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ERROR ESTIMATES FOR EMISSION LINES IN THE HYDROGEN AND HELIUM ISOSEQUENCES

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RESUMEN

Las líneas de emisión de los iones de las secuencias del hidrógeno y el helio son las más intensas en los espectros de rayos-X y pronto serán usadas para derivar temperaturas, densidades y estados de equilibrio en plasmas excitados colisionalmente. Hemos creado un nuevo código, *APEC*, que calcula las líneas de emisión de estos plasmas usando las tasas de excitación directas de electrones y protones y las tasas de recombinación radiativas y dielectrónicas. Mostramos las diferencias en emisividad calculadas por varios códigos para algunas líneas intensas de O VII y Fe XXVI, donde la excitación directa es el mecanismo principal. Las diferencias son en parte debidas a simples diferencias entre los códigos, pero la razón principal es que todavía hacen falta determinaciones teóricas y experimentales de las tasas atómicas. Aún existen grandes diferencias ($\sim 50\%$) en las tasas de excitación de iones hydrogenoides.

ABSTRACT

Emission lines from hydrogen and helium isosequence are among the strongest in X-ray spectra; they will soon be used to measure the temperature, density, and equilibrium state of collisionally excited, astrophysical plasmas. We have created a new plasma code, *APEC*, which calculates the emission from such a plasma. *APEC* calculates the line emission from the direct electron and proton excitation rate and the radiative and dielectronic recombination rate. We show how different collisional plasma codes give varying emissivities for some strong lines of O VII and Fe XXVI, where direct excitation is the primary effect. This variation is partly due to simple differences in the plasma code. However, the primary reason is that much work remains to be done on experimental and theoretical calculations of the atomic rates. Large ($\sim 50\%$) differences exist even for excitation rates for hydrogenic ions.

Key Words: **ATOMIC DATA — ATOMIC PROCESSES — LINE: FORMATION**

1. INTRODUCTION

We have developed a program which will calculate the line and continuum emission from a hot, collisionally ionized plasma, similar to the Raymond & Smith (1977; 1993 update, hereafter RS93), SPEX (Kaastra, Mewe, & Nieuwenhuijzen 1996), or Chianti (Dere et al. 1997) codes. Our project is a successor to the RS93 plasma code, but unlike that code we separate the problem into two distinct parts:

- *APEC*: the Astrophysical Plasma Emission Code. *APEC* calculates transition rates, performs a matrix inversion and creates model spectra as a function of temperature and ionization state.

- *APED*: the Astrophysical Plasma Emission Database. The database consists of a set of FITS format files containing wavelengths, oscillator strengths, fits to the collisional excitation rate coefficients, and other data.

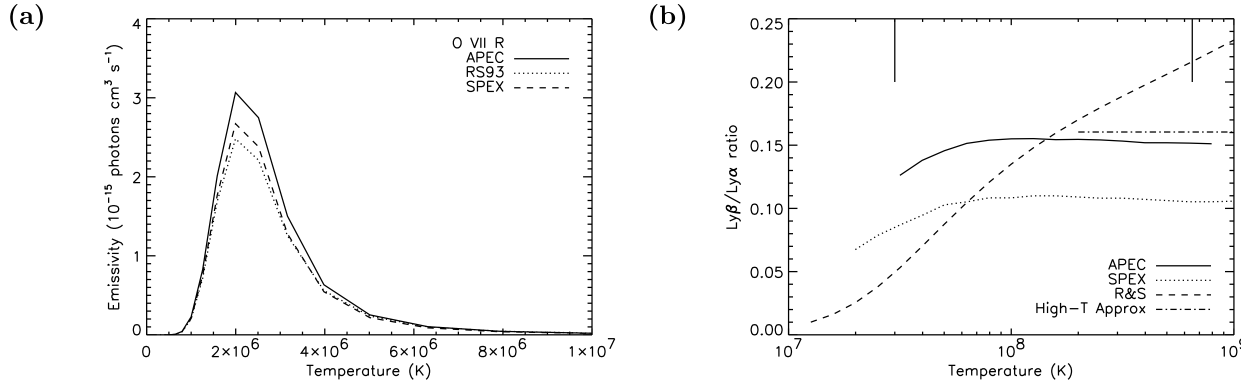

Fig. 1. *(a)* The O VII resonance line ($1s2p^1P_1 \rightarrow 1s^{21}S_0$) emissivity, as calculated by *APEC*, SPEX, and the RS93 code. At peak, the differences are $\sim 25\%$. *(b)* The Fe XXVI Lyβ to Lyα photon emissivity ratio, as a function of temperature. Despite the relative simplicity of this ion, the calculated rates have a variance of $\sim 25\%$. The vertical lines mark where the Fe XXVI relative abundance is $> 10\%$.

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There are many advantages to this approach. The code, once complete, will remain stable, while the database can be updated as new atomic rates become available. Different atomic rates can be compared using *APEC* to calculate their respective emission line strengths and ratios to see if the difference is observable. Also, if available, the database will contain error estimates for the wavelengths and rates. *APEC* can then use these to estimate the errors on both the emission intensities using a monte-carlo approach or other methods. A website has been created **http://hea-www.harvard.edu/APEC** which contains documentation and output from the *APEC*/*APED* combination, along with large portions of the *APED* database.

