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Quartet system of C IV

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Theoretical and experimental investigations of the quartet system of C IV are reported. Twenty-seven quartet-state energies are calculated. Based on this work, several lines observed for the first time in the extreme-ultraviolet beam-foil spectra of carbon (10—200 nm) are classified as $1s2pnl\,^4L-1s2pn'l'\,^4L'$ and $1s2snl\,^4L-1s2sn'l'\,^4L'$ ($n=2,3$; $n'=4,5$) transitions. The calculated fine structures for the quartet states are also reported. In addition, a list of new observed lines classified in C III and C IV is given.

I. INTRODUCTION

Recently, the quartet states of the lithiumlike ions have received a fair amount of attention. For light ions such as Li I,[1,2] Be II,[3-6] and B III (Ref. 6) detailed studies have been made both theoretically and experimentally. However, for systems with nuclear charge $Z \geq 6$, only limited data are available.

Most of the theoretical results on quartet states of C IV are limited to low-lying states and to a few angular symmetry states such as ^4S, $^4P^o$, and ^4P.[7-12] With the exception of $2s2p\,^4P^o$ and $2p2p\,^4P$ states, all theoretical calculations in the literature are nonrelativistic. Since relativistic effects contribute substantially to the energy of C IV, they should be included if reliable results are to be obtained. Very recently, the energies of the C IV $2s2p\,^4P^o$ and $2p2p\,^4P$ states have been calculated to high accuracy with configuration-interaction wave functions.[13]

In the present work, the method used in Ref. 13, which is not limited to low-lying states,[14] is applied for calculating higher excited quartet states: ^4S, $^4S^o$, $^4P^o$, ^4P, $^4D^o$, ^4D, $^4F^o$, and ^4F. A nonrelativistic Hamiltonian and variational method are used as a first step. The relativistic corrections and mass polarization effect are calculated using first-order perturbation theory. The wave function and the computational procedure used are similar to those of Chung and Davis.[5]

Experimental studies of the quartet system of C IV have been made previously using the beam-foil technique[15-18] and transitions occurring nearly exclusively in the wavelength region $\lambda < 40$ nm were classified in this system.

In this work, beam-foil spectra of carbon are recorded using a grazing incidence spectrometer ($\lambda = 10$—40 nm) and a Seya-Namioka-type spectrometer ($\lambda = 30$—200 nm). Transitions between quartet states are searched in these spectra on the basis of theoretical predictions.

II. THEORETICAL RESULTS

A. Center-of-gravity energy

The nonrelativistic energies ($E_{\rm nr}$) obtained in this work are given in Table I. For comparison purposes, the results for the ^4S and $^4P^o$ states of Larsson *et al.*[7] are also given. These are the most accurate theoretical calculations in which a large wave function and r_{ij} coordinates are explicitly employed. Their $2s2p\,^4P^o$ and $2s3s\,^4S$ energies are only slightly higher than those of the present work. However, for higher excited states, the deviation is much more substantial. Our results are lower than those of Lunell and Beebe[8] and Holøien and Geltman.[9]

In Table I the sum of the expectation values for the mass correction term and Darwin term[19] denoted as $\langle (H_1+H_2) \rangle$ is reported. The explicit forms for these operators are given in Ref. 13. For the C IV quartets, the energy contribution from this correction ranges from 0.25 to 0.30 eV, depending on whether the system has a $1s2s\,^3S$ or $1s2p\,^3P^o$ core. The contribution from the ^3S core is substantially larger than that of the $^3P^o$ core. This makes a term classification very straightforward: The $\langle (H_1+H_2) \rangle$ for states with a $^3P^o$ core is about -0.0093 a.u. whereas that of the ^3S is about -0.0104 a.u.

The mass polarization effect $\langle H_3 \rangle$ is also tabulated in Table I. Although this effect is very small, nevertheless, it can be experimentally observed by measuring the isotope shift of ^{12}C and ^{14}C. The calculated result given in this table is obtained by approximating the ^{12}C nucleus with six protons and six neutrons. The retardation effect $\langle H_4 \rangle$ is somewhat larger than $\langle H_3 \rangle$ for C IV. In general, $\langle H_3 \rangle$ and $\langle H_4 \rangle$ are opposite in sign except for those states where both effects are very small.

The center-of-gravity energies given by

$$E_{\rm CG} = E_{\rm nr} + \langle (H_1+H_2) \rangle + \langle H_3 \rangle + \langle H_4 \rangle$$

are quoted in Table I. The wavelengths calculated from the $E_{\rm CG}$ energies are given in Table II. The conversion factor used is 45.5656 nm/a.u.

