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Density dependence of solar emission lines of carbon-like ions†

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Abstract. Steady state level population of 15 levels of carbon-like ions: NeV, MgVII, SiIX, and SXI have been computed as a function of electron density and temperature taking into account collisional processes and spontaneous radiative ones. Photo-excitation among the ground term levels has also been considered. Knowing the level density, line intensities have been computed as a function of electron density and temperature. This study indicates that line intensity ratios for carbon-like ions can be used as a diagnostic in the determination of these two parameters of the solar plasma. The resulting line fluxes from these ions at earth distance are compared with observation.

Keywords. Density dependence; coronal emission lines; chromosphere; corona transition region; carbon-like ions; photo-excitation; solar plasma.

1. Introduction

The solar ultraviolet (UV) spectrum is now being made available with greater spectral and spatial resolution from satellite, rocket and skylab measurements. This spectrum contains a wealth of information on the physical conditions in the solar chromosphere and corona. In order to infer this information, a wide variety of atomic data are required. Considerable progress has been made in this direction especially in the case of ions like helium, lithium and beryllium isoelectronic sequences (see review by Gabriel and Jordan 1972). Recently boron-like ions have received considerable attention (Elwert and Raju 1975; Flower and Nussbaumer 1975a, b; Vernazza and Mason 1978; Dwivedi and Raju 1979). In addition, lines emitted from the ions of carbon, nitrogen and oxygen isoelectronic sequences could also act as a useful probe for solar atmosphere. Detailed investigations of nitrogen-like ions (Raju 1978; Feldman *et al* 1978) and oxygen-like ions (Raju and Dwivedi 1978) have already been reported. In the present investigation, density sensitivity of line intensities of carbon-like ions has been considered.* In view of their large elemental abundances, the ions considered are: NeV, MgVII, SiIX and SXI. According to ionisation calculations of Jordan (1969), NeV has a maximum relative ion abundance at $2{\cdot}5\times10^5$K, MgVII, at 5×10^5K, SiIX at 10^6K, and SXI at $1{\cdot}6\times10^6$K. Therefore,

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*After completing these calculations, the authors learnt that Mason and Bhatia (1978) have also noted density sensitivity of carbon-like line ratios.

lines emitted from these ions could act as a useful diagnostic for the solar chromosphere-corona transition region and the corona. Some lines from these ions are observed in the spectra of solar corona (Jordan 1971; Malinovsky and Heroux 1973; Dupree *et al* 1973; Behring *et al* 1976; Sandlin *et al* 1977).

The various physical processes considered in the present investigation are electron collisional excitations and spontaneous radiative de-excitations for permitted and intercombination transitions; electron as well as proton excitations and de-excitations, photo-excitations and spontaneous radiative de-excitations among the ground term levels. The radiative excitation rates for the considered transitions in the ultraviolet region contribute less than 20% to the total rates at an electron density of 10^7 and hence have been neglected. Moreover, at the temperatures of interest recombinations to the levels considered have also been neglected compared to the direct excitations.

2. Energy level scheme and atomic data

For computing various line intensities, we have considered transitions taking place between the first fifteen levels of carbon-like ions. These transitions have wavelengths greater than 150 Å for the ions considered here. In figure 1 we have schematically shown the adopted energy level model. The ground configuration consists of a triplet *P*, a singlet *D*, and a singlet *S* whereas the higher configuration forms a quintet *S*, a triplet *D*, a triplet *P*, a singlet *D*, a triplet *S*, and a singlet *P* term. Various transitions which have been taken into account for this investigation are as indicated in figure 1.

The atomic data required for detailed computation of line intensities for these ions have been taken from published results wherever available; otherwise we obtained

