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Solar plasma line diagnostics from Ne IV, Na V and A1 VII ions

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Abstract. We analyse the EUV emission lines from Ne IV, Na V and A1 VII ions and study their application as a diagnostic tool for solar plasma. We consider the 13 level atomic model for these ions and take account of the physical processes in the formation of emission lines relevant to solar atmosphere to set up statistical equilibrium equations for each level. We then study the line emissivity as a function of plasma density and temperature. We discuss the application of these emission lines as a plasma diagnostic making use of theoretical model and available observations made from space. We also discuss the theoretical line ratios for their applications in view of the current observations to be available from the CDS and the SUMER instruments on the spacecraft SOHO.

1. Introduction

EUV emission lines from the solar and astrophysical plasmas have been the subject of extensive study since the advent of space research. The solar chromosphere-corona transition region represents, essentially a low density high temperature plasma and under this condition, the elements are multiply ionised and are at various stages of ionisation. The radiation emitted by these ions lies in the EUV range and carries the information on the emitting regions. EUV emission lines from ions of nitrogen sequence have been used for estimating densities in the solar atmosphere (Feldman et al., 1978; Bhatia and Mason, 1980; Dwivedi and Raju, 1988; Raju and Dwivedi, 1990; Dwivedi, 1991). The EUV emission lines from these ions have been observed in different solar regions (Dupree et al. 1973; Behring et al. 1976; Sandlin et al., 1977; Dere, 1978; Vernazza and Reeves, 1978).

However, nitrogen like Ne IV, Na V and A1 VII solar ions have not received much attention. Raju and Dwivedi (1990) have studied them making use of spherically symmetric model for the quiet Sun. In view of the current high quality EUV data to be available from the CDS and SUMER instruments, we have carried out an extensive analysis of these ions for solar plasma diagnostics. As shown in Figure 1, Ne IV, Na V and A1 VII ions have their maximum fractional abundances at temperatures 1.6×10^5 K, 2.5×10^5 K and 6.3×10^5 K respectively, from the ionization equilibrium calculations of Arnaud and Rothenflug (1985). Thus emission lines from these ions emanate from the transition region. Although there are scanty observations for these ions especially for Na V and Al VII, we expect most of the lines to be observed with SOHO.