B. Fine structure

Recent spectroscopic measurements of the fine-structure wavelengths of the $1s2s2p\,^4P^o-1s2p2p\,^4P$ transition in the Li I sequence[17,20-23] have stimulated considerable amount of theoretical interest.[10-13] However, to our knowledge, the only fine-structure data available for

TABLE I. The energies of quartet system of C IV (in a.u.). E_{nr}, nonrelativistic energy; $\langle (H_1+H_2)\rangle$ mass correction term and Darwin term; $\langle H_3\rangle$, mass polarization term; $\langle H_4\rangle$, retardation term. E_{CG} center-of-gravity energy ($E_{\text{CG}}=E_{\text{nr}}+\langle (H_1+H_2)\rangle+\langle H_3\rangle+\langle H_4\rangle$).

Term	$-E_{\text{nr}}$ This work	$-10^2\langle (H_1+H_2)\rangle$	$-10^5\langle H_3\rangle$	$-10^4\langle H_4\rangle$	$-E_{\text{CG}}$ This work	$-E_{\text{nr}}$ Other works	$-E_{\text{exp}}$ This work
$1s\,2s\,3s\,^4S$	22.520 631	1.0924	−0.166	−0.069	22.531 546	22.519 93[a]	22.531 996
$1s\,2p\,3p\,^4S$	22.194 079	0.9533	+9.654	−2.125	22.203 496	22.188 51[a]	22.203 596
$1s\,2s\,4s\,^4S$	21.997 711	1.0657	+0.074	−0.034	22.008 366	21.996 78[a]	22.008 402
$1s\,2s\,5s\,^4S$	21.784 968	1.0405	+1.037	−0.287	21.795 354	21.781 77[a]	
$1s\,2p\,4p\,^4S$	21.748 218	0.9394	+7.805	−1.664	21.757 524	21.733 75[a]	
$1s\,2s\,6s\,^4S$	21.663 938	1.0550	−0.031	−0.015	21.674 486		
$1s\,2s\,2p\,^4P^o$	23.969 309	1.0821	+7.609	−1.693	23.980 037	23.969 19[a]	
$1s\,2s\,3p\,^4P^o$	22.422 499	1.0604	+2.597	−0.486	22.433 081	22.420 98[a]	22.433 260
$1s\,2p\,3s\,^4P^o$	22.279 031	0.9670	+8.613	−1.850	22.288 602	22.277 51[a]	22.288 885
$1s\,2p\,3d\,^4P^o$	22.112 594	0.9374	+8.823	−1.912	22.121 865	22.054 67[a]	22.122 129
$1s\,2p\,4d\,^4P^o$	21.722 642	0.9405	+8.408	−1.794	21.731 951		21.731 309
$1s\,2p\,2p\,^4P$	23.631 579	0.9619	+14.80	−3.408	23.641 006	23.628 43[b]	
$1s\,2p\,3p\,^4P$	22.182 004	0.9366	+10.21	−2.273	22.191 245		22.191 612
$1s\,2p\,4p\,^4P$	21.751 345	0.9294	+9.448	−2.041	21.760 529		21.760 598
$1s\,2p\,5p\,^4P$	21.556 585	0.9272	+9.213	−1.966	21.565 753		21.565 969
$1s\,2p\,6p\,^4P$	21.451 948	0.9264	+9.115	−1.934	21.461 110		
$1s\,2s\,3d\,^4D$	22.364 027	1.0440	−0.528	−0.110	22.374 451		22.374 539
$1s\,2p\,3p\,^4D$	22.220 369	0.9498	+10.63	−2.097	22.229 763		22.230 903
$1s\,2s\,4d\,^4D$	21.939 651	1.0511	−0.300	+0.005	21.950 160		21.950 424
$1s\,2p\,4p\,^4D$	21.765 503	0.9393	+8.883	−1.895	21.774 796		21.775 512
$1s\,2s\,5d\,^4D$	21.748 642	1.0410	+0.737	−0.148	21.759 045		21.759 614
$1s\,2p\,3d\,^4D^o$	22.132 368	0.9278	+7.130	−1.834	22.141 534		22.141 640
$1s\,2p\,4d\,^4D^o$	21.730 712	0.9264	+8.360	−1.866	21.739 873		21.739 433
$1s\,2p\,5d\,^4D^o$	21.546 101	0.9247	+8.686	−1.877	21.555 246		21.554 961
$1s\,2p\,4f\,^4F$	21.727 519	0.9267	+8.951	−1.885	21.736 687		21.736 717
$1s\,2p\,3d\,^4F^o$	22.171 137	0.9292	+12.22	−1.889	22.180 362		22.180 954
$1s\,2s\,4f\,^4F^o$	21.921 072	1.0509	−0.137	−0.011	21.931 579		21.931 683

[a] Larsson *et al.*, Ref. 7.

[b] Lunell and Beebe, Ref. 8.

quartets in the literature are those of the $2p2p\,^4P$ and $2s2p\,^4P^o$ states. In the present work, the fine-structure splittings for several quartet states are calculated. The results are quoted in Table III together with the energy for the $J_1=L+1.5$ state. It is apparent from this table that states with a $2p$ electron have a considerably larger splitting as compared with other states. A very illustrative example is the ^4D states. The $1s\,2snd\,^4D$ states have very

TABLE II. Wavelengths (in nm) associated with quartet states in C IV.