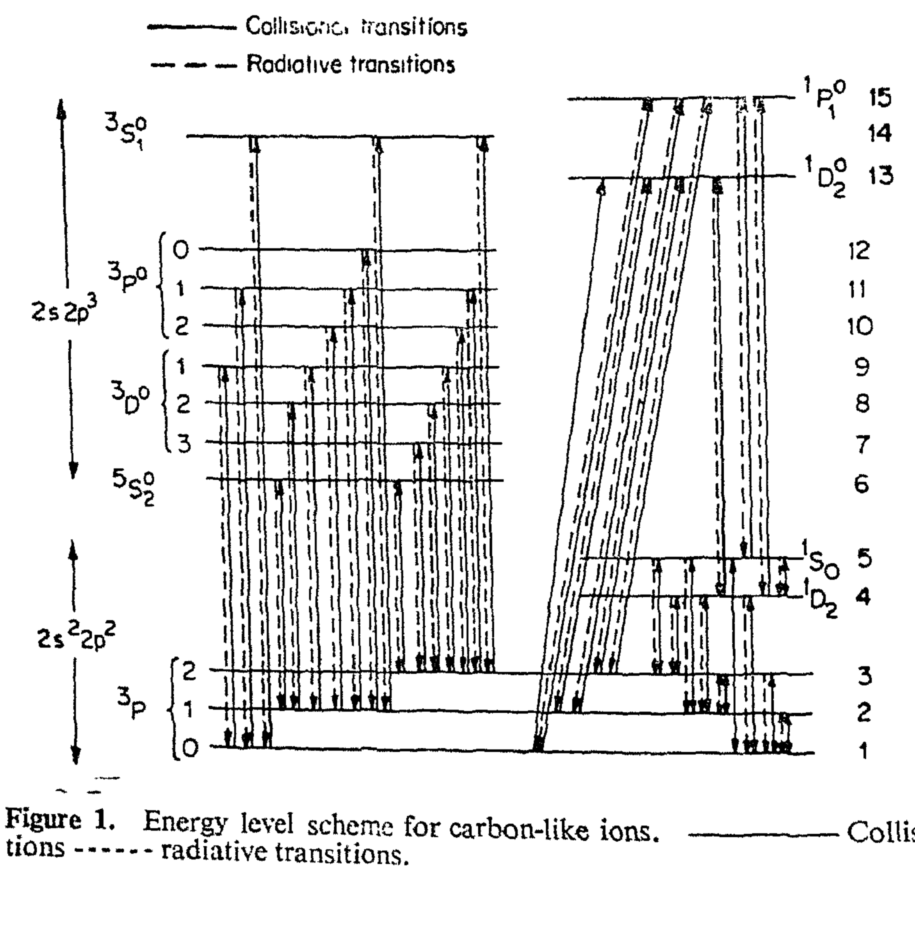

Figure 1. Energy level scheme for carbon-like ions. ——— Collisional transitions ------ radiative transitions.

them by interpolation. The allowed transition probabilities and oscillator strengths for NeV, MgVII and SiIX have been taken from the tabulation of Wiese *et al* (1966, 1969) and in the case of SXI from Kastner (1967). The data for the forbidden and $^5S_2^0$–^3P transitions have been taken from Kastner *et al* (1977) and Nussbaumer (1971). The transition probabilities for SiIX and SXI for intercombination transitions $^1D_2^0$–^3P and $^1P_1^0$–^3P have been taken from Kastner (1967) whereas for NeV and MgVII they have been estimated by extrapolation along the isoelectronic sequence. Wavelength values have been taken from various sources (Edlén 1972; Kelly and Palumbo 1973; Kastner *et al* 1977).

Collision strengths $\Omega\,(i, j)$, for NeV, and SiIX for the transitions $^3P_0$–$^3P_1$, $^3P_0$–$^3P_2$, and $^3P_1$–$^3P_2$ have been taken from Blaha (1969) and in the case of MgVII by interpolation. In order to estimate the collision strengths for other fine structure transitions for NeV and MgVII, we have used the values for the appropriate multiplet collision strengths given by Saraph *et al* (1969) and the relations cited therein

$$\Omega\,(^1S,\,^3P_J) = \frac{1}{9}(2J+1)\;\Omega\,(^1S,\,^3P),$$

$$\Omega\,(^1D,\,^3P_J) = \frac{1}{9}(2J+1)\;\Omega\,(^1D,\,^3P).$$

In the case of SiIX, these data have been obtained by interpolation. Collision strengths for SXI have been taken from Czyzak *et al* (1974). These data for intercombination transitions $^5S_2^0$–^3P, $^1D_2^0$–^3P and $^1P_1^{03}$–P have been estimated using the computed values for CaXV (Mason 1975) by scaling along the isoelectronic sequence. The scaling was done by multiplying the collision strengths for CaXV by a factor $Z^2(\mathrm{CaXV})/Z^2$ (ion), where Z is the residual charge on the ion. We have also taken into account proton excitations for $^3P_0$–$^3P_2$ and $^3P_1$–$^3P_2$. Due to lack of relevant data on proton rates, we have incorporated roughly the effect of proton excitation by increasing the electron collision strengths for these transitions by a factor of 2. We find this to be consistent with proton excitation rates for CaXV (Mason 1975) which belongs to carbon sequence.

