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Revised Analysis of the Spectrum of Singly Ionised Antimony: SbII

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Abstract.The spectrum of antimony was recorded in the 300 – 2080Ǻ region on a 3m normal incidence vacuum spectrograph, at the Physics Department, St. Francis Xavier University, Antigonish, Nova Scotia, Canada. The analysis is considerably extended to complete the configuration 5p6d, for the first time. All other reported levels of $5s5p^3$, 5p5d, 5p6s and 5p7s were also confirmed. The three transitions without good intensities at 95802.6, 93197.5 and 86066.8 cm^{-1} have been identified to establish the missing $5s5p^3$ $^1D_2$ level, fitting nicely into the least squares fitted calculations almost for all the reported levels of 5p6p, five of the 5p7p and two of the 5p4f, Beside that a few more levels with dual J values without any configuration assignment are also listed and I have tried to interpret these levels theoretically. The Hartree- Fock calculations with relativistic corrections using Cowan Codes for Sb II to get ab- initio energy parameters used in the level fitting calculations are used.

Introduction

The electronic distribution for ground state configuration of singly ionized antimony (Sb II) is $5s^2$ $5p^2$. Thus $5p^2$ is the ground configuration with 5 levels $^3P_{0,1,2}$ $^1D_2$ and $^1S_0$. $^3P_0$ being the ground most level. The excited configurations are of the type 5pnl constituting singlet and triplet structures. The internal excitation of 5s to 5p leads to $5s5p^3$ and there after $5s5p^25d$ + $5s5p^26s$ becomes 4-e system exhibiting extremely complex structure. The configurations of odd parity lying very close to each other and overlapping, therefore, strong interaction is seen in the entire sequence Te III - La VIII [1 - 6]. The leading multiplet of this spectrum was first reported by Lang and Vestine [7], followed by two more papers one by Krishnamurty [8] and the other by Murakawa and Suwa [9]. The three term lists were discordant, to provide a satisfactory array of energy levels. Charlotte E. Moore [10] used the line list published by Lang and Vestine in the region 691Å to 7343Å and unpublished measurements by W.F. Meggers (1272 Å - 8742 Å) to improve the level values of the published multiplets. The agreement was not good with the tolerance between the observed and calculated wave numbers. With a few more tentative revisions, she compiled the data in Atomic Energy Level , A.E.L (10). The limit was adapted from Murakawa and Suwa‘s paper at 133327.5 cm^{-1}.Arcimowicz, Joshi and Kaufman [11] published the $5p^2$- ($5s5p^3$ + 5p5d + 5p6s + 5p7s) transition array with theoretical support. Since Sb II sequence has been studied very well recently [1-6], therefore, once again Sb II was undertaken to present even better picture**.**

Experimental Procedures

The recorded plates at Zeeman lab Amsterdam using hollow cathode source, are the most suitable for singly ionized spectra as well as the plates recorded in Antigonish lab with triggered spark source using high inductance coil in the discharge circuit, also being quite good for Sb II lines. The National Institute of Standard and Technology (NIST) hollow cathode plates were also available to me at the time of the analysis. This provided me very good data to analyze the spectrum of singly ionized antimony atoms. The spectrum of antimony was recorded in the 300Å - 2080Å wavelength region on a 3m normal incidence vacuum spectrograph at the Antigonish laboratory. This Spectrograph is equipped with a 2400 lines/mm holographic grating giving an inverse dispersion of 1.385Å in the first order. The source used was a triggered spark with charging potential of 2-5 KV across a low inductance (few nano henry) capacitor of value 14.7 microfarad. Pure antimony powder was packed into the cavity of aluminium electrodes. The ionization discrimination among antimony lines belonging to different ionization stages was achieved by studying the line aspect (principally its length polarity) or its intensity when series inductance was introduced. All exposures were taken on Kodak SWR plates and the Spectrograms were measured on a grant comparator at the Antigonish laboratory in Canada and on an abbe comparator in Aligarh. The wavelengths were calculated by using internal standards of C, N, O, and Al [8]. The wavelength accuracy for the symmetric lines are ± 0.005Å in the wavelength region.

Independent analysis was performed for the resonance transitions without considering the published data [11]. All the ground levels reported by Arcimowicz [11] were confirmed. Further experimental details can be found in our earlier publication [12].

Results and Discussion

Hartree - Fock calculations are performed. The atomic energy structure expressed in Hartree- Fock Slater theory is in the form of complicated integro- differential equation. Which have been simplified so as to divide the whole complex into smaller manageable integrals, called "Slater Parameters" written in the form of F^k, G^k, R^k and ζ_{nl} and E_{av} including approximate relativistic and correlation energy corrections as explained , these integrals can be evaluated on rigorous treated simply as adjustable parameters in application to observed spectra.

The integral F^k (n_l,n_1) represent that part of the electrostatic energy which depends on the orientation of the l- vectors and is responsible for the separation of terms with different L- values in LS coupling notation those denoted by G^k (nl, nl) are the exchange integrals that give energies due to the exchange forces which depends on the spin orientations; they cause the splitting of terms with equal L but different total spin S, for instance the separation of singlet term from the triplet etc. ζ_{nl} is the magnetic spin orbit interaction responsible for fine structure splitting. E_{av} including approximate relativistic and correlation energy corrections. Relativistic Hartree- Fock Multi Configuration Interaction method have been utilized to predict the structure of the ions.

Using the scaling from the isoelectronic sequence members from Te III - La VIII [1-6] multi-configuration interaction calculations were performed to predict the $5p^2$- ($5s5p^3$ + 5p5d + 5p6d + 5p6s + 5p7s) transition array. All other levels of $5s5p^3$, 5p5d, 5p6s and 5p7s, reported in reference [11] were also confirmed. The three transitions without good intensities at 95802.6, 93197.5 and 86066.8 cm^{-1} have been identified to establish the missing $5s5p^3$, $^1D_2$ level in ref. [11], fitting nicely into the least squares fitted calculations. This is worth pointing out that the level 85094.1 (J=1) in ref [11] deviating by 1285 cm^{-1} is fitting very well in my least squares fit.

