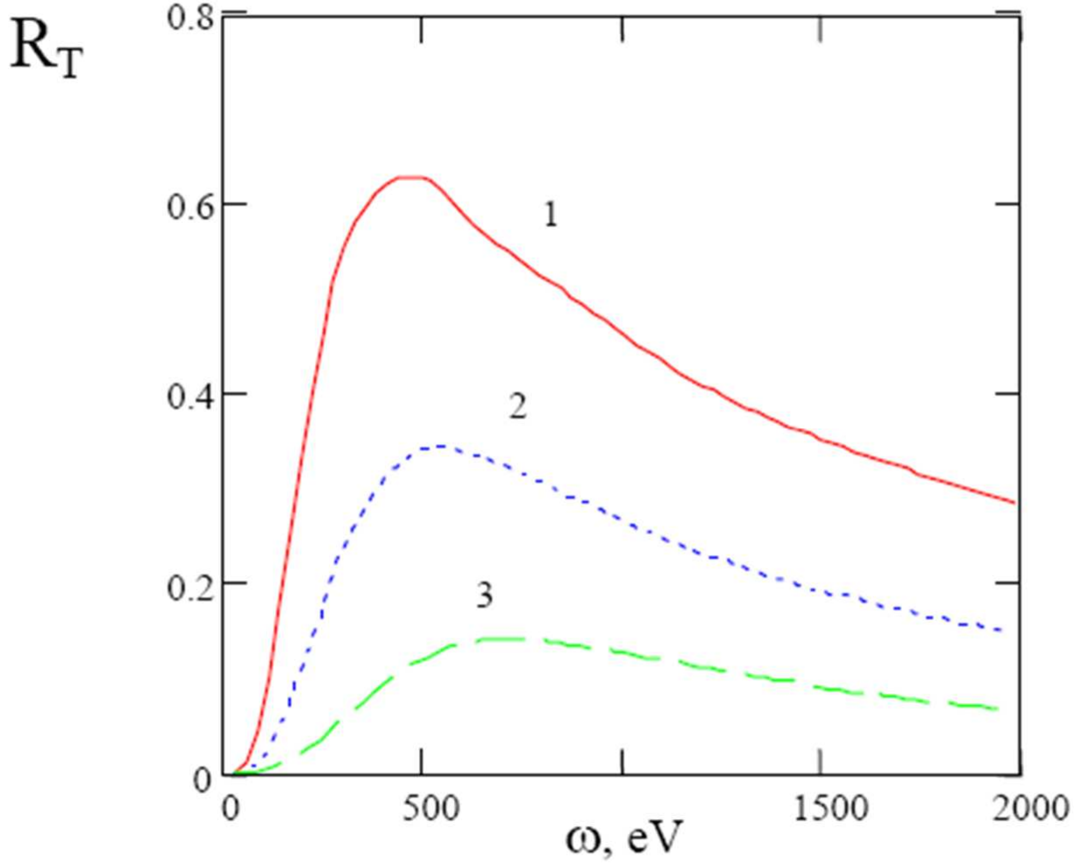


The Polarization to Static radiation ratio vs electron energy E (W ions charges Zi=5,10,20)

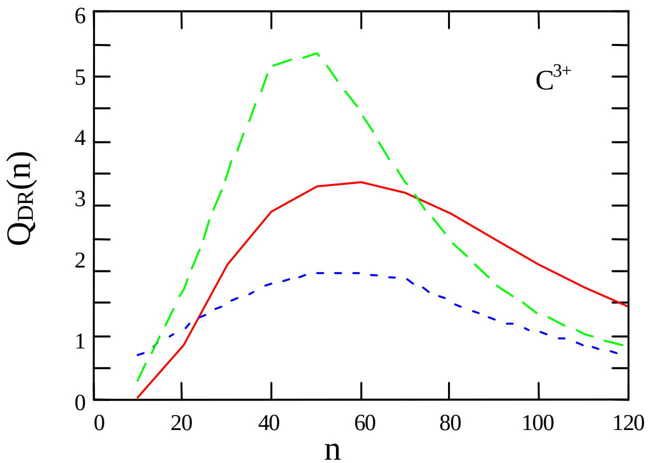


Enhanced R-factor for radiative recombination with core polarization effects

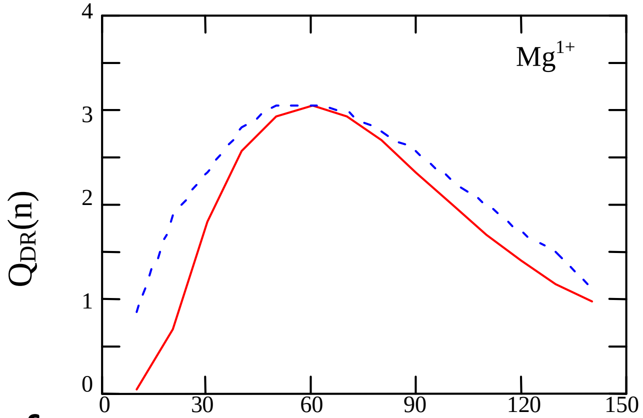
Enhanced factor R averaged over corona equilibrium for the temperature 500 eV for different heavy ions: 1 – W, 2 – Mo, 3 – Fe.