Photo-excitation rates, R_{ij}, have been considered only for the transitions $^3P_0$–$^3P_1$ and $^3P_1$–$^3P_2$. For other transitions photo-excitation rates are not significant. The rates R_{ij} used in the present study have been obtained using the expression

$$R_{ij} = \frac{\omega_j}{\omega_i} A_{ji}\;[\exp\,(h\nu_{ij}/KT_r)-1]^{-1}\;W,$$

where W is the dilution factor, ω the statistical weight, A_{ji} the spontaneous radiative transition probabilities, ν_{ij} the frequency of the transition, and T_r is the radiation temperature corresponding to the particular transition. The dilution factor has been assumed to be equal to 0·5 in all cases for the sake of simplicity in the computation. For estimating R_{ij} we have calculated T_r knowing the continuum flux at a given wavelength, with the help of mean solar balck body emission formula

$$J_\nu = 2h\nu^3/c^2\;[\exp\,(h\nu/KT_r)-1]^{-1}.$$

3. Line emission

The line emission from a given volume element in the solar atmosphere in a steady state is given by the expression

$$E(j, i) = (1/4\pi)\, A_{ji}\, h\nu_{ij}\, N_j \ (\text{ergs cm}^{-3}\ \text{s}^{-1}\ \text{sr}^{-1}),$$

where N_j is the level density for the upper level of the transition. Thus the problem reduces to the calculation of the population density (N_j) of the upper excited level. Assuming steady state condition, we have solved the statistical equilibrium equations for various levels with the electron density and temperature as parameters. Equilibrium equation for a given level (j) can be expressed as

$$N_j \Big[\sum_{i<j} (A_{ji} + N_e\, C_{ji}) + \sum_{k>j} N_e\, C_{jk}\Big]$$

$$= \sum_{i<j} N_i\, [R_{ij} + N_e\, C_{ij}] + \sum_{k>j} N_k\, [A_{kj} + N_e\, C_{kj}].$$

N_e is the electron density, and C the collision rate. The collision rates are expressed in terms of the collision strengths $\Omega\ (i, j)$ in the form

$$C_{ij} = 8{\cdot}63 \times 10^{-6}\ \Omega\,(i, j)\ \exp\,(-E_{ij}\,/KT_e)/\omega_i\, T_e^{\frac{1}{2}}\ (\text{cm}^{+3}\ \text{s}^{-1}) \qquad \text{(for excitations)},$$

$$C_{kj} = C_{jk}\ (\omega_j/\omega_k)\ \exp\,(E_{jk}/KT_e)\ (\text{cm}^{+3}\ \text{s}^{-1}) \qquad \text{(for de-excitations)},$$

where T_e is the electron temperature, K the Boltzmann constant and E_{ij} is the excitation energy. Collision rates in terms of absorption oscillator strengths can be expressed as (Van Regemorter 1962)

$$C_{ij} = 1{\cdot}70 \times 10^{-3}\ g f_{ij}\ \exp\,(-\,E_{ij}/KT_e)/E_{ij}\ (\text{eV})\ T_e^{1/2}\ (\text{cm}^{+3}\ \text{s}^{-1}),$$

where f_{ij} is the oscillator strength and g is the Gaunt factor. In order to simplify computations, we have assumed Gaunt factor to be equal to 0·8 for all the permitted transitions considered. This is reasonable for the allowed transitions which do not involve a change in the principal quantum number.

Since the level population of higher term levels is essentially determined by the ground term levels, the variation of the population of these levels with electron density will be reflected in the variation of line emission with electron density. Further, since the variation of relative ion abundance of an element exhibits sharply peaked behaviour with respect to temperature, it is reasonable to assume that the line emission takes place from a layer of effectively uniform density and temperature. In figures 2 to 5, we have shown line intensity ratios as a function of electron density for each of NeV, MgVII, SiIX, and SXI. The temperature values indicated in these figures are