I have tried to solve some of the ambiguity seen in Atomic Energy Level, AEL [10], where almost all the levels of 5p6p, five of the 5p7p and two of the 5p4f are reported. Beside that a few more levels with dual J values without any configuration assignment are also listed. I have tried to interpret these levels theoretically using the scaling factors of the parameters (both Slater as well as interaction) of unknown configurations were fixed at the predetermined values in accordance with the values in other iso electronic sequence spectra in the entire sequence Te III - La VIII [1 - 6]. It is interesting to mention that most of the 5p6p levels are interpreted well except a couple of singlet levels namely $^1P_1$ and $^1S_0$. For instance 5p6p $^1P_1$ given with a question mark at 87831.0 cm^{-1} did not fit at all, into my least squares fitted calculations, consequently a listed level at 90608.4 cm^{-1} without any designation was opted as 5p6p $^1P_1$ and the other singlet of 5p6p, namely $^1S_0$ was also found to be too low, therefore the level listed as 5p7p $^1S_0$ at 96910.9 cm^{-1} was considered for 5p6p $^1S_0$. This level fitted well with reasonable parameter values. In fact none of the 5p7p is calculated to be below 108691 cm^{-1} and this particular level 5p7p $^1S_0$ was calculated at 117693 cm^{-1}. Thus I can say confidently that none of the 5p7p reported levels belong to 5p7p configurations. However, only two levels of 5p4f are reported in reference [11] seems to be very close to my calculated values, may be correct.

It must be pointed out that the doubly excited configurations 5p6p, and 5p4f, though expected to give strong transitions to 5p5d and 5p6s configurations but lie outside the range of my investigation. My preliminary calculations show that the region is almost visible and even higher. Therefore, 5p6p and 5p4f levels could not be investigated. calculations show that the 5p (5d + 6s) - 5p (4f + 6p) transitions lie outside my region of investigation (above 3200Å), therefore, at the moment I was unable to confirm the reported levels of 5p4f and 5p6p configurations.

The classified lines of SbII are mentioned in table (1). The Fitted and HFR (Hartree Fock Relativistic Calculation) energy parameter values in cm^{-1} and scaling factors for odd parity configurations are given in table (2). The experimental and Least Squares Fitted percentage composition of odd parity configurations $5s5p^3$, 5p5d, 5p6d, 5p6s, 5p7s, and their level values are given in table (3). The Fitted and HFR (Hartree Fock Relativistic Calculation) energy parameter values in cm^{-1} and scaling factors for even parity configurations are given in table (4) and the observed and Least Square Fitted (LSF) energy levels in cm^{-1} for even parity configurations of $5s^25p^2$ and 5p6p are given in table (5).

Table (1). Classified lines of Sb II.

λ(Å)	ν (cm^{-1})	Int.	Classifications	Diff.
856.345	116775.4	30	$5s^25p^2$ $^3P_0$ - sp^3 $^1P_1$	-0.001
914.896*	109302.0	15	$5s^25p^2$ $^3P_1$ - 5p6d $^3P_0$	0.000
930.523*	107466.4	58	$5s^25p^2$ $^3P_0$ - 5p6d $^3D_1$	0.004
944.486*	105877.7	66	$5s^25p^2$ $^3P_2$ - 5p6d $^3D_3$	0.000
950.083	105254.0	23	$5s^25p^2$ $^3P_1$ - 5p7s $^1P_1$	-0.005
950.695*	105186.2	45	$5s^25p^2$ $^3P_0$ - 5p6d $^1P_1$	0.017
954.467	104770.5	10	$5s^25p^2$ $^3P_1$ - 5p7s $^3P_2$	-0.004
957.742*	104412.2	20	$5s^25p^2$ $^3P_1$ - 5p6d $^3D_1$	-0.006

Continue table (1).

λ(Å)	ν (cm⁻¹)	Int.	Classifications	Diff.
978.786	102167.4	60	$5s^25p^2\ ^3P_2$ -5p7s $^3P_2$	-0.008
983.614*	101665.9	10	$5s^25p^2\ ^3P_1$ - 5p6d $^3F_2$	0.002
984.856	101537.7	50	$5s^25p^2\ ^3P_0$ - 5p7s $^3P_1$	0.001
997.404*	100260.3	70	$5s^25p^2\ ^1D_2$ -5p6d $^1F_3$	0.000
997.450*	100255.7	26	$5s^25p^2\ ^3P_2$ - 5p6d $^3F_3$	-0.006
998.557*	100144.5	70	`$5s^25p^2\ ^1D_2$ - 5p6d $^3P_2$	0.000
1001.435*	99856.7	45	$5s^25p^2\ ^1D_2$ - 5p6d $^3P_1$	-0.002
1009.449*	99063.9	19	$5s^25p^2\ ^3P_2$ - 5p6d $^3F_2$	-0.013
1011.901*	98823.9	76	$5s^25p^2\ ^1D_2$ - 5p6d $^3D_2$	0.000
1015.407	98482.7	25	$5s^25p^2\ ^3P_1$ - 5p7s $^3P_1$	-0.001
1017.636	98267.0	10	$5s^25p^2\ ^3P_1$ - 5p7s $^3P_0$	0.000
1024.200	97637.2	71	$5s^25p^2\ ^3P_0$ - sp^3 $^3S_1$	-0.001
1042.98	95878.7	77	$5s^25p^2\ ^3P_2$ -5p7s $^3P_1$	0.004
1043.813*	95802.6*	25	$5s^25p^2\ ^3P_1$ - sp^3 $^1D_2$	-0.009
1046.923	95518.0	26	$5s^25p^2\ ^1D_2$ - 5p7s $^1P_1$	0.004
1052.254	95034.1	30	$5s^25p^2\ ^1D_2$ - 5p7s $^3P_2$	0.010
1056.227*	94676.6	54	$5s^25p^2\ ^1D_2$ - 5p6d $^3D_1$	-0.001
1057.279	94582.4	71	$5s^25p^2\ ^3P_1$ - sp^3 $^3S_1$	-0.006
1072.990*	93197.5*	27	$5s^25p^2\ ^3P_2$ - sp^3 $^1D_2$	0.009
1073.847*	93123.1	27	$5s^25p^2\ ^1D_2$ - 5p6d $^3F_3$	0.005
1076.783	92869.2	25	$5s^25p^2\ ^1S_0$ - sp^3 $^1P_1$	0.001
1082.260*	92399.2	40	$5s^25p^2\ ^1D_2$ - 5p6d $^1P_1$	-0.017
1087.211	91978.5	62	$5s^25p^2\ ^3P_2$ - sp^3 $^3S_1$	-0.002
1087.781*	91930.3	60	$5s^25p^2\ ^1D_2$ - 5p6d $^3F_2$	0.009
1094.555	91361.3	67	$5s^25p^2\ ^3P_0$ - 5p5d $^3P_1$	-0.001
1107.135	90323.2	42	$5s^25p^2\ ^3P_0$ - 5p5d $^1P_1$	0.006
1126.788	88747.8	35	$5s^25p^2\ ^1D_2$ - 5p7s $^3P_1$	-0.003
1126.879*	88740.7	35	$5s^25p^2\ ^1S_0$ - 5p6d $^3P_1$	0.002

Continue table (1).

