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Rotational Analysis of $A^2\Pi_u$-$X^2\Sigma_g^+$ System of $^{14}N_2^+$

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The absorption spectrum of N_2^+ has been studied using optical-heterodyne velocity modulation spectroscopy in the near-infrared region. The observed spectral lines were assigned to the (3,1), (4,2), (5,3), (8,5) bands of the $A^2\Pi_u$-$X^2\Sigma_g^+$ system and the line lists were provided. The (5,3) band was studied for the first time. Fourteen rotational-resolved bands in literatures were fitted together with our observed bands and the molecular constants were obtained for v_A=0−9 and v_X=0−5.

Key words: Absorption spectroscopy, Rotational analysis, N_2^+

I. INTRODUCTION

Fasbender observed a widespread band system of N_2^+ ranging from the visible to the near ultraviolet region in 1924 [1]. Since then, the spectrum of N_2^+ has become the subject of many spectroscopists. In 1932, Childs [2] predicted that a lower lying Π state, which was later identified as the $A^2\Pi_u$ state, was a perturbation of the $B^2\Sigma_u^+$-$X^2\Sigma_g^+$ system. Later, in 1950, Meinel [3] first observed the spectrum of the $A^2\Pi_u$-$X^2\Sigma_g^+$ system in an auroral emission in the near-infrared. So, the A-X system of N_2^+ is also called Meinel system.

The rotational analysis of the A-X system is the subject of this study. The early rotational study was performed by Douglas [4]. Colburn and Douglas [5] reported the constants of v_A=2−3. Gottscho *et al.* [6] deduced new molecular rotational constants for the $A^2\Pi_u$ and $X^2\Sigma_g^+$ states of the N_2^+. Benesch *et al.* [7] measured an extensive emission spectrum for eight bands of the Meinel system. However, the eight bands were not fitted until Miller [8] fitted them together with the (4, 0) band, which was recorded by Miller *et al.* using the fluorescence spectrum. Thus, Miller *et al.* reported the molecular constants for v_A=0−4 and v_X=0−2. Since then, many spectroscopists have studied the Meinel system.

Velocity modulation spectroscopy (VMS) [9] is an useful technique in the study of molecular ions and has applied extensively to study the spectrum of N_2^+. In 1987, the (7,3) band [10] was studied. Later, the (6,1) and (13,6) bands [11], the (8,3) band [12], the (2,5) band [13], the (9,4) and (11,5) bands [14], the (6,3) band [15], the (12,6) band [16], the (15,8) band [17], the (7,2) and (7,4) bands [18], the (3,3) and (4,4) bands [19], the (11,5) and (12,6) bands [20], were also studied using VMS.

We report the observation of the absorption spectrum of N_2^+ using optical heterodyne velocity modulation spectroscopy (OH-VMS), the spectrum was recorded in the region from 11250 cm^{-1} to 12900 cm^{-1}. Part of rotational lines were assigned to four bands of the Meinel system. The assigned lines combined with those early reported rotational-resolved lines were included in a group fitting to determine molecular constants.

II. EXPERIMENTS

The experimental setup has been described in our previous work [21] in detail. N_2^+ was produced by discharging the mixture of N_2 (25 Pa) and He (600 Pa) flowing continuously in the absorption cell. The mixture was discharged at the current of 400 mA (peak to peak) at 23 kHz. The incident laser beam was frequency-modulated with an electro optical modulator (EOM) driven at 480 MHz. The acquired signal from a detector was first demodulated by a double-balance mixer at a frequency of 480 MHz and further demodulated by a lock-in amplifier at 23 kHz. The wavelength of the laser beam was determined by an attached wavemeter of the laser system and was further calibrated by the iodine spectrum [22] using an additional iodine reference absorption cell.

III. SPECTRAL ANALYSIS

The observed line shape of single line using OH-VMS was the second derivative Gaussian. The overlapped absorption spectrum was fitted to determine the accuracy line center. Figure 1 shows a portion of the spectrum and the corresponding assignments.

The rotational analysis was aided by the Pgopher program [23]. The $X^2\Sigma_g^+$ state was fitted using the standard Hund's case (b), which consisted of the electronic

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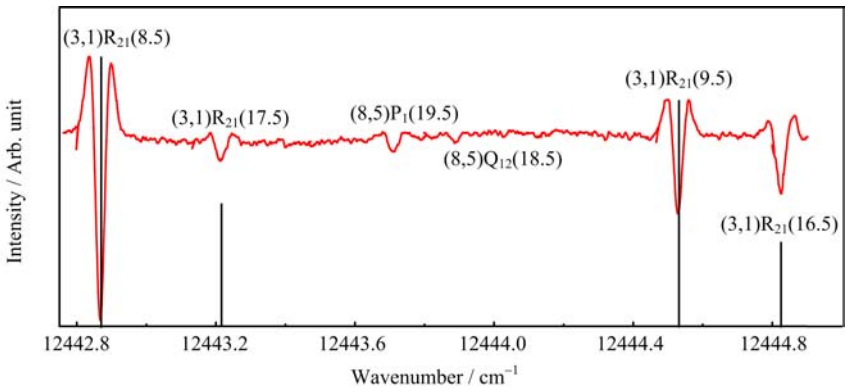

FIG. 1 Partial spectrum of the $A^2\Pi_u$-$X^2\Sigma_g^+$ system of N_2^+ observed using the optical heterodyne velocity modulation absorption spectroscopy. The stick lines show the calculations and relativity intensities performed using Pgopher program [23].

and vibrational energy T, the rotational constant B, the quartic centrifugal distortion constant D, and the spin-rotation constant γ. The $A^2\Pi_u$ state was fitted using the standard Hund's case (a) and the constants T, B, D, the spin-orbit coupling constant A, the centrifugal distortion of the spin-orbit constant A_D, the lambda doubling constants p and q.

Totally, we assigned 986 lines to the (3,1), (4,2), (5,3), (8,5) bands in the $A^2\Pi_u$-$X^2\Sigma_g^+$ system of N_2^+. All the assigned lines are listed in Table I. Each band was first analyzed separately using the Pgopher program [23]. Briefly, the (3,1) band contains 244 lines with a reported rms of 0.0028 cm^{-1}, the (4,2) band contains 269 lines with a rms (root mean square) of 0.0037 cm^{-1}, the (5,3) band contains 247 lines with a rms of 0.0036 cm^{-1}, the (8,5) band contains 226 lines with a rms of 0.0033 cm^{-1}.