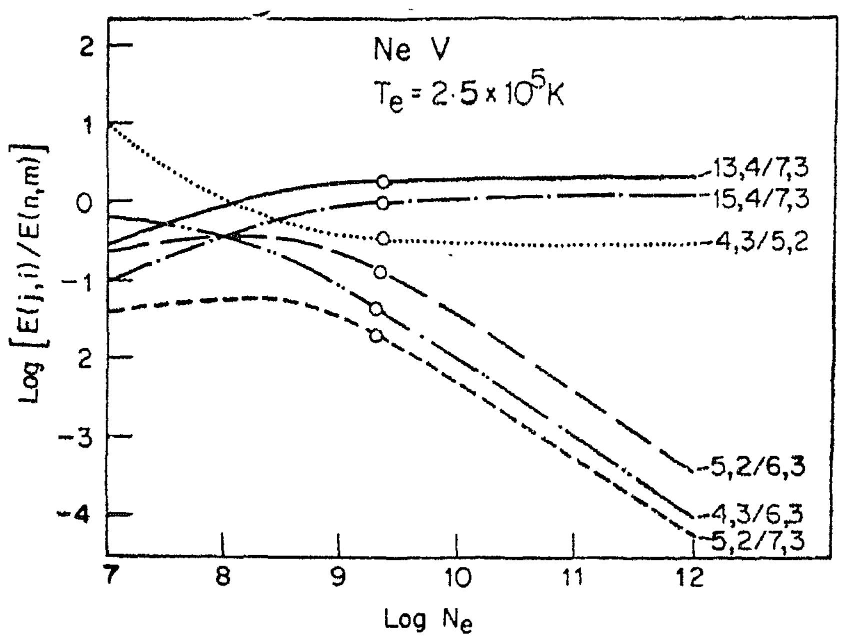

Figure 2.

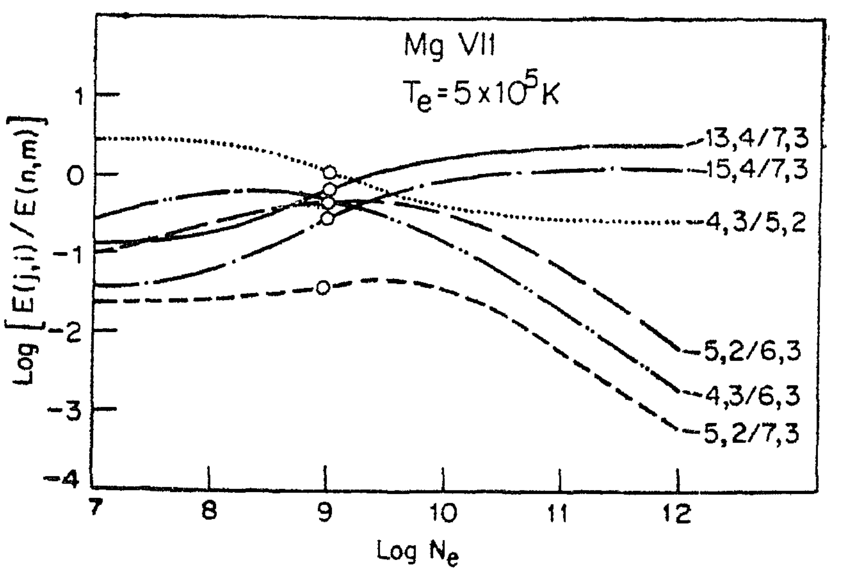

Figure 3.

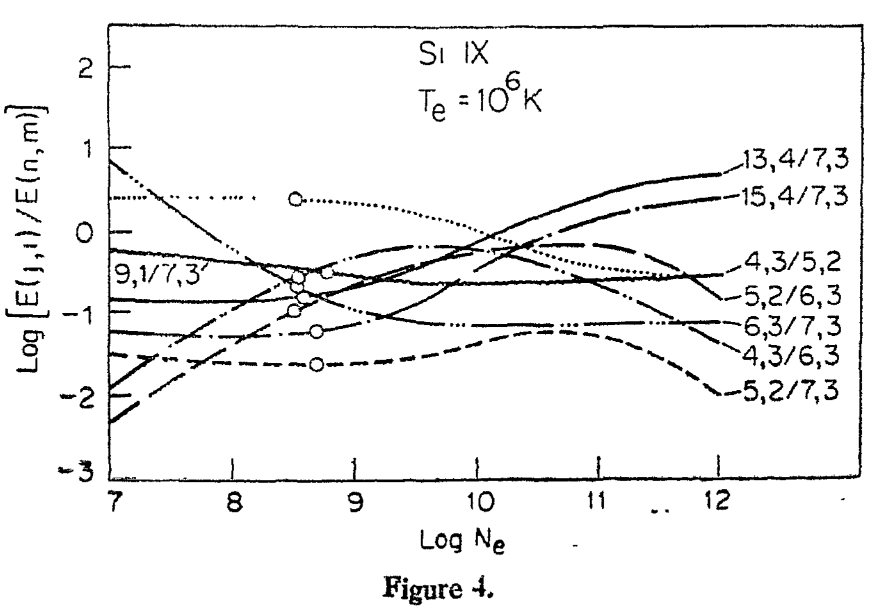

Figure 4.