Experiment[a]	I[b]	This work Theory	Assignments	Other experiments
		18.089	$2s\,2p\,^4P^o$—$2p\,6p\,^4P$	
		18.873	$2s\,2p\,^4P^o$—$2p\,5p\,^4P$	
		19.763	$2s\,2p\,^4P^o$—$2s\,6s\,^4S$	
		20.502	$2s\,2p\,^4P^o$—$2p\,4p\,^4S$	
		20.516	$2s\,2p\,^4P^o$—$2s\,5d\,^4D$	
20.529±0.005	w	20.529	$2s\,2p\,^4P^o$—$2p\,4p\,^4P$	20.521[g]
20.67 ±0.01	(b1)	20.662	$2s\,2p\,^4P^o$—$2p\,4p\,^4D$	20.66[d],20.62(b1)[e]
		20.857	$2s\,2p\,^4P^o$—$2s\,5s\,^4S$	
21.843±0.005	vw	21.846	$2p\,2p\,^4P$—$2p\,5d\,^4D^o$	21.8[d],21.83[e],21.843[g]
22.451±0.005	m	22.447	$2s\,2p\,^4P^o$—$2s\,4d\,^4D$	22.44[d,e],22.45[g]
23.110±0.005	vw	23.110	$2s\,2p\,^4P^o$—$2s\,4s\,^4S$	23.08[e],23.14[g]
23.860±0.015	vw	23.868	$2p\,2p\,^4P$—$2p\,4d\,^4P^o$	
23.962±0.005	m	23.967	$2p\,2p\,^4P$—$2p\,4d\,^4D^o$	24.05[d],24.00[e],23.972[g]
25.478±0.005	m	25.473	$2s\,2p\,^4P^o$—$2p\,3p\,^4P$	25.43[d,h],25.46[e],25.475[g]
25.650±0.005	vw	25.648	$2s\,2p\,^4P^o$—$2p\,3p\,^4S$	25.656[g],25.66[h]
		26.033	$2s\,2p\,^4P^o$—$2p\,3p\,^4D$	

TABLE II. (*Continued*).

