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DIELECTRONIC RECOMBINATION MEASUREMENTS OF IRON M-SHELL IONS MOTIVATED BY ACTIVE GALACTIC NUCLEI X-RAY ABSORPTION FEATURES

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Abstract. XMM-Newton and Chandra observations of active galactic nuclei (AGN) show rich spectra of X-ray absorption lines. These observations have detected a broad unresolved transition array (UTA) between 15-17 Å. This is attributed to inner-shell photoexcitation of M-shell iron ions. Modeling these UTA features is currently limited by uncertainties in the low-temperature dielectronic recombination (DR) data for M-shell iron. In order to resolve this issue, and to provide reliable iron M-shell DR data for plasma modeling, we are carrying out a series of laboratory measurements using the heavy-ion Test Storage Ring (TSR) at the Max-Plank-Institute for Nuclear Physics in Heidelberg, Germany. Currently, laboratory measurements of low temperature DR can only be performed at storage rings. We use the DR data obtained at TSR, to calculate rate coefficients for plasma modeling and to benchmark theoretical DR calculations. At temperatures where these ions are predicted to form in photoionized gas, we find a significant discrepancy between our experimental results and previously recommended DR rate coefficients. Here we report our recent experimental results for DR of Mg-like Fe XV forming Al-like Fe XIV.

1. INTRODUCTION

A new absorption feature between 15-17 Å has been detected in recent Chandra and XMM Newton X-ray observations of active galactic nuclei (AGNs). This has been identified as an unresolved transition array (UTA) due mainly to 2p → 3d inner shell absorption in M-shell iron ions. AGN photoionization models generally match spectral features from abundant second and third row elements but over-predict the average iron ionization stage derived from these UTAs. This is believed to be due to an underestimation of the relevant low temperature dielectronic recombination (DR) rate coefficients for M-shell iron (Netzer 2004; Kraemer et al. 2004). To address this issue we have initiated a series of laboratory DR measurements for iron M-shell ions. Here we report our recent progress.

DR is a two-step recombination process which begins when a free electron collides with an ion, collisionally excites a bound electron in the target, and is simultaneously captured in the Rydberg level n. The electron excitation can be labeled $Nl_j \rightarrow N'l'_{j'}$ where N is the principal quantum number of the core electron, l its orbital angular momentum, and j its total angular momentum. The resulting doubly-excited state lies in the continuum of the recombined system. This intermediate state can either autoionize (the time reverse of the capture process) or decay by emitting a photon. DR is complete when the intermediate state emits a photon, thereby reducing the total energy of the system to below the ionization threshold of the recombined system.

2. HEAVY ION STORAGE RING EXPERIMENTS

At the Test Storage Ring (TSR) of the Max-Plank-Institute for Nuclear Physics in Heidelberg, Germany, electron-ion collision experiments are performed using the merged electron-ion beams technique. Measurements can be carried out for most ions of the cosmically abundant elements H, He, C, N, O, Ne, Na, Mg, Al, Si, S, Ar, Ca, Fe, and Ni. Ions are injected into the ring, stored, and their initial energy spread is reduced using electron cooling. The electrons and ions are merged over a distance of 1.5 m. After cooling, electrons and ions possess the same relative velocity. In contrast to previous experiments, where the electron beam of the cooler was also used as an electron target for recombination experiments, in the present experiments a newly installed separate electron beam (Sprenger et al., 2004) was used. This additional electron beam is hereafter denoted as the electron target.

For the DR measurements the electron energy of the electron target beam was alternatingly chopped between measurement and reference energies by switching the acceleration voltage for the target electron beam accordingly. The number of recombined ions is recorded as a function of the corresponding relative energy. The measured recombination signal, normalized to the primary electron and ion beam intensities, represents the DR cross section times the relative velocity averaged over the relative velocity spread between the electrons and ions (i.e., a merged-beams rate coefficient). There are advantages when a separate electron target is used for recombination measurements. First, the electron cooler can be used continuously for the cooling of the ion beam. Thus, the low velocity and spatial spread of the ion beam is maintained at all times. Second, the electron target was specifically designed for providing an electron beam with a very low initial energy spread (Sprenger et al., 2004). Both of these results in a higher experimental resolving power in the present measurement as compared to previous measurements with the electron cooler.