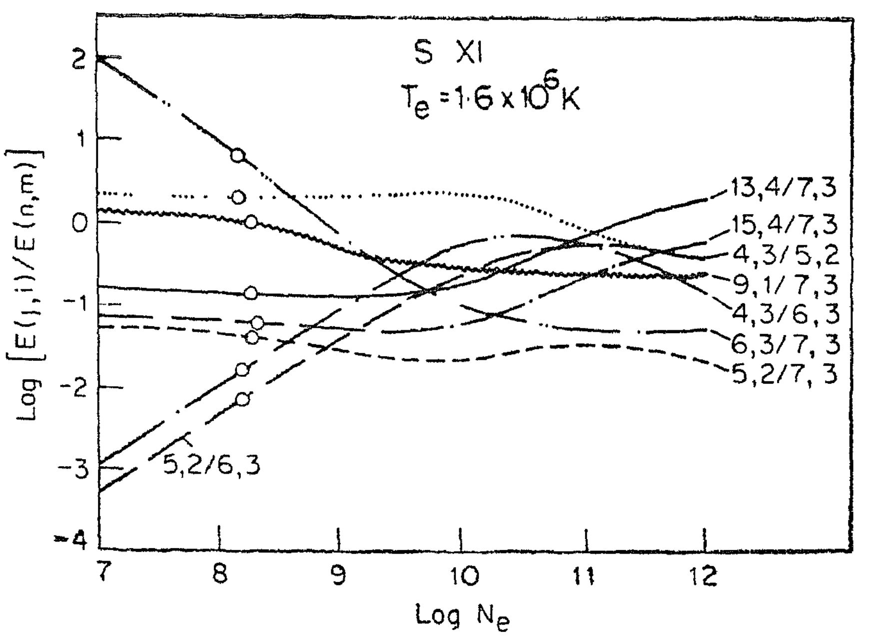

Figure 5.

Figures 2 to 5. Intensity ratios $E(j, i)/E(n, m)$ as a function of N_e. Open circles correspond to the calculated intensity ratios based on the model of Elzner (1976). T_e corresponds to the temperature for the maximum relative ion abundance of the element.

those at which the relative ion abundance of the element is maximum. These line intensity ratios are rather insensitive to temperature variation.

4. Results and discussion

Not many lines are observed from these ions with calibrated intensities suitable for density determinations. In order to check if the density sensitivity of our line ratios falls into a range useful for solar work, we have calculated the relevant intensity ratios using a spherically symmetric model for the quiet sun (Elzner 1976). The ratios thus obtained are shown by open circles in figures 2 to 5. They fall on the density sensitive portion of the curves, thereby providing a direct method for determining N_e.

From figures 2 to 5 we notice that the forbidden lines with transitions ${}^1S_0$–${}^3P_1$ and ${}^1D_2$–${}^3P_2$ relative to the intersystem line ${}^5S_2{}^0$–${}^3P_2$ are density-sensitive, particularly suitable for active regions. Forbidden line ${}^1S_0$–${}^3P_1$ relative to the allowed line ${}^3D_3$–${}^3P_2$ could also be used as a density indicator for active regions. The intensity ratios of forbidden lines corresponding to transitions ${}^1D_2$–${}^3P_2$ and ${}^1S_0$–${}^3P_1$ for the ions MgVII, SiIX, and SXI could also be useful for active region conditions. Mason and Bhatia (1978) have not explicitly discussed these forbidden line ratios. However, using their data we find that their ratios for various densities in the relevant range are 20% smaller than ours. Using a working model for quiet sun (Elzner 1976) we find that for SiIX the expected flux ratio for these forbidden lines falls on our intensity ratio curve as expected. But based on the calculations of Mason and Bhatia (1978), it is not attained within the relevant electron density range. Sandlin *et al* (1977) have observed in two active regions off the limb, lines corresponding to the intersystem transitions ${}^5S_2^0$–${}^3P_1$ and ${}^5S_2^0$–${}^3P_2$ as well as forbidden transition ${}^1S_0$–${}^3P_2$ of NeV. In the case of MgVII, they observe the forbidden line with transition ${}^1S_0$–${}^3P_2$. However, two forbidden lines corresponding to the transitions ${}^1D_2$–${}^3P_1$ and ${}^1D_2$–${}^3P_2$ are observed for

