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A. A. Nikitin, O. A. Yakubovskii

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**Abstract**

**Full Text**

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A. A. Nikitin, O. A. Yakubovskii

# Lines of Forbidden Transitions Associated with the First Excited Configurations $sp^2$ in Isoelectronic Coronal Sequences

## Quadrupole Transitions in the Configurations $sp^2$

*(Presented by Academician V. G. Fesenkov, 18 I 1964)*

In the isoelectronic sequences B I, C II, N III, ···and Al I, Si II, P III, ···the first excited configurations are $2s2p^2$ and $3s3p^2$, with terms ${}^4P, {}^2D, {}^2S, {}^2P$. Recent investigations ([1–3]) have shown that, in interpreting the processes of ionization and excitation in the solar corona, in the chromosphere of the Sun, and in the envelopes of nonstationary stars, it is necessary to know the structure of the spectrum that arises both in transitions between the terms $sp^2$ and in transitions from these terms to the ground term $s^2p\,{}^2P$.

The study of quadrupole transitions is the first part of work devoted to the investigation of forbidden lines associated with the configurations $sp^2$ for the elements B I, C II, N III, ···and Al I, Si II, P III, ···. In subsequent sections forbidden transitions of other types will be considered. The line strength for a quadrupole transition in $LS$-coupling is determined by the formula ([4])

$$S_q(\alpha SLJ, \alpha' S' L' J') = \frac{(2J+1)(2J'+1)}{(2S+1)} \begin{Bmatrix} L & J & S \\ J' & L' & 2 \end{Bmatrix}^2 |\langle \alpha SL \| Q \| \alpha' S' L' \rangle|^2 , \tag{1}$$

where $\langle \alpha SL \| Q \| \alpha' S' L' \rangle$ is the submatrix element of the quadrupole transition. Using the formulas given in ([4]), one can obtain the following expression for the submatrix element in the case of the configuration $sp^2$:

$$\langle p^2(L_0S_0)\,sSL_0\|Q\|p^2(L_0'S_0)\,sSL_0'\rangle = (-1)^{S_0+S+L_0'+1/2}$$
$$\times\left[(2S+1)(2L_0+1)^2(2L_0'+1)^2(2S_0+1)\right]^{1/2}\begin{Bmatrix} L_0 & L_0' & 2\\ L_0' & L_0 & 0\end{Bmatrix}\begin{Bmatrix} 1 & L_0 & 0\\ L_0' & 1 & 2\end{Bmatrix}$$
$$\times(nsl_0\|q\|nsl_0), \tag{2}$$

$$(nsl\|q\|nsl) = \left[\frac{2l(2l+1)(l+1)}{(2l-1)(2l+3)}\right]^{1/2}\int_0^\infty r^2P^2(nl\mid r)\,dr.$$

Substituting in (1), (2) the values $L_0, S_0, L_0', S$, we find that for the configuration $sp^2$ the strengths of the quadrupole lines for the transitions ${}^2S, {}^2D-{}^2P$ are equal to zero, i.e., these transitions are forbidden; for the transition ${}^2D-{}^2S$ the line strengths are:

$$S_q^{(1)}({}^2S_{1/2}-{}^2D_{3/2}) = \frac{16}{25}N_q^2(np,np),$$

$$S_q^{(2)}({}^2S_{1/2}-{}^2D_{5/2}) = \frac{24}{25}N_q^2(np,np), \tag{3}$$

$$N_q(np,np) = \int_0^\infty r^2P^2(np\mid r)\,dr, \qquad n=2,3.$$

The probability of a quadrupole transition is given by the formula

$$A_{21}^{(k)} = 1324\,i^5S_q^{(k)}, \qquad k=1,2; \tag{4}$$

$i$ is the radiation frequency in rydbergs; two values of $S_q^{(k)}$ are given in formula (3).

The results of calculations from (4) for B I, C II, N III, . . . are given in Table 1. The values of $N_q$ from B I to F V were found with the wave functions given in (5). For the other elements a semiempirical formula was obtained

$$N_q = \frac{p_0}{Ay^2+By+1}; \tag{5}$$

$p_0 = 5.45$; $A = 0.148$; $B = 1.058$; $y = 0, 1, 2, \ldots$ for B I, C II, N III, . . . Formula (5) is a generalization of the well-known formula for hydrogen-like ions $N_q \sim 1/y^2$ and represents well the values of $N_q$ from B I to F V. For Ne VI the exact value of $N_q$, calculated on the basis of (6), is 0.53, whereas by (5) it is 0.55.

The wavelengths were found from (7); for S XII–A XIV the mean wavelengths were taken from (8).

