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The far infrared spectrum of C_3O_2

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The far infrared spectrum of carbon suboxide, $^{12}C_3{}^{16}O_2$, has been recorded at a resolution of 0.003 cm^{-1} in the region from 15 to 130 cm^{-1} with a Bomem interferometer. Altogether 18 bands involving the excitation of up to 8 quanta in the low frequency quasilinear bending mode ν_7 were analyzed rotationally. A total of 1320 far infrared lines together with 231 microwave lines taken from Karyakin *et al.* [J. Mol. Spectrosc. **94**, 283 (1982)] have been fitted to an effective model. Improved effective constants have been obtained for all the l sublevels of $v_7 = 0$ to 4 and for $l = 1$ of $v_7 = 5$. Constants have been obtained for the first time for the levels 5^3 and 5^5 and some of the l sublevels of $v_7 = 6$, 7, and 8. Data for the lower lying levels were fitted to a realistic linear model and some data were also fitted to a bent model.

I. INTRODUCTION

Carbon suboxide (C_3O_2) is a quasilinear molecule, i.e., it is a molecular system that has a "floppy" large amplitude vibration. As a result, its geometry can be properly represented neither by a linear, nor by a bent model. In fact, it lies somewhere between these two limits (see for example Ref. 1). Nevertheless, C_3O_2 is usually treated as if it were linear and the descriptive language appropriate for this type of molecule is used to characterize the energy levels. With this notation, the lowest energy bending level of C_3O_2 is ν_7 which has π_u symmetry. The energy levels in this manifold will be referred to throughout this paper using the linear molecule notation v_7^l.

The ν_7 vibration involves bending at the central carbon atom and it is indeed the quasilinear bending mode. The very low frequency of only 18.3 cm^{-1} leads to a vibration rotation fundamental in the submillimeter region[2] but the large anharmonicity of the vibration resulting from the quasilinear vibrational potential causes this spectrum to extend to more than 70 cm^{-1} in the far infrared.

The data now available on the ν_7 manifold of C_3O_2 result, not only from analysis of the submillimeter spectrum,[2] but also from infrared and Raman spectra of the 6 other modes of vibration which have been studied by a number of workers.[3-8] Up to the present time, all the l sublevels of the vibrational levels with $v_7 = 0$ to 4 have been characterized with precise, but effective, rotational and vibrational constants. Above $v_7 = 5$, precise effective rotational constants have only been obtained for the two levels 5^1 and 6^2 and the vibrational energy is known for levels with v_7 up to 12 with an uncertainty of 0.1 cm^{-1} (see Table I of Ref. 9, Table V of Ref. 2 and Table VII of Ref. 6).

Information on ν_7 is not easily obtained from the midinfrared bands of C_3O_2 because each sub-band appears as part of an extremely complex band system involving many hot bands due to the low value of ν_7 itself. In order to improve our knowledge of the ν_7 manifold we have therefore recorded the far infrared spectrum in the region from 15 to 130 cm^{-1} and have analyzed as much as the density of the spectrum allowed in order to obtain precise vibrational and rotational constants characterizing the ν_7 manifold as high in energy as possible. We propose to use this new data as an aid to extend the analysis of the spectrum of the ν_6 bending mode around 540 cm^{-1} started previously.[8] This study is of interest because many levels corresponding to the simultaneous excitation of more than one π vibration can be observed. This band system affords an excellent example of the consequences of what may be termed a vibrational Renner–Teller interaction.

II. EXPERIMENTAL DETAILS

A. Sample

Carbon suboxide was prepared by the dehydration of malonic acid with phosphorus pentoxide as described by Long *et al.*[10] and Miller and Fateley.[11] Impurities were found to be CO_2, in larger amounts, and SO_2, in very small quantities. The CO_2 was removed by pumping on the sample kept at − 117 C in a liquid/solid ethanol bath for about ten hours. During this process, the composition of the sample was monitored by recording the infrared spectrum in the region of the ν_3 fundamentals of CO_2 [near 2349 cm^{-1} (Ref. 12)] and C_3O_2 [near 2290 cm^{-1} (Ref. 3)]. No attempt was made to remove the SO_2 because of the tiny amounts involved and because its spectrum did not interfere much with that of C_3O_2. The purified C_3O_2 was stored at liquid nitrogen temperature until required for use.

B. Spectra

Spectra were recorded at a resolution of 0.003 cm^{-1} with a modified Bomem DA3.002 spectrophotometer (see Johns[13]) and ratioed against empty cell backgrounds. The sample cell was of the type described by White,[14] set to an absorption path length of 16 meters and fitted with polyethylene windows 0.82 mm thick. Two different silicon bolometers, cooled to 1.2 K, were used with mylar beam splitters of 50 and 25 μm thickness and characterized by band passes

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ranging from 5 to 50 cm^{-1} and 15 to 130 cm^{-1}, respectively. At first, spectra were recorded at room temperature but it appeared that the density of lines was so high, especially in the region above 40 cm^{-1}, that no analysis would be possible. Accordingly, two other spectra, one in each of the wave number regions mentioned above, were recorded with the sample cooled at − 60 C in order to reduce the density of lines. For these latter spectra, the sample pressure was 3.4 Torr, which is approximately the vapor pressure of carbon suboxide at this temperature.

C. Calibration

The spectrum was calibrated, in the region from 15 to 33 cm^{-1}, with the submillimeter measurements of C_3O_2 given by Karyakin *et al.*[2] and with SO_2 line measurements available over the whole region and listed by Carlotti *et al.*[15] Comparison between the measured wave numbers on two different spectra of the same region showed that the accuracy of measurement was better than 0.0002 cm^{-1}. Evidence from fitting the data (see Sec. IV) indicates that the precision of measurement obtained in the present spectra is of the order of 0.0001 cm^{-1}.

III. ANALYSIS

The far infrared spectrum of carbon suboxide from 16 to 85 cm^{-1} is presented at low resolution in Fig. 1. The spectrum involves a very large number of lines (more than 2000 lines have been measured in the 20 cm^{-1} region from 40 to 60 cm^{-1}) and shows little obvious regularity above 47 cm^{-1}. In the region above 70 cm^{-1}, only an apparently continuous absorption without any structure is observed. As Fig. 1 shows, there are a number of Q branchlike features of which the lowest one (at about 18 cm^{-1}) is associated with the fundamental, ν_7, whereas those at higher energy are associated with hot bands involving the multiple excitation of this degenerate bending mode.

We started the analysis in the region below 47 cm^{-1} because it is clear and reasonably well resolved. Bands were easily located and analyzed using the constants published by Fusina *et al.*[3,9] and Lolck and Brodersen.[6] Among these, we have completely analyzed the bands 3^1–2^0, 3^3–2^2, 4^4–3^3, and 4^2–3^1 for which Karyakin *et al.* had assigned a portion of the P_e and/or P_f branches.[2] Furthermore, we have assigned the 8 lines reported but not identified by these authors (Table IV of Ref. 2) as P_e lines of the latter band with J values ranging from 65 to 83. Part of this low wave number region of the far infrared spectrum is illustrated in Fig. 2 which shows, at high resolution, the spectrum around the origin of the 4^4–3^3 band with the assignments obtained during this work.