SiIX and SXI. For the two active regions Sandlin *et al* (1977) quote the following intensity values, relative to the FeXII line at 1242 Å, for the above mentioned forbidden transitions: 0·05 for NeV line at 1574·82 Å and 1·9 for MgVII line at 1189·82 Å for the active region AR 12300 at 40″ above the limb; 2·5 for MgVII line at 1189·82 Å and 6·6 and 11 for SiIX at 1984·88 Å and 2149·26 Å respectively whereas 0·4 and 2·8 for SXI at 1614·51 Å and 1826·21 Å for the active region AR 12114 at 4 arc sec above the limb. The NeV and MgVII lines correspond to the transition $^1S_0$–$^3P_1$ whereas SiIX and SXI lines correspond to the transitions $^1D_2$–$^3P_1$ and $^1D_2$–$^3P_2$ respectively. Sandlin *et al* (1977) have quoted the conversion factor to get the absolute intensity only in the case of active region 4 arc sec off the limb. In view of the intensity ratios discussed above, lines corresponding to the transition $^5S_2^0$–$^3P_2$ of MgVII, SiIX, and SXI must definitely be observable in active regions.

In tables 1 to 4, we have listed calculated fluxes from the entire solar disk at earth's distance for various strong and weak lines. Calculated fluxes for these lines may be useful in resolving difficulties associated with line identification, masking, or blending due to lines arising from the ions of other isoelectronic sequences. The fluxes were calculated using the spherically symmetric model for the quiet sun (Elzner 1976). The relative abundance values for Ne, Mg, Si and S have been taken from Kato (1976). With longer exposures it should be possible to observe some of the weaker lines also, particularly across the limb. Calculated fluxes for some of the lines are comparable with those reported by Dupree *et al* (1973) and Malinovsky and Heroux (1973). In the extreme cases they agree within a factor of 2 to 3. The discrepancies in the calculated and observed flux values could be ascribed to uncertainties in atomic parameters, relative abundances, model atmosphere, and ionisation equilibrium values on the one hand and in measurements on the other. Behring *et al* (1976) have reported relative eye estimates for some of the lines

Table 1. Calculated fluxes from the entire solar disk at earth's distance. NeV—Ion $n(\mathrm{Ne})/n(\mathrm{H}) = 3{\cdot}98 \times 10^{-5}$

Transition	λ(Å)	Flux (10^{-3} ergs cm^{-2} s^{-1})	
		Calculated	Observed
(14, 2)	358·48	0·42	—
(14, 3)	359·39	0·69	—
(15, 4)	365·61	0·86	—
(13, 4)	416·20	1·64	—
(10, 3)	482·99	0·73	1·00‡
(8, 2)	569·83	0·41	—
(7, 3)	572·34	0·82	1·05‡
(6, 2)	1136·50†	0·04	—
(6, 3)	1145·60†	0·12	—
(5, 2)	1574·82†	0·02	—
(4, 3)	3426·84	0·006	—

†Observed lines in active regions from Sandlin *et al* (1977)
‡Observed values from Dupree *et al* (1973)
*Observed values from Malinovsky and Heroux (1973)
**Observed values from Behring *et al* (1973)
^{b}denotes that the line is blended

Table 2. Calculated fluxes from the entire solar disk at earth's distance. MeVII—Ion; $n(\mathrm{Mg})/n(\mathrm{H}) = 3{\cdot}16 \times 10^{-5}$