Using VMS, many other bands in the A-X system have been previously studied. We adopted some bands in this work and fitted them in a group fitting. The selected bands were the (6,1) band [11], the (2,5) band [13], the (8,3) band [12], the (9,4) band [14], the (7,2) and (7,4) bands [18], the (3,3) and (4,4) bands [19]. However, not all the lines reported in the literatures were adopted in the group fitting. As shown in Fig.2 for the selected bands, the two vibrational levels have an interconnection with the other levels. So, the (13,6) band [11] and (11,5) band [14] were not used even though they have good line lists. For the above bands, not all the lines were used in the fitting. Some reported positions in literatures deviating the calculated ones too much were omitted in our fitting. The omitted lines are the $R_{11}(14.5)$, $P_{21}(5.5)$, $R_{21}(9.5)$ in the (6,1) band, the $P_{22}(12.5)$ in the (3,3) band.

Besides the VMS, other techniques have been used to measure the rotational-resolved spectrum of N_2^+. Miller *et al.* [8] reported the spectrum of (4, 0) band measured using the laser-induced fluorescence technique. Their reported resolution is 0.004 cm^{-1}. Their lines are all used in the group fitting. Ferguson *et al.* [24] measured the (0,0), (0,1), (1,0), (1,2) bands of the $A^2\Pi_u$-$X^2\Sigma_g^+$ system using the Fourier transform emission spectroscopy technique. The reported frequency covered the spectral region from 3500 cm^{-1} to 11500 cm^{-1}. There are 768 lines ($J \leq 23.5$) reported for these four bands and the $R_{12}(12.5)$ and $R_{21}(5.5)$ in the (0,0) band, the $P_{11}(13.5)$ in the (1,0) band, the $R_{12}(19.5)$ in the (1,2) band were omitted in our group fitting. Bachir *et al.* [25] measured the (2,0) bands of the $A^2\Pi_u$-$X^2\Sigma_g^+$ system using laser optogalvanic spectroscopy and all the lines were used in our fitting.

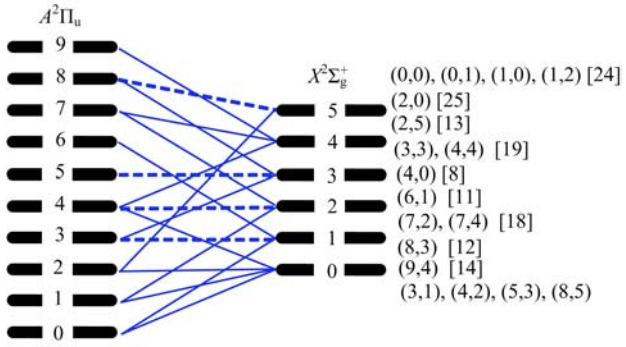

FIG. 2 The vibrational bands used in the group fitting. The dash lines show the bands studied in this work and the solid lines show the bands reported in the literatures.

IV. RESULTS

The group fitting contained 3497 lines and 91 parameters were estimated. For each vibration level, the constants of T, A, B, D, p, q, A_D were fitted. All the lines were fitted with the same weight and a rms of 0.0053 cm^{-1}. The estimated parameters along with one standard deviation error are listed in Table II for the $X^2\Sigma_g^+$ state. We fixed $T_{v''=0}=0$ and made other

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TABLE I Wavenumbers (in cm^{-1}) of rotational lines in the (3,1), (4,2), (5,3), and (8,5) bands of the second negative system for N_2^+. Numbers in the parentheses indicate $(\nu_{cal.}-\nu_{obs.})\times10^4$ cm^{-1}.

Band	J	P_{11}	P_{12}	P_{22}	P_{21}	Q_{11}	Q_{12}
(3,1)	0.5						
	1.5			12399.0073(11)		12333.5470(46)	12325.9440(−35)
	2.5		12314.5339(14)	12392.7385(15)		12334.1405(40)	12322.7430(−11)
	3.5		12307.5251(16)			12334.2120(20)	12319.0234(30)
	4.5	12318.9845(58)	12299.9934(−17)	12379.0653(16)		12333.7628(−16)	12314.7801(24)
	5.5	12314.7204(−63)	12291.9489(1)	12371.6589(13)		12332.8005(−8)	12310.0187(10)
	6.5	12309.9504(−70)	12283.3848(−18)	12363.8693(−7)		12331.3206(−21)	12304.7438(13)
	7.5	12304.6669(−61)		12355.6984(−7)		12329.3294(−14)	12298.9544(1)
	8.5	12298.8722(−33)	12264.7236(−1)	12347.1415(−12)	12381.2653(−73)	12326.8296(17)	12292.6565(9)
	9.5	12292.5661(−15)	12254.6273(−9)	12338.1967(−21)	12376.1179(−4)	12323.8183(17)	12285.8502(11)
	10.5	12285.7513(−5)	12244.0282(−12)	12328.8678(30)	12370.5728(−5)	12320.3002(6)	12278.5363(−11)
	11.5	12278.4296(−12)	12232.9230(−1)	12319.1383(0)	12364.6348(−2)	12316.2782(−13)	12270.7213(−21)
	12.5	12270.6071(−4)	12221.3189(−4)	12309.0166(−2)	12358.3056(47)	12311.7580(−10)	12262.4097(−1)
	13.5	12262.2828(−19)	12209.2170(−18)	12298.4984(6)	12351.5692(11)	12306.7408(0)	12253.5996(0)
	14.5	12253.4657(5)	12196.6235(−9)	12287.5750(−36)	12344.4344(3)	12301.2261(−15)	12244.2964(10)
	15.5	12244.1517(0)	12183.5368(−24)	12276.2550(−18)	12336.8953(−10)	12295.2220(0)	12234.4992(−8)
	16.5	12234.3483(12)	12169.9667(7)	12264.5291(−8)	12328.9573(52)	12288.7247(−17)	12224.2154(−7)
	17.5	12224.0537(−2)		12252.3957(0)	12320.6004(15)	12281.7422(−11)	12213.4446(−15)
	18.5	12213.2760(13)	12141.3668(2)	12239.8519(0)		12274.2767(17)	12202.1916(−10)
	19.5	12202.0126(7)	12126.3498(40)	12226.8991(29)	12302.6588(24)	12266.3226(−11)	12190.4563(−17)
	20.5	12190.2665(−15)	12110.8509(34)	12213.5286(18)	12293.0620(−6)	12257.8902(−13)	12178.2419(−24)
	21.5	12178.0457(6)	12094.8723(−19)	12199.7415(0)	12283.0493(−16)	12248.9802(−2)	12165.5555(17)
	22.5	12165.3480(27)	12078.4272(−9)	12185.5411(23)	12272.6204(9)	12239.5900(−21)	12152.3892(7)
	23.5	12152.1727(20)	12061.5101(−13)	12170.9127(−41)	12261.7656(−8)	12229.7286(1)	12138.7517(14)

