Vol 16 No 10, October 2007
1009-1963/2007/16(10)/2934-04
Chinese Physics
© 2007 Chin. Phys. Soc.
and IOP Publishing Ltd

Transition probabilities for NII 2p4f–2p3d and $2s2p^2 3d$–$2s2p^2 3p$ obtained by a semiclassical method*

Shen Xiao-Zhi(申晓志)[a], Yuan Ping(袁 萍)[a)b)†], Zhang Hua-Ming(张华明)[a)c)], and Wang Jie(王 杰)[a)]

[a)] *College of Physics and Electronic Engineering, Northwest Normal University, Lanzhou* 730070, *China*
[b)] *Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou* 730000, *China*
[c)] *Thunder Prevention and Observation Center of Shanxi Province, Taiyuan* 030002, *China*

(Received 25 January 2007; revised manuscript received 17 March 2007)

Based on NII spectra, some transition probabilities for 2p4f–2p3d and $2s2p^2 3d$–$2s2p^2 3p$ are obtained by a semiclassical method. The results are in good agreement with other measurements and the data reported by the National Institute of Standards and Technology. The transition probability for a line of 424.18nm is reported for the first time. Meanwhile, a feasible method of calculating transition parameters related to special excited configurations or highly excited states is provided.

Keywords: NII ion, transition probability, semiclassical method
PACC: 3270, 3270F

1. Introduction

Nitrogen is among the most abundant elements in the universe. The research on transition properties for NII is one of the most interesting subjects in atmospheric physics, atmospheric chemistry, laboratory plasmas and other relevant fields. Some theoretical and experimental studies have been carried out on this subject in the past. Based on the close-coupling approximation, Luo and Pradhan have obtained the oscillator strengths for carbon-like ions by $\boldsymbol{R}$-matrix method.[1] In their work on NII, the excited configurations were lower than 2p5s and limited to the LS-coupling. Bell *et al*[2,3] calculated the oscillator strengths and radiative transition probabilities of $2pnl$ ($n \leq 4$, $l < 2$) by using the configuration interaction code (CIV3). Adopting the multi-configuration Dirac-Fock method, Yuan and collaborators[4,5] have obtained the transition probabilities for NII with $n \leq 3$, and well considered the influence of electron correlation and relaxation effects. In addition, Musielok *et al*[6] have reported experimental transition probabilities for a fairly large number of lines (52) from 3p–3s and 3d–3p transition arrays of NII from a wall stabilized arc source.

So far, little research on the transition for NII 2p4f has been done. The configuration 2p4f has a particular fine structure which appears in pairs, and it can be described by the LK-coupling scheme (pair coupling).[7] Since the energy level splitting is only several cm^{-1} in every pair of energy levels, it is sensitive to the influence of various effects, which gives rise to certain difficulties in theoretical research on transitions of this configuration. Mar *et al*[8] have obtained 12 experimental transition probabilities of 2p4f–2p3d. But the line with a wavelength of 424.18 nm was not specified in their work. The transition of this line is so intensive that it has been observed obviously in many experiments.[9−12]

In the present work, according to experiment spectra, transition probabilities of some particular configurations for NII are obtained by using a semiclassical method. The results are in good agreement with other experimental results and the data reported by the National Institute of Standards and Technology (NIST). Meanwhile, a way to obtain transition parameters of some particular excited configurations or highly excited states is also provided.

2. Experimental results and discussion

2.1. Electron temperature

Figure 1 shows the spectra of a lightning return stroke in coastal area of Guangdong, southern China.

*Project supported by the National Natural Science Foundation of China (Grant No 40475007).
†E-mail: yuanp@nwnu.edu.cn

The spectra were obtained by a slitless spectrograph, and the experimental setup has been previously described in detail.[13] The line with a wavelength of 517.95 nm has been observed obviously in this work. It originates from the transition of inner-shell excited configuration 2s2p^{2}3d-2s2p^{2}3p. In Mar's work, this line is not reported.[8]