λ(Å)	**ν (cm⁻¹)**	**Int.**	**Classifications**	**Diff.**
1132.432	88305.5	50	$5s^25p^2$ $^3P_1$ - 5p5d $^3P_1$	0.006
1133.939	88188.2	47	$5s^25p^2$ $^3P_1$ - sp^3 $^3P_2$	-0.009
1135.440	88071.6	55	$5s^25p^2$ $^3P_1$ - 5p5d $^3P_0$	0.000
1145.888	87268.6	39	$5s^25p^2$ $^3P_1$ - 5p5d $^1P_1$	-0.003
1161.888*	86066.8*	61	$5s^25p^2$ $^1D_2$ - sp^3 $^1D_2$	-0.001
1166.827	85702.5	27	$5s^25p^2$ $^3P_2$ - 5p5d $^3P_1$	-0.001
1168.439	85584.3	69	$5s^25p^2$ $^3P_2$ - sp^3 $^3P_2$	-0.005
1168.675	85567.0	35	$5s^25p^2$ $^3P_2$ - 5p5d $^1F_3$	0.006
1175.172*	85093.9*	71	$5s^25p^2$ $^3P_0$ - 5p5d $^3D_1$	0.007
1178.589	84847.2	44	$5s^25p^2$ $^1D_2$ - sp^3 $^3S_1$	-0.005
1196.735*	83560.7	58	$5s^25p^2$ $^1S_0$ - 5p6d $^3D_1$	0.003
1205.239	82971.1	76	$5s^25p^2$ $^3P_1$ - 5p5d $^3D_2$	-0.003
1210.638	82601.1	75	$5s^25p^2$ $^3P_2$ - 5p5d $^3D_3$	-0.008
1218.927	82039.4	68	$5s^25p^2$ $^3P_1$ - 5p5d $^3D_1$	-0.004
1230.286*	81281.9	50	$5s^25p^2$ $^1S_0$ - 5p6d $^1P_1$	0.003
1244.292	80367.0	20	$5s^25p^2$ $^3P_2$ - 5p5d $^3D_2$	0.005
1258.867	79436.5	25	$5s^25p^2$ $^3P_2$ - 5p5d $^3D_1$	-0.015
1272.741	78570.6	72	$5s^25p^2$ $^1D_2$- 5p5d $^3P_1$`	0.005
1274.670	78451.7	55	$5s^25p^2$ $^1D_2$ - sp^3 $^3P_2$	0.012
1274.922	78436.2	75	$5s^25p^2$ $^1D_2$- 5p5d $^1F_3$	-0.005
1289.768	77533.3	65	$5s^25p^2$ $^1D_2$- 5p5d $^1P_1$	0.000
1296.358	77139.2	62	$5s^25p^2$ $^3P_0$ - sp^3 $^3P_1$	0.007
1317.540	75899.0	83	$5s^25p^2$ $^3P_0$ - 5p6s $^1P_1$	0.00
1325.054	75468.6	31	$5s^25p^2$ $^1D_2$ - 5p5d $^3D_3$	0.007
1327.394	75335.6	54	$5s^25p^2$ $^3P_1$ - 5p5d $^3F_2$	0.006
1349.810	74084.5	45	$5s^25p^2$ $^3P_1$ - sp^3 $^3P_1$	-0.003
1354.883	73807.1	68	$5s^25p^2$ $^3P_1$ - sp^3 $^3P_0$	0.000
1356.287	73730.7	44	$5s^25p^2$ $^1S_0$ - sp^3 $^3S_1$	0.009

Continue table (1).

λ(Å)	ν (cm^{-1})	Int.	Classifications	Diff.
1358.009	73637.2	50	$5s^25p^2$ $^3P_1$ - 5p6s $^3P_2$	0.036
1365.451	73235.9	29	$5s^25p^2$ $^1D_2$ - 5p5d $^3D_2$	-0.002
1372.808	72843.4	37	$5s^25p^2$ $^3P_1$ - 5p6s $^1P_1$	0.006
1374.913	72731.9	22	$5s^25p^2$ $^3P_2$ -5p5d $^3F_2$	0.009
1383.057	72303.6	45	$5s^25p^2$ $^1D_2$ - 5p5d $^3D_1$	0.009
1384.662	72219.8	72	$5s^25p^2$ $^3P_1$ - 5p5d $^1D_2$	0.002
1387.565	72068.7	69	$5s^25p^2$ $^3P_2$ - 5p5d $^3F_3$	0.007
1398.969	71481.2	7	$5s^25p^2$ $^3P^2$ - sp^3 $^3P_1$	-0.008
1407.749	71035.4	68	$5s^25p^2$ $^3P^2$ - 5p6s $^3P_2$	0.005
1436.423	69617.4	74	$5s^25p^2$ $^3P^2$ - 5p5d $^1D_2$	-0.022
1438.110	69535.7	72	$5s^25p^2$ $^3P^0$ – 5p6s $^3P_1$	0.010
1442.271	69335.1	45	$5s^25p^2$ $^3P_1$ - 5p5d $^1D_2$	-0.001
1482.457	67455.6	60	$5s^25p^2$ $^1S_0$ - 5p5d $^3P_1$	-0.006
1498.549	66731.2	68	$5s^25p^2$ -$^3P_2$ - 5p5d $^1D_2$	0.007
1504.189	66481.0	72	$5s^25p^2$ $^3P_1$ – 5p6s $^3P_1$	-0.002
1505.623	66417.7	71	$5s^25p^2$ $^1S_0$ - 5p5d $^1P_1$	0.000
1508.446	66293.4	18	$5s^25p^2$ $^3P_0$ - sp^3 $^3D_1$	-0.027
1513.255	66082.7	72	$5s^25p^2$ $^3P_1$ -5p6s $^3P_0$	0.000
1524.358	65601.4	60	$5s^25p^2$ $^1D_2$ -5p5d $^3F_2$	-0.012
1539.935	64937.8	71	$5s^25p^2$ $^1D_2$ -5p5d $^3F_3$	-0.006
1554.018	64349.3	68	$5s^25p^2$ $^1D_2$ -sp^3 $^3P_1$	0.000
1564.813	63905.4	57	$5s^25p^2$ $^1D_2$ - 5p6s $^3P_2$	-0.031
1565.511	63876.9	75	$5s^25p^2$ $^3P_2$ –5p6s $^3P_1$	0.011
1576.114	63447.2	100	$5s^25p^2$ $^3P_1$ -sp^3 $^3D_2$	0.004
1581.365	63236.5	100	$5s^25p^2$ $^3P_1$ -sp^3 $^3D_1$	0.011
1584.578	63108.3	75	$5s^25p^2$ $^1D_2$- 5p6s $^1P_1$	0.009
1600.405	62484.2	72	$5s^25p^2$ $^1D_2$ -5p5d $^1D_2$	0.016
1606.973	62228.8	100	$5s^25p^2$ $^3P_2$ - sp^3 $^3D_3$	0.003