**Table 1**

| Element | $\lambda(^2D_{3/2} - {}^2S_{1/2})$ | $\lambda(^2D_{5/2} - {}^2S_{1/2})$ | $N_q$ | $A_{21}^{(1)}$ | $A_{21}^{(2)}$ |
|---|---|---|---|---|---|
| B I | 6367.8 | 6367.8 | 5.45 | 1.51 | 2.26 |
| C II | 4638.0 | 4637.6 | 2.47 | 1.50 | 2.24 |
| N III | 3336.5 | 3335.6 | 1.47 | 2.78 | 4.17 |
| O IV | 2672.6 | 2671.6 | 0.95 | 3.55 | 5.32 |
| F V | 2238.8 | 2237.7 | 0.67 | 4.29 | 6.43 |
| Ne VI | 1866.8 | 1866.1 | 0.55 | 7.01 | 10.51 |
| Na VII | 1696.3 | 1695.3 | 0.43 | 7.01 | 10.51 |
| Mg VIII | 1515.6 | 1515.1 | 0.35 | 8.07 | 12.10 |
| Al IX | 1371.2 | 1371.2 | 0.29 | 9.10 | 13.65 |
| Si X | 1252.8 | 1252.8 | 0.24 | 10.11 | 15.17 |
| P XI | 1160.2 | 1160.2 | 0.21 | 10.81 | 16.22 |
| S XII | 1047 | 1047 | 0.19 | 13.50 | 20.24 |
| Cl XIII | 1014 | 1014 | 0.16 | 12.07 | 18.10 |
| A XIV | 957 | 957 | 0.14 | 12.47 | 18.71 |

Table 2 gives analogous results for Al I, Si II, P III, . . . As for Table 1, the wavelengths were taken from (7) or (8). The quantity $N_q$ was determined by the semiempirical formula obtained with the aid of Slater functions (9),

**Table 2**

| Element | $\lambda(^2D_{3/2} - {}^2S_{1/2})$ | $\lambda(^2D_{5/2} - {}^2S_{1/2})$ | $N_q$ | $E$ | $A_{21}^{(1)}$ | $A_{21}^{(2)}$ |
|---|---|---|---|---|---|---|
| Al I | 7825 | 7825 | 31.8 | 0.44 | 18.3 | 27.5 |
| Si II | 4681.6 | 4685.1 | 11.7 | 1.20 | 32.1 | 48.2 |
| P III | 3954.7 | 3959.4 | 6.3 | 2.22 | 21.8 | 32.8 |
| S IV | 3404.5 | 3406.5 | 4.0 | 3.48 | 18.9 | 28.4 |
| Cl V | 2993.1 | 2998.7 | 2.8 | 4.98 | 17.7 | 26.5 |
| A VI | 2679 | 2679 | 2.1 | 6.71 | 16.8 | 25.2 |
| K VII | 2427.4 | 2437.2 | 1.6 | 8.66 | 16.4 | 24.5 |
| Ca VIII | 2221.4 | 2234.1 | 1.3 | 10.83 | 16.2 | 24.3 |
| Sc IX | 2055.5 | 2055.5 | 1.1 | 13.27 | 16.1 | 24.2 |
| Ti X | 1910 | 1910 | 0.9 | 15.78 | 16.5 | 24.7 |
| V XI | 1784 | 1784 | 0.8 | 18.60 | 16.7 | 25.1 |
| Cr XII | 1674 | 1674 | 0.7 | 20.43 | 19.0 | 28.5 |

| Element | $\lambda(^2D_{3/2}-{}^2S_{1/2})$ | $\lambda(^2D_{5/2}-{}^2S_{1/2})$ | $N_q$ | $E$ | $A_{21}^{(1)}$ | $A_{21}^{(2)}$ |
|---|---|---|---|---|---|---|
| Mn XIII | 1578 | 1578 | 0.5 | 26.44 | 15.3 | 23.0 |
| Fe XIV | 1493 | 1493 | 0.5 | 28.67 | 18.3 | 27.5 |
| Co XV | 1417 | 1417 | 0.4 | 31.58 | 18.2 | 27.4 |
| Ni XVI | 1349 | 1349 | 0.4 | 33.45 | 21.0 | 31.3 |

$$N_q = \frac{14}{E}, \tag{6}$$

where $E$ is the ionization energy from the ground state $3s^2 3p\,{}^2P$, in rydbergs. For Ti X, V XI, . . . the approximate values of $E$ were found by extrapolation. The exact

the value $N_q = 0.56$ is known only for Fe XIV ([10]), which is comparable with the value of $N_q$ obtained from formula (6).

A certain scatter in the values of $A_{21}^{(1,2)}$ in Table 2 is due to the approximate nature of the wavelength values used in the calculation; moreover, beginning with Cr XII and further on, deviations from $LS$-coupling become appreciable, which also introduces an error into the calculation.

For Si X our calculations agree well with the calculations ([11]), carried out only for Si X and Fe XIV. In the case of Fe XIV there is a discrepancy of approximately a factor of two, caused by different values of the quantity $i$ entering into (5).

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Leningrad State University
named after A. A. Zhdanov

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*Note: Figure translations are in progress. See original paper for figures.*