Band	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(3,1)	0.5			12337.3527(−10)			12415.5497(10)
	1.5	12404.1419(−5)		12341.7571(30)			12420.3002(−63)
	2.5	12401.2914(−51)	12412.7041(15)	12345.6325(−8)	12334.2378(−46)		
	3.5	12398.0690(−26)	12413.2797(11)	12348.9937(11)		12413.5173(24)	12428.6790(−22)
	4.5	12394.4682(19)	12413.4787(55)	12351.8343(10)		12413.3404(47)	12432.2947(0)
	5.5	12390.4798(6)	12413.2857(10)	12354.1570(−2)		12412.7772(60)	12435.5185(−44)
	6.5	12386.1061(−21)	12412.7106(−4)	12355.9663(1)	12329.4062(59)		12438.3608(−25)
	7.5			12357.2625(−1)	12326.9129(62)	12410.4791(19)	12440.8103(−31)
	8.5	12376.2076(13)	12410.3962(−23)	12358.0481(−7)	12323.9082(35)	12408.7445(20)	12442.8675(−28)
	9.5	12370.6717(11)	12408.6553(9)	12358.3300(30)	12320.3984(15)	12406.6122(0)	12444.5287(−25)
	10.5	12364.7410(−6)	12406.5143(−6)	12358.1043(44)	12316.3859(−2)	12404.0867(31)	12445.7905(−27)
	11.5	12358.4175(8)	12403.9772(2)	12357.3704(4)	12311.8727(−21)	12401.1556(18)	12446.6513(−21)
	12.5	12351.6946(14)	12401.0398(18)	12356.1392(−6)	12306.8658(−1)	12397.8219(18)	12447.1063(−25)
	13.5	12344.5676(−9)	12397.6964(14)	12354.4105(−13)	12301.3623(3)	12394.0796(0)	12447.1574(10)
	14.5	12337.0393(−7)	12393.9459(7)	12352.1880(−4)	12295.3670(14)	12389.9300(4)	12446.7911(−23)
	15.5	12329.1060(10)	12389.7869(9)	12349.4703(−18)	12288.8804(11)	12385.3672(−3)	12446.0158(−13)
	16.5	12320.7610(−1)	12385.2121(−25)	12346.2643(−7)	12281.9019(−36)	12380.3911(3)	12444.8255(7)
	17.5	12312.0063(4)	12380.2288(2)	12342.5687(−7)	12274.4461(−4)	12374.9978(8)	12443.2131(−8)
	18.5	12302.8381(10)	12374.8267(12)	12338.3862(−10)	12266.5062(17)	12369.1823(−14)	12441.1816(−3)
	19.5	12293.2533(7)	12369.0021(−9)		12258.0803(−12)	12362.9488(−1)	12438.7298(34)
	20.5	12283.2513(11)	12362.7586(−3)	12328.5735(24)	12249.1767(−29)	12356.2890(−13)	12435.8423(−30)
	21.5	12272.8302(22)		12322.9443(36)		12349.2050(−10)	12432.5381(17)

To be continued.

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Table I continued.

