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

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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: $Z$, $Z_i$, $E$

b) universal scalings for atomic processes.

**General approach - quasiclassical methods:** V.A.Astapenko,
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).
The universal classical functions $g_0(\varepsilon)$ and $g_1(\varepsilon)$ (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]

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

Gaunt factor (defined with respect to $Z = Z_{\text{nucleus}} = 74$)

Solid – quasiclassical
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]

<table>
<thead>
<tr>
<th>Z</th>
<th>T[keV]</th>
<th>Nucleus</th>
<th>Ne-like</th>
<th>Ar-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>----</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>7.5</td>
<td>8.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Fe</td>
<td>3</td>
<td>3.1</td>
<td>3.5</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1.1</td>
<td>1.2</td>
<td>0.10</td>
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<td></td>
<td>30</td>
<td>0.37</td>
<td>0.40</td>
<td>0.027</td>
</tr>
<tr>
<td>42</td>
<td>1</td>
<td>24</td>
<td>26</td>
<td>7.4</td>
</tr>
<tr>
<td>Mo</td>
<td>3</td>
<td>11</td>
<td>12</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4.1</td>
<td>4.5</td>
<td>0.72</td>
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<td>1.7</td>
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<tr>
<td>74</td>
<td>1</td>
<td>94</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
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<td>3</td>
<td>44</td>
<td>48</td>
<td>16</td>
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<tr>
<td></td>
<td>30</td>
<td>7.3</td>
<td>8.2</td>
<td>1.4</td>
</tr>
</tbody>
</table>
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

Ratio \( R(w) = \frac{K_{pl}(w)}{K_{st}(w)} \) for tungsten ions charges \( Z_i = 20, 38 \) and electron energies 1 and 10 keV.
The Polarization to Static radiation ratio vs electron energy $E$ (W ions charges $Z_i=5,10,20$)
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 Mg$^{1+}$ ion: solid curve – universal formula; dotted line – calculation [1]

**Reference**


**The ISAN site:**  [http://www.isan.troitsk.ru/](http://www.isan.troitsk.ru/)
Recombination rates of Fe$^{2+}$ ion vs. electron temperature

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, $Z_{\text{eff}}=1$. 

$\lambda$, Å

Intensity, photon/$(s \, m^2 \, sr \, Å)$

$\Delta \omega = 4.73 \, Å$

$x \times 10^{15}$
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?