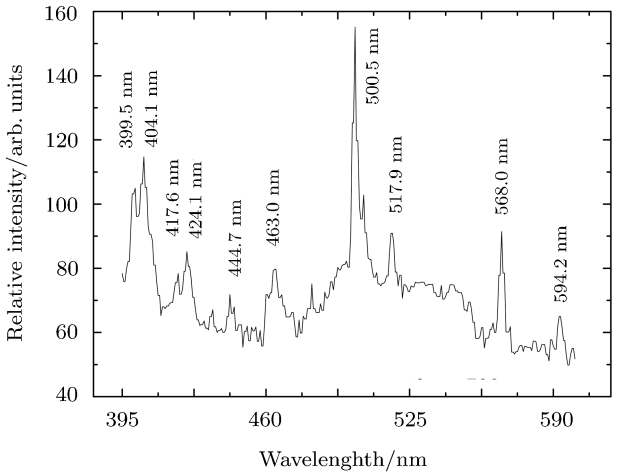


Fig.1. The spectra in a lightning return stroke.

The electron temperature of lightning channel is calculated on the two essential assumptions:[14,15] (a) channel plasma is in the local thermodynamic equilibrium (LTE) and (b) channel is optically thin. Under the LTE assumption, the intensity ratio of two lines belonging to the same atomic species is given by[16]

$$\frac{I_1}{I_2} = \frac{A_1 g_1 \lambda_2 U_2 n_1}{A_2 g_2 \lambda_1 U_1 n_2} \exp\Big[-\frac{E_1 - E_2}{kT}\Big], \qquad (1)$$

where I is relative intensity of line; λ, g, A and E are the wavelength, statistical weight, transition probability and upper excitation energy of corresponding transition, respectively; T, U and n are the electron temperature, partition function and the number density of particles, respectively. Subscripts 1 and 2 refer to the first and second lines. In the case that two lines belong to the same ionization stage, U_1 and U_2 are equal, likewise, $n_1 = n_2$. Then, Eq.(1) becomes

$$\frac{I_1}{I_2} = \frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1} \exp\Big[-\frac{E_1 - E_2}{kT}\Big], \qquad (2)$$

Assuming line 2 to be the reference line, line 1 to represent the spectral line of the same ions, Eq.(2) can be changed as follow:

$$\ln\Big[\frac{I_1 \lambda_1}{g_1 A_1}\Big] = -\frac{1}{kT} E_1 + c\,, \qquad (3)$$

For configurations whose fine structures are represented by the LS-coupling scheme, it is easy to acquire their transition parameters through theoretical calculation.[1–4] Thus, these parameters can be adopted to calculate electron temperatures. According to relative intensity of spectral lines and theoretical values of corresponding transition parameters,[1–4] electron temperatures can be obtained through the linear fitting of Eq.(3). In the present work, 20 groups of spectral data at different sites of lighting channel (SLC) are chosen to calculate electron temperatures, separately.

In practical calculation, taking $\ln[\frac{I_1\lambda_1}{g_1 A_1}]$ as the y-axis and E_1 as the x-axis, a slope parameter can be obtained by fit. Figure 2(a) shows a fitting example at SLC 3. Since this fitting parameter is equal to $-1/kT$, then the electron temperature can be calculated. Figure 2(b) gives the electron temperatures of 20 SLCs. It can be seen that there are some discrepancy in the electron temperature of different SLCs. On the one hand, it is due to the characteristic of lightning discharge channel. On the other hand, the relative intensities of lines and other factors also have some influence on the calculated results.

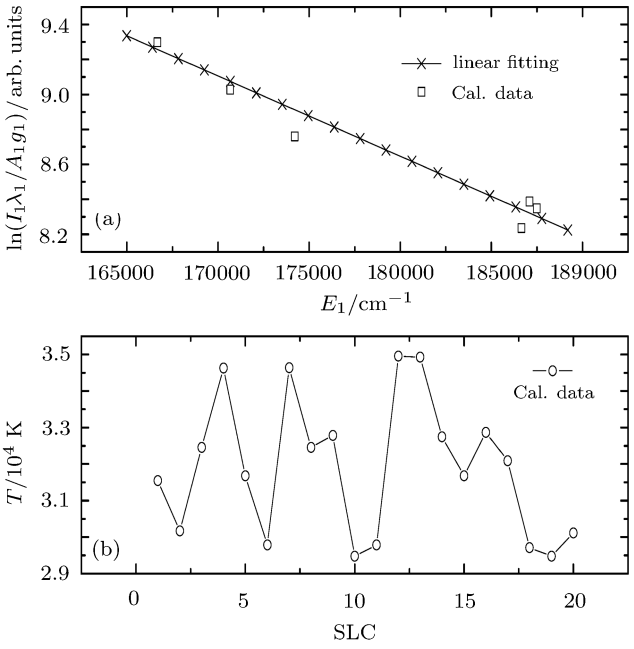


Fig.2. A fitting example at SLC 3 (a) and electron temperature at different SLCs (b).

