THEORETICAL EMISSION LINE STRENGTHS FOR NeVII
COMPOSED TO EUV SOLAR OBSERVATIONS

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Abstract. Theoretical electron-temperature-sensitive NeVII emission line ratios, calculated using accurate $R$-matrix electron impact excitation rates, are presented for $R_1 = I(895.2 \text{ Å})/I(465.2 \text{ Å})$, $R_2 = I(561.7 \text{ Å})/I(465.2 \text{ Å})$ and $R_3 = I(564.5 \text{ Å})/I(465.2 \text{ Å})$. A comparison of these with observational data for several solar features obtained with the Harvard S-055 spectrometer on board Skylab reveals good agreement between theory and experiment. This provides observational support for the accuracy of the atomic physics adopted in the calculations, and the methods employed in the derivation of the theoretical diagnostics.

1. Introduction

Emission lines arising from $\Delta n = 0$ (2–2) transitions in Be-like ions are frequently detected in the spectra of the solar transition region and corona (Widing and Feldman, 1989; Sandlin et al., 1986). These transitions may be used to infer the electron density ($N_e$) and temperature ($T_e$) of the emitting plasma through diagnostic line ratios, although to determine these reliably requires the adoption of accurate atomic data in the calculations, especially for electron impact excitation rates and $f$-values (Dufton and Kingston, 1981).

For several years we have been involved in an extensive series of Be-like ion $N_e$- and $T_e$-diagnostic calculations for solar plasmas (see Keenan, 1990, and references therein), using electron excitation rates either determined with the $R$-matrix code (Berrington et al., 1977, 1985; Berrington, 1985; Dufton, Kingston, and Scott, 1983), or interpolated from these (Keenan et al., 1986; Keenan, 1988). Very recently, Keenan, McCann, and Widing (1990) have used the atomic data of Berrington et al. (1985) for NeVII to evaluate relative populations and, hence, emission line strengths for this ion, which incorporated several improvements over the previous calculations of Dufton, Doyle, and Kingston (1979), including more accurate electron impact excitation rates and inclusion of reliable proton rates for transitions among the 2s2p $^3P$ levels (see Keenan et al., 1990, for more details). In this paper we use the Keenan et al. (1990) results to derive theoretical line ratios, and compare these with EUV solar observations from Skylab to investigate their usefulness as $T_e$-diagnostics.

2. Theoretical Ratios

The model ion adopted for NeVII has been discussed in detail by Keenan et al. (1990). Briefly, the six energetically lowest LS states were included in the calculations, namely $2s^2\,^1S$, $2s2p\,^3P,\,^1P$; $2p^2\,^3P,\,^1D$, and $^1S$, making a total of ten levels when the fine


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structure splitting in the triplet terms is included. Only collisional excitation and de-excitation by electrons and protons (the latter in the case of transitions among 2s2p^3P), and spontaneous radiative de-excitation processes were considered, and the plasma was assumed to be optically thin. Further details may be found in Keenan et al. (1990).

In Figures 1–3 we plot the theoretical ratios

\[ R_1 = \frac{I(2s^2 \, ^1S - 2s2p \, ^3P_1)}{I(2s^2 \, ^1S - 2s2p \, ^1P)} , \]

\[ R_2 = \frac{I([2\rightarrow 2] + [1\rightarrow 1])}{I(2s^2 \, ^1S - 2s2p \, ^1P)} , \]

and

\[ R_3 = \frac{I([2\rightarrow 1])}{I(2s^2 \, ^1S - 2s2p \, ^1P)} \]

as a function of electron temperature at a density of \( N_e = 10^{11} \text{ cm}^{-3} \), where we have used \([J' \rightarrow J]\) to denote a transition of the type 2s2p^3P_{J'} - 2p^2^3P_{J}. These ratios are insensitive to variations in the electron density when \( N_e \leq 3 \times 10^{11} \text{ cm}^{-3} \), and an

![Graph showing the relationship between R1/10^2 ratio and log Te](image)

Fig. 1. The theoretical NeVII emission line ratio

\[ R_1 = \frac{I(2s^2 \, ^1S - 2s2p \, ^3P_1)}{I(2s^2 \, ^1S - 2s2p \, ^1P)} = \frac{I(895.2 \text{ Å})}{I(465.2 \text{ Å})} , \]

where \( I \) is in energy units, plotted as a function of electron temperature at an electron density of \( N_e = 10^{11} \text{ cm}^{-3} \).
Fig. 2. The theoretical Ne VII emission line ratio

\[ R_2 = I(2s^2 3p^3 P_2 - 2p^2 3P_2 + 2s2p^3 P_1 - 2p^2 3P_1)/I(2s^2 1S - 2s2p 1P), \]

where \( I \) is in energy units, plotted as a function of electron temperature at an electron density of \( N_e = 10^{11} \text{ cm}^{-3} \).

inspection of the figures shows that \( R_1 - R_3 \) are, hence, potentially very useful \( T_e \)-diagnostics for all but the highest density solar features. For example, \( R_1 \) varies by a factor of 4.6 between \( \log T_e = 5.4 \) and 6.3, while \( R_2 \) changes by a factor of 2.3 over the same temperature interval.

