

**Conspicuous QED Effects in the Positron-Impact Ionization of  $U^{91+}$** Hsiao-Ling Sun,<sup>1</sup> Ju-Tang Hsiao,<sup>2</sup> Sheng-Fang Lin,<sup>1</sup> and Keh-Ning Huang<sup>1,3</sup><sup>1</sup>*Institute of Atomic and Molecular Sciences, Academia Sinica  
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The positron-impact ionization of  $U^{91+}$  is studied in the two-potential distorted-wave approximation in QED theory. The effects of the transverse-photon interactions between charges as well as vacuum polarization are analyzed. QED effects conspicuously enhance the cross section at all incident energies.

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**I. INTRODUCTION**

Impact ionization processes of atoms and ions by charged particles are fundamental for understanding the collision mechanisms and atomic structure. Knowledge of ionization cross sections has wide applications for the understanding of physical phenomena in astrophysics, plasma physics, and radiation physics. In particular, information on the ionization cross sections of highly charged ions by charged particles is important in the study of high-temperature plasmas. However, the inherent difficulties are in obtaining extensive data on the ionization cross sections of highly charged ions in both theory and experiment.

Electron-impact ionization cross sections for  $U^{91+}$ - $U^{90+}$  were first measured by Claytor *et al.* [1] at 222 keV electron energy in the heavy-ion channeling experiment. Electron-impact ionization cross sections for some intermediate- and high- $Z$  hydrogenlike ions were obtained by Marrs *et al.* [2, 3], O'Rourke *et al.* [4], and Watanabe *et al.* [5] in electron-beam ion trap (EBIT) experiments. Pindzola *et al.* [6] calculated the direct electron-impact-ionization cross sections for  $U^{91+}$  and  $U^{90+}$  in lowest-order quantum electrodynamics (QED), and Moores and Pindzola [7] evaluated the cross sections of electron-impact ionization for hydrogenic ions with nuclear charge  $Z$  between 26 and 92 using a relativistic distorted-wave method. Later, Pindzola *et al.* [8] calculated the electron-impact ionization for  $U^{91+}$  including exchange effects. Effects of the transverse-photon interaction were investigated by Moores and Reed [9] in relativistic distorted-wave calculations for high- $Z$  hydrogenlike ions. The ionization cross sections of  $1s$  for a variety of ions with one to four bound electrons and nuclear charge  $Z$  in the range of 10 to 92 were studied by Fontes *et al.* [10] within the relativistic distorted-wave approximation with the transverse-photon interaction. For positron-impact ionization, on the other hand, only that for  $U^{90+}$  has been