The identification and analysis of bands occurring in the region above 47 cm^{-1} appeared to be more difficult because of the unusual progressions of bands arising from the high anharmonicity of the ν_7 bending mode and the increasing density of lines due to the larger number of possible l sublevels as v_7 increases. As an example, a portion of this region is presented in Fig. 3. It shows the spectrum around the origin of the 7^7–6^6 band with the assignments obtained in the present work. Comparison between Figs. 2 and 3 gives an idea of how bad the situation becomes in Fig. 2, the Q branch is easily seen whereas in Fig. 3 it is very much harder to locate. The use of a program based on a Loomis–Wood diagram[16]

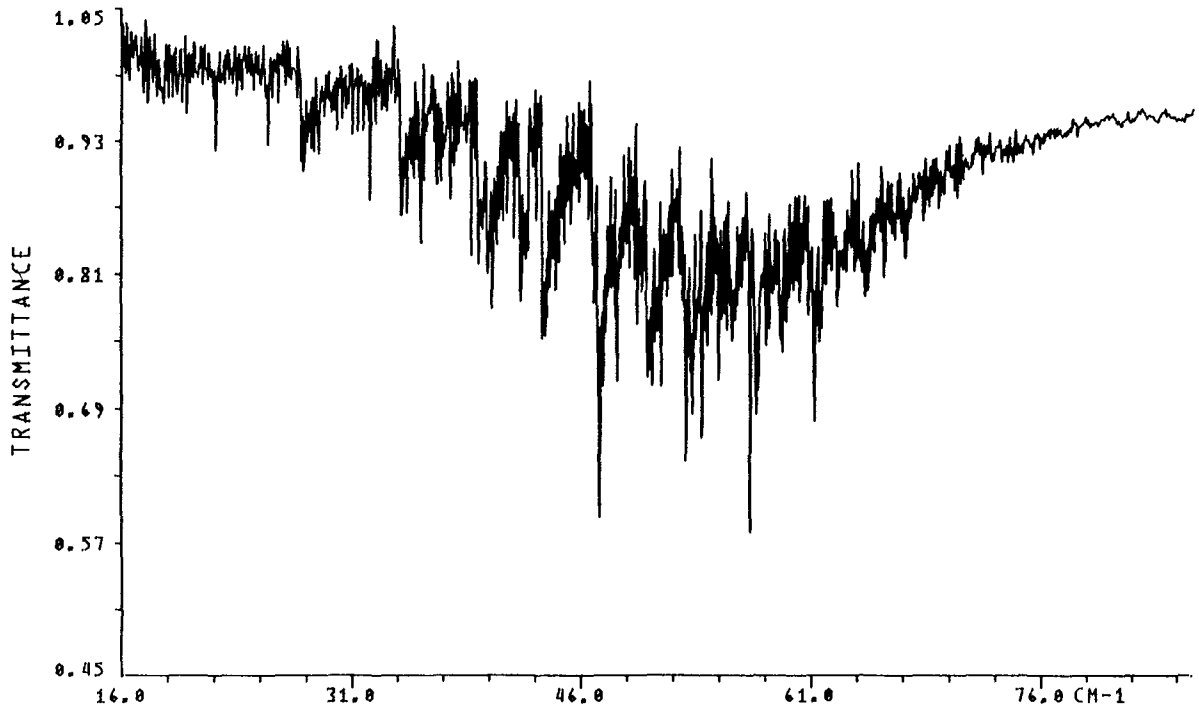

FIG. 1. The far infrared spectrum of C_3O_2 (3.4 Torr, 16 m path, − 60 C) in the region from 16 to 85 cm^{-1}. The Q branch near 18 cm^{-1} is associated with the ν_7 fundamental. The increasingly dense structure appearing at higher wave numbers is due to the presence of many hot bands involving ν_7.

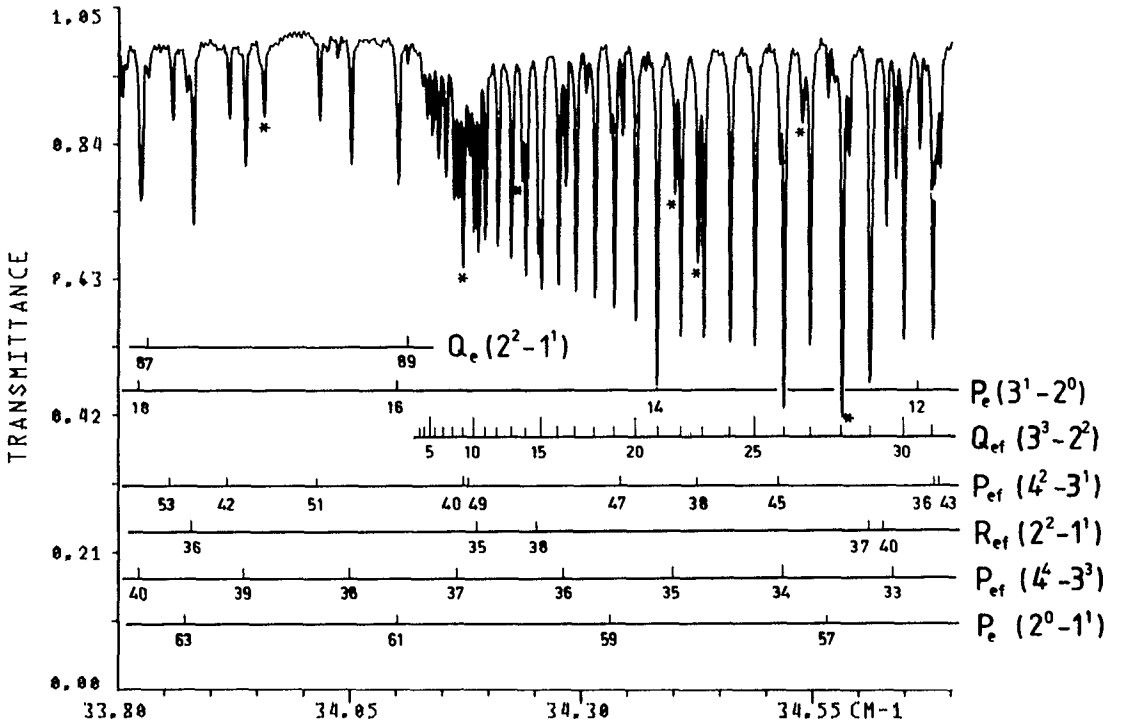

FIG. 2. Part of the far infrared spectrum of C_3O_2 around the origin of the 4^4–3^3 band, showing the beginning of the Q branch associated with this band. All the lines appearing in this region are assigned. Those labeled with an asterisk are due to SO_2 or blended with an SO_2 line (Ref. 15). This figure illustrates the appearance of the spectrum in the region below 47 cm^{-1} (see text).