3. Results and Discussion

The \( 2s^2 1S - 2s2p^3 P_1, [2-1], [2-2] + [1-1] \) and \( 2s^2 1S - 2s2p 1P \) transitions in Ne VII have been observed at wavelengths of 895.2 Å, 564.5 Å, 561.7 Å, and 465.2 Å, respectively, in solar emission line spectra obtained with the Harvard S-055 spectrometer on board Skylab (Doyle, 1983). This instrument, which covered the wavelength region 280–1350 Å, observed a spatial area of 5 \( \times \) 5 arc sec with a spectral resolution of approximately 1.6 Å (FWHM) using an integration time of 0.04 s and a step length of 0.2112 Å. It is discussed in detail by Reeves, Huber, and Timothy (1977) and Reeves et al. (1977).

In Table I we summarise the observed values of \( R_1 = I(895.2 \text{ Å})/I(465.2 \text{ Å}), \)
Fig. 3. The theoretical Ne vii line ratio

$$R_3 = \frac{I(2s2p \,^3P_2 - 2p^2 \,^3P_1)}{I(2s^2 \,^1S - 2s2p \,^1P)} = \frac{I(564.5 \text{ Å})}{I(465.2 \text{ Å})},$$

where $I$ is in energy units, plotted as a function of electron temperature at an electron density of $N_e = 10^{11} \text{ cm}^{-3}$.

$R_2 = \frac{I(561.7 \text{ Å})}{I(465.2 \text{ Å})}$, and $R_3 = \frac{I(564.5 \text{ Å})}{I(465.2 \text{ Å})}$ for several solar features, along with the sources of the data. All these events have electron densities $N_e < 3 \times 10^{11} \text{ cm}^{-3}$ (see individual references in Table I), so that the $R_1 - R_3$ line ratios are only sensitive to variations in electron temperature. Also shown in the table are the electron temperatures derived from these ratios using the calculations in Figures 1–3. An inspection of the table reveals that the values of $T_e$ determined from $R_1 - R_3$ are generally compatible, with discrepancies of typically 0.3 dex. This corresponds to only a $\sim 20\%$ change in $R_2$ or $R_3$, which is well within the estimated errors in the observational data ($\sim 30\%$; Noyes et al., 1985). Furthermore, the derived electron temperatures are in excellent agreement with that of maximum Ne vii fractional abundance in ionisation equilibrium, $\log T_{\text{max}} = 5.7$ (Arnaud and Rothenflug, 1985), with differences averaging only 0.2 dex. This provides observational support for the accuracy of the atomic data adopted in the calculations, and the methods employed in the determination of the theoretical line ratios.
## TABLE I

Observed NeVII emission line ratios and the derived logarithmic electron temperatures

<table>
<thead>
<tr>
<th>Solar feature</th>
<th>$R_1$</th>
<th>$R_2$</th>
<th>$R_3$</th>
<th>Source</th>
<th>$\log T_e(R_1)$</th>
<th>$\log T_e(R_2)$</th>
<th>$\log T_e(R_3)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiet Sun</td>
<td>0.045</td>
<td>-</td>
<td>-</td>
<td>Vernazza and Reeves (1978)</td>
<td>5.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sunspot</td>
<td>0.035</td>
<td>-</td>
<td>0.012</td>
<td>Noyes et al. (1985)</td>
<td>5.9</td>
<td>-</td>
<td>5.6</td>
</tr>
<tr>
<td>Coronal hole</td>
<td>0.033</td>
<td>-</td>
<td>-</td>
<td>Vernazza and Reeves (1978)</td>
<td>5.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Active region</td>
<td>0.030</td>
<td>-</td>
<td>-</td>
<td>Doyle, Mason, and Vernazza (1985)</td>
<td>5.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7 September, 1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flare 12:55 UT</td>
<td>0.028</td>
<td>0.045</td>
<td>0.010</td>
<td>Doyle (1983)</td>
<td>6.0</td>
<td>5.6</td>
<td>5.9</td>
</tr>
<tr>
<td>7 September, 1973</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Flare 14:03 UT</td>
<td>-</td>
<td>0.031</td>
<td>0.010</td>
<td>Doyle (1983)</td>
<td>-</td>
<td>6.0</td>
<td>5.9</td>
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<tr>
<td>7 September, 1973</td>
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<tr>
<td>Flare 15:52 UT</td>
<td>0.058</td>
<td>0.047</td>
<td>0.011</td>
<td>Doyle (1983)</td>
<td>5.6</td>
<td>5.4</td>
<td>5.8</td>
</tr>
</tbody>
</table>
4. Conclusions

There are two principal solutions:

(1) Theoretical Ne VII emission line ratios \( R_1 = I(895.2 \, \text{Å})/I(465.2 \, \text{Å}), \) \( R_2 = I(561.7 \, \text{Å})/I(465.2 \, \text{Å}), \) and \( R_3 = I(564.5 \, \text{Å})/I(465.2 \, \text{Å}), \) derived using accurate electron impact excitation rates calculated with the \( R \)-matrix code by Berrington et al. (1985), are found to vary significantly with electron temperature, but to be insensitive to changes in the electron density when \( N_e \leq 3 \times 10^{11} \, \text{cm}^{-3} \). Hence, they are potentially useful \( T_e \)-diagnostics for all but the highest density solar features.

(2) Electron temperatures derived from the observed value of \( R_1 - R_3 \) for several solar features obtained with the Harvard S-055 spectrometer on board Skylab are compatible, with discrepancies of typically 0.3 dex. Furthermore, they are in good agreement with the temperature of maximum Ne VII fractional abundance in ionisation equilibrium, \( \log T_{\text{max}} = 5.7 \) (Arnaud and Rothenflug, 1985), with differences averaging only 0.2 dex. This provides experimental support for the accuracy of the atomic data adopted in the calculations, and the methods employed in the derivation of the theoretical diagnostics.

Acknowledgement

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References