Experimental data for electron-impact ionization, electron-ion recombination and photoionization of tungsten ions

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Outline

I. Introduction
atomic data needs – atomic data situation

II. Electron-ion recombination of W\textsuperscript{q+} ions

III. Photoionization of W\textsuperscript{q+} ions

IV. Electron impact ionization of W\textsuperscript{q+} ions

V. Summary

Evolution of tungsten ion charge states in a plasma

T. Pütterich, R. Neu, R. Dux, A. D. Whiteford, M. G. O’Mullane and the ASDEX Upgrade Team

rate coefficients for ionization and recombination required
Ionization: CADW calculations of Loch et al. (2005)
Recombination: Burgess – Bethe (1965 – 1976) with ad hoc modifications

Data situation

Theoretical predictions for ionization and recombination of complex many-electron ions such as W\textsuperscript{q+} (with q \ll Z) have been unreliable in the past.

Experiments were (and still are) needed to test and to guide theoretical approaches

Example of existing experimental data:
electron-impact ionization of W\textsuperscript{1+}

Before this CRP: experimental cross section data available for

electron-impact ionization of W\textsuperscript{q+}
\[ e + W^{q+} \rightarrow W^{(q+1)+} + 2e : \quad q = 1, \ldots, 10 \]

photoionization of W\textsuperscript{q+}
\[ h\nu + W \rightarrow W^+ + e : \quad q = 0 \]

electron-ion recombination of W\textsuperscript{q+}
\[ e + W^{q+} \rightarrow W^{(q-1)+} + h\nu \] (time-reversed photoionization)

no absolute cross section measurements available

the presence of long-lived metastable ions is a general issue
Example of existing theoretical data:
electron-impact ionization of W$^{5+}$

Experiment:

Theory:

CADW theory looks quite good
but did not account for the metastables

The only previously existing data for photoionization
of tungsten atoms or ions


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Recombination of W$^{q+}$ ions using the TSR ring

The storage ring TSR

TSR ion storage ring in Heidelberg
unique facility with optimal features for the purpose
  cooler plus target
  excellent energy resolution

The TSR has been shut down but might be moved to CERN
A cryogenic electrostatic ring (CSR) is being built in Heidelberg

Even a storage ring cannot guarantee the absence of metastables

The principle of electron-ion merged beams experiments

independently absolute cross sections
and rate coefficients obtained

Recombination of W$^{20+}$ ions at the TSR storage ring

Excited-state population in a beam of W$^{18+}$ ions

1671 levels in configurations 4f$^{10}$, 4f 5s, 4f 5p
sum of 1652 short-lived levels

17 long-lived levels from 4f$^{10}$ and 4f 5s configurations

Metastable ions can be present even in storage-ring experiments

26.09.2014: 31 citations in google scholar
Plasma recombination rate coefficient of \(W^{20+}\) ions

N. R. Badnell, C. P. Ballance, D. C. Griffin, M. O’Mullane, PRA 2012

Recombination of \(W^{18+}\) ions:

Just published

Experimental Cooperation Working on \(W^q+\) Recombination

IAMP, Giessen
Stefan Schippers
Kaija Spruck
Arno Becker
Dietrich Bernhardt
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MPI-K, Heidelberg
M. Grieser, C. Krantz, R. Repnow, A. Wolf

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Overview of the experimental setup at the ALS

Photoionization of \(W^q+\) and \(W^{2q+}\) ions: absolute data

All data on this page are still to be published in the open literature.
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Electron-ion interaction region

- Energy-defining electrode
- Collector
- Ions
- Cathode

Electron current: 450 mA at 1 keV

Electron-ion collision energy [eV]

Cross section (10^-17 cm^2)

Stenke et al., 1994

Electron-impact single ionization of W^{5+}

\[ e + W^{5+} \rightarrow W^{6+} + 2e \]

Cross section (10^-17 cm^2)

Stenke et al., 1994

Present absolute

Present scan

Theory V. Jonauskas

24% metastables

Electron-ion collision energy (eV)

Cross section (Mb)

Electron-ion collision energy (eV)

Electron-impact single ionization of W^{19+}

\[ e + W^{19+} \rightarrow W^{20+} + 2e \]

Direct ionization: 4f, 4d, 4p

Excitation autoionization: 4d, 4p, 4s

Mixed ground- and excited

Ground configuration

Mix of ground- and excited

Plasma rate coefficients for electron-impact single ionization of W^{19+}

Electron energy (eV)

Electron temperature (10^5 K)

Ground rate

Excited 4f rate

The experimental absolute cross sections can be nicely reproduced by CADW calculations.
Electron-impact ionization of low to moderately charged W\(^q^+\) ions:
\(q = 1, 2, 3, \ldots, 19\)

all scan measurements are from the present tungsten ion project;
the red curves cover „the new terrain“

we can provide reliable rate coefficients for ground-state ionization on the basis of CADW modeling of the data

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Completed work on W\(^q^+\) ions (absolute experimental cross sections with accompanying theoretical work and plasma rate coefficients)

recombination: \(W^{18+}, W^{19+}, W^{20+}, W^{21+}\)

photoionization:
\(W^+\) \(\sigma_{1s-2s}, \sigma_{1s-3s}, \sigma_{1s-4s}\)
\(W^\#\) \(\sigma_{2s-3s}, \sigma_{2s-4s}\)
\(W^\#\) \(\sigma_{3s-4s}\)
\(W^{4+}\) \(\sigma_{4s-5}\)
\(W^{5+}\) \(\sigma_{5s-6}\)

electron impact ionization: verified and complemented work by Stenke et al. for single ionization of W\(^q^+\), \(q=1,2,\ldots,10\) added new theoretical background

and

Thank you for your attention!