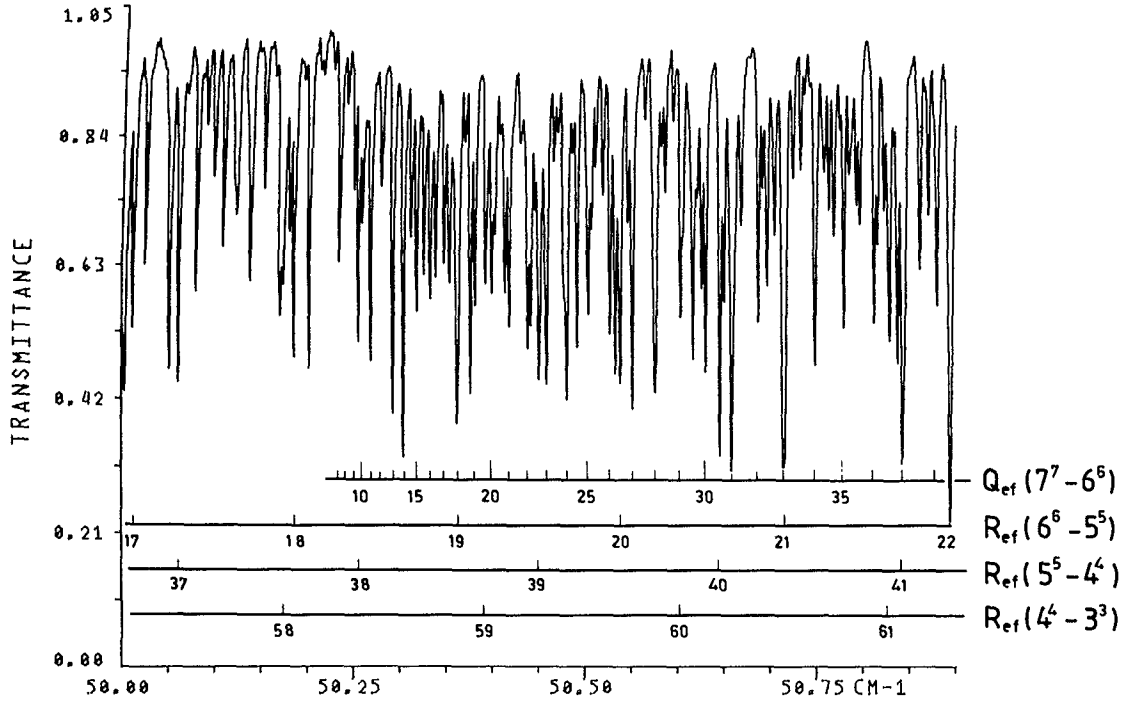

FIG. 3. Part of the far infrared spectrum of C_3O_2 around the origin of the 7^7–6^6 band. The assignments obtained for the Q branch associated with this band are presented in this figure together with those obtained for the R branch of three other bands. Six others branches have been identified in this region; they are not shown in order to keep the figure uncluttered. This figure illustrates the increasing density of lines in the spectrum in the region above 47 cm^{-1} (see text).

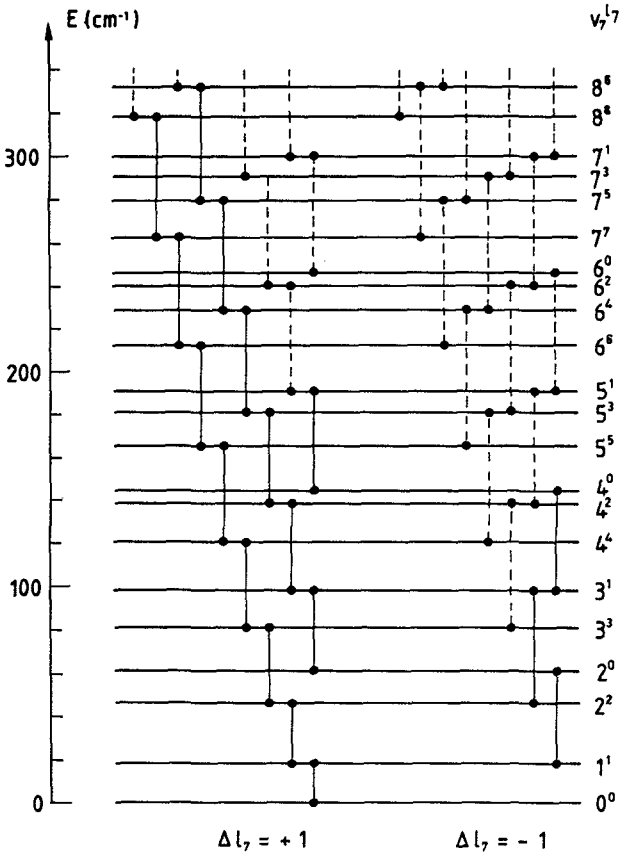

FIG. 4. Representation of the energy levels in the v_7 manifold up to the highest level observed in the present work. All the allowed transitions occurring between these levels are drawn. Those corresponding to $\Delta l_7 = +1$ are shown on the left of the figure and those associated with $\Delta l_7 = -1$ are on the right. The transitions corresponding to bands analyzed here are drawn with solid lines. The dashed lines correspond to transitions not analyzed in this work.

proved to be helpful in the analysis of this very dense region of the spectrum. Even so, it has not been possible to locate and identify all the bands.

Figure 4 summarizes the situation at the end of this work. It shows a schematic energy level diagram of the structure of the v_7 manifold up to the 8^6 level which is the highest level we have observed in the ground electronic state of C_3O_2. All the allowed transitions occurring between these levels have been drawn. Those giving rise to bands analyzed in the present work are drawn as solid lines; the dashed lines correspond to bands not analyzed. It can be noted from Fig. 4 that we have been able to analyze five times as many bands characterized by the selection rule $\Delta l_7 = +1$ as we have for bands with $\Delta l_7 = -1$. This situation occurs not only because these latter bands are weaker than those with $\Delta l_7 = +1$ but also because they tend to fall in the dense region above 47 cm^{-1} where they are badly overlapped by the stronger $\Delta l_7 = +1$ bands.

All the lines assigned in the present work and included in the least-squares fits (see Sec. IV below) are collected in Table I together with their identifications. These 1320 lines represent 34% of all the measured lines and belong to 18 different bands.

IV. RESULTS AND DISCUSSION

A. Effective model

During the analysis, we have fitted each band to effective parameters. More precisely, the rotational structure of each l sublevel represented in Fig. 4 was assumed to be expressed by the formula (see Jensen and Johns[8])

$$F(J) = B\{J(J+1) - l^2\} - D\{J(J+1) - l^2\}^2 + H\{J(J+1) - l^2\}^3 + L\{J(J+1) - l^2\}^4 + N\{J(J+1) - l^2\}^5, \quad (1)$$

with an additional term [The factor multiplying q_B differs from the one given in Ref. 8. The expression given here is the most often used (see, for example, Ref. 17)],

$$\pm\tfrac{1}{2}\{q_B\{J(J+1)\} - q_D\{J(J+1) - l^2\}^2 + q_H\{J(J+1) - l^2\}^3 + q_L\{J(J+1) - l^2\}^4 + q_N\{J(J+1) - l^2\}^5\} \quad (2)$$

added for each of the sublevels characterized by a value of l greater than zero. Each line within a band was fitted using the expression

$$\nu(J'') = \nu_0 + F'(J') - F''(J''). \quad (3)$$

At the end of the analysis, these same formulas were used in a simultaneous fit of the 18 bands analyzed in this work together with 231 lines belonging to 5 bands also analyzed by Karyakin *et al.*, i.e., the bands 1^1–0^0, 2^2–1^1, 3^1–2^0, 3^3–2^2 and 4^4–3^3.[2] The results of this fit consisted of a set of 105 constants characterizing 18 levels in the v_7 manifold and are presented in Table II. The standard deviation obtained was 0.0001 cm^{-1} for the far infrared lines and 0.000 002 8 cm^{-1} (84 kHz) for the microwave lines. The value obtained for the far infrared lines is a little higher than we had expected. This is probably due to the density of the spectrum in the region above 47 cm^{-1} which leads to a significant reduction in the precision of measurement of individual lines. The residuals obtained for all the far infrared lines are presented in Table I.