Continue table (1).

λ(Å)	**ν (cm⁻¹)**	**Int.**	**Classifications**	**Diff.**
1634.297	61188.4	56	$5s^25p^2$ $^1S_0$ - 5p5d $^3D_1$	0.001
1643.550	60843.9	100	$5s^25p^2$ $^3P_2$ - sp^3 $^3D_2$	-0.003
1649.270	60632.9	100	$5s^25p^2$ $^3P_2$ -sp^3 $^3D_1$	0.014
1677.847	59600.2	64	$5s^25p^2$ $^1D_2$ - 5p5d $^1D_2$	-0.005
1762.236	56746.1	75	5s25p2 $^1D_2$ –5p6s $^3P_1$	-0.008
1814.964	55097.5	100	$5s^25p^2$ $^1D_2$ - sp^3 $^3D_3$	-0.003
1861.771	53712.3	64	$5s^25p^2$ $^1D_2$ - sp^3 $^3D_2$	0.000
1869.086	53502.1	33	$5s^25p^2$ $^1D_2$ - sp^3 $^3D_1$	-0.008
1878.513	53233.6	54	$5s^25p^2$ $^1S_0$ - sp^3 $^3P_1$	0.003
1923.325	51993.3	66	$5s^25p^2$ $^1S_0$ - 5p6s $^1P_1$	-0.009
2054.717	48668.5	100	$5s^25p^2$ $^3P_1$ - sp^3 $^5S_2$	-0.017
2170.860	46064.7	100	$5s^25p^2$ $^3P_2$ - sp^3 $^5S_2$	-0.007
2191.526	45630.3	100	$5s^25p^2$ $^1S_0$ - 5p6s $^3P_1$	-0.003
2359.258	42386.2	10	$5s^25p^2$ $^1S_0$ - sp^3 $^3D_1$	0.004
2568.528	38932.8	15	$5s^25p^2$ $^1D_2$ - sp^3 $^5S_2$	0.016

λ(Å) = wave length in Angstrom,

ν (cm^{-1}) = wave number in cm^{-1}

Int. = Intensity, Diff. = Difference

Table (2). Fitted and HFR energy parameteric values (cm-1) and scaling factors for the odd parity configurations of Sb II

Parameter	LSF	Accuracy	HF	LSF/HF
E_{av} (5s5p^3)	80053	213	78656	1.021
F^2 (5p,5p)	32038	1074	40013	0.801
α_{5p}	-233	-78		
ζ_{5p}	3660	464	3526	1.038
G^1(5s,5p)	34147	316	53006	0.644
E_{av}(5s^{2}5p5d)	82787	140	83232	0.995
ζ_{5p}	4145	268	3899	1.063
ζ_{5d}	94	(fixed)	93	1.013
F^2 (5p,5d)	18802	1611	21218	0.886
G^1(5p,5d)	14980	493	20851	0.718
G^3(5p,5d)	10815	1362	12859	0.841
E_{av}(5s^{2}5p6d)	109466	110	109909	0.997
ζ_{5p}	4403	157	4071	1.082
ζ_{6d}	34	(fixed)	34	1.000
F^2(5p,6d)	5422	1051	5953	0.911
G^1(5p,6d)	3165	679	4975	0.636
G^3(5p,6d)	2261	1103	3237	0.699
E_{av}(5s^{2}5p7d)	120264	91	12078	0.996
ζ_{5p}	4743	139	4102	1.156
ζ_{7d}	17	(fixed)	17	1.000
F^2(5p,7d)	2202	901	2634	0.836
G^1(5p,7d)	1653	615	2141	0.772
G^3(5p,7d)	922	(fixed)	1418	0.650
E_{av}(5s^{2}5p6s)	73944	187	74464	0.994
ζ_{5p}	4220	233	3978	1.061
G^1(5p,6s)	2745	881	4141	0.663

Continue table (2).

Parameter	**LSF**	**Accuracy**	**HF**	**LSF/HF**
$E_{av}(5s^25p7s)$	105787	145	106310	0.996
ζ_{5p}	4331	195	4082	1.061
$G^1(5p,7s)$	877	758	1101	0.797
$E_{av}(5s^25p8s)$	117893	14	119000	0.991
ζ_{5p}	3949	185	4106	0.962
$G^1(5p,8s)$	362	(fixed)	482	0.750