Band	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(3,1)	22.5	12261.9825(−17)		12316.8328(18)	12229.9468(5)	12341.6878(−64)	12428.8020(43)
	23.5	12250.7163(−6)	12341.4757(−7)				
	J	P_{11}	P_{12}	P_{22}	P_{21}	Q_{11}	Q_{12}
(4,2)	0.5						
	1.5			12040.1712(−38)	12047.6921(36)	11974.6336(33)	11967.1091(−25)
	2.5	11967.0955(70)	11955.8128(17)	12033.9584(−26)	12045.2252(−33)	11975.2130(33)	11963.9263(−55)
	3.5	11963.9035(41)	11948.8650(12)	12027.3686(9)	12042.3963(73)	11975.2703(0)	11960.2269(−63)
	4.5		11941.3991(3)	12020.3936(−8)	12039.1719(27)	11974.8149(15)	11956.0217(44)
	5.5	11955.9582(−82)	11933.4170(−5)	12013.0403(5)	12035.5670(−8)	11973.8393(−13)	11951.2896(39)
	6.5	11951.2175(−81)	11924.9217(−3)	12005.3040(16)		11972.3506(−32)	11946.0449(45)
	7.5	11945.9636(−74)	11915.9154(11)	11997.1815(8)	12027.2070(−71)	11970.3533(−19)	11940.2817(−19)
	8.5	11940.1973(−76)	11906.3915(−54)	11988.6733(7)	12022.4508(−72)	11967.8447(−22)	11934.0167(−8)
	9.5	11933.9291(−5)	11896.3701(−23)	11979.7778(19)	12017.3060(−68)	11964.8312(−4)	11927.2449(0)
	10.5	11927.1468(−9)	11885.8351(−84)	11970.4919(35)	12011.7737(−24)	11961.3109(−7)	11919.9690(7)
	11.5	11919.8631(13)	11874.8134(4)	11960.8085(8)	12005.8453(−2)	11957.2893(−4)	11912.1906(2)
	12.5	11912.0776(29)	11863.2889(50)	11950.7341(27)	11999.5180(−3)	11952.7690(6)	11903.9160(21)
	13.5	11903.7901(11)	11851.2565(−25)	11940.2556(−13)	11992.7935(14)	11947.7529(25)	11895.1417(0)
	14.5	11895.0070(−5)	11838.7413(0)	11929.3860(41)	11985.6641(−1)	11942.2394(12)	11885.8793(29)
	15.5	11885.7328(−1)	11825.7373(36)	11918.1082(42)	11978.1342(20)	11936.2370(26)	11876.1220(14)
	16.5	11875.9675(−4)	11812.2451(63)	11906.4243(37)	11970.1932(−3)	11929.7411(−3)	11865.8755(−15)
	17.5	11865.7138(−13)	11798.2548(−47)	11894.3330(33)	11961.8434(−23)	11922.7620(4)	11855.1489(8)
	18.5	11854.9750(−19)	11783.8064(79)	11881.8311(21)	11953.0874(10)	11915.2976(4)	11843.9356(−6)
	19.5	11843.7591(33)	11768.8598(16)	11868.9184(20)	11943.9132(−3)	11907.3502(−2)	11832.2421(−16)
	20.5	11832.0540(0)	11753.4381(−30)	11855.5842(−58)	11934.3286(37)	11898.9228(−4)	11820.0722(−6)
	21.5	11819.8745(7)	11737.5468(−28)	11841.8498(19)	11924.3185(1)	11890.0190(14)	11807.4257(2)
	22.5	11807.2183(11)	11721.1783(−76)	11827.6916(34)	11913.8937(14)	11880.6375(20)	11794.3052(14)
	23.5	11794.0856(−7)		11813.1102(8)	11903.0426(−20)	11870.7773(−11)	11780.7134(37)
	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(4,2)	0.5	12047.7029(5)	12051.4641(−27)	11978.4032(−2)	11974.6461(19)		12056.5420(−14)
	1.5	12045.2536(20)	12052.7822(20)	11982.7488(−22)	11975.2347(19)	12053.7398(31)	12061.2433(27)
	2.5	12042.4239(25)	12053.7212(76)	11986.5716(−75)	11975.3074(47)		12065.5585(18)
	3.5	12039.2074(−34)	12054.2721(62)	11989.8950(62)		12054.4804(31)	12069.4929(27)
	4.5	12035.6178(−9)	12054.4388(32)	11992.6851(35)	11973.8960(45)	12054.2721(1)	12073.0406(12)
	5.5	12031.6419(−17)	12054.2147(−64)	11994.9601(10)		12053.6792(−12)	12076.2023(1)
	6.5	12027.2819(−17)	12053.6155(−48)	11996.7244(13)	11970.4291(45)	12052.7021(18)	12078.9780(18)
	7.5	12022.5354(−13)	12052.6253(−56)	11997.9809(51)	11967.9286(30)	12051.3294(3)	12081.3593(3)
	8.5	12017.3967(−40)	12051.2453(−52)	11998.7253(58)	11964.9235(40)	12049.5616(−29)	12083.3484(6)
	9.5	12011.8701(−32)	12049.4746(−19)	11998.9541(−23)	11961.4083(−5)	12047.4023(−12)	12084.9430(30)
	10.5	12005.9502(−17)	12047.3050(−13)	11998.6851(−39)	11957.3952(−9)	12044.8439(3)	12086.1341(15)
	11.5	11999.6330(−10)	12044.7383(11)	11997.9124(−73)	11952.8846(5)	12041.8799(−21)	12086.9279(51)
	12.5	11992.9143(−28)	12041.7649(−14)	11996.6462(−49)	11947.8767(14)	12038.5159(0)	12087.3109(31)
	13.5	11985.7963(−21)	12038.3918(8)	11994.8808(−46)	11942.3738(14)	12034.7426(−1)	12087.2850(3)
	14.5	11978.2759(3)	12034.6086(1)	11992.6183(−69)	11936.3760(−19)	12030.5572(−25)	12086.8517(10)
	15.5	11970.3466(4)	12030.4155(−7)	11989.8760(34)	11929.8976(35)	12025.9614(−29)	12086.0039(7)
	16.5	11962.0048(−28)	12025.8104(−12)	11986.6310(10)	11922.9219(−16)	12020.9520(−21)	12084.7398(3)
	17.5	11953.2587(11)	12020.7948(27)	11982.8988(−5)	11915.4696(12)	12015.5245(−21)	12083.0580(9)
	18.5	11944.0940(0)	12015.3565(11)	11978.6814(−13)	11907.5328(20)	12009.6777(−20)	12080.9551(15)
	19.5	11934.5140(−6)	12009.5001(8)	11973.9811(−9)	11899.1130(1)	12003.4074(−38)	12078.4285(18)
	20.5	11924.5190(16)	12003.2220(6)	11968.7991(0)	11890.2130(−36)	11996.7244(55)	12075.4714(−27)

To be continued.

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Table I continued.