The constants reported in Table II for the levels with $v_7 = 0$ to 4 and the level 5^1 agree within error estimates (3σ) with those obtained in previous studies[3,8] but the precision has been improved by more than an order of magnitude. The constants derived for the levels 5^3, 5^5, and those with $v_7 = 6$, 7, and 8 are new.

Values of the effective B constants determined for all the levels characterized in the present work are gathered in Fig. 5 which shows the evolution of the effective B constant with vibrational excitation (v_7). The top solid curve links the values of B for the l sublevels having $l_7 = v_7$ (curve A), the middle solid curve links those sublevels having $l_7 = v_7 - 2$ (curve B) and the bottom solid curve links those sublevels with $l_7 = v_7 - 4$ (curve C). In a "true" linear molecule such as acetylene in its ground electronic state (see for example Ref. 18), these curves would be fairly close to straight lines. It appears clear that for C_3O_2 these dependencies are far from linear. As a consequence, when fitting the data to a linear model (see Sec. B below), one can expect to derive vibration–rotation interaction constants (α_7^0, γ_{77}^0,...) much larger than is usual for a linear molecule. On the other hand,

TABLE I. Identification, Observed wave numbers[a] (cm^{-1}), and Residuals ($cm^{-1} \times 10^5$) for transitions assigned in the far infrared spectrum of carbon suboxide. An asterisk beside an observed wave number means that the corresponding line has not been included in the least-squares fit.

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
1	1	2	f	0	0	2	e	18.18525	5	1	1	35	e	0	0	34	e	24.16269	7
1	1	4	f	0	0	4	e	18.19859	5	2	2	23	f	1	1	24	f	24.18335	−13
1	1	6	f	0	0	6	e	18.21964	15	2	2	21	f	1	1	22	f	24.45033	−3
1	1	8	f	0	0	8	e	18.24805	−2	2	2	22	e	1	1	23	e	24.53827	−9
1	1	10	f	0	0	10	e	18.28427	1	1	1	37	e	0	0	36	e	24.54667	−8
1	1	12	f	0	0	12	e	18.32813	5	1	1	82	f	0	0	82	e	24.64242	−7
1	1	14	f	0	0	14	e	18.37949	−4	1	1	39	e	0	0	38	e	24.93579	11
1	1	16	f	0	0	16	e	18.43859	0	2	2	17	f	1	1	18	f	24.99492	−2
1	1	18	f	0	0	18	e	18.50526	−3	2	2	18	e	1	1	19	e	25.01115	10
1	1	24	f	0	0	24	e	18.75128	11	2	2	16	e	1	1	17	e	25.25741	13
1	1	26	f	0	0	26	e	18.84845	4	2	2	15	f	1	1	16	f	25.27280	24
1	1	32	f	0	0	32	e	19.18588	−5	1	1	41	e	0	0	40	e	25.32966	17
1	1	7	e	0	0	6	e	19.26806	26	2	2	14	e	1	1	15	e	25.51015	2
1	1	34	f	0	0	34	e	19.31375	4	2	2	13	f	1	1	14	f	25.55383	13
1	1	36	f	0	0	36	e	19.44914	2	3	3	74	f	2	2	75	f	25.71760	−7
1	1	38	f	0	0	38	e	19.59225	9	1	1	43	e	0	0	42	e	25.72808	−14
1	1	40	f	0	0	40	e	19.74293	9	3	3	75	e	2	2	76	e	25.81406	−17
2	2	61	f	1	1	62	f	19.85037	−20	2	2	10	e	1	1	11	e	26.03568	−5
1	1	42	f	0	0	42	e	19.90119	6	2	2	9	f	1	1	10	f	26.12645	0
1	1	11	e	0	0	10	e	19.91382	21	1	1	45	e	0	0	44	e	26.13198	5
1	1	44	f	0	0	44	e	20.06716	12	3	3	68	f	2	2	69	f	26.16089	9
1	1	48	f	0	0	48	e	20.42169	2	3	3	69	e	2	2	70	e	26.20246	−12
1	1	15	e	0	0	14	e	20.57702	12	2	2	8	e	1	1	9	e	26.30866	15
1	1	50	f	0	0	50	e	20.61039	2	1	1	47	e	0	0	46	e	26.54071	4
2	2	53	f	1	1	54	f	20.63910	−5	3	3	61	e	2	2	62	e	26.79724	0
1	1	52	f	0	0	52	e	20.80662	−2	3	3	60	f	2	2	61	f	26.81119	−1
2	2	51	f	1	1	52	f	20.84708	−6	3	1	77	e	2	0	78	e	26.87450	−22
1	1	17	e	0	0	16	e	20.91527	13	1	1	49	e	0	0	48	e	26.95458	9
2	2	66	e	1	1	67	e	20.98155	27	3	3	59	e	2	2	60	e	26.95942	7
1	1	54	f	0	0	54	e	21.01055	8	3	3	58	f	2	2	59	f	26.98475	13
2	2	49	f	1	1	50	f	21.05921	−15	3	1	75	e	2	0	76	e	27.07199	−1
2	2	64	e	1	1	65	e	21.08357	15	3	3	57	e	2	2	58	e	27.12686	9
2	2	62	e	1	1	63	e	21.19091*	36	3	3	56	f	2	2	57	f	27.16239	−3
1	1	56	f	0	0	56	e	21.22191	7	3	3	54	f	2	2	55	f	27.34463	1
1	1	19	e	0	0	18	e	21.25791	8	1	1	51	e	0	0	50	e	27.37343	0
2	2	47	f	1	1	48	f	21.27583	4	3	1	71	e	2	0	72	e	27.47219	9
2	2	60	e	1	1	61	e	21.30286	5	3	3	53	e	2	2	54	e	27.47722	−6
2	2	58	e	1	1	59	e	21.42075*	41	3	3	52	f	2	2	53	f	27.53129	7
1	1	58	f	0	0	58	e	21.44086	13	2	2	6	e	1	1	6	f	27.63632	7
2	2	45	f	1	1	46	f	21.49663*	25	2	2	5	f	1	1	5	e	27.64356	13
2	2	56	e	1	1	57	e	21.54317	−5	2	2	8	e	1	1	8	f	27.64901	4
1	1	21	e	0	0	20	e	21.60493	−3	3	3	51	e	2	2	52	e	27.66030	0
1	1	60	f	0	0	60	e	21.66725	15	3	1	69	e	2	0	70	e	27.67497	−4
2	2	52	e	1	1	53	e	21.80523*	−29	2	2	12	e	1	1	12	f	27.68469	10
1	1	62	f	0	0	62	e	21.90109	14	2	2	9	f	1	1	9	e	27.69342	6
2	2	41	f	1	1	42	f	21.94983	5	2	2	14	e	1	1	14	f	27.70751	0
1	1	23	e	0	0	22	e	21.95656	−3	3	3	50	f	2	2	51	f	27.72230	3
1	1	64	f	0	0	64	e	22.14220	−3	2	2	11	f	1	1	11	e	27.72824	−5
2	2	39	f	1	1	40	f	22.18270	17	2	2	16	e	1	1	16	f	27.73383	−1
2	2	46	e	1	1	47	e	22.24168	−10	2	2	18	e	1	1	18	f	27.76359	1
1	1	25	e	0	0	24	e	22.31274	1	2	2	13	f	1	1	13	e	27.76986	−1
1	1	66	f	0	0	66	e	22.39089	−4	2	2	15	f	1	1	15	e	27.81816	7
1	1	68	f	0	0	68	e	22.64717	17	2	2	22	e	1	1	22	f	27.83342	6
2	2	35	f	1	1	36	f	22.65966	−18	2	2	19	f	1	1	19	e	27.93445	7
1	1	27	e	0	0	26	e	22.67348	5	2	2	28	e	1	1	28	f	27.96388	5
2	2	40	e	1	1	41	e	22.73133	−11	2	2	21	f	1	1	21	e	28.00242	−4
1	1	29	e	0	0	28	e	23.03867	−6	2	2	30	e	1	1	30	f	28.01422	0
2	2	36	e	1	1	37	e	23.08841	−13	2	2	32	e	1	1	32	f	28.06800	−7
2	2	31	f	1	1	32	f	23.15278	12	2	2	23	f	1	1	23	e	28.07711	−2
1	1	72	f	0	0	72	e	23.18126	15	3	1	65	e	2	0	66	e	28.08691	8
2	2	34	e	1	1	35	e	23.27652	5	3	3	46	f	2	2	47	f	28.11773	−3
1	1	31	e	0	0	30	e	23.40883	16	2	2	34	e	1	1	34	f	28.12538	−1
2	2	32	e	1	1	33	e	23.47085	14	2	2	25	f	1	1	25	e	28.15835	−5
2	2	27	f	1	1	28	f	23.66071	7	2	2	36	e	1	1	36	f	28.18615	−1
2	2	30	e	1	1	31	e	23.67146	13	1	1	55	e	0	0	54	e	28.22696	3
1	1	33	e	0	0	32	e	23.78335	7	3	3	45	e	2	2	46	e	28.23991	−3
2	2	28	e	1	1	29	e	23.87855	18	2	2	38	e	1	1	38	f	28.25039	−1
2	2	25	f	1	1	26	f	23.92023	1	3	1	63	e	2	0	64	e	28.29584	−3
2	2	26	e	1	1	27	e	24.09203	16	2	2	40	e	1	1	40	f	28.31811	1