Configuration	**Parameter**	**LSF**	**Accu.**	**HF**	**LSF/HF**
$5s5p^3$ -$5s^2$ 5p5d	$R^1(5p,5p;5s,5d)$	20549	339	30746	0.668
$5s5p^3$ -$5s^2$ 5p6d	$R^1(5p,5p;5s,6d)$	10273	170	15371	0.668
$5s5p^3$ -$5s^2$ 5p7d	$R^1(5p,5p;5s,7d)$	6739	111	10084	0.668
$5s5p^3$ -$5s^2$ 5p6s	$R^1(5p,5p;5s,6s)$	-1544	-25	-2309	0.668
$5s5p^3$ -$5s^2$ 5p7s	$R^1(5p,5p;5s,7s)$	-926	-15	-1385	0.668
$5s5p^3$ -$5s^2$ 5p8s	$R^1(5p,5p;5s,8s)$	-647	-11	-968	0.668
$5s^25p5d$ -$5s^25p6d$	$R^0(5p,5d;5p,6d)$	0	0	0	
	$R^2(5p,5d;5p,6d)$	5381	89	8052	0.668
	$R^1(5p,5d;6d,5p)$	6609	109	9888	0.668
	$R^3(5p,5d;6d,5p)$	4185	69	6262	0.668
$5s^25p5d$ -$5s^25p7d$	$R^0(5p,5d;5p,7d)$	0	0	0	
	$R^2(5p,5d;5p,7d)$	3245	54	4855	0.668
	$R^1(5p,5d;7d,5p)$	4259	70	6372	0.668
	$R^3(5p,5d;7d,5p)$	2713	45	4059	0.668
$5s^25p5d$ -$5s^25p6s$	$R^2(5p,5d;5p,6s)$	-7308	-121	-1093	0.668
	$R^1(5p,5d;6s,5p)$	-2985	-49	-4466	0.668
$5s^25p5d$ -$5s^25p7s$	$R^2(5p,5d;5p,7s)$	-3026	-50	-4528	0.668
	$R^1(5p,5d;7s,5p)$	-1601	-26	-2395	0.668
$5s^25p5d$ -$5s^25p8s$	$R^2(5p,5d;5p,8s)$	-1899	-31	-2841	0.668
	$R^1(5p,5d;8s,5p)$	-1071	-18	-1602	0.668

Continue table (2).

Configuration	Parameter	LSF	Accu.	HF	LSF/HF
$5s^25p6d$ -$5s^25p7d$	R^0(5p,6d;5p,7d)	0	0	0	
	R^2(5p,6d;5p,7d)	2319	38	3469	0.668
	R^1(5p,6d;7d,5p)	2176	36	3256	0.668
	R^3(5p,6d;7d,5p)	1428	24	2136	0.668
$5s^25p6d$ -$5s^25p6s$	R^2(5p,6d;5p,6s)	-1057	-17	-1581	0.668
	R^1(5p,6d;6s,5p)	-909	-15	-1360	0.668
$5s^25p6d$ -$5s^25p7s$	R^2(5p,6d;5p,7s)	-2040	-34	-3052	0.668
	R^1(5p,6d;7s,5p)	-579	-10	-866	0.668
$5s^25p6d$ -$5s^25p8s$	R^2(5p,6d;5p,8s)	-1385	(fixed)	-1732	0.800
	R^1(5p,6d;8s,5p)	-454	(fixed)	-605	0.750
$5s^25p7d$ -$5s^25p6s$	R^2(5p,7d;5p,6s)	-271	(fixed)	-362	0.750
	R^1(5p,7d;6s,5p)	-537	(fixed)	-716	0.750
$5s^25p7d$ -$5s^25p7s$	R^2(5p,7d;5p,7s)	-969	(fixed)	-1292	0.750
	R^1(5p,7d;7s,5p)	-367	(fixed)	-489	0.750
$5s^25p7d$ -$5s^25p8s$	R^2(5p,7d;5p,8s)	-972	(fixed)	-1295	0.750
	R^1(5p,7d;8s,5p)	-261	(fixed)	-349	0.750
$5s^25p6s$ -$5s^25p7s$	R^0(5p,6s;5p,7s)	0	(fixed)	0	
	R^1(5p,6s;7s,5p)	1541	(fixed)	2054	0.750
$5s^25p6s$ -$5s^25p8s$	R^0(5p,6s;5p,8s)	0	(fixed)	0	
	R^1(5p,6s;8s,5p)	997	(fixed)	1329	0.750
$5s^25p7s$ -$5s^25p8s$	R^0(5p,7s;5p,8s)	0	(fixed)	0	
	R^1(5p,7s;8s,5p)	545	(fixed)	727	0.750
		σ (mean error)	**=**	**268**	

Table (3). The experimental and fitted energy level values (cm^{-1}) and their LS- percentage compositions of odd parity configurations of Sb II

E(obs)	E(LSF)	Diff.	LS-composition
J=0			
69137.0	69142.0	-5.0	98% $5s^25p6s$ ^3P
76862.0	77039.0	-177.0	63% $5s5p^3$ (^2P) ^3P + 34% $5s^25p5d$ ^3P
91125.0	91100.0	25.0	65% $5s^25p5d$ ^3P + 34% $5s5p^3$ (^2P) ^3P
101321.0	101317.0	4.0	100% $5s^25p7s$ ^3P
112357.0n	112617.0	-260.0	97% $5s^25p6d$ ^3P
	113901.0		99% $5s^25p8s$ ^3P
	122999.0		99% $5s^25p7d$ ^3P
J=1			
66291.0 69536.0	66369.0 69530.0	-78.0 6.0	65% $5s5p^3$ (^2D) ^3D + 27% $5s^25p5d$ ^3D 74% $5s^25p6s$ ^3P + 25% $5s^25p6s$ ^1P
75898.0	75887.0	11.0	56% $5s^25p6s$ ^1P +16% $5s^25p6s$ ^3P +11% $5s5p^3$ (^2P) ^3P + 9% $5s^25p5d$ ^3P
85094.0	85207.0	-113.0	48% $5s^25p5d$ ^3D+ 20% $5s5p^3$ (^2D) ^3D +12% $5s^25p5d$ ^1P + 9% $5s^25p5d$ ^3P
90323.0	90004.0	319.0	59% $5s^25p5d$ ^1P + 16% $5s^25p5d$ ^3D +15% $5s5p^3$ (^2P) ^1P
91360.0	91223.0	137.0	51% $5s^25p5d$ ^3P + 27% $5s5p^3$ (^2P) ^3P+7% $5s^25p5d$ ^3D+ 4% $5s\ 5p^3(^2D)$ ^3D
97636.0	97558.0	78.0	85% $5s5p^3$ (^4S) ^3S + 5% $5s^25p5d$ ^1P
101531.0	101537.0	-6.0	70% $5s^25p7s$ ^3P + 29% $5s^25p7s$ ^1P
105190.0n	104942.0	248.0	34% $5s^25p6d$ ^1P + 24% $5s5p^3$ (^2P) ^1P +22% $5s^25p6d$ ^3D + 8% $5s^25p6d$ ^3P
107461.0	107642.0	-181.0	45% $5s^25p6d$ ^3D + 35% $5s5p^3$ $(^2P)^1P$ +8% $5s^2\ 5p\ 6d$ ^3P + 5% $5s^25p5d$ ^1P
108309.0	108311.0	-2.0	68% $5s^25p7s$ ^1P + 28% $5s^25p7s$ ^3P
112647.0	112525.0	122.0	78% $5s^25p6d$ ^3P + 19% $5s^25p6d$ ^3D
	113905.0		61% $5s^25p8s$ ^3P + 30% $5s^25p8s$ ^1P+4% $5s^25p6d$ ^1P
114354.0n	114713.0	-359.0	38% $5s^25p6d$ ^1P + 20% $5s^25p7d$ ^1P +11% $5s^25p7d$ ^3D + 7% $5s^25p6d$ ^3D

Continue Table (3).