This work				
Experiment[a]	I[b]	Theory	Assignments	Other experiments
28.381±0.005	s	28.379	$2s\,2p\ ^4P^o$—$2s\,3d\ ^4D$	28.4[d],28.40[e],28.38[g]
30.000±0.005	m	29.994	$2p\,2p\ ^4P^o$—$2p\,3d\ ^4P^o$	30.00[e],30.002[g]
30.390±0.005	m	30.388	$2p\,2p\ ^4P$—$2p\,3d\ ^4D^o$	30.34[d],30.35[e],30.382[g]
31.467±0.005	m	31.457	$2s\,2p\ ^4P^o$—$2s\,3s\ ^4S$	31.46[d],31.45[e],31.456[g]
33.700±0.005	w	33.692	$2p\,2p\ ^4P$—$2p\,3s\ ^4P^o$	33.72[e],33.695[g]
		55.064	$2p\,3s\ ^4P^o$—$2p\,6p\ ^4P$	
		60.065	$2s\,3p\ ^4P^o$—$2s\,6s\ ^4S$	
63.03 ±0.02	w	63.036	$2p\,3s\ ^4P^o$—$2p\,5p\ ^4P$	
		66.966	$2p\,3d\ ^4D^o$—$2p\,6p\ ^4P$	
67.41 ±0.02	vw	67.553	$2p\,3p\ ^4D$—$2p\,5d\ ^4D^o$	
67.64 ±0.02	vw	67.601	$2s\,3p\ ^4P^o$—$2s\,5d\ ^4D$	
		68.960	$2p\,3d\ ^4P^o$—$2p\,6p\ ^4P$	
		71.450	$2s\,3p\ ^4P^o$—$2s\,5s\ ^4S$	
		71.644	$2p\,3p\ ^4P$—$2p\,5d\ ^4D^o$	
		79.136	$2p\,3d\ ^4D^o$—$2p\,5p\ ^4P$	
		81.936	$2p\,3d\ ^4P^o$—$2p\,5p\ ^4P$	
		85.798	$2p\,3s\ ^4P^o$—$2p\,4p\ ^4S$	
86.27 ±0.03	vw	86.286	$2p\,3s\ ^4P^o$—$2p\,4p\ ^4P$	
88.74 ±0.02	w	88.682	$2p\,3s\ ^4P^o$—$2p\,4p\ ^4D$	88.75[g,h]
		91.531	$2p\,3p\ ^4D$—$2p\,4d\ ^4P^o$	
		93.011	$2p\,3p\ ^4D$—$2p\,4d\ ^4D^o$	
94.36 ±0.02	m	94.354	$2s\,3p\ ^4P^o$—$2s\,4d\ ^4D$	
96.48 ±0.02	w	96.630	$2p\,3p\ ^4S$—$2p\,4d\ ^4P^o$	
		99.208	$2p\,3p\ ^4P$—$2p\,4d\ ^4P^o$	
		100.949	$2p\,3p\ ^4P$—$2p\,4d\ ^4D^o$	
102.57 ±0.02	m	102.700	$2p\,3d\ ^4F^o$—$2p\,4f\ ^4F$	
102.89 ±0.02	m	102.886	$2s\,3d\ ^4D$—$2s\,4f\ ^4F^o$	102.88[g,h]
107.26 ±0.02	vw	107.285	$2s\,3p\ ^4P^o$—$2s\,4s\ ^4S$	
		112.351	$2p\,3d\ ^4F^o$—$2p\,4p\ ^4D$	
112.53 ±0.02	m	112.549	$2p\,3d\ ^4D^o$—$2p\,4f\ ^4F$	
		119.593	$2p\,3d\ ^4D^o$—$2p\,4p\ ^4P$	
		124.245	$2p\,3d\ ^4D^o$—$2p\,4p\ ^4D$	
		125.062	$2p\,3d\ ^4P^o$—$2p\,4p\ ^4S$	
126.04 ±0.02	w	126.103	$2p\,3d\ ^4P^o$—$2p\,4p\ ^4P$	
		131.287	$2p\,3d\ ^4P^o$—$2p\,4p\ ^4D$	
134.42 ±0.02	vs	134.422[c]	$2s\,2p\ ^4P^o$—$2p\,2p\ ^4P$	134.6[d],134.59[e],134.42[f,g]
		163.457	$2p\,4d\ ^4D^o$—$2p\,6p\ ^4P$	
		168.237	$2p\,4d\ ^4P^o$—$2p\,6p\ ^4P$	
		180.395	$2s\,3d\ ^4D$—$2p\,3d\ ^4P^o$	
		187.557	$2s\,3s\ ^4S$—$2p\,3s\ ^4P^o$	
		188.413	$2s\,3p\ ^4P^o$—$2p\,3p\ ^4P$	
		195.630	$2s\,3d\ ^4D$—$2p\,3d\ ^4D^o$	
		198.468	$2s\,3p\ ^4P^o$—$2p\,3p\ ^4S$	
		207.542	$2p\,4p\ ^4D$—$2p\,5d\ ^4D^o$	
		208.816	$2s\,4d\ ^4D$—$2p\,4d\ ^4P^o$	
		216.680	$2s\,4d\ ^4D$—$2p\,4d\ ^4D^o$	
		221.966	$2p\,4p\ ^4P$—$2p\,5d\ ^4D^o$	
		223.583	$2s\,5d\ ^4D$—$2p\,5d\ ^4D^o$	
		224.110	$2s\,3p\ ^4P^o$—$2p\,3p\ ^4D$	
		233.798	$2s\,4f\ ^4F^o$—$2p\,4f\ ^4F$	
		234.764	$2s\,3d\ ^4D$—$2p\,3d\ ^4F^o$	

[a] The quoted uncertainties represent the error on the position of the line maximum (except for the 134.42-nm transition—see text).

[b] Observed intensity. vw, very weak; w, weak; m, mean; s, strong; vs, very strong; bl, blended line.

[c] Value obtained by taking into account the radiative correction of Ref. 12 (see Ref. 13).

[d] Berry *et al.*, Ref. 15.

[e] Buchet-Poulizac, Ref. 16.

[f] Livingston and Berry, Ref. 17.

[g] To *et al.*, Ref. 18.

[h] Jacques *et al.*, Ref. 26.

TABLE III. The fine structure of quartet system of C IV. $J_1=L+1.5$; $J_2=L+0.5$; $J_3=L-0.5$; $J_4=L-1.5$ (in cm^{-1}).

Term	$-E_{J_1}$ (a.u.)	E_{J_1}-E_{J_2}	E_{J_2}-E_{J_3}	E_{J_3}-E_{J_4}
$1s2s2p\ ^4P^o$	23.979 819	94.27	3.778	
$1s2s3p\ ^4P^o$	22.433 026	23.50	1.523	
$1s2p3s\ ^4P^o$	22.288 355	104.82	11.41	
$1s2p3d\ ^4P^o$	22.121 974	−37.09	−32.08	
$1s2p4d\ ^4P^o$	21.732 083	−46.22	−35.38	
$1s2p2p\ ^4P$	23.640 857	39.91	76.01	
$1s2p3p\ ^4P$	22.191 127	34.09	53.50	
$1s2p4p\ ^4P$	21.760 414	33.94	49.44	
$1s2p5p\ ^4P$	21.565 639	33.82	48.09	
$1s2p6p\ ^4P$	21.460 998	33.57	47.38	
$1s2s3d\ ^4D$	22.374 421	9.522	2.706	−0.014
$1s2p3p\ ^4D$	22.229 472	86.17	36.81	12.19
$1s2s4d\ ^4D$	21.950 155	1.917	0.246	−0.301
$1s2p4p\ ^4D$	21.774 528	78.90	33.93	11.38
$1s2s5d\ ^4D$	21.759 024	6.496	2.371	0.515
$1s2p3d\ ^4D^o$	22.141 468	6.979	26.51	24.52
$1s2p4d\ ^4D^o$	21.739 809	6.198	26.25	24.48
$1s2p4f\ ^4F$	21.736 650	−2.807	18.07	23.75
$1s2p3d\ ^4F^o$	22.180 110	64.64	32.82	14.09
$1s2s4f\ ^4F^o$	21.931 575	1.156	0.309	−0.096