Band	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(4,2)	21.5	11914.0989(−16)	11996.5224(25)	11963.1377(21)	11880.8419(−18)	11989.6000(−10)	12072.0960(22)
	22.5	11903.2607(−14)	11989.3903(−25)	11956.9942(11)	11870.9965(6)	11982.0522(−35)	12068.2875(36)
	23.5	11891.9975(−30)	11981.8355(−27)				
(5,3)	J	P_{11}	P_{12}	P_{22}	P_{21}	Q_{11}	Q_{12}
	0.5						
	1.5			11684.0974(14)		11618.4692(−17)	11611.0267(−23)
	2.5		11599.8458(21)	11677.9356(−26)		11619.0397(37)	11607.8733(1)
	3.5	11607.8450(41)	11592.9598(8)	11671.4020(20)	11686.2659(−5)	11619.0852(10)	11604.2028(21)
	4.5	11604.1561(−30)	11585.5676(92)	11664.4815(9)	11683.0546(−71)	11618.6150(−17)	11600.0137(11)
	5.5		11577.6434(−2)	11657.1805(14)	11679.4699(−46)	11617.6336(−16)	11595.3121(14)
	6.5	11595.2449(−59)	11569.2149(−14)	11649.4981(42)	11675.4992(−41)	11616.1405(−9)	11590.0977(9)
	7.5	11590.0280(4)	11560.2756(−30)	11641.4203(−31)	11671.1452(−12)	11614.1371(−3)	11584.3724(−6)
	8.5	11584.2969(23)	11550.8337(7)	11632.9675(17)	11666.3995(−24)	11611.6246(−7)	11578.1399(−17)
	9.5	11578.0519(−21)		11624.1222(31)	11661.2661(−15)	11608.6077(1)	11571.4029(−21)
	10.5	11571.3032(−50)	11530.4333(55)	11614.8840(31)	11655.7397(−16)	11605.0876(9)	11564.1689(30)
	11.5	11564.0609(11)	11519.4731(−7)	11605.2520(29)	11649.8211(5)	11601.0632(−19)	11556.4266(−3)
	12.5	11556.3112(−4)	11508.0188(−37)	11595.2208(−4)	11643.5014(−15)	11596.5455(1)	11548.1871(−34)
	13.5	11548.0629(−31)	11496.0738(−30)	11584.7957(7)	11636.7840(−19)	11591.5306(5)	11539.4558(−37)
	14.5	11539.3224(−34)		11573.9682(1)	11629.6663(−8)	11586.0220(3)	
	15.5	11530.0925(−11)	11470.7220(84)	11562.7400(19)	11622.1465(26)	11580.0238(11)	11520.5191(−52)
	16.5	11520.3674(−47)	11457.3029(13)	11551.0974(−53)	11614.2202(62)	11573.5331(−24)	11510.3243(−8)
	17.5	11510.1609(−28)	11443.4119(56)	11539.0556(−42)	11605.8739(−12)	11566.5628(4)	11499.6333(−83)
	18.5	11499.4665(−44)	11429.0336(34)	11526.6057(−16)	11597.1301(53)	11559.1059(3)	11488.4842(82)
	19.5	11488.3010(49)	11414.1774(14)	11513.7349(−82)	11587.9620(9)	11551.1642(−30)	11476.8331(25)
	20.5	11476.6468(53)	11398.8473(13)	11500.4626(−27)	11578.3835(17)	11542.7471(−21)	11464.7147(70)
	21.5	11464.5108(14)	11383.0468(42)			11533.8504(−31)	11452.1099(7)
	22.5	11451.9040(23)		11472.6629(10)		11524.4826(6)	11439.0393(21)
	23.5	11438.8219(15)		11458.1335(6)		11514.6336(−28)	
	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(5,3)	0.5			11622.2078(23)	11618.4850(3)		11700.2897(4)
	1.5	11689.1100(−27)	11696.5682(29)	11626.4992(−11)	11619.0609(19)	11697.4968(−32)	11704.9242(−16)
	2.5	11686.2966(−20)	11697.4806(37)	11630.2770(−6)	11619.1220(56)	11698.0391(5)	11709.1796(−5)
	3.5	11683.1035(3)	11698.0102(38)	11633.5367(−16)	11618.6612(30)	11698.2000(63)	11713.0507(−2)
	4.5	11679.5251(−1)	11698.1513(−9)	11636.2819(−19)	11617.6885(26)	11697.9662(27)	11716.5361(−3)
	5.5	11675.5636(4)	11697.9121(−7)	11638.5140(−17)	11616.2047(34)	11697.3490(28)	11719.6343(−2)
	6.5	11671.2144(−12)	11697.2863(1)	11640.2335(−23)	11614.2079(14)	11696.3394(0)	11722.3438(7)
	7.5	11666.4787(−16)	11696.2693(−9)	11641.4406(−54)	11611.7048(11)		11724.6577(−19)
	8.5	11661.3546(−7)		11642.1471(−14)	11608.6971(19)		11726.5815(−1)
	9.5	11655.8370(−12)		11642.3441(−16)	11605.1823(−12)		11728.1052(−12)
	10.5	11649.9263(−3)		11642.0376(−21)	11601.1685(−27)	11688.3704(5)	11729.2291(−20)
	11.5	11643.6183(1)	11688.2665(27)	11641.2312(−19)	11596.6627(20)	11685.3780(−9)	11729.9520(−10)
	12.5	11636.9107(2)	11685.2654(18)	11639.9271(−10)	11591.6590(44)	11681.9834(3)	11730.2698(4)
	13.5	11629.7989(−19)	11681.8579(−7)	11638.1250(−21)	11586.1623(68)	11678.1802(3)	11730.1829(55)
	14.5	11622.2872(3)	11678.0465(3)	11635.8290(−34)	11580.1653(−4)	11673.9675(6)	11729.6766(22)
	15.5	11614.3668(6)	11673.8234(−5)	11633.0454(−9)	11573.6856(−21)	11669.3425(12)	11728.7618(41)
	16.5	11606.0344(−21)	11669.1903(12)	11629.7698(−10)	11566.7240(2)	11664.3015(6)	
	17.5	11597.2954(−1)	11664.1404(9)	11626.0133(52)	11559.2793(31)	11658.8434(1)	11725.6751(20)
	18.5	11588.1401(−9)	11658.6725(−2)	11621.7586(−16)	11551.3444(−26)	11652.9648(−15)	11723.5046(42)
	19.5	11578.5686(−23)	11652.7888(23)	11617.0281(−7)	11542.9305(−78)	11646.6656(−23)	11720.9112(68)

To be continued.

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Table I continued.