3. RECENT LABORATORY RESULTS

As an example of our recent results, the measured merged-beams dielectronic recombination rate coefficient for Fe XV forming Fe XIV via $\Delta N = 0$ core electron

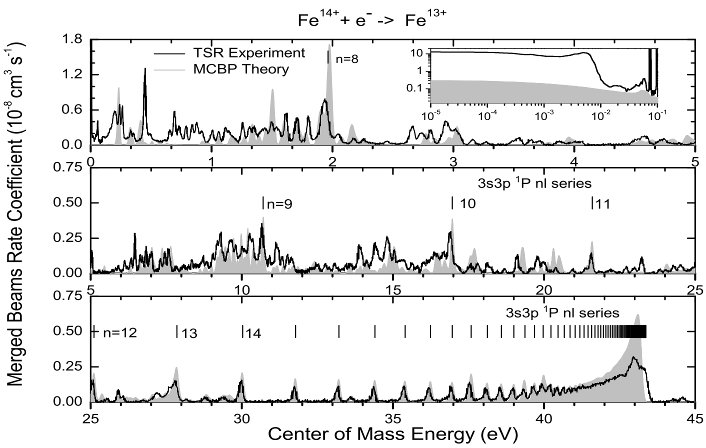

Figure 1: Measured DR resonance spectrum for Fe^{14+} forming Fe^{13+} via $\Delta N = 0$ core electron excitations (thick solid curve). The energy range spans from zero relative energy up to the $3s3p(^1P_1)nl$ DR series limit at 43.6 eV. The gray shaded curve is our calculated multiconfiguration Breit-Pauli (MCBP) results for ground state Fe^{14+}.

excitations (Lukic et al. 2007) is shown in Fig.1 The energy range spans from zero relative energy up to the $3s3p(^1P_1)nl$ DR series limit at 43.6 eV. This exceedingly rich resonance structure shows the importance of DR laboratory measurements and has triggered new theoretical studies. We have convolved our merged-beams DR data with a Maxwellian energy distribution to produce a plasma rate coefficient. As detailed by Schippers et al. (2004), there are three issues in deriving the cross section that require special consideration: the experimental energy spread, the recombination rate enhancement at low energies, and field ionization of high Rydberg states in the storage-ring bending magnets.

In Fig. 2 we compare our experimentally-derived plasma recombination rate coefficient with the DR rate coefficient of Arnaud & Raymond (1992). In the temperature range where Fe XV is expected to form in a photoionized plasma (Kallman & Bautista 2001), the experimentally-derived plasma rate coefficient is several orders of magnitude larger than the presently available theoretical DR data of Arnaud & Raymond (1992). In order to improve agreement between AGN models and observations Netzer (2004) arbitrarily increased the low temperature DR rate coefficient for all the M-shell iron ions. Our experimentally derived rate for Fe XV is still about an order of magnitude larger than his deliberate modification of the theoretical DR data. The estimated rate coefficient of Kreamer at al. (2004) is a factor of over three times smaller. As a reference we show the recommended RR rate coefficient of Arnaud & Raymond (1992). The RR contribution is insignificant relative to DR at all temperatures considered here.

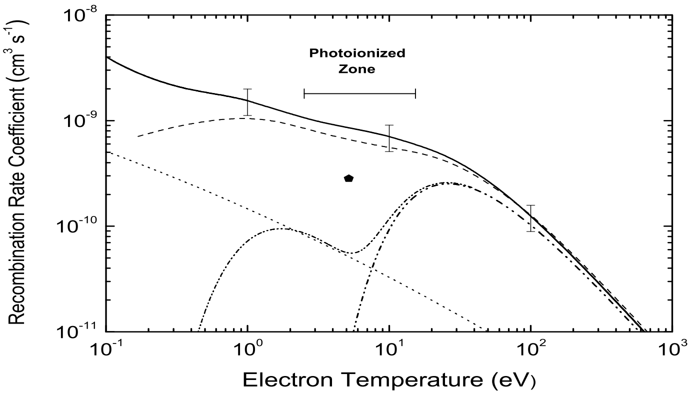

Figure 2: Maxwellian-averaged $3 \rightarrow 3$ DR rate coefficients for Fe XV forming Fe XIV. The thick solid curve represents our experimentally derived rate coefficient plus the theoretical estimate for unmeasured contributions due to capture into states with $n >$ 80. The error bars show our estimated total experimental uncertainty of ±29%. Also shown is the recommended DR rate coefficient of Arnaud & Raymond (1992; thick dot-dot-dashed curve) and its modification by Netzer (2004; thin dot-dot-dashed curve). The filled pentagon at 5.2 eV represents the estimated rate coefficient from Kraemer et al. (2004). The dashed curve shows our MCBP calculations for $n_{max} = 1000$. As a reference we show the recommended RR rate coefficient of Arnaud & Raymond (1992; dotted curve). The horizontal line shows the temperature range over which Fe XV is predicted to form in photoionized gas (Kallman & Bautista 2001).

4. CONCLUSION

We are in the process of carrying out DR measurements for other M-shell iron ions. As they become available, we recommend that these experimentally-derived plasma rate coefficients be incorporated into future models of AGN spectra in order to arrive at more reliable results.

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