small splittings whereas those of the $1s2pnp\ ^4D$ states are much larger.

III. EXPERIMENTAL TECHNIQUE AND RESULTS

C^+ beams of about 1 μA (diameter 5 or 10 mm) are supplied by a 2- or a 3-MV Van de Graaff accelerator equipped with an rf source into which CO gas was admitted. Beam light emitted after the carbon foil ($\simeq 10$ μg/cm^2) is observed with a grazing-incidence spectrometer ($\lambda = 10$–40 nm) or with a Seya-Namioka-type spectrometer ($\lambda = 30$–200 nm). The grazing-incidence spectrometer is equipped with a curved exit slit and five channeltron detectors; the Seya-Namioka with three channeltron detectors ($\lambda < 125$ nm) or with an EMR542G photomultiplier tube ($\lambda > 105$ nm). These two beam-foil spectroscopy arrangements are described in detail in Refs. 24 and 25, respectively.

Typical spectra of carbon between 22 and 26 nm and between 119 and 137 nm are shown in Figs. 1 and 2, respectively. The experimental linewidths [full width at half-maximum (FWHM)] are about 0.04 nm with the grazing-incidence spectrometer and 0.07 nm with the Seya-Namioka spectrometer.

The wavelengths of the lines appearing in our spectra and assigned to transitions between quartet states in C IV on the basis of theoretical predictions are reported in Table II together with rough estimations of the observed line intensities. This table shows that an excellent agreement exists between our theoretical and experimental wavelengths.

TABLE IV. Newly observed lines in C III.

λ (nm)	Intensity[a]	Assignment
172.54	w	$2p3p\ ^3P_2$—$2p4d\ ^3D^o_3$
170.33	m	$2s4p\ ^1P^o_1$—$2p4p\ ^1P_1$
162.32	w	$2s4d\ ^1D_2$—$2p4d\ ^1D^o_2$
154.58	m	$2s5p\ ^3P^o_{1,2}$—$2p5p\ ^3P_2$
150.16	s	$2s4p\ ^3P^o_{0,1,2}$—$2p4p\ ^3P_{1,2}$
149.37	s	$2s4s\ ^3S_1$—$2p4s\ ^3P^o_2$
149.14	vw	$2s4d\ ^3D_{1,2,3}$—$2p4d\ ^3P^o_2$
140.36	vw	$2p3d\ ^3D^o_{1,2,3}$—$2p5p\ ^3P_2$
135.66	s	$2p3s\ ^3P^o_{1,2}$—$2p4p\ ^3D_{2,3}$
131.43	(b1)	$2p3s\ ^3P^o_2$—$2p4p\ ^3P_{1,2}$
131.33	(b1)	$2p3s\ ^3P^o_{0,1}$—$2p4p\ ^3P_{1,2}$
130.18	vw	$2p3d\ ^1D^o_2$—$2p5p\ ^1D_2$
129.15	vw	$2p3d\ ^3F^o_{3,4}$—$2p5f\ ^3F_4$
114.35	vw	$2p3p\ ^3D_{2,3}$—$2p5d\ ^3D^o_3$

[a] vw, very weak; w, weak; m, mean; s, strong; bl, blended line.

TABLE V. Newly observed lines in C IV.

λ (nm)	Intensity[a]	Assignment
165.44	m	$4d\ ^2D$—$6p\ ^2P^o$
165.39	m	$4p\ ^2P^o$—$6s\ ^2S$
163.77	vs	$4d\ ^2D$—$6f\ ^2F^o$
144.01	m	$4s\ ^2S$—$6p\ ^2P^o$
135.30[b]	m	$4f\ ^2F^o$—$7g\ ^2G$
135.14	m	$4d\ ^2D$—$7f\ ^2F^o$
131.56	m	$4p\ ^2P^o$—$7d\ ^2D$
121.38	w	$4d\ ^2D$—$8f\ ^2F^o$
121.06	w	$4s\ ^2S$—$7p\ ^2P^o$
118.44	vw	$4p\ ^2P^o$—$8d\ ^2D$

[a] vw, very weak; w, weak; m, mean; vs, very strong.

[b] Previously observed in Ref. 26 but at 135.20 nm.

