Near Threshold Resonant Processes in Plasmas

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Support from DOE

Threshold resonances strongly contribute to recombination.
Accurate energy is wildly important.
Resonances of C\({\text{\textsuperscript{2+}}}\) with \(2p4L\) character are within \(~\frac{1}{2}\) eV of threshold

\[0.1 \text{ eV} = 1160 \text{ K}\]

Dielectronic recombination in cold plasmas!
Thermal Rates: DR only

Figure 6.—$\Delta n = 0$ DR rate coefficients in a plasma: this work (thick solid line; systematic uncertainty ±15%), McLaughlin & Hahn (1983; dashed line), Nussbaumer & Storey (1983; dash-double-dotted line), Romanik (1988; dash-dotted line), Safronova et al. (1997; thin solid line), and Mazzotta et al. (1998; dotted line).
Thermal Rates: DR+RR

derived from experiment

RR and DR have same rate \( \sim 800 \) K

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**Fig. 8.**—Experimental total C iv recombination rate coefficients in a plasma corrected for the influence of the finite experimental resolution (thick solid line; systematic error \( \pm 15\% \)). The comparison with our pure DR rate coefficient (dotted line) shows that RR is noticeable up to \( \sim 30,000 \) K. The thick dash-dotted line is our total recombination rate coefficient uncorrected for the influence of the finite experimental resolution. The other lines are C iv RR rate coefficients of Péquignot et al. (1991; thin solid line) and corresponding RR rate coefficients (see text) for \( n_{\text{max}} = 20 \) (thin dashed line) and \( n_{\text{max}} = 40 \) (thin dash-dotted line).
All Near Threshold States

Energies & multiplicities from NIST database

Energies of all 2p4L states within $\frac{1}{2}$ eV of threshold

Why bother with negative energy states?
Plasmas Populate Negative E

solid $T = 0.1 \text{ eV, } 2.2\text{E}6 \text{ cm}^{-3}$, dotted $T = 0.1 \text{ eV, } 2.2\text{E}8 \text{ cm}^{-3}$
dash $T = 0.4 \text{ eV, } 2.2\text{E}6 \text{ cm}^{-3}$, dot-dash $T = 0.1 \text{ eV, } 2.2\text{E}8 \text{ cm}^{-3}$
Negative E States “Autoionize”

Bound even-parity $J = 0$ and 2 spectra of Ca: A multichannel quantum-defect theory analysis

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Mixture into the 4snd Rydberg series
Number of Participating States

Compute thermal average of $2 J_r + 1$

0.1 eV, 2.2E6 cm$^{-3}$:
Positive E: 7.2    Negative E: 11.6

0.1 eV, 2.2E8 cm$^{-3}$:
Positive E: 7.2    Negative E: 44

0.4 eV, 2.2E6 cm$^{-3}$:
Positive E: 47    Negative E: 13.5

0.4 eV, 2.2E8 cm$^{-3}$:
Positive E: 47    Negative E: 32
Ratio to Thermal @ 250 K

solid 1.0E4 cm$^{-3}$, dotted 1.0E5 cm$^{-3}$
dash 1.0E6 cm$^{-3}$, dot-dash 1.0E7 cm$^{-3}$
Contribution of Near Threshold States to Recombination in Plasmas

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\[ T = 2.8 \text{ eV} \]

\[ 10^4, 10^6, 10^8 \text{ cm}^{-3} \]
Contribution to Recombination Rate

Blue line = experiment, red line = correct Autostructure, black line = Autostructure (states below 70 meV shifted below threshold)
Symbols include negative E states (unshifted & shifted Auto)
Dielectronic recombination in $\text{C}^{3+}$ above and below the ionization threshold

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**DR cross section**    convolved 0.02 eV
The plot shows the critical n-shell at which the Mg7+ Rydberg levels blend with their nearest neighbor.
Population modeling of the Rydberg states

- We used ADAS204 to model the population of the 'negative energy' electrons.
  - Semi-empirical data for everything, except for DR (AUTOSTRUCTURE).
- We also investigated the role of allowing a doubly excited state embedded in the Rydberg 'continuum' to allow the Rydberg states to radiate.
- Results are shown for Mg7+ for Te = 5.8 \times 10^4 \text{ K} (top plot) and 4.47 \times 10^7 \text{ K} (bottom plot)
Concluding Remarks

Perturber states just below threshold might contribute as much or more to low T processes.

Compact states embedded in Rydberg series often left out.

Simple theory if energy width is greater than Rydberg spacing (or big collisional width of Rydberg state).

Possible important processes: photo-recombination, electron impact excitation (weak transitions), dissociative recombination in molecular ions.

Super accurate energy not necessarily important; energy error less than T.