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
2	2	29	*f*	1	1	29	*e*	28.34060	−3	3	3	23	*e*	2	2	24	*e*	30.74375	11
2	2	42	*e*	1	1	42	*f*	28.38927	2	3	1	41	*e*	2	0	42	*e*	30.75263	2
2	2	5	*f*	1	1	4	*f*	28.39626	−6	2	2	86	*e*	1	1	86	*f*	30.77232	−14
2	2	44	*e*	1	1	44	*f*	28.46386	1	3	3	22	*f*	2	2	23	*f*	30.86992	0
3	1	61	*e*	2	0	62	*e*	28.50696	−11	4	2	67	*f*	3	1	68	*f*	30.90126	7
3	3	42	*f*	2	2	43	*f*	28.53117	1	1	1	67	*e*	0	0	66	*e*	30.91574	−9
2	2	33	*f*	1	1	33	*e*	28.54908	1	2	2	63	*f*	1	1	63	*e*	30.93113	−3
2	2	6	*e*	1	1	5	*e*	28.56645*	−24	3	1	39	*e*	2	0	40	*e*	30.99189	1
2	2	48	*e*	1	1	48	*f*	28.62330	−4	3	3	21	*e*	2	2	22	*e*	30.99986	2
3	3	41	*e*	2	2	42	*e*	28.65147	4	2	2	20	*e*	1	1	19	*e*	31.01021	−7
2	2	50	*e*	1	1	50	*f*	28.70809	−10	2	2	21	*f*	1	1	20	*f*	31.02780	−1
2	2	7	*f*	1	1	6	*f*	28.71329	−9	4	4	67	*f*	3	3	68	*f*	31.08274	−16
3	1	59	*e*	2	0	60	*e*	28.72053	1	4	2	65	*f*	3	1	66	*f*	31.11613	14
3	3	40	*f*	2	2	41	*f*	28.74452	−10	3	3	20	*f*	2	2	21	*f*	31.12875	−8
2	2	37	*f*	1	1	37	*e*	28.78343	−12	2	2	65	*f*	1	1	65	*e*	31.14022	9
2	2	52	*e*	1	1	52	*f*	28.79643	−1	4	4	66	*e*	3	3	67	*e*	31.17375	−15
3	3	39	*e*	2	2	40	*e*	28.86457	−3	4	4	65	*f*	3	3	66	*f*	31.25048	−14
2	2	54	*e*	1	1	54	*f*	28.88810	6	3	3	19	*e*	2	2	20	*e*	31.26064	−6
2	2	8	*e*	1	1	7	*e*	28.89583	−20	4	4	64	*e*	3	3	65	*e*	31.34249	4
2	2	39	*f*	1	1	39	*e*	28.91051	−1	2	2	67	*f*	1	1	67	*e*	31.35525	4
3	3	38	*f*	2	2	39	*f*	28.96252	−9	2	2	23	*f*	1	1	22	*f*	31.37212	−2
2	2	56	*e*	1	1	56	*f*	28.98291	−6	3	3	18	*f*	2	2	19	*f*	31.39225	−4
2	2	9	*f*	1	1	8	*f*	29.03372	−10	4	4	63	*f*	3	3	64	*f*	31.42260	−3
2	2	41	*f*	1	1	41	*e*	29.04395	−1	3	1	35	*e*	2	0	36	*e*	31.47917	−2
1	1	59	*e*	0	0	58	*e*	29.10164	6	3	3	17	*e*	2	2	18	*e*	31.52620	0
3	1	55	*e*	2	0	56	*e*	29.15433	−3	4	2	61	*f*	3	1	62	*f*	31.55436	−8
2	2	10	*e*	1	1	9	*e*	29.23196	−3	2	2	69	*f*	1	1	69	*e*	31.57633	−1
2	2	62	*e*	1	1	62	*f*	29.28743	7	4	4	61	*f*	3	3	62	*f*	31.59909	14
2	2	45	*f*	1	1	45	*e*	29.33009	−1	3	3	16	*f*	2	2	17	*f*	31.66032	1
2	2	11	*f*	1	1	10	*f*	29.35776	12	2	2	25	*f*	1	1	24	*f*	31.71999	4
3	1	53	*e*	2	0	54	*e*	29.37481	−8	3	1	33	*e*	2	0	34	*e*	31.72734	1
2	2	64	*e*	1	1	64	*f*	29.39512	−9	2	2	24	*e*	1	1	23	*e*	31.76706	−1
3	3	34	*f*	2	2	35	*f*	29.41217	1	3	3	15	*e*	2	2	16	*e*	31.79640	7
2	2	47	*f*	1	1	47	*e*	29.48274	−4	2	2	71	*f*	1	1	71	*e*	31.80346	−6
2	2	66	*e*	1	1	66	*f*	29.50613	−5	1	1	71	*e*	0	0	70	*e*	31.85626	13