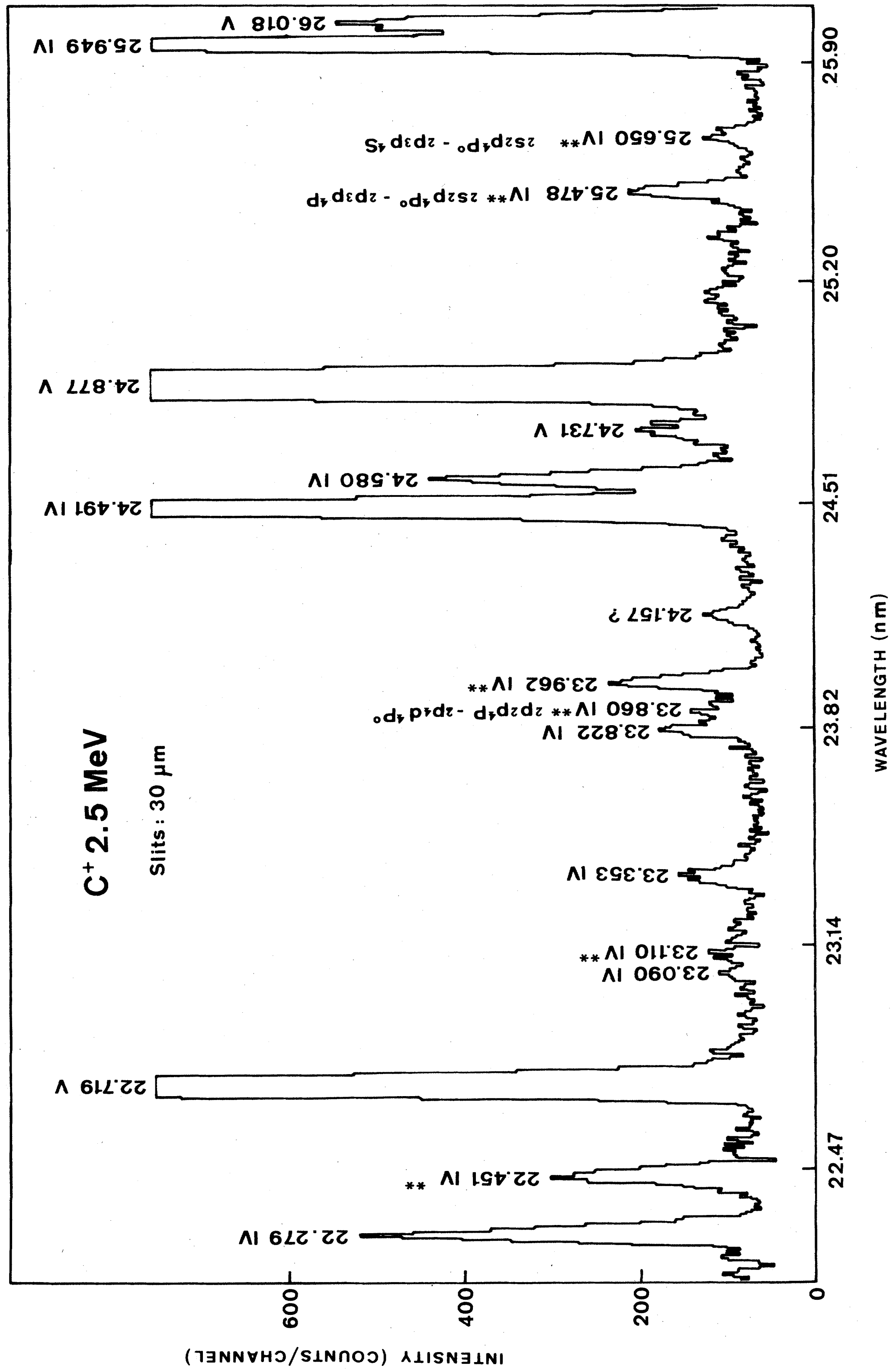

FIG. 1. A section of the beam-foil spectrum of carbon between 22 and 26 nm (grazing-incidence spectrometer). Assignments of newly classified lines are indicated.