E(obs)	E(LSF)	Diff.	LS-composition
	116796.0		46% $5s^25p7d$ ^3D + 18% $5s^25p6d$ ^1P +14% $5s^25p7d$ ^3P + 8% $5s5p^3$ (^2P) ^1P
	120032.0		67% $5s^25p8s$ ^1P + 30% $5s^25p8s$ ^3P
	122965.0		75% $5s^25p7d$ ^3P + 24% $5s^25p7d$ ^3D
	124193.0		69% $5s^25p7d$ ^1P + 16% $5s^25p7d$ ^3D +6% $5s^25p7d$ ^3P
J=2			
51723.0	51806.0	-83.0	98% $5s5p^3$ (^4S) ^5S
66502.0	66459.0	43.0	63% $5s5p^3$ (^2D) ^3D + 25% $5s^2$ $5p5d$ ^3D +6% $5s5p^3$ (^2P) ^3P
72390.0	72386.0	4.0	54% $5s^25p5d$ ^1D + 19% $5s^25p5d$ ^3F +10% $5s5p^3$ (^2D) ^1D + 7% $5s^25p5d$ ^3P
75275.0	75259.0	16.0	81% $5s^25p6s$ ^3P + 5% $5s^25p5d$ ^3F +5% $5s5p^3$ (^2P) ^3P + 5% $5s^25p5d$ ^3P
76692.0	76737.0	-45.0	61% $5s^25p5d$ ^3F +11% $5s^25p6s$ ^3P +9% $5s^25p5d$ ^3P + 6% $5s5p^3$ (^2P) ^3P
78391.0	78265.0	126.0	31% $5s5p^3$ (^2P) ^3P + 22% $5s^25p5d$ ^3P +21% $5s^25p5d$ ^1D + 12% $5s^25p5d$ ^3F
86025.0	85817.0	208.0	46% $5s^2$ $5p5d$ ^3D + 20% 5s25p5d ^3P +15% $5s5p^3$ (^2P) ^3P +13% $5s5p^3$ (^2D) ^3D
91243.0	91044.0	199.0	33%$5s^25p5d$ ^3P +26% $5s^25p5d$ ^3D +25% $5s5p^3$ (^2P) ^3P+11% $5s5p^3$ (^2D) ^3D
98856.0	99147.0	- 291.0	62% $5s5p^3$ (^2D) ^1D + 16% $5s^25p5d$ ^1D+14% $5s^25p6d$ ^1D
104723.0	104798.0	-75.0	80% $5s^25p6d$ ^3F + 10% $5s^25p6d$ ^3D +4% $5s^25p6d$ ^1D
105536.0n	105881.0	- 345.0	44% $5s^25p6d$ ^3P + 28% $5s^25p6d$ ^3D+18% $5s^25p6d$ ^1D + 6% $5s5p^3$ (^2D) ^1D
107825.0	107826.0	-1.0	99% $5s^25p7s$ ^3P
111617.0n	111687.0	-70.0	42%$5s^25p6d$ ^1D +35% $5s^25p6d$ ^3D+17% $5s^25p6d$ ^3F +4% $5s5p^3$ (^2D)^1D
112933.0n	112461.0	472.0	53% $5s^25p6d$ ^3F + 16% $5s^25p7d$ ^1D +5% $5s^25p7d$ ^3D
		46.0	47% $5s^25p7d$ ^3P + 33% $5s^25p7d$ ^3D +18% $5s^25p7d$ ^1D
		20.0	100% $5s^25p8s$ ^3P

Continue Table (3).

E(obs)	E(LSF)	Diff.	LS-composition
		11.0	57% $5s^25p7d$ ^1D +19% $5s^25p7d$ ^3D
		339.0	49% $5s^25p7d$ ^3P + 42% $5s^2$ 5p7d ^3D+7% $5s^25p7d$
J=3			
67885.0	67643.0	242.0	72% $5s5p^3$ (^2D) ^3D + 26% $5s^25p5d$ ^3D
77727.0	77741.0	-14.0	92% $5s^25p5d$ ^3F
88259.0	88245.0	14.0	60% $5s^25p5d$ ^3D + 20% $5s5p^3$ (^2D) ^3D +13% $5s^25p5d$ ^1F + 5% $5s^25p5d$ ^3F
91226.0	91569.0	-343.0	80% $5s^25p5d$ ^1F + 12% $5s^25p5d$ ^3D
105916.0n	105580.0	336.0	59% $5s^25p6d$ ^3F + 21% $5s^25p6d$ ^3D +18% $5s^25p6d$ ^1F
111529.0n	111606.0	-77.0	60% $5s^25p6d$ ^3D + 34% $5s^25p6d$ ^3F
113150.0n	113137.0		68% $5s^25p6d$ ^1F + 17% $5s^25p6d$ ^3D+5% $5s^25p6d$ ^3F + 5% $5s^25p7d$ ^1F
	116008.0		50% $5s^25p7d$ ^3F + 22% $5s^25p7d$ ^3D +20% $5s^25p7d$ ^1F + 6% $5s^25p6d$ ^1F
	122616.0		59% $5s^25p7d$ ^3D + 38% $5s^25p7d$ ^3F
	123534.0		71% $5s^25p7d$ ^1F + 18% $5s^25p7d$ ^3D +9% $5s^25p7d$ ^3F
J=4			
81083.0	81226.0	-143.0	100% $5s^25p5d$ ^3F
	111110.0		99% $5s^25p6d$ ^3F
	122310.0		100% $5s^25p7d$ ^3F