Band	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(5,3)	20.5	11568.5799(−34)	11646.4779(−9)	11611.8167(9)	11534.0529(11)		11717.8839(11)
	21.5	11558.1735(−28)	11639.7457(−18)	11606.1187(−41)	11524.6872(−24)	11632.7985(0)	
	22.5	11547.3458(−23)	11632.5921(12)	11599.9533(18)		11625.2267(29)	
	23.5	11536.0917(−55)					
	J	P_{11}	P_{12}	P_{22}	P_{21}	Q_{11}	Q_{12}
(8,5)	0.5				12652.1131(24)		
	1.5						12571.7858(48)
	2.5	12571.7609(29)	12560.8275(−39)	12638.7322(−8)		12579.5068(−35)	12568.5793(−37)
	3.5	12568.5550(42)	12553.9863(32)			12579.4018(−34)	12564.8329(−25)
	4.5		12546.5829(−34)		12643.4383(−33)	12578.7508(−9)	12560.5395(1)
	5.5	12560.4941(52)	12538.6432(9)	12617.8941(1)		12577.5523(12)	12555.7026(62)
	6.5			12610.1049(55)		12575.8042(−8)	12550.3113(33)
	7.5	12550.2347(−43)	12521.1218(19)	12601.8853(68)	12630.9577(13)	12573.5119(−34)	12544.3781(21)
	8.5	12544.2926(−52)	12511.5456(2)	12593.2321(26)	12625.9400(−3)	12570.6812(−27)	12537.9057(33)
	9.5	12537.8149(−2)		12584.1523(16)		12567.3121(−9)	12530.8882(−14)
	10.5	12530.7914(−17)	12490.7795(−18)	12574.6411(10)		12563.4055(8)	12523.3359(−38)
	11.5	12523.2319(−21)	12479.5964(−2)	12564.6969(13)	12608.3054(23)	12558.9614(1)	12515.2534(−17)
	12.5	12515.1385(−17)	12467.8802(1)	12554.3170(18)	12601.5553(14)	12553.9863(11)	12506.6354(−27)
	13.5	12506.5135(−5)	12455.6357(12)	12543.4980(14)	12594.3640(−21)	12548.4807(22)	
	14.5		12442.8678(55)	12532.2368(−11)	12586.7379(7)	12542.4422(−15)	12487.8122(−48)
	15.5	12487.6721(−24)	12429.5652(−9)	12520.5367(−1)	12578.6609(−43)		12477.6148(−28)
	16.5	12477.4634(−25)	12415.7435(−50)	12508.3893(−20)		12528.7967(−16)	12466.8962(8)
	17.5	12466.7326(−19)	12401.4133(14)		12561.1847(20)	12521.1955(35)	12455.6522(−4)
	18.5	12455.4808(−18)		12482.7561(−29)	12551.7700(19)	12513.0653(−9)	12443.8906(−9)
	19.5	12443.7113(−9)		12469.2674(−10)	12541.9048(31)	12504.4194(−33)	12431.6126(−15)
	20.5	12431.4278(21)		12455.3249(−8)	12531.5802(−16)	12495.2603(−30)	12418.8254(29)
	21.5	12418.6269(20)		12440.9290(−3)		12485.5902(2)	12405.5203(17)
	22.5	12405.3149(31)		12426.0766(−9)	12509.5781(43)	12475.4031(−13)	12391.7049(7)
	23.5	12391.4852(−30)		12410.7710(21)	12497.8810(−13)	12464.7083(3)	12377.3833(22)
	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(8,5)	0.5	12652.1251(6)	12655.7723(−29)	12582.7212(−7)			12660.6041(−33)
	1.5		12656.9685(11)			12657.7649(50)	
	2.5	12646.7880(19)	12657.7348(−21)	12590.3642(16)	12579.4368(−6)	12658.1158(10)	12669.0077(−25)
	3.5	12643.4836(6)	12658.0833(7)	12593.3570(−14)		12658.0465(17)	12672.5712(−37)
	4.5		12657.9979(−55)	12595.8020(−37)	12577.6010(−6)	12657.5474(−8)	12675.7148(15)
	5.5		12657.4941(−35)	12597.7071(10)		12656.6207(−27)	12678.4251(16)
	6.5	12631.0253(0)	12656.5603(−33)	12599.0632(21)	12573.5904(62)	12655.2668(−15)	12680.7022(−14)
	7.5	12626.0184(−1)	12655.1968(−26)	12599.8733(10)	12570.7665(45)	12653.4787(−23)	12682.5527(14)
	8.5	12620.5797(−17)	12653.3994(−34)	12600.1437(20)	12567.4026(23)	12651.2579(−11)	12683.9646(2)
	9.5	12614.7120(−3)	12651.1726(9)	12599.8733(20)	12563.5049(37)	12648.6017(15)	12684.9414(10)
	10.5	12608.4083(−5)	12648.5048(11)	12599.0632(0)	12559.0593(−77)		12685.4737(−32)
	11.5	12601.6692(4)		12597.7240(46)	12554.1003(2)	12641.9636(14)	12685.5696(−18)
	12.5	12594.4890(−12)	12641.8483(10)	12595.8469(49)	12548.6034(8)	12637.9792(10)	12685.2195(−17)
	13.5	12586.8715(10)	12637.8556(15)	12593.4355(22)	12542.5760(−10)	12633.5481(5)	12684.4251(12)
	14.5	12578.8107(30)	12633.4156(13)	12590.4959(7)		12628.6699(18)	12683.1755(−15)
	15.5	12570.3001(7)	12628.5278(22)	12587.0222(−75)	12528.9500(0)		
	16.5	12561.3445(9)	12623.1901(44)	12583.0364(−26)	12521.3552(23)	12617.5534(3)	12679.3249(4)
	17.5	12551.9391(10)	12617.3915(−8)	12578.5239(−9)	12513.2421(59)	12611.3123(−9)	
	18.5	12542.0830(20)	12611.1450(18)	12573.4915(26)	12504.5956(−63)	12604.6131(−25)	

To be continued.

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Table I continued.

Band	J	Q_{22}	Q_{21}	R_{11}	R_{12}	R_{22}	R_{21}
(8,5)	19.5	12531.7676(−26)	12604.4359(−5)	12567.9349(17)	12495.4563(45)	12597.4575(−8)	
	20.5	12521.0029(−11)	12597.2670(−28)	12561.8584(−7)		12589.8389(−4)	
	21.5	12509.7783(−23)	12589.6444(27)	12555.2691(7)		12581.7546(−24)	
	22.5	12498.0986(2)	12581.5548(47)	12548.1639(15)		12573.2045(−50)	
	23.5	12485.9551(−5)	12572.9930(−4)				

TABLE II Molecular constants (in cm^{-1}) for $A^2\Pi_u$ state of N_2^+. Numbers in parentheses denote one standard deviation in unit of the last quoted digit.

v'		T	B	A	$p\times10^3$	$q\times10^4$	$D\times10^6$	$A_D\times10^5$
0	Fitted	9015.99833(85)	1.7349961(108)	−74.64603(99)	4.663(72)	−3.069(36)	5.8373(168)	−6.64(41)
	Ref.[24]	9015.9987(6)	1.735015(10)	−74.6489(7)	4.517(36)	−3.053(11)	5.8765(7)	−5.83(19)
1	Fitted	10889.45577(81)	1.7162171(112)	−74.6396(10)	4.906(79)	−3.273(41)	5.8891(178)	−7.79(46)
	Ref.[24]	10889.4524(7)	1.716229(10)	−74.6408(8)	4.870(44)	−3.255(14)	5.9093(8)	−6.78(26)
2	Fitted	12732.84285(66)	1.6973600(113)	−74.6363(10)	4.938(87)	−3.321(43)	5.9127(184)	−7.00(46)
	Ref.[13]		1.697391(67)	−74.6332(18)	4.87	−3.08	5.91(10)	−8.00(11)
	Ref.[25]	12732.8643(14)	1.697384(14)	−74.63628(79)	4.878(44)	−3.298(10)	5.9368(81)	−7.05(20)
	Ref.[26]	12732.83795(40)	1.6973673(17)	−74.63666(73)	5.017(44)	−3.336(13)	5.9319(14)	−6.06(18)
3	Fitted	14546.1609(11)	1.6784526(113)	−74.62562(85)	5.544(72)	−3.618(37)	5.9794(179)	−7.24(38)
	Ref.[19]	14546.1795	1.678413(11)	−74.62560(40)	5.406(32)	−3.650(12)	5.936(10)	
	Ref.[26]		1.678321(21)	−74.62533(88)	5.487(57)	−3.607(23)	5.904(21)	−7.04(34)
4	Fitted	16329.48767(65)	1.6594056(102)	−74.61399(67)	5.818(63)	−3.848(35)	5.9636(163)	−8.56(33)
	Ref.[19]	16329.4901(−31)	1.659406(10)	−74.61571(31)	5.857(29)	−3.837(19)	5.968(18)	
	Ref.[26]		1.659380	−74.61103	5.947	−3.969	5.891	−10.65
5	Fitted	18082.7691(14)	1.6403647(136)	−74.6014(11)	6.267(98)	−3.987(50)	6.0258(232)	−8.52(51)
6	Fitted	19806.1556(15)	1.621087(11)	−74.5948(15)	6.60(30)	−4.86(28)	6.004[a]	−9.65[a]
	Ref.[11]		1.620900(23)	−74.6004(17)	5.44(27)	−3.94(29)	5.579(65)	−20.2
	Ref.[15]		1.621161(20)	−74.58373(66)	7.161(61)	−4.457(31)	6.004(29)	−9.65(33)
7	Fitted	21499.53638(90)	1.6019344(113)	−74.55900(84)	7.947(74)	−4.826(41)	6.0494(189)	−12.28(40)
	Ref.[18]		1.601866(20)	−74.55939(76)	7.854(64)	−4.771(31)	5.940(25)	−11.96(34)
	Ref.[26]		1.602056(36)	−74.5602(13)	8.210(99)	−4.695(43)	6.230(46)	−11.91(59)
8	Fitted	23162.9983(12)	1.5826695(128)	−74.53514(94)	9.380(84)	−5.415(48)	6.1110(217)	−12.92(45)
	Ref.[12]		1.5826506(72)	−74.5356(13)	9.98(19)	−5.435(74)	6.086(14)	−13.04(60)
	Ref.[26]		1.582612(30)	−74.5371(11)	9.30(10)	−5.324(46)	6.068(38)	−12.04(46)
9	Fitted	24796.5836(12)	1.5631956(139)	−74.4982(13)	12.13(12)	−6.467(78)	6.082(25)	−18.03(70)
	Ref.[14]		1.5631780(73)	−74.4976(14)	12.79(20)	−6.348(64)	5.992(12)	−18.40(59)

