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Dielectronic Recombination In Active Galactic Nuclei

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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 $\sim$ 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. Here we report our recent experimental results for DR of Fe XIV forming Fe XIII.

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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 (Fe III - XVI). 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 begins when a free electron collides with an ion, excites a bound electron in the target, and is simultaneously captured. 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. Energy conservation requires that the kinetic energy of the incident electron E_k and the binding energy released E_b sum up to the excitation energy of the core electron ΔE in the presence of the captured electron, i.e., $\Delta E = E_k + E_b$. Because E_b and ΔE are quantized, the kinetic energies at which DR can go forward is also quantized. Thus DR is a resonant process, as can be seen in Fig. 1a.

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. For the DR measurements, the electron beam is detuned from cooling conditions and the number of recombined ions is recorded as a function of the corresponding relative energy. The recombination products are separated from the primary beam using the first bending magnet in the ring after the electrons and ions are demerged. The recombined ions are stopped and counted using a particle detector. 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). Further details can be found in Schmidt et al. (2006) and references therein.

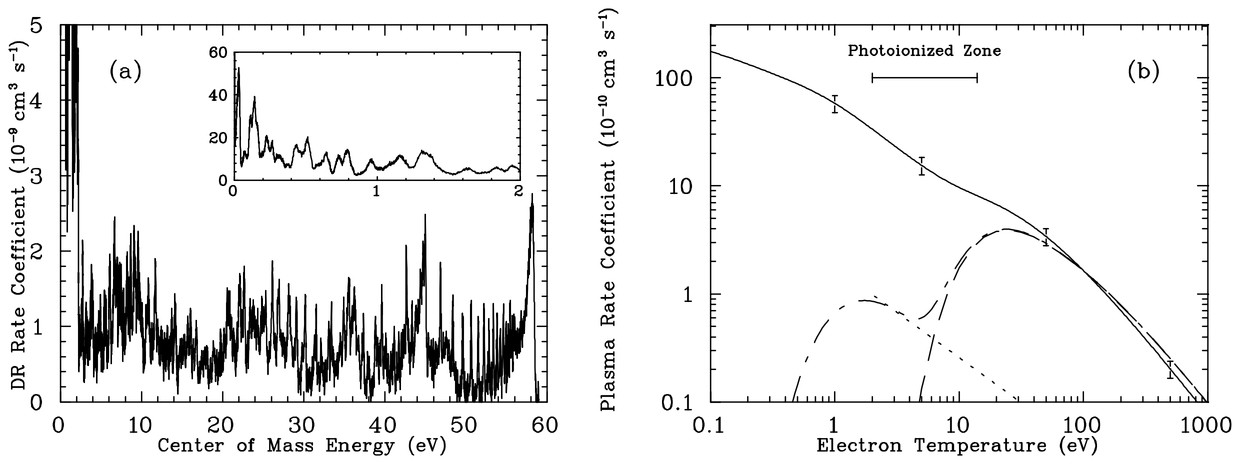

Fig. 1.— (a) Measured TSR DR resonance spectrum for Fe XIV forming Fe XIII via $\Delta n = 0$ core electron excitations. (b) DR plasma rate coefficient for Fe XIV forming Fe XIII via $\Delta n = 0$ core electron excitations. The solid curve is our experimentally-derived plasma rate coefficient. The experimental uncertainty is estimated to be $\pm 18\%$. Also shown are the recommended DR data of Arnaud & Raymond (1992; dashed curve), the deliberate modification of the DR data by Netzer (2004; dash-dotted curve), and the recommended RR data of Woods et al. (1981; dotted curve). The temperature range where Fe XIV is predicted to form in a photoionized plasma (Kallman & Bautista 2001) is shown by the horizontal line which shows where the Fe XIV fractional abundance exceeds 10% of its peak value.

3. Recent Laboratory Results

As an example of our recent results, we show in Fig. 1a the measured DR resonance spectrum for Fe XIV forming Fe XIII via $\Delta n = 0$ core electron excitations (Schmidt et al. 2006). The energy range spans from zero relative energy up to the $3s^2 3d(^2D)$ DR series limit at ~ 58.9 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 coeficient. In Fig. 1b we compare our experimentally-derived plasma recombination rate coefficient with the DR rate coefficient of Arnaud & Raymond (1992). In the temperature range where Fe XIV 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). Netzer (2004) in order to improve agreement between AGN models and observations arbitrarily increased the low temperature DR rate coefficient for all the M-shell iron ions. Our experimentally-derived rate for Fe XIV is still about an order of magnitude larger than his deliberate modification of the theoretical DR data. Also shown in Fig. 1b is the the recommended radiative recombination (RR) rate coefficient of Woods et al. (1981). The RR contribution is insignificant relative to DR at all temperatures considered here.

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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