Transition	λ(Å)	Flux (10^{-3} ergs cm^{-2} s^{-1})		
		Calculated	Observed	
(14, 1)	276·15	0·39	0·4*	
(14, 2)	277·01	1·10	1·4*	9**
(14, 3)	278·41	1·85	2·4*	7**
(15, 4)	280·74	0·49	—	
(13, 4)	319·02	1·21	—	
(11, 1)	363·77	0·42	—	
(12, 2)	365·24	0·40	—	
(10, 2)	365·24	0·55	—	
(11, 2)	365·24	0·32	—	
(11, 3)	367·67	0·53	—	9**
(10, 3)	367·68	1·59	—	
(9, 1)	429·13	0·41	—	
(9, 2)	431·22	0·32	—	4**
(8, 2)	431·22	0·94	—	
(8, 3)	434·71	0·31	—	10**
(7, 3)	434·92	1·83	—	
(6, 2)	851·00	0·06	—	
(6, 3)	864·00	0·17	—	
(5, 2)	1189·82†	0·07	—	
(4, 3)	2629·47	0·08	—	

Symbols explained in footnote to table 1.

Table 3. Calculated fluxes from the entire solar disk at earth's distance. SiIX—Ion; $n(\mathrm{Si})/n(\mathrm{H}) = 5{\cdot}01 \times 10^{-5}$

Transition	λ(Å)	Flux (10^{-3} ergs cm^{-2} s^{-1})			
		Calculated		Observed	
(14, 1)	223·72	0·88	2·4*		6**
(14, 2)	225·03[b]	2·53	4·5*		24**
(14, 3)	227·01	4·05	7·9*		22**
(15, 4)	227·30	0·21	—		
(13, 4)	258·10	0·55	—		5**
(11, 1)	290·63	0·96	2·1*		
(12, 2)	292·83	0·96		(1·38)	
(11, 2)	292·83	0·71	4·3*	(1·56)	15**
(10, 2)	292·83	1·08		(1·36)	
(11, 3)	296·19	1·13	6·3*	(2·49)	
(10, 3)	296·19	3·04		(3·81)	20**
(9, 1)	342·97	1·02	—		10**
(9, 2)	345·01	0.76	—		
(8, 2)	345·10	2·05	—		16**
(8, 3)	349·77	0·66	—		
(7, 3)	349·96	3·17	—		20**
(6, 2)	672·00	0·31	—		
(6, 3)	696·00	0·77	—		
(5, 2)	949·90	0·08	—		
(4, 2)	1984·88†	0·10	—		
(4, 3)	2149·26†	0·21	—		

Symbols explained in footnote to table 1.

Table 4. Calculated fluxes from the entire solar disk at earth's distance. SXI—ion; $n(S)/n(H) = 1{\cdot}99 \times 10^{-5}$

Transition	λ(Å)	Flux (10^{-8} ergs cm^{-2} s^{-1})	
		Calculated	Observed
(14, 1)	186·85	0·33	—
(14, 2)	188·68^b	0·95	1·6*
(14, 3)	191·26	1·39	2·3*
(15, 4)	190·37	0·03	—
(13, 4)	215·95	0·08	—
(11, 1)	239·81	0·39	1·4*
(10, 3)	246·90^b	0·38	1·5*
(11, 3)	247·12^b	0·43	1·6*
(9, 1)	281·40	0·56	2·3*
(9, 2)	285·58^b	0·51	1·4*
(8, 2)	285·83^b	0·48	1·6*
(7, 3)	291·59	0·57	0·85*
(6, 2)	555·00	1·68	—
(6, 3)	578·00	3·68	—
(5, 2)	782·76	0·02	—
(4, 2)	1614·51†	0·03	—
(4, 3)	1826·21†	0·05	—

Symbols explained in footnote to table 1.

discussed here. They are also listed here for the sake of comparison. Based on our calculation for absolute fluxes, lines with transition $^5S_2{}^0$–$^3P_1$ of SiIX and SXI (tables 3 and 4) have sufficient intensity for observation whereas the corresponding line of MgVII (table 2) may also be observable with longer exposure. Lines corresponding to the transition $^1D_2$–$^3P_2$ of NeV and MgVII, whereas with transition $^1S_0$–$^3P_1$ of SiIX and SXI should have observable flux in active regions.