DR rates in quasiclassical approximation



Distribution of DR rates (in units 10^{-12} cm^3/s) over n for the C^{3+} ion at the electron temperature $T_e=10^5$ K: solid curve – universal formula; dotted line – calculation [3]; long dashed line- calculation [2]



(the input atomic data – energy levels and oscillator strengths are needed)

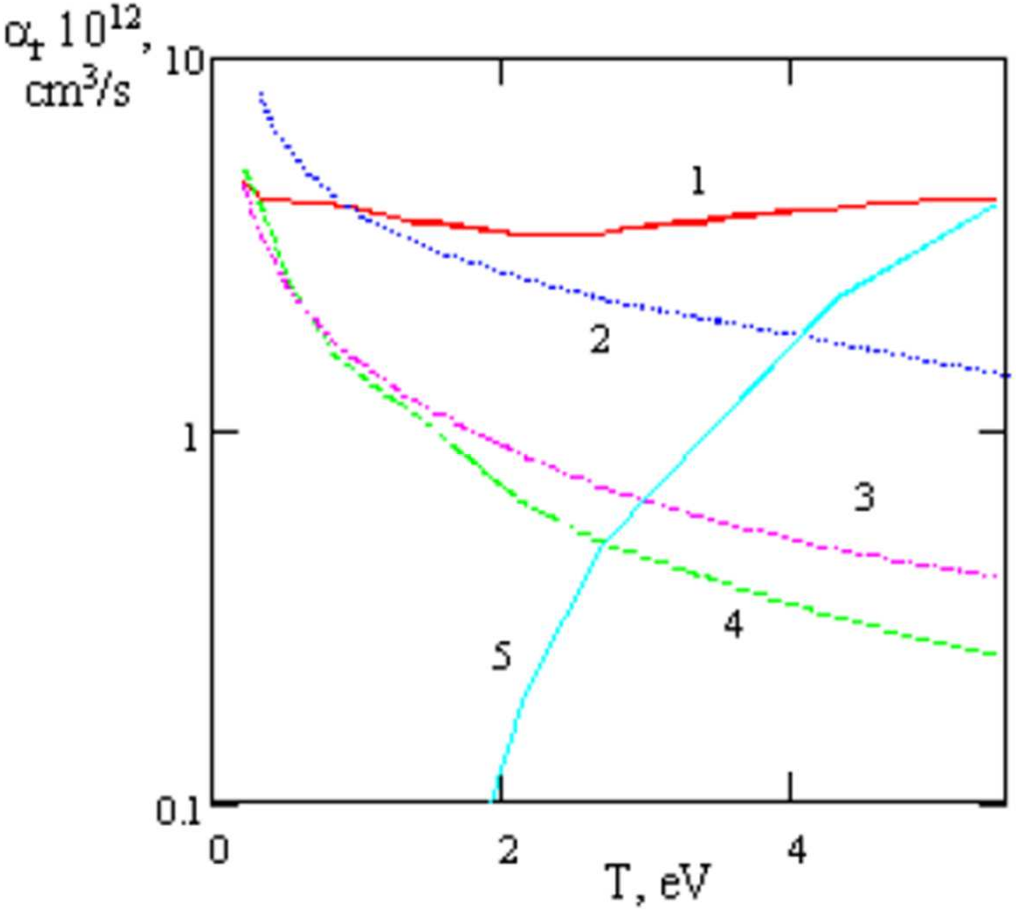
The same but for the Mg1+ ion: solid curve – universal formula; dotted line – calculation [1]

Reference

1. K. LaGattuta and Yu. Hahn, Phys. Rev. Lett. V. **51**, 558 (1983)
2. D. R. Rosenfeld, Astroph. J. V. **398**, 386 (1992)
3. J. Li and Yu. Hahn, Z. Phys. V. **D41**, 19 (1997)

The ISAN site: http://www.isan.troitsk.ru/

Recombination rates of Fe^{2+} ion vs. electron temperature



1- total recombination rate (close coupling S. N. Nahar, Phys. Rev. A 55, 1980 (1997), 83 atomic states),