[a] The fixed constants in the group fitting.

parameters variable. The parameters in Ref.[11, 13–15, 18, 19, 24–26] are also cited in the Table III for comparison. The constants of the X state are in excellent agreement with those reported in literatures.

The constants for the $A^2\Pi_u$ state are summarized in Table II. We initially fitted with all the constants variable. However, we found the obtained constants of D and A_D for v'=6 may have errors. As shown in Fig.3, the initially obtained values of D with the v' except v'=6. The A_D shows the similar phenomenon. As shown in Fig.2, only the (6,1) band is fitted relating to v'=6. This band provided only 59 lines with a reported residual of 0.01294 cm^{-1}. Bachir *et al.* [15] fitted 244 lines with N (total angular momentum excluding nuclear and electron spin) up to 28 of the (6,3) band and reported the constants of v'=6. Unfortunately, they did not provided the line lists and thus the lines could not be used in our fitting. Since Hadj Bachir *et al.* used lines with higher N value, we used their hyperfine constants and fixed in our finally fitting. As shown in Table III, our constants compare well with those in literatures and are mostly better in precision.

The T_v and B_v were finally fitted as the usual polynomial expressions $\alpha_v=\alpha_e+\alpha_1(v+1/2)+\alpha_2(v+1/2)^2+\ldots$

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TABLE III Molecular constants (in cm^{-1}) for $X^2\Sigma_g^+$ state of N_2^+. Numbers in parentheses denote one standard deviation in unit of the last quoted digit.

v''		T	B	$\gamma\times10^3$	$D\times10^6$
0	Fitted	0	1.92235403(983)	9.252(30)	5.9114(151)
	Ref.[24]	0	1.922366(10)	9.316(29)	5.941(7)
	Ref.[25]	0	1.922384(14)	9.203(35)	5.9479(82)
	Ref.[26]	0	1.922366	9.316	5.941
1	Fitted	2174.7430(10)	1.9034377(109)	9.262(34)	6.0031(168)
	Ref.[11]		1.90335	8.63	5.909
	Ref.[24]	2174.7493(8)	1.903410(10)	9.243(30)	5.970(8)
	Ref.[26]		1.903300(20)	9.156(43)	5.904(21)
2	Fitted	4316.98587(76)	1.8842825(105)	9.261(32)	5.9839(166)
	Ref.[18]		1.884231(22)	9.469(59)	5.906(35)
	Ref.[24]	4316.9807(9)	1.884294(11)	9.243(42)	6.007(9)
	Ref.[26]		1.884229(15)	9.32(12)	5.904(38)
3	Fitted	6426.4404(12)	1.8650348(119)	9.249(35)	6.0753(195)
	Ref.[15]		1.864977(20)	9.205(39)	6.015(31)
	Ref.[19]		1.864995(10)	9.164(10)	6.029(9)
4	Fitted	8502.91225(86)	1.8455091(112)	9.159(33)	6.0449(187)
	Ref.[14]		1.845478(43)	9.244(79)	5.923(82)
	Ref.[18]		1.845600(37)	9.98(11)	6.162(47)
	Ref.[19]		1.845524(11)	9.137(11)	6.074(20)
	Ref.[26]		1.845440(21)	9.187(47)	5.942(27)
5	Fitted	10546.0770(12)	1.8258931(132)	9.218(47)	6.1290(226)
	Ref.[13]		1.825916(70)	9.190(96)	6.11(11)
	Ref.[14]		1.825767(63)	8.884(90)	6.00(19)
	Ref.[26]		1.825855(32)	9.128(61)	6.114(42)

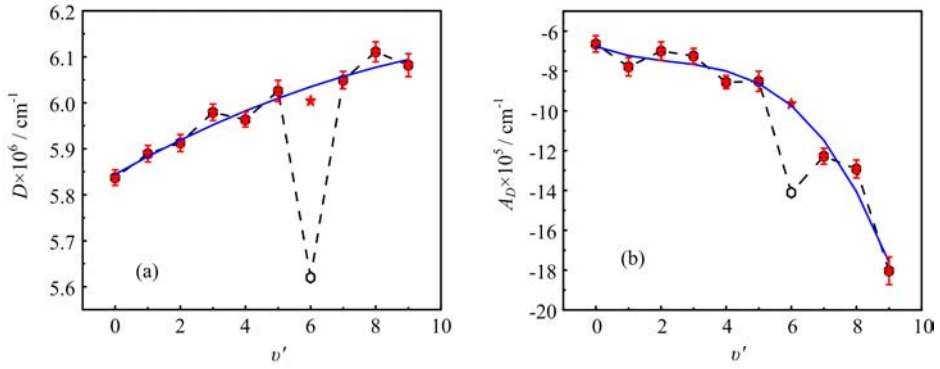

FIG. 3 The D and A_D for the $A^2\Pi_u$ state. The circles were obtained with all constants variable. The stars were obtained with $D_{v'=6}$ and $A_{D_{v'=6}}$ fixed at those in Ref.[15]. The solid lines were obtained from the polynomial fitting (second order for D and third order for A_D) of stars.

to obtain equilibrium molecular constants, as listed in Table IV. The obtained vibrational equilibrium molecular constants compare well with those reported in literatures [19, 24] and are closer to those in Ref.[19]. Tarsitano *et al.* [19] obtained the vibrational equilibrium molecular constants based on v'=0−13 and v''=0−6. Their fitting included more vibrational levels but the band origins coming from different fitting results. The equilibrium rotational molecular constants for the A-X system were rarely reported. Ferguson *et al.* [24] reported equilibrium rotational parameters using molecular constants. In this work, we added many rotational-resolved bands studied in recent years and handled them using a group fitting. Thus, we provided a set

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TABLE IV Molecular constants (in cm^{-1}) for $X^2\Sigma_g$ and $A^2\Pi_u$ states of N_2^+. Numbers in parentheses denote one standard deviation in unit of the last quoted digit.