In this paper, we focus on two isosequences, the hydrogenic and helium-like ions, represented by Fe XXVI and O VII, respectively. Calculating the emission from these ions in a collisionally-ionized plasma suffers due to the lack of theoretical or measured collision strengths and dielectronic satellite line rates to high principal quantum numbers. We compare calculations from SPEX v1.10, RS93, and *APEC* for these ions, and show the variance in different calculations of the underlying rates.

2. LINE EMISSION

Figure 1 compares the predicted emissivity for the O VII resonance line at 21.60 Å, and the Fe XXVI Lyα (1.78 Å) to Lyβ (1.50 Å) ratio. These are among the strongest lines in thermal X-ray plasmas due to the relatively high abundance of oxygen and iron, and the wide range of temperatures over which hydrogenic and helium-like ions are found. At low densities, direct electron excitation from the ground state of the O VII ion forms the O VII resonance line emission. This is not the case for all transitions; cascades and recombination create most of the O VII forbidden line emission, for example. The variation among the three codes, therefore, must be due to differences in the ionization balance and/or the collisional excitation rate.

In the case of the Fe XXVI ion, we can remove the dependence on the ionization balance by comparing the ratio of the Lyβ ($n = 3 \rightarrow 1$) photon emissivity to the Lyα ($n = 2 \rightarrow 1$) photon emissivity. For this comparison, we summed over the fine structure lines ($2p^2P_{1/2}$ and $2p^2P_{3/2}$ both go to $1s^2S_{1/2}$). Comparing the same three codes along with the high temperature Bethe limit (Burgess & Tully 1978), we see that there are significant ($\sim 50\%$) variations even in this simple case. Again, the primary contribution to the Lyα and Lyβ emission is direct excitation and the ionization balance. Since the latter drops out in the ratio, we should examine the excitation rate calculations.

3. ATOMIC RATE COMPARISON

Figure 2 shows the effective electronic collision strengths for Fe XXVI, from Kisielius, Berrington, & Norrington (1996)(hereafter KBN96) and from Sampson, Goett, & Clark (1983), along with the fit used by *APEC*.

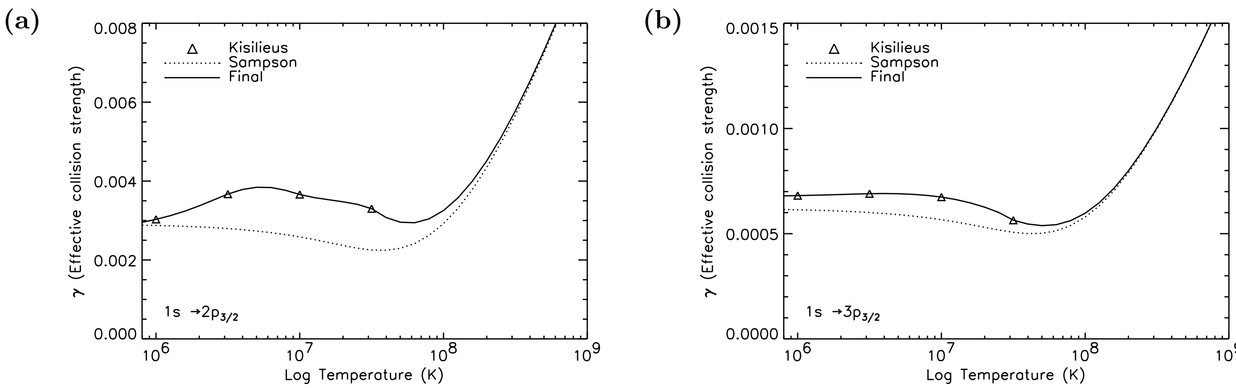

Fig. 2. *(a)* Collision strengths for Lyα from Kisielius et al. (1996) and Sampson et al. (1983). *(b)* Same, for Lyβ.

(The collision strengths or excitation rates used by RS93 and SPEX were not readily available to us.) The KBN96 calculations were done as part of the Iron Project, and used the RMATRIX code which included many resonances at low energies, which increased the overall rate at low temperatures (Hummer et al. 1993). The Sampson et al. (1983) calculation, however, used a distorted wave formulation which did not include resonances but did run to higher temperatures. However, both of these methods suffer from not considering the effect of continuum states, which for hydrogenic ions are very close to the excited states. This problem can be addressed using either the continuum close-coupling method or the R-Matrix pseudostates method, as discussed in Bray & Stelbovics (1995). However, these calculations have not been done except for very light ($Z = 1 - 4$) ions.

For *APEC*, we simply merged the two calculations of KBN96 and Sampson et al. (1983), and used a simple isosequence scaling law to generate data for the other needed ions. However, as the discrepancy between the two calculations is $\sim 50\%$, more data, especially experimental, is urgently needed. With reliable data, the hydrogenic Lyβ to Lyα ratio is a straightforward temperature diagnostic. Currently, however, an X-ray astronomer attempting to use this ratio would find the available codes more confusing than useful.

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