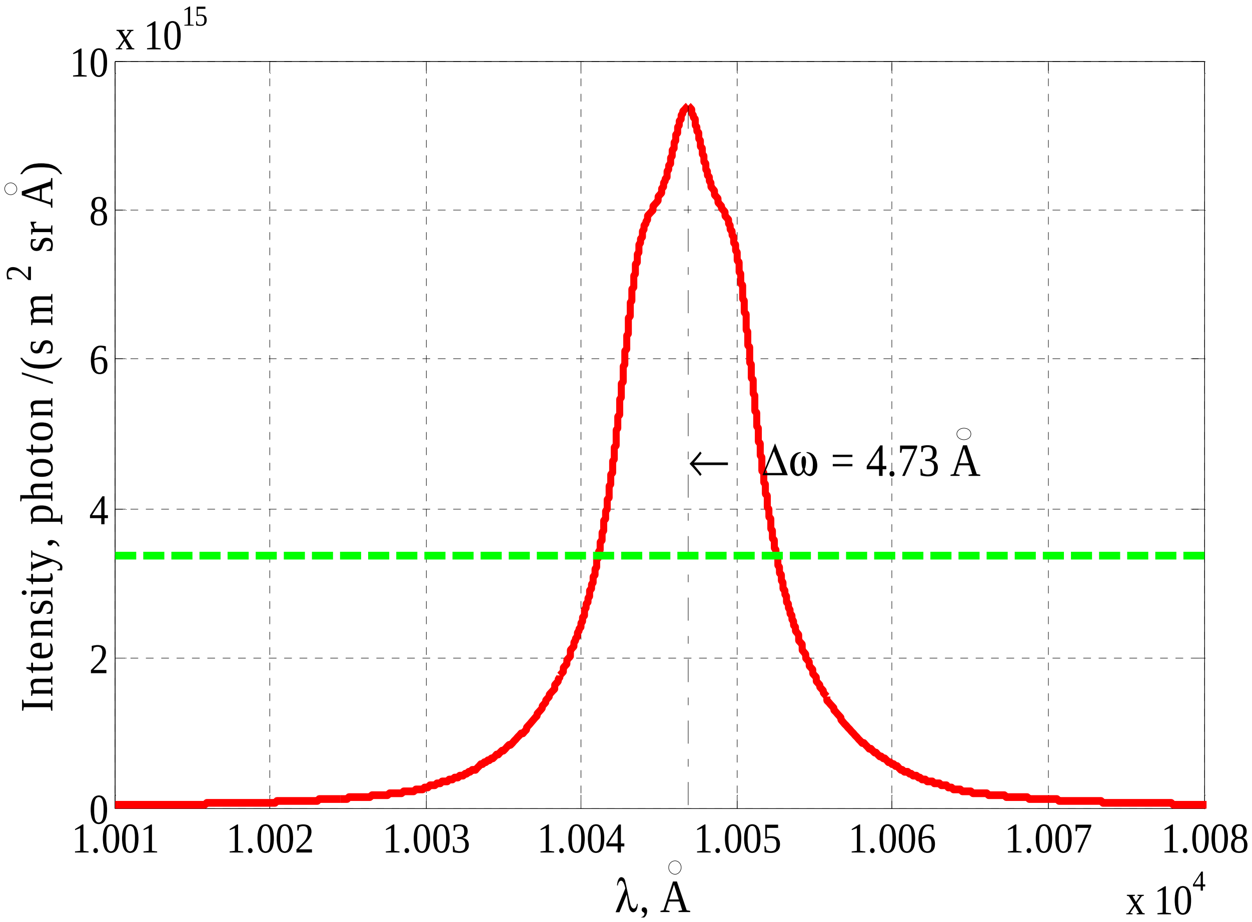
2- total radiative recombination rate (quasiclassical method with core polarization effects),

3- radiative recombination rate (Kramers approx.),

4- recombination rate (static core),

5-dielectronic recombination rate.

Bremsstrahlung Background together with Balmer P7 line shapes for ITER TS chord



The integral along the chord.
Green line is the contribution of continuum, Zeff=1.

6. Conclusions

1. Universal Quasiclassical Codes (UQC) are effective methods for calculations of radiative-collisional processes with tungsten ions in tokamak plasmas including ITER conditions, providing:

   a) quit good precision atomic data for Br, RR, DR;

   b) scaling laws for atomic processes.

2. These codes need the support of more complex codes both atomic ones (energy levels, oscillator strengths) and plasma modeling codes (B2-EIRENE, transport code ASTRA, etc.) Configuration averaged atomic data are needed.

3. The codes are accessible:

   - Kurchatov Institute website (next year);

   - RAS Institute of Spectroscopy website;

   - semi-analytical formulas from surveys referenced above.

PROBLEMS

- 1 Determinations of configurations (= Dynamics+kinetics are nonseparable – superconfigurations for ground states?)
- 2. Atomic core polarization effects are of importance for ions with complex cores – close coupling ?.
- 3. General: what kinds of atomic data and their precisions for W we need?