3	3	33	*e*	2	2	34	*e*	29.53327	−5	4	4	58	*e*	3	3	59	*e*	31.87487	−12
1	1	61	*e*	0	0	60	*e*	29.54688	−8	3	3	14	*f*	2	2	15	*f*	31.93309	21
2	2	12	*e*	1	1	11	*e*	29.57454	0	4	4	57	*f*	3	3	58	*f*	31.96458	8
3	1	51	*e*	2	0	52	*e*	29.59787	−5	3	1	31	*e*	2	0	32	*e*	31.97858	6
2	2	68	*e*	1	1	68	*f*	29.62041	19	4	2	57	*f*	3	1	58	*f*	32.00444	−9
2	2	13	*f*	1	1	12	*f*	29.68478	−7	2	2	73	*f*	1	1	73	*e*	32.03672	4
2	2	70	*e*	1	1	70	*f*	29.73745	21	4	4	56	*e*	3	3	57	*e*	32.06157	16
3	3	31	*e*	2	2	32	*e*	29.76577	−12	2	2	27	*f*	1	1	26	*f*	32.07125	−1
2	2	51	*f*	1	1	51	*e*	29.80723	2	2	0	80	*e*	1	1	81	*e*	32.09414	10
3	1	49	*e*	2	0	50	*e*	29.82351	1	3	3	12	*f*	2	2	13	*f*	32.20992	−9
2	2	72	*e*	1	1	72	*f*	29.85729	10	4	4	54	*e*	3	3	55	*e*	32.25228	2
3	3	30	*f*	2	2	31	*f*	29.87987	0	2	2	75	*f*	1	1	75	*e*	32.27546*	−32
2	2	14	*e*	1	1	13	*e*	29.92374	6	1	1	73	*e*	0	0	72	*e*	32.33477	7
1	1	63	*e*	0	0	62	*e*	29.99783	7	4	2	72	*e*	3	1	73	*e*	32.41035	18
3	3	29	*e*	2	2	30	*e*	30.00330	7	2	2	29	*f*	1	1	28	*f*	32.42614	6
2	2	15	*f*	1	1	14	*f*	30.01546	0	4	4	52	*e*	3	3	53	*e*	32.44756	2
3	1	47	*e*	2	0	48	*e*	30.05166	−4	4	2	53	*f*	3	1	54	*f*	32.46623	3
2	2	76	*e*	1	1	76	*f*	30.10575	17	2	2	77	*f*	1	1	77	*e*	32.52079	−1
3	3	28	*f*	2	2	29	*f*	30.12073	17	2	2	28	*e*	1	1	27	*e*	32.54935	−7
2	2	55	*f*	1	1	55	*e*	30.15690	0	3	3	9	*e*	2	2	10	*e*	32.63443	15
2	2	78	*e*	1	1	78	*f*	30.23361*	−27	4	4	50	*e*	3	3	51	*e*	32.64719	−3
3	3	27	*e*	2	2	28	*e*	30.24532	1	4	2	51	*f*	3	1	52	*f*	32.70139	4
2	2	16	*e*	1	1	15	*e*	30.27941	5	3	1	25	*e*	2	0	26	*e*	32.75088	4
4	4	77	*f*	3	3	78	*f*	30.30810*	−13	2	2	79	*f*	1	1	79	*e*	32.77170	0
2	2	57	*f*	1	1	57	*e*	30.34126	11	3	3	8	*f*	2	2	9	*f*	32.77806	15
2	2	17	*f*	1	1	16	*f*	30.34941	−7	2	2	31	*f*	1	1	30	*f*	32.78446	0
4	4	76	*e*	3	3	77	*e*	30.39916	−1	1	1	75	*e*	0	0	74	*e*	32.81890	−3
4	2	71	*f*	3	1	72	*f*	30.48054	8	4	4	48	*e*	3	3	49	*e*	32.85128	−2
3	3	25	*e*	2	2	26	*e*	30.49204	−9	3	3	7	*e*	2	2	8	*e*	32.92282	7
3	1	43	*e*	2	0	44	*e*	30.51626	7	4	2	49	*f*	3	1	50	*f*	32.93939	3
2	2	59	*f*	1	1	59	*e*	30.53168	5	2	2	30	*e*	1	1	29	*e*	32.95011	3
3	3	24	*f*	2	2	25	*f*	30.61571	14	3	1	23	*e*	2	0	24	*e*	33.01472	7
2	2	18	*e*	1	1	17	*e*	30.64169	11	2	2	81	*f*	1	1	81	*e*	33.02827	−15
2	2	19	*f*	1	1	18	*f*	30.68707	15	4	4	46	*e*	3	3	47	*e*	33.05977	2
2	2	61	*f*	1	1	61	*e*	30.72838	7	3	3	6	*f*	2	2	7	*f*	33.06871	3