	$X^2\Sigma_g^+$			$A^2\Pi_u$		
	This work	Ref.[19]	Ref.[24]	This work	Ref.[19]	Ref.[24]
T_e	0	0	0	9167.4709(194)	9167.4672(58)	9167.4669(81)
ω_e	2207.0045(322)	2207.0115(60)	2206.997(11)	1903.5492(170)	1903.5598(46)	1903.5438(47)
$\omega_e x_e$	16.06117(1253)	16.0616(23)	16.0561(47)	15.05490(396)	15.0573(14)	15.0519(10)
$\omega_e y_e$	−0.0428(138)	−0.04289(25)	−0.04356(55)	0.004176(261)	0.00451(16)	0.003905(58)
$\omega_e z_e$					−2.02(60)	
B_e	1.9317636(352)		1.93223(19)	1.7443622(409)		1.74486(15)
$\alpha_e \times 10^3$	18.7618(275)		19.25(6)	18.7048(190)		19.049(29)
$\beta_e \times 10^5$	−8.894(446)			−3.819(184)		

of reliable equilibrium rotational molecular constants.

V. CONCLUSION

The absorption spectra of N_2^+ were observed in region from 11250 to 12900 cm^{-1}. We assigned 986 lines to the (3,1), (4,2), (5,3), (8,5) bands of the $A^2\Pi_u$-$X^2\Sigma_g^+$ system. To our knowledge, the (5,3) band was studied for the first time. The available rotational-resolved bands of the A-X system were group fitted to get the molecular constants. However, the spectral data are not good enough for some bands, such as, the (6,3) band. Some hot bands were not used in the group fitting because they did not have close relationship with the levels studied in the group fitting. In summary, more rotational-resolved bands are needed to do an extensively study for the A-X system of N_2^+. This study provide good equilibrium vibrational constants and may be the best equilibrium rotational constants for A-X system by now.

VI. ACKNOWLEDGMENTS

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[1] M. Fasbender, Z. Phys. **30**, 73 (1924).
[2] W. H. J. Childs, P. Roy. Soc. Lond. Series A **137**, 641 (1932).
[3] A. B. Meinel, Astrophys. J. **112**, 562 (1950).
[4] A. E. Douglas, Astrophys. J. **117**, 380 (1953).
[5] E. A. Colbourn and A. E. Douglas, J. Mol. Spectrosc. **65**, 332 (1977).
[6] R. A. Gottscho, R. W. Field, K. A. Dick, and W. Benesch, J. Mol. Spectrosc. **74**, 435 (1979).
[7] W. Benesch, D. Rivers, and J. Moore, J. Opt. Soc. Am. **70**, 792 (1980).
[8] T. A. Miller, T. Suzuki, and E. Hirota, J. Chem. Phys. **80**, 4671 (1984).
[9] C. S. Gudeman and R. J. Saykally, Annu. Rev. Phys. Chem. **35**, 387 (1984).
[10] M. B. Radunsky and R. J. Saykally, J. Chem. Phys. **87**, 898 (1987).
[11] D. T. Cramb, A. G. Adam, D. M. Steunenberg, A. J. Merer, and M. C. L. Gerry, J. Mol. Spectrosc. **141**, 281 (1990).
[12] B. Lindgren, P. Royen, and M. Zackrisson, J. Mol. Spectrosc. **146**, 343 (1991).
[13] W. C. Ho, W. Jäger, D. T. Cramb, I. Ozier, and M. C. L. Gerry, J. Mol. Spectrosc. **153**, 692 (1992).
[14] B. Lindgren, P. Royen, and M. Zackrisson, J. Mol. Spectrosc. **156**, 319 (1992).
[15] I. H. Bachir, J. Mol. Spectrosc. **170**, 601 (1995).
[16] A. Al-Khalili, H. Ludwigs, and P. Royen, J. Mol. Spectrosc. **183**, 200 (1997).
[17] A. Al-Khalili, H. Ludwigs, and P. Royen, Chem. Phys. Lett. **284**, 191 (1998).
[18] Y. Y. Liu, C. X. Duan, S. H. Wu, H. Zhang, and Y. Q. Chen, J. Mol. Spectrosc. **208**, 144 (2001).
[19] C. G. Tarsitano and T. Oka, J. Mol. Spectrosc. **219**, 263 (2003).
[20] S. H. Wu, Y. Q. Chen, H. Zhuang, X. H. Yang, Z. Y. Bi, L. S. Ma, and Y. Y. Lu, J. Mol. Spectrosc. **209**, 133 (2001).
[21] R. J. Wang, Y. Q. Chen, P. P. Cai, J. J. Lu, Z. Y. Bi, X. H. Yang, and L. S. Ma, Chem. Phys. Lett. **307**, 339 (1999).
[22] S. Gerstenkorn and J. Chevillard, *ORSAY Laboratoire Aimé Cotton CNRSII*, http://www.lac.u-psud.fr/-Atlas-de-l-iode-et-du-tellure-.
[23] C. M. Western, PGOPHER, a Program for Simulating Rotational Structure, University of Bristol, http://pgopher.chm.bris.ac.uk.
[24] D. W. Ferguson, R. K Narahari, P. A. Martin, and G. Guelachvili, J. Mol. Spectrosc. **153**, 599 (1992).
[25] I. H. Bachir, H. Bolvin, C. Demuynck, J. L. Destombes, and A. Zellagui, J. Mol. Spectrosc. **166**, 88 (1994).
[26] R. Bandyopadhyaya, A. Bhowal, S. Datta, S. K. Sanyal, D. Collet, J. L. Destombes, I. H. Bachir, and T. R. Huet, Chem. Phys. Lett. **286**, 311 (1998).

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