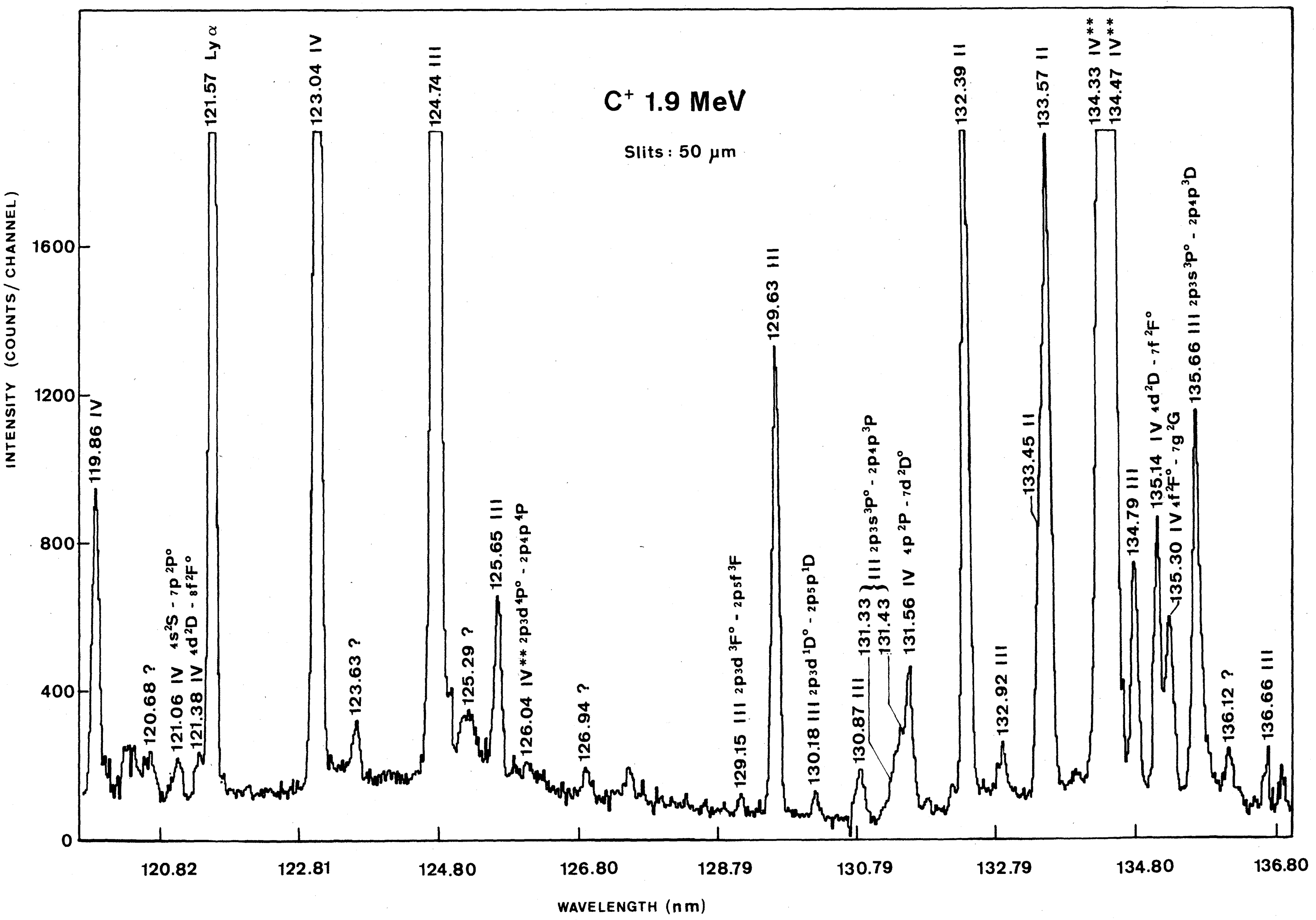

FIG. 2. A section of the beam-foil spectrum of carbon between 119 and 137 nm (Seya-Namioka-type spectrometer). Assignments of newly classified lines are indicated.

Due to the wavelength resolution of the beam-foil spectra, the fine structure of the multiplets cannot generally be resolved. However, for the 134.4-nm transition two fine-structure components are observed and the wavelength quoted is that of their center of gravity. Moreover, some predicted lines which are blended with other carbon lines cannot be observed.

The experimental wavelengths of the lines reported previously by other authors[15–18,26] are quoted in Table II. However, some classifications based on earlier theoretical data have been changed. We note that eleven lines are observed for the first time in this work.

The term energies (E_{exp}) derived by a least-squares calculation from our observed wavelengths are listed in Table I. (The energies of the $1s\,2s\,2p\;^4P^o$ and $1s\,2p\,2p\;^4P$ terms have been kept constant and equal to the theoretical values). There is a very good agreement between our experimental and theoretical term energies. All the theoretical energies ($-E_{\text{CG}}$) lie slightly above their corresponding experimental values ($-E_{\text{exp}}$) except for the $1s\,2p\,4d\;^4P^o$ term. Let us note that the error for this term energy is larger than for the other terms due to the error on the wavelength determination for the $1s\,2p^2\,^4P$—$1s\,2p\,4d\;^4P^o$ transition which is blended with a C IV line (see Table II).

We show in Fig. 3 the transitions observed in the quartet system of C IV on a partial term diagram. In this figure the absolute scale for the $2s\,2p\;^4P^o$ energy is set to be 294.084 eV above the $1s^2 2s\;^2S$ energy of C IV. It is obtained by a direct calculation of this ^2S state. This result agrees with a recent $2s\,2p\;^4P^o$—$1s^2 2s\;^2S$ transition measurement of Brenn[27] where $a \pm 0.1$-eV experimental uncertainty is quoted. It is very different from the 294.72 eV of Berry *et al.*[15] and the 294.552 eV of To *et al.*[18]

IV. NEW OBSERVED LINES IN C III AND C IV

Many lines appearing in our beam-foil spectra remain unidentified. We have classified twenty-four among them in C III and C IV from known level energies.[28] In Tables IV and V, these new observed lines in C III and C IV are quoted together with their classifications and estimations of their intensities. Some new observed lines can be seen in the spectrum shown in Fig. 2.