Table (4). Least Squares Fitted (LSF) Parameters in cm^{-1} for Even Parity Configurations of Sb II

configuration	parameter	LSF	Accuracy	HF	LSF/HF
$5s^25p^2$	$E_{av}(5s^2\,5p^2)$	9624	121	9251	
	$F^2(5p,5p)$	35138	643	39878	0.881
	α_{5p}	-100	(fixed)		
	ζ_{5p}	3417	181	3513	0.973
$5p^4$	$E_{av}(5p^4)$	167135	(fixed)	166845	0.999
	$F^2(5p,5p)$	34159	(fixed)	40187	0.850
	α_{5p}	-200	(fixed)		
	ζ_{5p}	3547	(fixed)	3547	1.000
$5s^25p4f$	$E_{av}(5s^25p4f)$	111063	(fixed)	110780	0.999
	ζ_{5p}	4096	(fixed)	4096	1.000
	ζ_{4f}	1	(fixed)	1	1.000
	$F^2(5p,4f)$	5224	(fixed)	6146	0.850
	$G^2(5p,4f)$	1676	(fixed)	2235	0.750
	$G^4(5p,4f)$	1097	(fixed)	1463	0.750
$5s^25p5f$	$E_{av}(5s^2\,5p\,5f)$	121728	(fixed)	121435	0.999
	ζ_{5p}	4106	(fixed)	4106	1.000
	ζ_{5f}	0	(fixed)	0	0.667
	$F^2(5p,5f)$	2516	(fixed)	2960	0.850
	$G^2(5p,5f)$	1072	(fixed)	1429	0.750
	$G^4(5p,5f)$	707	(fixed)	943	0.750
$5s^25p6p$	$E_{av}(5s^25p6p)$	90158	80	91291	0.982
	ζ_{5p}	4248	116	4079	1.041
	ζ_{6p}	658	146	594	1.107
	$F^2(5p,6p)$	7960	557	9499	0.838
	$G^0(5p,6p)$	1575	99	2560	0.615
	$G^2(5p,6p)$	1737	(fixed)	2895	0.600
$5s^25p7p$	$E_{av}(5s^25p7p)$	113494	(fixed)	113205	0.999

Continue Table (4).

configuration	parameter	LSF	Accuracy	HF	LSF/HF
	ζ_{5p}	4105	(fixed)	4105	1.000
	ζ_{7p}	235	(fixed)	235	1.000
	$F^2(5p,7p)$	2914	(fixed)	3429	0.850
	$G^0(5p,7p)$	617	(fixed)	823	0.750
	$G^2(5p,7p)$	754	(fixed)	1005	0.750
$5s^25p^2$ - $5p^4$	$R^1(5s,5s;5p,5p)$	37394	(fixed)	53420	0.700
$5s^25p^2$ -$5s^25p4f$	$R^2(5p,5p;5p,4f)$	-6175	(fixed)	-8822	0.700
$5s^25p^2$ -$5s^25p5f$	$R^2(5p,5p;5p,5f)$	-5043	(fixed)	-7205	0.700
$5s^25p^2$ -$5s^25p6p$	$R^0(5p,5p;5p,6p)$	993	(fixed)	1418	0.700
	$R^2(5p,5p;5p,6p)$	4484	(fixed)	6406	0.700
$5s^25p^2$ -$5s^25p7p$	$R^0(5p,5p;5p,7p)$	522	(fixed)	745	0.700
	$R^2(5p,5p;5p,7p)$	2267	(fixed)	3239	0.700
$5s^25p4f$ -$5s^25p5f$	$R^0(5p,4f;5p,5f)$	0	(fixed)	0	
	$R^2(5p,4f;5p,5f)$	2430	(fixed)	3472	0.700
	$R^2(5p,4f;5f,5p)$	1247	(fixed)	1781	0.700
	$R^4(5p,4f;5f,5p)$	819	(fixed)	1170	0.700
$5s^25p4f$ -$5s^25p6p$	$R^2(5p,4f;5p,6p)$	3010	(fixed)	4300	0.700
	$R^2(5p,4f;6p,5p)$	-441	(fixed)	-630	0.700
$5s^25p4f$ -$5s^25p7p$	$R^2(5p,4f;5p,7p)$	803	(fixed)	1147	0.700
	$R^2(5p,4f;7p,5p)$	-156	(fixed)	-223	0.700
$5s^25p5f$ -$5s^25p6p$	$R^2(5p,5f;5p,6p)$	1373	(fixed)	1962	0.700
	$R^2(5p,5f;6p,5p)$	-439	(fixed)	-627	0.700
$5s^25p5f$ -$5s^25p7p$	$R^2(5p,5f;5p,7p)$	1042	(fixed)	1488	0.700
	$R^2(5p,5f;7p,5p$	2978	(fixed)	4254	0.700
	$R^0(5p,6p;7p,5p)$	1010	(fixed)	1443	0.700
	$R^2(5p,6p;7p,5p)$	1181	(fixed)	1688	0.700
			σ (Mean Error)	**=**	**233**

Table (5). Observed and Least Squares Fitted (LSF) Energy levels in cm^{-1} for Even Parity Configurations of Sb II

E(obs)	E(LSF)	diff.	LS-composition.
J=0.0			
0.0	145.0	-145.0	95% $5s^25p^2$ ^3P + 4% $5s^25p^2$ ^1S
23905.0	23736.0	169.0	93% $5s^25p^2$ ^1S + 4% $5s^25p^2$ ^3P
86495.0	86437.0	58.0	88% $5s^25p6p$ ^3P + 12% $5s^25p6p$ ^1S
96911.0	96994.0	-83.0	85% $5s^25p6p$ ^1S + 12% $5s^25p6p$ ^3P
	109916.0		81% $5s^25p7p$ ^3P + 18% $5s^25p7p$ ^1S
	117693.0		80% $5s^25p7p$ ^1S + 19% $5s^25p7p$ ^3P
	166597.0		94% $5p^4$ ^3P + 5% $5p^4$ ^1S
	189198.0		93% $5p^4$ ^1S + 5% $5p^4$ ^3P
J=1			
3055.0	2861.0	194.0	99% $5s^25p^2$ ^3P
83826.0	83912.0	-86.0	64% $5s^25p6p$ ^3D + 33% $5s^25p6p$ ^1P
86052.0	86031.0	21.0	44% $5s^25p6p$ ^3P + 20% $5s^25p6p$ ^1P + 18% $5s^25p6p$ ^3D + 18% $5s^25p6p$ ^3S
90608.0	90671.0	-63.0	41% $5s^25p6p$ ^3P + 40% $5s^25p6p$ ^1P + 17% $5s^25p6p$ ^3D
93001.0	92906.0	95.0	79% $5s^25p6p$ ^3S + 14% $5s^25p6p$ ^3P + 7% $5s^25p6p$ ^1P
	108691.0		72% $5s^25p7p$ ^3D + 25% $5s^25p7p$ ^1P
	109497.0		49% $5s^25p7p$ ^3P + 26% $5s^25p7p$ ^3S +14% $5s^25p7p$ ^1P +11% $5s^25p7p$ ^3D
	113843.0		99% $5s^25p4f$ ^3D
	114973.0		52% $5s^25p7p$ ^1P + 29% 5s25p7p ^3P + 17% $5s^25p7p$ ^3D
	115707.0		71% $5s^25p7p$ ^3S + 22% $5s^25p7p$ ^3P + 8% $5s^25p7p$ ^1P
	124124.0		100% $5s^25p5f$ ^3D
	166007.0		99% $5p^4$ ^3P