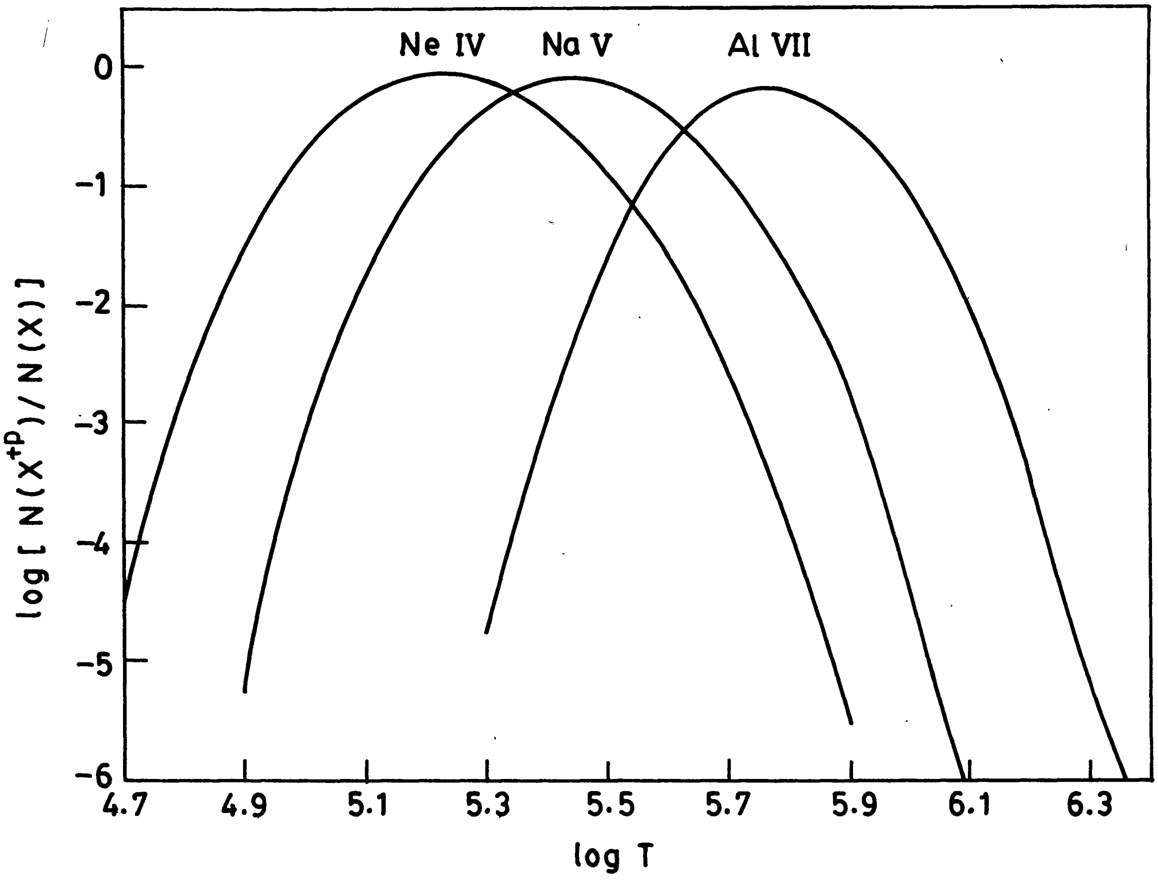

Figure 1. $N(X^{+p})/N(X)$ as a function of temperature from Arnaud and Rothenflug (1985).

2. Line emissivity and atomic data

The line emissivity per unit volume, per unit time, per unit solid angle, from optically thin plasmas is given by

$$\epsilon(\lambda_{ij}) = \frac{1}{4\pi} N_j A_{ji} \frac{hc}{\lambda_{ij}} \text{ ergs cm}^{-3} \text{ s}^{-1} \text{ sr}^{-1}$$

where A_{ji} is the spontaneous transition probability and N_j is the number density of the upper level j and can be parametrised as,

$$N_j(X^{+p}) = \frac{N_j(X^{+p})}{N(X^{+p})} \frac{N(X^{+p})}{N(X)} \frac{N(X)}{N(H)} \frac{N(H)}{N_e} N_e$$

Here, X^{+p} is the p^{th} ionisation stage of the element X; $N(X^{+p})/N(X)$ the ionisation ratio of the ion X^{+p} relative to the total number density of the element; $N(X)/N(H)$ is the abundance of the element X relative to hydrogen, which may not be constant in the solar atmosphere; $N(H)/N_e$ is the hydrogen abundance which is taken to be 0.8 for a fully ionised plasma, and $N_j(X^{+p})/N(X^{+p})$ is the population of level j relative to the total number density of the ion X^{+p} and is determined by solving the detailed statistical equilibrium equations for the ion. The line emissivity ratio of the two lines emitted from the same ion can, therefore, be expressed as -

$$R = \frac{\epsilon(\lambda_{ij})}{\epsilon(\lambda_{kl})} = \frac{A_{ji}}{A_{lk}} \frac{\lambda_{kl}}{\lambda_{ij}} \frac{N_j(X^{+p})}{N_l(X^{+p})}$$

