I R A M P
15(2), July 2024, pp. 85-87

ISSN: 2229-39-44

Dielectronic Recombination in Pb^{78+} Near the Ionization Threshold

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ABSTRACT: Semi-relativistic perturbation theory calculations are carried out for dielectronic recombination cross sections involving the $1s^22s2pnl$ subshells of Pb^{77+} as found above the Pb^{78+} $1s^22s^2$ ionization threshold. We included levels in the $1s^22s2pnl$ subshells of Pb^{77+} for n = 7 - 20 and l = 0 - 4. Theoretical dielectronic recombination cross sections are presented for the $1s^22s2p19l$ subshells of Pb^{77+} to compare with planned experimental dielectronic recombination measurements at CRYRING.

1. INTRODUCTION

Resonance states near the ionization threshold may contribute to dielectronic recombination in astrophysical and laboratory plasmas[1, 2]. Recently dielectronic recombination has been observed in electron collisions with highly charged atomic ions in the synchrotron storage ring CRYRING[3] in the FAIR complex in Darmstadt, Germany[4].

In this paper semi-relativistic perturbation theory calculations are made for dielectronic recombination cross sections involving the $1s^22s2pnl$ subshells of Pb^{77+} lying above the the Pb^{78+} $1s^22s^2$ ionization threshold. Theoretical dielectronic recombination cross sections are presented for the $1s^22s2p19l$ subshells of Pb^{77+} to compare with future experimental dielectronic recombination measurements[5].

The rest of the paper is structured as follows: in section 2 we review theory, in section 3 we present results, and in section we give a brief summary. Unless otherwise stated, all quantities are given in atomic units.

2. THEORY

The dielectronic recombination cross section for an *N* electron ground level with statistical weight g_i combining into an (N+1) electron doubly excited level with statistical weight g_j is given by[6]:

$$\sigma_{i\to j} = \frac{\pi^2}{E_c \Delta E_c}\frac{g_j}{2g_i}A_a(j\to i)B_j \tag{1}$$

where E_c is the energy of the continuum electron and ΔE_c is bin width. The branching ratio for radiative stabilization is given by:

$$B_j = \frac{\sum_n A_r(j\to n)}{\sum_k A_a(j\to k) + \sum_n A_r(j\to n)} \ , \tag{2}$$

where the radiative rate is given by:

$$A_r(j\to n) = 2\pi| < n|D|j > |^2 \ , \tag{3}$$

where D is the dipole radiation field operator, and the autoionization rate is given by:

$$A_a(j \to n) = 4/k| < n|V|j > |^2 \ , \tag{4}$$

where V is the electrostatic interaction between electrons. The electron linear momentum is taken as $k = \sqrt{2|E_{jn}|}$ for the evaluation of the autoionization rates.

Dielectronic recombination cross sections are calculated using a configuration-average distorted-wave (CADW) approximation[7]. The bound state wavefunctions and energies employed in the CADW calculations are calculated in a semi-relativistic Hartree-Fock approximation[8].

3. PLANNED EXPERIMENT

The CRYRING[3] in the FAIR complex in Darmstadt, Germany[4] is a magnetic heavy ion storage ring. Ions are kept in orbit with 12 dipole magnets connected by 12 straight sections. There are 6 straight sections that implement beam focussing, while the additional 6 straight sections are interleaved that provide ion injection, electron cooling, ion extraction, and diagnostics. Heavy metals like Ta, W, Pb, and U are studied at CRYRING to better understand their atomic collision properties.

4. THEORETICAL RESULTS

Semi-relativistic autoionization rate calculations were carried out for the 70 $1s^2 2s2pnl$ n = 7 - 20 l = 0 - 4 subshells of Pb^{77+} that lie above the $1s^2 2s^2$ ionization threshold of Pb^{78+}. Semi-relativistic radiative rate calculations were carried out for the decay of the 70 subshells to the 17 $1s^2 2s2pnl$ n = 3 - 6 l = 0 - 4 subshells of Pb^{77+} that lie below the $1s^2 2s^2$ ionization threshold of Pb^{78+}. Using a bin width of ΔE_c = 5.44 eV the cross sections are presented in Figure 1 over an energy range from 0.0 eV to 2000.0 eV. Simple extrapolations were made to n = 1000 and l = 12 for the cross sections.

Semi-relativistic radiative rate calculations were also carried out for the decay of the 70 subshells to the 17 $1s^2 2s2pnl$ n = 3 - 6 l = 0 - 4 subshells and the 70 $1s^2 2s^2 nl$ n = 7 - 20 l = 0 - 4 subshells of Pb^{77+} that lie below the $1s^2 2s^2$ ionization threshold of Pb^{78+}. With only a 2% increase in the radiative rates there was little change in the cross sections as presented in Figure 1.

To compare with future experiments semi-relativistic autoionization rate calculations were carried out for the 5 $1s^2 2s2p19l$ l = 0 - 4 subshells of Pb^{77+}. Semi-relativistic radiative rate calculations were carried out for the decay of the 5 subshells to the 17 $1s^2 2s2pnl$ n = 3 - 6 l = 0 - 4 subshells of Pb^{77+} that lie below the $1s^2 2s^2$ ionization threshold of Pb^{78+}. Using a bin width of ΔE_c = 0.27 eV the cross sections are presented in Figure 2 over an energy range from 1670.0 eV to 1690.0 eV.

5. SUMMARY

Semi-relativistic perturbation theory has been applied to calculate the dielectronic recombination in Pb^{78+}. To compare with future experiments, semi-relativistic dielectronic recombination cross sections in Pb^{78+} near the ionization potential involving the Pb^{77+} $1s^2 2s2pnl$ n = 19 l = 0 - 4 states were calculated. In the future we plan to make more dielectronic recombination cross section calculations for highly charged atomic ions to compare with experiment.

Acknowledgments

This work was supported in part by grants from the US National Aeronautics and Space Administration and the US Department of Energy. Computational work was carried out at the National Energy Research Scientific Computing Center (NERSC) in Berkeley, California.

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