

Extreme Atomic Physics: *Interspecies Radiative Transition* in Warm and Superdense Plasma Mixtures

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Superdense plasmas, having mass densities ranging from tens to over millions of grams per cubic centimeter, widely exist in planetary interiors and astrophysical objects such as brown-dwarf cores and white dwarfs. How atoms, the fundamental “building blocks” of matter, behave under such extreme density conditions is not yet well understood, even in single-species plasmas. Seeking a deeper understanding of atomic physics in superdense plasmas is now becoming possible because these extreme states of matter can be created and probed in the laboratory by using powerful lasers or pulsed-power machines. Here, we have applied the thermal density functional theory (DFT) to investigate the radiation spectra of superdense iron–zinc (Fe–Zn) plasma mixtures at mass densities of $\rho = 250$ to 2000 g/cm^3 and temperatures of $kT = 50$ to 100 eV , accessible by imploding double-shell targets. Our *ab initio* calculations reveal two *new* and uniquely extreme atomic physics phenomena—firstly, an *interspecies radiative transition* (IRT); and, secondly, the *breaking down of the dipole-selection rule* for radiative transitions in isolated atoms. Our *first-principles* DFT calculations predict that for superdense plasma mixtures, both interatomic radiative transitions and dipole-forbidden intra-atomic transitions can become comparable to the normal intra-atomic K_α -emission signal because of the superdense environment.

For a warm and superdense Fe–Zn plasma of $\rho = 1000 \text{ g/cm}^3$ and $kT = 50 \text{ eV}$ with $1s$ vacancies of both Fe and Zn ions, the calculated emission coefficient as a function of photon energy is shown by the solid red line in Fig. 1. To identify the IRT fea-

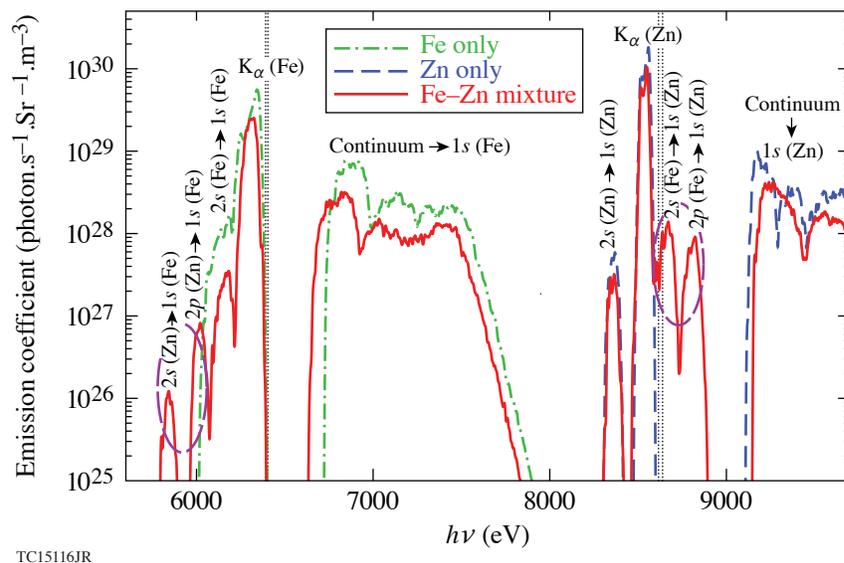


Figure 1

The emission spectra of superdense plasmas of Fe only, Zn only, and a Fe–Zn mixture having $1s$ vacancy at $\rho = 1000 \text{ g/cm}^3$ and $kT = 50 \text{ eV}$, calculated by DFT using *ABINIT*.

tures, we also plotted the spectra of single-species Fe (dashed–dotted green line) and Zn (dashed blue line) plasmas in Fig. 1, respectively. Again, these pure plasmas have the same density and temperature conditions as those of the Fe–Zn mixture. From Fig. 1, one can clearly see that four new spectral peaks appear in the superdense Fe–Zn plasma mixtures (highlighted by the dashed ellipse): the two new emission lines located at $h\nu \approx 8666$ eV and $h\nu \approx 8816$ eV correspond to transitions from the $2s$ and $2p$ states of the Fe ion to the $1s$ hole of the Zn ion, while the other two new peaks at $h\nu \approx 5838$ eV and $h\nu \approx 6012$ eV belong to radiative transitions of $2s/2p$ electrons of the Zn ion to the $1s$ vacancy of Fe. Besides these new interatomic K_α emissions, the dominant intra-atomic K_α lines for each species are, of course, present in the emission spectra in Fig. 1. The vertical dotted black lines mark the normal intra-atomic K_α locations of ambient Fe and Zn, respectively. The red shift of the intra-atomic K_α line is caused by the increased electron screening resulting from the dense plasma environment. In addition, the intra-atomic $2s \rightarrow 1s$ transitions for each species, although being about three orders of magnitude weaker than the normal intra-atomic K_α lines, also appear as a consequence of the breaking down of the dipole-selection rule due to the density-induced distortion of $2s$ states. Finally, the continuum emissions from free electrons filling $1s$ holes of Fe and Zn ions are also present in the emission spectra, as expected (shown by Fig. 1).

Interspecies and dipole-forbidden radiative transitions were not previously considered for emissivity/opacity calculations in extremely dense plasma mixtures, directly impacting our understanding of astrophysical objects and, more generally, of the extreme atomic physics that can occur in plasma mixtures at very high energy densities.

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