2.2. Transition probabilities

According to the above-mentioned method, electron temperatures obtained by choosing different lines should be the same for a certain spectrum. Using the

calculated electron temperatures and known transition parameters, the requested transition probabilities can be evaluated. Equation (2) can be expressed as

$$\frac{g_1 A_1}{I_1 \lambda_1} = C_{\rm slc} \exp\Big[\frac{E_1}{kT}\Big], \tag{4}$$

where $C_{\rm slc}$ is a function of lines with unknown transition parameters, and the transition parameters of line 1 have been known. Taking $[\frac{g_1 A_1}{I_1 \lambda_1}]$ as the y-axis and $\exp[\frac{E_1}{kT}]$ as the x-axis, $C_{\rm slc}$ can be obtain by linear fitting. Figure 3 shows a fitting example at SLC 3. Then, unknown transition probabilities are obtained as follows:

$$A_2 = C_2 C_{\rm slc} \exp\Big[\frac{E_2}{kT}\Big], \tag{5}$$

where C_2 is calculated from the parameters of line 2. Corresponding to every $C_{\rm slc}$, transition probabilities of different lines can be evaluated (e.g. 404.13 nm, 417.62 nm, 424.18 nm and 517.95 nm). For the calculated transition probability of each line, 20 values have been obtained in the present work. The results are shown in Fig.4. We can find that the transition probability of 404.13 nm is obviously larger than those of 417.62 nm, 424.18 nm and 517.95 nm. The calculated transition probabilities of these four lines all have a certain deviation. Finally, the transition probabilities are reported together with mean values and their uncertainty, which are listed in Table 1 in detail. It can be seen that the results in this work are in good agreement with Mar's data[8] and the value reported by the NIST. Besides, the transition probability for a line of 424.18nm is reported for the first time.

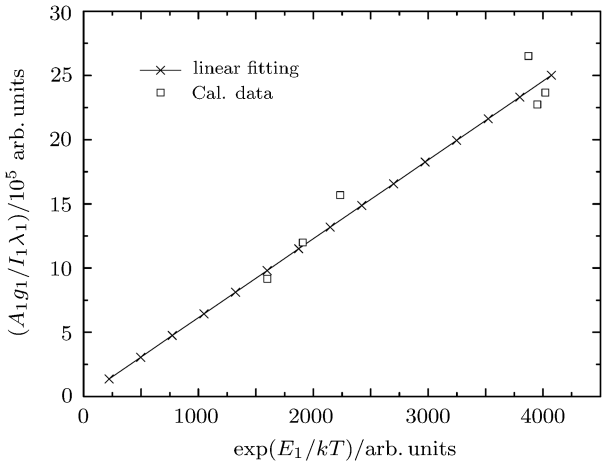


Fig.3. Linear fit to get parameter $C_{\rm slc}$.

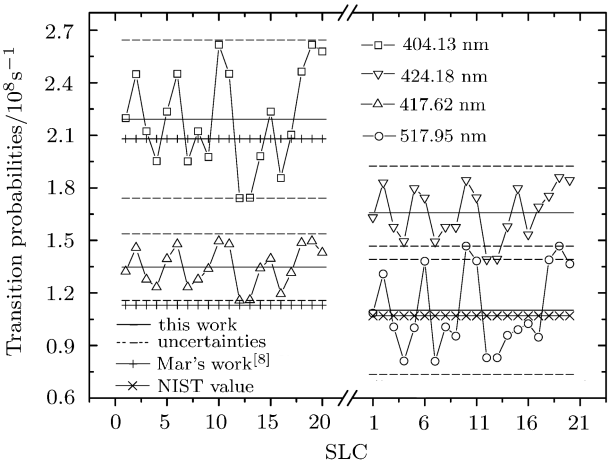


Fig.4. Some transition probabilities in this work.