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
4	2	62	e	3	1	63	e	33.10972	−3	3	3	34	f	2	2	34	e	34.79882	7
4	4	45	f	3	3	46	f	33.16491	5	2	0	54	e	1	1	55	e	34.80780	−3
4	2	47	f	3	1	48	f	33.18022	−2	1	1	83	e	0	0	82	e	34.81302	11
4	2	60	e	3	1	61	e	33.25464	0	3	3	35	e	2	2	35	f	34.83195	6
4	4	44	e	3	3	45	e	33.27262	4	3	3	36	f	2	2	36	e	34.88010	−3
3	1	21	e	2	0	22	e	33.28179	6	3	3	37	e	2	2	37	f	34.91383	0
1	1	77	e	0	0	76	e	33.30893	10	4	2	33	f	3	1	34	f	34.94590	−6
2	2	32	e	1	1	31	e	33.35709	10	3	1	9	e	2	0	10	e	34.95382	−2
4	4	43	f	3	3	44	f	33.38010	5	3	3	38	f	2	2	38	e	34.96628	3
4	2	58	e	3	1	59	e	33.40166	−9	3	3	39	e	2	2	39	f	35.00018	1
4	2	45	f	3	1	46	f	33.42396	−1	4	4	29	f	3	3	30	f	35.00702	−10
2	0	66	e	1	1	67	e	33.43706	−24	2	2	43	f	1	1	42	f	35.01095	3
4	4	42	e	3	3	43	e	33.48987	10	2	2	40	e	1	1	39	e	35.04614	4
2	2	35	f	1	1	34	f	33.51201	3	3	3	40	f	2	2	40	e	35.05713	−1
2	0	64	e	1	1	65	e	33.65311	−8	3	3	6	f	2	2	5	f	35.06917	13
4	2	43	f	3	1	44	f	33.67055	0	3	3	41	e	2	2	41	f	35.09095	5
4	4	40	e	3	3	41	e	33.71133	2	4	4	28	e	3	3	29	e	35.13154	10
2	2	34	e	1	1	33	e	33.77014	3	3	3	42	f	2	2	42	e	35.15287	4
1	1	79	e	0	0	78	e	33.80465	19	3	3	43	e	2	2	43	f	35.18609	9
4	2	52	e	3	1	53	e	33.85884	−7	4	2	31	f	3	1	32	f	35.20943	−9
2	0	62	e	1	1	63	e	33.87414	−25	5	3	73	e	4	2	74	e	35.21803	10
2	2	37	f	1	1	36	f	33.88120	3	3	3	7	e	2	2	6	e	35.23085	2
4	2	41	f	3	1	42	f	33.91999	2	4	2	36	e	3	1	37	e	35.23943	3
4	4	38	e	3	3	39	e	33.93720	1	3	1	7	e	2	0	8	e	35.24452	19
4	2	50	e	3	1	51	e	34.01740	−5	3	3	44	f	2	2	44	e	35.25343	7
4	4	37	f	3	3	38	f	34.05157	5	3	3	45	e	2	2	45	f	35.28552	8
2	2	89	f	1	1	89	e	34.11287	14	2	0	50	e	1	1	51	e	35.30078	0
3	3	3	e	2	2	3	f	34.12899	14	1	1	85	e	0	0	84	e	35.32584	7
3	3	4	f	2	2	4	e	34.13354	17	5	5	64	f	4	4	65	f	35.35041	−5
3	3	5	e	2	2	5	f	34.13909	7	3	3	46	f	2	2	46	e	35.35883	7
3	3	6	f	2	2	6	e	34.14584	4	4	4	26	e	3	3	27	e	35.38331	11
3	3	7	e	2	2	7	f	34.15378	7	3	3	47	e	2	2	47	f	35.38931	10
3	3	8	f	2	2	8	e	34.16278	1	5	5	63	e	4	4	64	e	35.44242	11
4	4	36	e	3	3	37	e	34.16751	10	3	3	48	f	2	2	48	e	35.46904	−4
4	2	48	e	3	1	49	e	34.17932	−18	4	2	29	f	3	1	30	f	35.47580	−8
3	3	10	f	2	2	10	e	34.18431	6	2	2	42	e	1	1	41	e	35.48344	2
2	2	36	e	1	1	35	e	34.18941	4	4	4	25	f	3	3	26	f	35.51065	−1
3	3	11	e	2	2	11	f	34.19667	4	5	5	62	f	4	4	63	f	35.53441	−2
3	3	12	f	2	2	12	e	34.21031	4	3	1	5	e	2	0	6	e	35.53823	−2
3	3	13	e	2	2	13	f	34.22487	1	3	3	9	e	2	2	8	e	35.55783	8
3	3	14	f	2	2	14	e	34.24089	5	3	3	50	f	2	2	50	e	35.58437	3
3	3	15	e	2	2	15	f	34.25758	−1	5	3	67	e	4	2	68	e	35.60042	−14
3	3	16	f	2	2	16	e	34.27600	4	3	3	51	e	2	2	51	f	35.60963	2
4	4	35	f	3	3	36	f	34.28383	−15	5	3	62	f	4	2	63	f	35.62200	0
3	3	17	e	2	2	17	f	34.29484	−1	4	2	32	e	3	1	33	e	35.63151	0
1	1	81	e	0	0	80	e	34.30583	1	4	4	24	e	3	3	25	e	35.63922	−2
3	3	18	f	2	2	18	e	34.31562	−1	3	3	10	f	2	2	9	f	35.72287	−1
3	3	19	e	2	2	19	f	34.33661	2	3	3	53	e	2	2	53	f	35.72621	4
4	2	46	e	3	1	47	e	34.34518	−14	5	3	65	e	4	2	66	e	35.73857	−22
3	3	20	f	2	2	20	e	34.35988	1	4	2	27	f	3	1	28	f	35.74497	−9
3	3	21	e	2	2	21	f	34.38292	8	4	4	23	f	3	3	24	f	35.76882	−2
4	4	34	e	3	3	35	e	34.40196	0	2	2	47	f	1	1	46	f	35.78295	6
3	3	22	f	2	2	22	e	34.40871	1	2	0	46	e	1	1	47	e	35.80912	2
3	3	23	e	2	2	23	f	34.43361	3	5	5	59	e	4	4	60	e	35.81816	−10
3	3	24	f	2	2	24	e	34.46214	3	3	3	54	f	2	2	54	e	35.82997	4
3	3	25	e	2	2	25	f	34.48889	9	4	2	30	e	3	1	31	e	35.83566	−11
3	3	27	e	2	2	27	f	34.54855	5	3	3	55	e	2	2	55	f	35.84697	3
2	0	56	e	1	1	57	e	34.56766	6	3	3	11	e	2	2	10	e	35.88929	10
3	3	3	e	2	2	2	e	34.59052	4	4	4	22	e	3	3	23	e	35.89962	8
2	2	41	f	1	1	40	f	34.63074	13	5	5	58	f	4	4	59	f	35.91470	9
4	4	32	e	3	3	33	e	34.64091	9	2	2	44	e	1	1	43	e	35.92668	6
3	3	30	f	2	2	30	e	34.65021	10	3	3	56	f	2	2	56	e	35.96042	7
3	1	11	e	2	0	12	e	34.66693	19	3	3	57	e	2	2	57	f	35.97193	6
3	3	31	e	2	2	31	f	34.68136	6	5	3	58	f	4	2	59	f	36.00504	16
4	2	42	e	3	1	43	e	34.68914	−10	5	5	57	e	4	4	58	e	36.01233	−5
3	3	32	f	2	2	32	e	34.72217	8	4	2	25	f	3	1	26	f	36.01710	4
5	5	71	e	4	4	72	e	34.73958	−8	4	2	28	e	3	1	29	e	36.04580	7
3	3	4	f	2	2	3	f	34.74904	16	3	3	12	f	2	2	11	f	36.05663	11
3	3	33	e	2	2	33	f	34.75442	4	2	0	44	e	1	1	45	e	36.06853	−1
4	4	31	f	3	3	32	f	34.76176	−2	3	3	58	f	2	2	58	e	36.09603	11