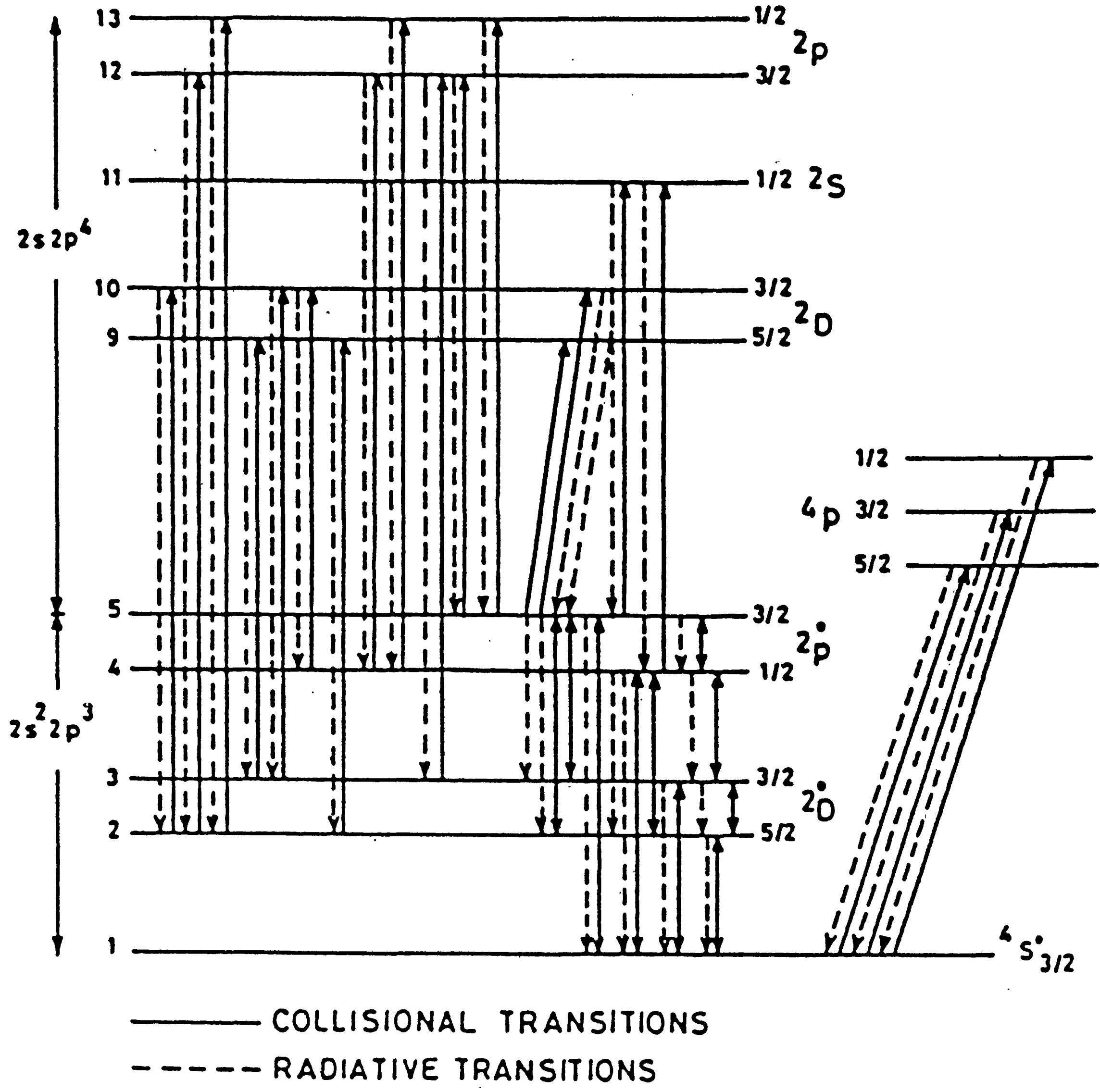

Figure 2. Schematic energy level atomic model for nitrogen-like ions.

The schematic energy level atomic model comprising the first 13 levels of nitrogen-like ions is shown in Figure 2. The ground configuration consists of $2s^22p^3$ states and contains five fine structure levels namely $^4S^0_{3/2}$, $^2D^0_{3/2}$, $^2D^0_{5/2}$, $^2P^0_{1/2}$ and $^2P^0_{3/2}$. The higher configuration consists of $2s2p^4$ states with fine structures ^4P, ^2D, ^2S and ^2P levels. In the figure, the collisional processes are shown by solid lines and the radiative processes by broken lines. The atomic data needed to compute the line emissivities are the following : (i) wavelengths, (ii) radiative transition probabilities and (iii) collision strengths. In the case of Ne IV, these values have been taken from the calculations of Bhatia and Kastner (1988). For Na V and A1 VII, the collision strengths values have been obtained by interpolation along the iso-electronic sequence. For interpolation, we have used the values of Bhatia and Kastner (1988) for Ne IV and for Mg VI, Si VIII and S X from Bhatia and Mason (1980). The transition probabilities and the wavelengths have been taken from the tabulation of Wiese et al. (1969).

3. Results and discussion

The population of higher excited levels are essentially governed by the first five levels of the ground configuration (cf. Figure 2). We have computed and studied the variation of ground level populations as a function of N_e and T_e. We find that ground level populations do not vary with temperature variation. In Table 1, we have listed the EUV lines for Ne IV, Na V and A1 VII ions.