V. CONCLUSION

The present theoretical and experimental studies of the C IV quartet system lead to a term diagram for this system

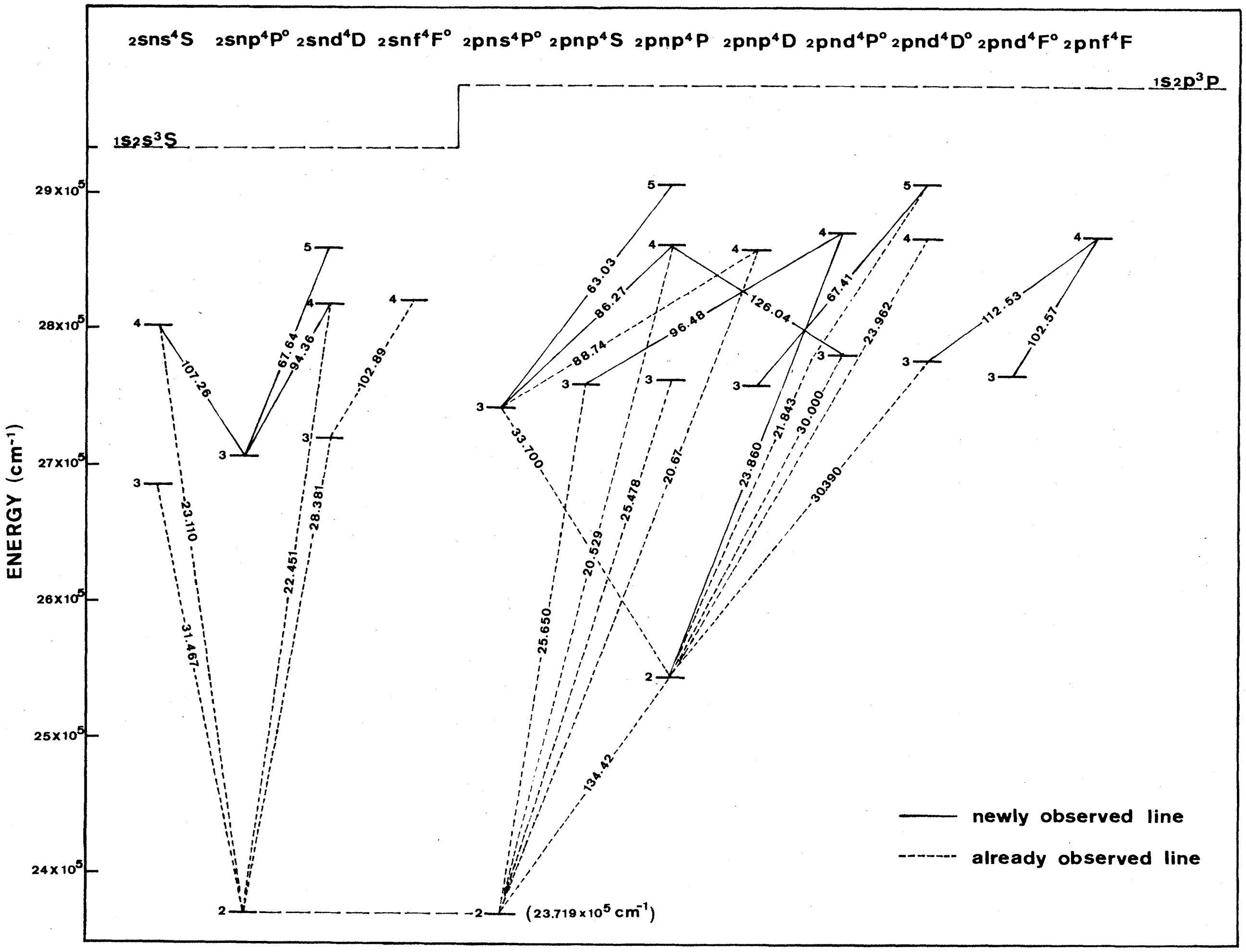

FIG. 3. Term diagram of the quartet system of C IV.

more reliable and complete than those previously reported. Twenty-seven quartet states have been calculated together with 20 fine-structure splittings which are significant for many of these quartets. Twenty-seven lines appearing in the beam-foil spectra of carbon (11 observed for the first time) have been classified in the quartet system of C IV. The wavelengths observed for these transitions are in very good agreement with our theoretical predictions and with the other experimental data available. Twenty-four new lines appearing in our spectra have also been identified as transitions between known energy levels in C III and C IV.

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