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Nuclear Instruments and Methods in Physics Research B 235 (2005) 231–234
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Measurement of electron impact collisional excitation cross sections of Ni to Ga-Like Gold

M.J. May [a], P. Beiersdorfer [a,*], N. Jordan [a], J.H. Scofield [a], K.J. Reed [a], S.B. Hansen [a], K.B. Fournier [a], M.F. Gu [b], G.V. Brown [c], F.S. Porter [d], R. Kelley [d], C.A. Kilbourne [d], K.R. Boyce [d]

[a] *Lawrence Livermore National Laboratory, L-260, Livermore, CA 94550, USA*
[b] *Stanford University, Stanford, CA 94305, USA*
[c] *Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD 21218, USA*
[d] *NASA-Goddard Space Flight Center, Code 662, Greenbelt, MD 20700, USA*

Available online 26 April 2005

Abstract

We are measuring the cross sections for the 3d → 4f and 3d → 5f excitations in Ni- to Ga-like Au in beam plasmas created in the Livermore electron beam ion trap EBIT-I. The measurements are possible by using the high-resolution broadband coverage of the Goddard Space Flight Center micro-calorimeter. The cross sections are determined from the ratio of the intensity of the collisionally excited lines to the intensity of the radiative recombination lines. The value of the excitation cross section of the $3d_{3/2} \rightarrow 5f_{5/2}$ transition in Au^{50+} (Cu-like) is presented and compared to distorted wave calculations.

PACS: 34.80.Kw; 32.30.Rj; 32.70.Fw

Keywords: Electron-impact excitation cross sections; Gold M-shell; Microcalorimeter; EBIT

1. Introduction

Accurate electron-impact excitation cross sections are needed for proper interpretation of the spectral emission of highly charged ions and utilizing spectral measurements for plasma diagnostics. The determination of the ionization balance for a given plasma temperature is especially sensitive to the values of the excitation cross sections used to correlate the intensity of a given line to the abundance of the corresponding ion species. Knowing the correct charge state distribution

* Corresponding author. Fax: +1 925 423 2302.
E-mail address: beiersdorfer@llnl.gov (P. Beiersdorfer).

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doi:10.1016/j.nimb.2005.03.179

(CSD) in turn is critical for understanding radiation levels, energy deposition, energy balance, etc. of high temperature plasmas. Two high density experiments with different plasma conditions have been done with the NOVA laser to determine the ionization balance of Au ($Z = 79$). Foord et al. [1] inferred the charge state distribution of a gold microdot heated to $T_e = 2.2$ keV in steady state. Glenzer et al. [2] measured the CSD of gold in a fusion hohlraum plasma with $T_e = 2.6$ keV, $n_e = 1.4 \times 10^{21}$ cm^{-3}, and a soft X-ray radiation temperature of 210 eV. The CSDs were inferred by comparing the measured 5f → 3d spectrum with atomic physics calculations using electron impact excitation cross sections from the Hebrew University Lawrence Livermore Atomic Code (HULLAC) [3]. The experimentally inferred CSDs were in reasonable agreement with the modeled values from RIGEL [4]. However, the analysis was complicated by the transient nature of the laser produced plasma and the many competing atomic processes.

A CSD of gold was determined at low density ($\sim 10^{12}$ cm^{-3}) in a plasma with an electron temperature of 2.5 keV [5]. The plasma was created at the Livermore electron beam ion trap EBIT-II. The charge balance was inferred by fitting the observed 5f → 3d spectrum with modeled spectrum from HULLAC in a method similar to that done in the Nova experiments. Despite the relatively simple atomic physics in the low density EBIT-II plasma, significant differences existed between the experimentally inferred CSD and the simulations from several available codes.

Because inaccuracies in the calculated cross sections will introduce errors in the inferred CSD, the question arises how good are the calculated excitation cross sections and how large are the uncertainties. Accurate measurements of the cross sections will reduce this uncertainty. To this end, we have started measurements of the cross sections for the 3d → 4f and 3d → 5f excitations in Ni- to Ga-like Au from EBIT-I plasmas. Here we present the measurement of the $3d_{3/2} \rightarrow 5f_{5/2}$ transitions in Au^{50+} Cu-like. The experimentally determined cross sections are compared with the calculated cross sections from HULLAC, the Flexible Atomic Code (FAC) [6] and the Distorted Wave Code (DWS) [7].

2. Plasmas at the Livermore electron beam ion trap

The gold plasmas for the measurements were created in the Livermore electron beam ion trap EBIT-I [8,9]. Plasmas having a monoenergetic electron beam with energies, E_{beam}, of 2.92, 3.53 and 4.54 and 5.54 ± 0.04 keV were utilized for the cross section measurements. The electron beam had a Gaussian electron energy distribution with a full width half maximum of ≈50 eV. The data presented here were taken by using two different trapping cycles. The first had a single beam energy. The second started at a lower energy (e.g. 2.92 keV) for 43 ms and then switched to a higher energy (e.g. 5.54 keV) for 7 ms. The lower beam energy created the ions of interest. The higher beam energy excited the transitions necessary for the cross section measurements. Each trapping cycle condition was repeated continuously for 8 to 12 s before the trap was emptied. Each experimental condition required repeating the trapping cycle at the same conditions for ≈12 h to record sufficient signal in the weak radiative recombination (RR) emission. Details of the experimental conditions can be found in [5,10,11].

The GSFC microcalorimeter (XRS) [12,13] at Livermore recorded the collisionally excited gold lines from the 4f → 3d and 5f → 3d X-ray transitions between 2.0 and 4.0 keV and the RR features of Ni recombining into Cu, Cu recombining into Zn, etc., from 5.0 to 8.0 keV. A sample raw spectrum is shown in Fig. 1 for a plasma having $E_{beam} = 4.54$ keV. The XRS detector head consisted of an array of 30 active ion-implanted thermistors with a 8.5 μm thick HgTe photon absorber. The thermistors directly measured the temperature change of a single photon absorbed by the HgTe absorber which was cooled to 59 mK. The maximum count rate was limited to ≈100 counts per second across the entire array. The spectral resolution was ≈12 eV across the entire spectral range for these measurements.

3. Cross section calculations

HULLAC [3], FAC [6] and DWS [7] were used to calculate the electron impact collisional cross