Table 1. The calculated transition probabilities as comparing with the results cited from other work.

Wavelength/nm	Transition	Transition probability		Ratio	
		Present work	Measurement[8]	$T_{\rm w}$/Wiese[17]*	$T_{\rm w}$/NIST**
404.13	2p4f G(9/2)$_5$-2p3d ^{3}F$^{\rm o}_4$	2.19±0.45	2.08	0.83±0.17	
417.62	2p4f F(5/2)$_3$-2p3d ^{1}D$^{\rm o}_2$	1.35±0.19	1.13	0.62±0.09	
424.18	2p4f F(7/2)$_4$-2p3d ^{3}D$^{\rm o}_3$	1.66±0.27			
517.95	2s2p^{2}3d ^{5}F$_5$-2s2p^{2}3p ^{5}D$^{\rm o}_4$	1.10±0.37			1.02±0.34

*ratio between the transition probability ($T_{\rm w}$) obtained in the present work and that cited from Ref.[17]. **ratio between the transition probability ($T_{\rm w}$) obtained in the present work and that cited from the NIST.

3. Conclusions

Based on the spectra of lightning return stroke, electron temperatures have been obtained from relative intensities and theoretical transition parameters of some lines. On this basis, some transition probabilities for NII 2p4f–2p3d and 2s2p^{2}3d–2s2p^{2}3p are achieved. The results are in good agreement with Mar's data[8] and the value reported by the NIST. For the first time, the transition probability for a line of 424.18 nm is reported. Meanwhile, a semiclassi-

cal method of obtaining transition parameters of some particular excited configurations is provided. A feasible approach to solving transitions of highly excited states is also presented.

References

[1] Luo D and Pradhan A K 1989 *J. Phys. B: At. Mol. Opt. Phys.* **22** 3377

[2] Bell K L, Ramsbottom C A and Hibbert A 1992 *J. Phys. B: At. Mol. Opt. Phys.* **25** 1735

[3] Bell K L, Hibbert A and Stafford R P 1995 *Phys. Scr.* **52** 240

[4] Yang P, Liu X S, Zhang Y J, Xie L Y and Dong C Z 2002 *Acta. Phys. Sin.* **51** 2495 (in Chinese)

[5] Yang P, Liu X S, Xie L Y, Zhang Y J and Dong C Z 2003 *Chinese Phys.* **12** 271

[6] Musielok J, Bridges J M, Djurovic S and Wiese W L 1996 *Phys. Rev.* A **53** 3122

[7] Cowan R D 1981 *The Theory of Atomic Structure and Spectra* (London: University of California Press) p128

[8] Mar S, Perez C, Gonzalez V R, Gigosos M A, del Val1 J A, de la Rosa I and Aparicio J A 2000 *Astron. Astrophys. Suppl. Ser.* **144** 509

[9] Yang Z H, Wang Y D, Ma X W, Xu Q, Zhao M C and Liu H P 1994 *J. At. Mol. Phys.* **11** 147 (in Chinese)

[10] Dempsey J T, Storey J W V and Phillips A 2005 *Publ. Astron. Soc. Aust.* **22** 91

[11] Baldwin J A, Verner E M, Verner D A, Ferland G J, Martin P G, Korista K T and Rubin R H 2000 *Astrophys. J. Suppl.* S **129** 229

[12] Liu X W, Luo S G, Barlow M J, Danziger I J and Storey P J 2001 *Mon. Not. R. Astron. Soc.* **327** 141

[13] Yuan P, Qie X S, Lü S H, Chen G Y and Zhang G Z 2006 *Spectrosc. Spect. Anal.* **26** 733 (in Chinese)

[14] Griem H R 1964 *Plasma Spectroscopy* (New York: McGraw-Hill) p148

[15] Uman M A and Orville R E 1965 *J. Geophys. Res.* **70** 5491

[16] Lochte-Holtgrevem W 1968 *Plasma Diagnostics* (Amsterdam: North-Holland) p181

[17] Wiese W L, Fuhr J R and Deters T M 1996 *J. Phys. Chem. Ref. Data Monograph* 7 (New York: AIP)