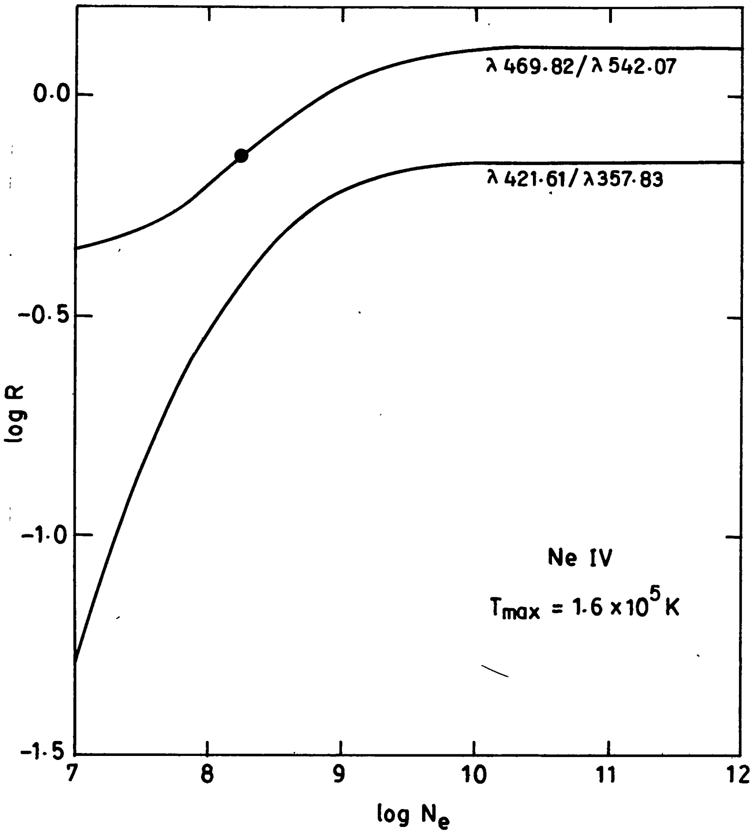

Figure 3a. Theortical line emission ratios for Ne IV ion as a function of electron density at $T_{max} = 1.6 \times 10^5$ K. The observation is shown by a dot in this figure.

Table 1. Ne IV, Na V and Al VII EUV emission lines

Transition	Wavelength (Å)		
$2s2p^4$ - $2s^22p^3$	Ne IV	Na V	Al VII
$^2P_{1/2}$ - $^2D^0_{3/2}$	357.83	307.15	239.03
$^2P_{1/2}$ - $^2P^0_{1/2}$	387.13	332.54	259.03
$^2P_{1/2}$ - $^2P^0_{3/2}$	387.13	332.59	259.22
$^2P_{3/2}$ - $^2D^0_{3/2}$	358.73	308.29	240.74
$^2P_{3/2}$ - $^2D^0_{5/2}$	358.72	308.26	240.77
$^2P_{3/2}$ - $^2P^0_{1/2}$	388.23	333.88	261.04
$^2P_{3/2}$ - $^2P^0_{3/2}$	388.22	333.92	261.22
$^2S_{1/2}$ - $^2P^0_{1/2}$	421.50	360.32	279.05
$^2S_{1/2}$ - $^2P^0_{3/2}$	421.61	360.37	279.26
$^2D_{3/2}$ - $^2D^0_{3/2}$	469.87	400.71	309.01
$^2D_{3/2}$ - $^2D^0_{5/2}$	469.77	400.67	309.07
$^2D_{3/2}$ - $^2P^0_{1/2}$	521.74	445.05	343.28
$^2D_{3/2}$ - $^2P^0_{3/2}$	521.74	445.12	343.60
$^2D_{5/2}$ - $^2D^0_{3/2}$	469.92	400.77	309.06
$^2D_{5/2}$ - $^2D^0_{5/2}$	469.82	400.73	309.12
$^2D_{5/2}$ - $^2P^0_{3/2}$	521.82	445.19	343.65
$^4P_{1/2}$ - $^4S^0_{3/2}$	541.83	459.90	352.16
$^4P_{3/2}$ - $^4S^0_{3/2}$	542.07	461.05	353.78
$^4P_{5/2}$ - $^4S^0_{3/2}$	543.89	463.26	356.89
$2s^2$ $2p^3$ - $2s^2$ $2p^3$			
$^2P^0_{3/2}$ - $4S^0_{3/2}$	1601.51	1379.4	1072.2
$^2P^0_{1/2}$ - $4S^0_{3/2}$	1601.69	1380.2	1075.3
$^2D^0_{5/2}$ - $4S^0_{3/2}$	2421.86	2101.5	1645.8
$^2D^0_{3/2}$ - $4S^0_{3/2}$	2424.85	2100.4	1647.4