Continue Table (5).

E(obs)	E(LSF)	diff.	LS-composition.
J=2			
5659.0	5423.0	236.0	89% $5s^25p^2$ ^3P + 10% $5s^25p^2$ ^1D
12790.0	13241.0	451.0	89% $5s^25p^2$ ^1D + 10% $5s^25p^2$ ^3P
86184.0	86167.0	17.0	70% $5s^25p6p$ ^3D + 16% $5s^25p6p$ ^1D + 14% $5s^25p6p$ ^3P
91718.0	91679.0	39.0	62% $5s^25p6p$ ^3P + 27% $5s^25p6p$ ^3D+ 11% $5s^25p6p$ ^1D
93853.0	93861.0	-8.0	73% $5s^25p6p$ ^1D + 23% $5s^25p6p$ ^3P
	107020.0		60% $5s^25p4f$ ^3F + 23% $5s^25p4f$ ^1D + 17% $5s^25p4f$ ^3D
	109610.0		58% $5s^25p7p$ ^3D + 25% $5s^25p7p$ ^1D + 17% $5s^25p7p$ ^3P
	113167.0		39% $5s^25p4f$ ^3D + 39% $5s^25p4f$ ^3F + 21% $5s^25p4f$ ^1D
	114076.0		55% $5s^25p4f$ ^1D + 43% $5s^25p4f$ ^3D
	115343.0		55% $5s^25p7p$ ^3P + 35% $5s^25p7p$ ^3D + 9% $5s^25p7p$ ^1D
	116206.0		65% $5s^25p7p$ ^1D + 27% $5s^25p7p$ ^3P + 6% $5s^25p7p$ ^3D
	117788.0		51% $5s^25p5f$ ^3F + 26% $5s^25p5f$ ^1D + 20% $5s^25p5f$ ^3D
	123823.0		45% $5s^25p5f$ ^3F + 42% $5s^25p5f$ ^3D + 13% $5s^25p5f$ ^1D
	124314.0		59% $5s^25p5f$ ^1D + 37% 5s25p5f ^3D
	161877.0		93% $5p^4$ ^3P + 6% $5p^4$ ^1D
	172287.0		93% $5p^4$ ^1D + 6% $5p^4$ ^3P
J=3			
91583.0	91576.0	7.0	100% $5s^25p6p$ ^3D
	106695.0		64% $5s^25p4f$ ^3G + 29% $5s^25p4f$ ^1F + 5% $5s^25p4f$ ^3F
	106867.0		41% $5s^25p4f$ ^3F + 39% $5s^25p4f$ ^3D+15% $5s^25p4f$ ^1F + 4% $5s^25p4f$ ^3G

Continue Table (5).

E(obs)	E(LSF)	diff.	LS-composition.
	112414.0		43% $5s^25p4f\ ^1F$ + 31% $5s^25p4f\ ^3G$ + 25% $5s^25p4f\ ^3F$
	113011.0		57% $5s^25p4f\ ^3D$ + 29% $5s^25p4f\ ^3F$ + 13% $5s^25p4f\ ^1F$
	115288.0		98% $5s^25p7p\ ^3D$
	117478.0		72% $5s^25p5f\ ^3G$ + 20% $5s^25p5f\ ^1F$ + 8% $5s^25p5f\ ^3F$
	117649.0		48% $5s^25p5f\ ^3D$ + 32% $5s^25p5f\ ^3F$ + 18% $5s^25p5f\ ^1F$
	123450.0		47% $5s^25p5f\ ^1F$ + 27% $5s^25p5f\ ^3G$
	123731.0		+ 25% $5s^25p5f\ ^3F$ +50% $5s^25p5f\ ^3D$ + 35% $5s^25p5f\ ^3F$ + 15% $5s^25p5f\ ^1F$
<u>**J=4**</u>	106982.0		41% $5s^25p4f\ ^3G$ + 34% $5s^25p4f\ ^3F$ +25% $5s^25p4f\ ^1G$
	112559.0		64% $5s^25p4f\ ^3F$ + 31% $5s^25p4f\ ^3G$ + 4% $5s^25p4f\ ^1G$
	113655.0		70% $5s^25p4f\ ^1G$ + 27% $5s^25p4f\ ^3G$
	117692.0		43% $5s^25p5f\ ^3G$ + 29% $5s^25p5f\ ^3F$ +28% $5s^25p5f\ ^1G$
	123526.0		67% $5s^25p5f\ ^3F$ + 31% $5s^25p5f\ ^3G$
	124116.0		70% $5s^25p5f\ ^1G$ + 26% $5s^25p5f\ ^3G$ + 4% $5s^25p5f\ ^3F$
<u>**J=5**</u>	113129.0		100% $5s^25p4f\ ^3G$
	123739.0		100% $5s^25p5f\ ^3G$

Conclusion

The analysis is considerably extended to complete the configuration 5p6d, for the first time. All other reported levels of $5s5p^3$, 5p5d, 5p6s and 5p7s were also confirmed. The three transitions without good intensities at 95802.6, 93197.5 and 86066.8 cm^{-1} have been identified to establish the missing $5s5p^3\ ^1D_2$ level. Almost for all the reported levels of 5p6p, five of the 5p7p and two of the 5p4f, I have tried to interpret these levels theoretically

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