From figures 2 and 3, we see that the line intensity ratios with transitions $^1D_2^0$–$^1D_2$ and $^1P_1^0$–$^1D_2$ relative to the strongest line corresponding to the transition $^3D_3^0$–$^3P_2$ for NeV and MgVII could be used as density indicator for quiet sun regions. Our model calculations help us make the definite conclusion that singlet to singlet lines of NeV and MgVII are intense enough for observation. Further, the line intensity ratios for singlet to singlet relative to triplet to triplet transitions are useful probes for the quiet sun. We also get this density sensitivity in the expected electron density region. In the case of SiIX and SXI, these ratios could be useful for active regions. Calculated flux values for SXI lines in the range 190 Å–285 Å have greater discrepancy over observed ones. This could partly be ascribed to blending of these lines. The intensity ratio from our computed flux values for the transition $^3D_1^0$–$^3P_0$ relative to $^3D_3^0$–$^3P_2$ of SXI falls on our intensity ratio curve within the relevant electron density range. However, our computed intensity ratio for these two transitions does not compare well with the intensity ratios given by Mason and Bhatia (1978). Further, we see that the calculated line flux (table 4) for SXI line corresponding to the transition $^3D_1^0$–$^3P_0$ is four times smaller than the observed one. We suspect that the line with transition $^3D_1^0$–$^3P_0$ of SXI may be blended.

5. Conclusion

The solar emission lines of the carbon-like ions: NeV, MgVII, SiIX, and SXI in the ultraviolet region are sensitive to electron density. Therefore, the solar ultraviolet lines from these ions are useful to probe the emitting regions of the solar atmosphere. Furthermore, we find that there are many lines from these ions which have observable flux values but no observational data are currently available. The calculated fluxes based on a working model for solar chromosphere-corona transition region and the corona should help in resolving difficulties associated with line identifications.

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References

Allen C W 1973 *Astrophysical quantities* (London: Athlone Press) p. 31
Blaha M 1969 *Astron. Astrophys.* **1** 42
Behring W E, Cohen L, Feldman U and Doschek G A 1976 *Astrophys. J.* **203** 521
Czyzak S J, Aller L H and Euwema R N 1974 *Astrophys. J. Suppl.* **28** 465
Dupree A K, Huber M C E, Noyes R W, Parkinson W H, Reeves E M and Withbroe G L 1973 *Astrophys. J.* **182** 321
Dwivedi B N and Raju P K 1979 under preparation
Edlén B 1972 *Solar Phys.* **24** 356
Elwert G and Raju P K 1975 *Astrophys. Space Sci.* **38** 369
Elzner L R 1976 *Astron. Astrophys.* **47** 9
Feldman U, Doschek G A, Mariska J T, Bhatia A K and Mason H E 1978 *Astrophys. J.* **226** 674
Flower D R and Nussbaumer H 1975a *Astron. Astrophys.* **45** 145
Flower D R and Nussbaumer H 1975b *Astron. Astrophys.* **45** 349
Gabriel A H and Jordan C 1972 in *Case studies in atomic collision Physics* eds. E McDaniel and M C McDowel, Vol. 2 (Amsterdam: North Holland) p 210
Jordan C 1969 *Mon. Not. R. Astron. Soc.* **142** 501
Jordan C 1971 *Solar Phys.* **21** 381
Kastner S O 1967 *Solar Phys.* **2** 196
Kastner S O, Bhatia A K and Cohen L 1977 *Phys. Scr.* **15** 259
Kato T 1976 *Astrophys. J. Suppl.* **30** 397
Kelly R L and Palumbo L J 1973 *Atomic and ionic emission lines below* 2000Å, NRL Report 7599
Malinovsky M and Heroux L 1973 *Astrophys. J.* **181** 1009
Mason H E 1975 *Mon. Not. R. Astron. Soc.* **170** 651
Mason H E and Bhatia A K 1978 *Mon. Not. R. Astron. Soc.* **184** 423
Nussbaumer H 1971 *Astrophys. J.* **166** 411
Raju P K 1978 *Bull. Astron. Soc. India.* **6** 45
Raju P K and Dwivedi B N 1978 *Solar Phys.* (in press)
Sandlin G D, Brueckner G E and Tousey R 1977 *Astrophys. J.* **214** 898
Saraph H E, Seaton M J and Shemming J 1969 *Philos. Trans. R. Soc. London* **A264** 77
Van Regemorter H 1962 *Astrophys. J.* **136** 906
Vernazza J E and Mason H E 1978 *Astrophys. J* **226** 720
Wiese W L, Smith M W and Glennon B M 1966 *Atomic transition probabilities; Hydrogen through Neon* (Washington: Natl. Bur. Standards) Vol. 1
Wiese W L, Smith M W and Miles B M 1969 *Atomic transition probabilities. Sodium through calcium* (Washington: Natl. Bur. Standards)