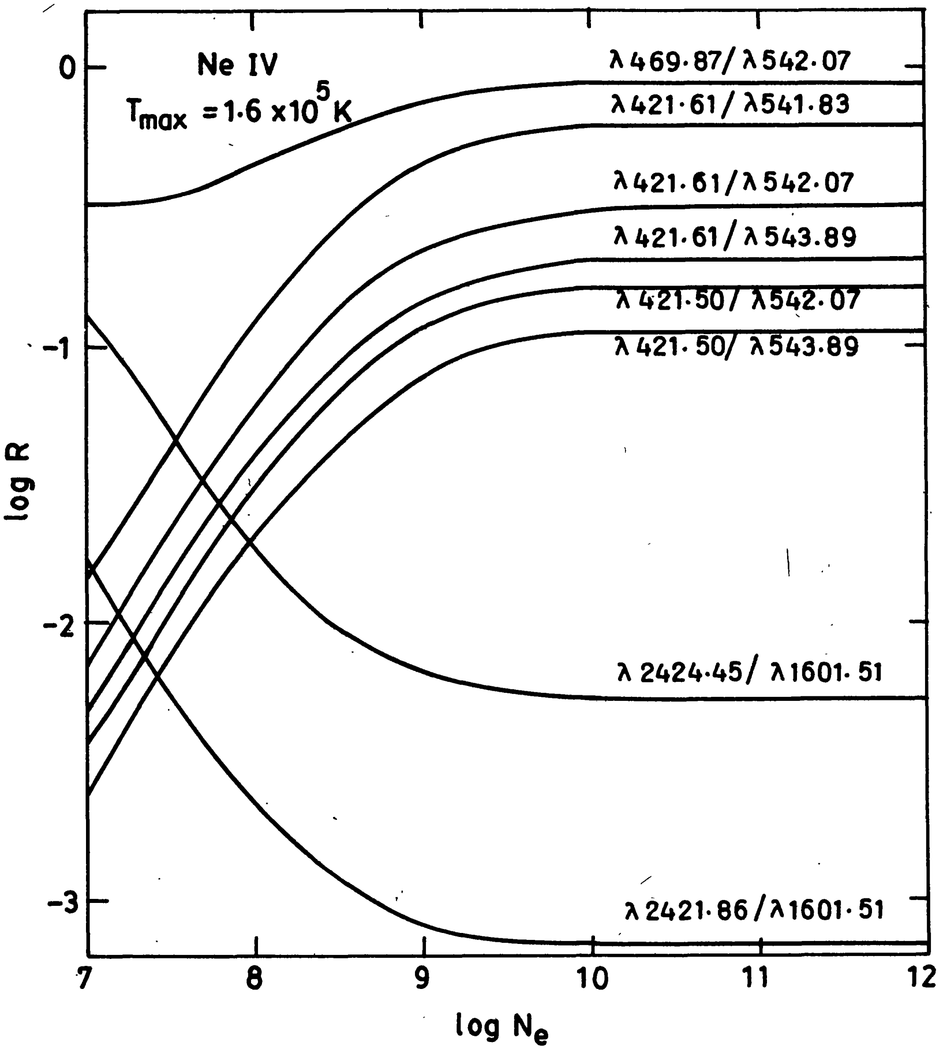

Figure 3b. Theoretical line emission ratios for Ne IV ion as a function of electron density at $T_{max} = 1.6 \times 10^5$ K.

In Figures 3a and 3b, we have shown the line emissivity ratios as a function of electron density for Ne IV ion at $T_{max} = 1.6 \times 10^5$ K. The lines plotted in Figure 3a are observed. The observations by Dupree et al. (1973) for λ469.82 Å and λ542.07 Å lines for quiet regions of solar atmosphere at solar maximum, have the intensities 6.84 and 9.46 ergs cm^{-2} s^{-1} sr^{-1} respectively. Using this observation, we derive an electron density of 1.7×10^8 cm^{-3}, from theoretical line emissivity ratio curve of Figure 3a. The dot in the figure is the observed line intensity ratio. We also see that the line emissivity ratios are sensitive to the density in the range $10^7 - 10^{10}$ cm^{-3}. Therefore, the line ratios from Ne IV ion can be used to determine density in different solar structures in chromosphere-corona transition region. As a matter of fact, Ne IV line ratios are very sensitive to density variations in the sources for $N_e < 10^7$ cm^{-3} and are suitable for probing the planetary nebulae. The line emissivity ratios as a function of electron density for Na V ion at $T_{max} = 2.5 \times 10^5$ K and for A1 VII ion at $T_{max} = 6.3 \times 10^5$ K are shown in Figures 4 and 5 respectively. These density-sensitive line ratios are also useful diagnostics for density range 10^7 to 10^{10} cm^{-3} using Na V lines and 10^7 to 10^{11} cm^{-3} using

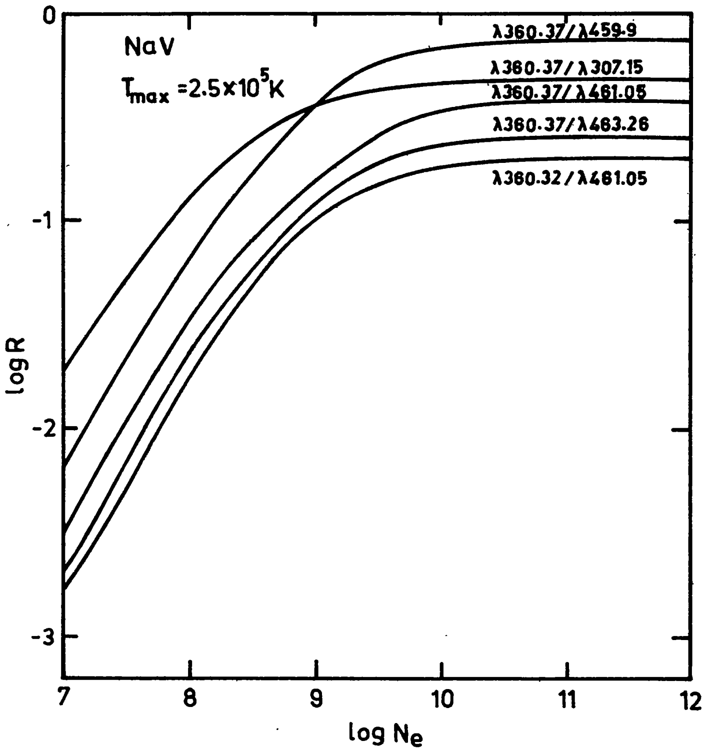

Figure 4. Theoretical line emission ratios for Na V ion as a function of electron density at $T_{max} = 2.5 \times 10^5$ K.

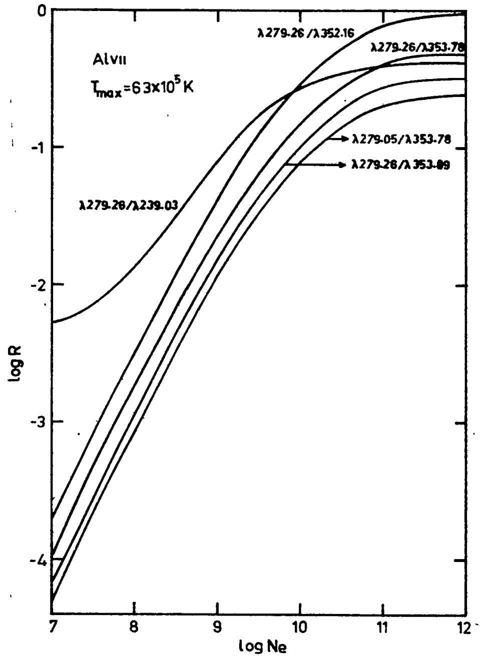

Figure 5. Theoretical line emission ratios for A1 VII ion as a function of electron density at $T_{max} = 6.3 \times 10^5$ K.

A1 VII lines. Observations from the CDS instrument with spectral range (150-800 Å) and SUMER instrument with spectral range (500-1610 Å) on the spacecraft SOHO are likely to provide data with excellent spectral, spatial and temporal resolution, to study in detail the density and temperature structure in the chromosphere-corona transition region and fine structures in it, making use of solar ions investigated in this paper.

Conclusion

Based on present investigation, we find that, line ratio curves of Ne IV, Na V and A1 VII ions show density sensitivity over a wide range of densities, and they, in principle, should be useful to infer densities in different solar structures in the chromosphere-corona transition region and other astrophysical sources. We are presently looking for observations from SOHO to make use of this theoretical study to infer physical parameters of the emitting plasma.

In conclusion, the present study will be useful in analysing the observations from the CDS and SUMER instruments on SOHO. The study of possible implications of abundance anomalies from these ions is underway.

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