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
3	3	59	e	2	2	59	f	36.10110	18	2	0	34	e	1	1	35	e	37.41160	−22
5	5	56	f	4	4	57	f	36.11089	6	4	2	15	f	3	1	16	f	37.41904	4
4	4	20	e	3	3	21	e	36.16418	5	3	1	32	f	2	0	32	e	37.43051	9
2	2	49	f	1	1	48	f	36.17471	8	5	3	44	f	4	2	45	f	37.44598	−16
5	3	59	e	4	2	60	e	36.18782	14	5	5	43	e	4	4	44	e	37.48561	−8
5	3	56	f	4	2	57	f	36.20091	0	3	1	7	e	2	0	6	e	37.53211	−4
5	5	55	e	4	4	56	e	36.21064	5	3	1	34	f	2	0	34	e	37.55398	1
3	3	13	e	2	2	12	e	36.22517	5	5	5	42	f	4	4	43	f	37.59851	−5
4	2	26	e	3	1	27	e	36.26158	3	3	3	79	e	2	2	79	f	37.60569	−14
4	2	23	f	3	1	24	f	36.29182	−3	5	3	43	e	4	2	44	e	37.64122	0
4	4	19	f	3	3	20	f	36.29799	−2	5	3	42	f	4	2	43	f	37.66585	−5
5	5	54	f	4	4	55	f	36.31115	3	3	1	36	f	2	0	36	e	37.68450	10
2	0	42	e	1	1	43	e	36.33127	−1	4	2	13	f	3	1	14	f	37.70773	−3
5	3	57	e	4	2	58	e	36.34905	9	5	5	41	e	4	4	42	e	37.71246	−1
3	3	63	e	2	2	63	f	36.37112	−5	3	3	78	f	2	2	78	e	37.74875	−2
2	2	46	e	1	1	45	e	36.37572	10	2	2	52	e	1	1	51	e	37.75661	10
3	3	62	f	2	2	62	e	36.38273	−1	3	3	22	f	2	2	21	f	37.79173	3
5	3	54	f	4	2	55	f	36.39995	−13	3	1	38	f	2	0	38	e	37.82159	−2
5	5	53	e	4	4	54	e	36.41305	15	5	5	40	f	4	4	41	f	37.82720	−18
4	4	18	e	3	3	19	e	36.43290	−7	5	1	59	e	4	0	60	e	37.83770	15
3	1	2	f	2	0	2	e	36.44639	16	6	4	73	f	5	3	74	f	37.86596	11
3	1	4	f	2	0	4	e	36.45949	−5	5	3	40	f	4	2	41	f	37.88947	13
3	1	8	f	2	0	8	e	36.50902	8	3	3	23	e	2	2	22	e	37.97238	2
3	3	64	f	2	2	64	e	36.53416	4	4	2	11	f	3	1	12	f	37.99927	−3
3	1	10	f	2	0	10	e	36.54499	1	6	4	72	e	5	3	73	e	38.03969	−1
3	3	15	e	2	2	14	e	36.56567	12	3	1	42	f	2	0	42	e	38.11608	7
3	1	12	f	2	0	12	e	36.58865	8	3	3	24	f	2	2	23	f	38.15211	6
2	0	40	e	1	1	41	e	36.59707	−6	3	1	11	e	2	0	10	e	38.17481	13
5	5	51	e	4	4	52	e	36.61929	−1	2	2	59	f	1	1	58	f	38.19259	10
3	1	14	f	2	0	14	e	36.63972	5	6	4	69	f	5	3	70	f	38.20431	2
3	3	67	e	2	2	67	f	36.65735	2	4	2	10	e	3	1	11	e	38.21492	18
3	1	16	f	2	0	16	e	36.69833	8	2	2	54	e	1	1	53	e	38.22789	9
4	4	16	e	3	3	17	e	36.70615	9	2	0	28	e	1	1	29	e	38.24901	−7
4	2	22	e	3	1	23	e	36.71145	10	3	1	44	f	2	0	44	e	38.27299	0
5	5	50	f	4	4	51	f	36.72391	−6	5	3	37	e	4	2	38	e	38.27988	−2
3	3	16	f	2	2	15	f	36.73735	12	4	2	9	f	3	1	10	f	38.29368	6
2	2	48	e	1	1	47	e	36.83024	−8	5	5	36	f	4	4	37	f	38.29723	2
3	1	20	f	2	0	20	e	36.83783	16	3	3	25	e	2	2	24	e	38.33542	8
4	4	15	f	3	3	16	f	36.84414	−6	5	3	36	f	4	2	37	f	38.34754	4
4	2	19	f	3	1	20	f	36.84977	−7	6	4	67	f	5	3	68	f	38.37873	7
3	3	68	f	2	2	68	e	36.85317	5	3	1	46	f	2	0	46	e	38.43629	−7
3	1	3	e	2	0	2	e	36.90333	9	4	2	8	e	3	1	9	e	38.48860	−10
3	3	17	e	2	2	16	e	36.91061	12	3	3	26	f	2	2	25	f	38.51690	8
3	1	22	f	2	0	22	e	36.91856	12	2	0	26	e	1	1	27	e	38.53248	−10
5	5	48	f	4	4	49	f	36.93654	3	5	5	34	f	4	4	35	f	38.53818	−3
4	2	20	e	3	1	21	e	36.94557	−4	6	4	65	f	5	3	66	f	38.55642	−14
3	3	71	e	2	2	71	f	36.95891	4	5	3	34	f	4	2	35	f	38.58237	0
2	2	53	f	1	1	52	f	36.97003	20	4	2	7	f	3	1	8	f	38.59060	−12
3	1	24	f	2	0	24	e	37.00657	8	5	5	33	e	4	4	34	e	38.66023	0
5	3	48	f	4	2	49	f	37.01748	9	6	4	64	e	5	3	65	e	38.69242	−4
3	3	70	f	2	2	70	e	37.02093	5	6	6	65	f	5	5	66	f	38.71165	−25
5	5	47	e	4	4	48	e	37.04430	−4	5	3	33	e	4	2	34	e	38.73252	−3
5	3	49	e	4	2	50	e	37.05274	2	6	4	63	f	5	3	64	f	38.73811	2
3	3	18	f	2	2	17	f	37.08430	2	2	0	24	e	1	1	25	e	38.81811	4
3	1	26	f	2	0	26	e	37.10185	7	3	1	15	e	2	0	14	e	38.83076	7
3	3	73	e	2	2	73	f	37.11524	0	6	4	62	e	5	3	63	e	38.86795	−16
4	4	13	f	3	3	14	f	37.12367	1	3	3	28	f	2	2	27	f	38.88619	20
4	2	17	f	3	1	18	f	37.13299	−3	6	6	63	f	5	5	64	f	38.90196	−3
2	0	36	e	1	1	37	e	37.13744	−11	5	5	31	e	4	4	32	e	38.90730	0
5	5	46	f	4	4	47	f	37.15303	−8	6	4	61	f	5	3	62	f	38.92332	3
4	2	18	e	3	1	19	e	37.18623	−4	3	1	52	f	2	0	52	e	38.96366	2
3	3	72	f	2	2	72	e	37.19422	−4	5	1	51	e	4	0	52	e	38.99276	−18
3	1	28	f	2	0	28	e	37.20430	5	6	6	62	e	5	5	63	e	38.99848	−1
3	1	5	e	2	0	4	e	37.21603	4	2	2	63	f	1	1	62	f	39.02810	14
5	3	46	f	4	2	47	f	37.22986	−14	5	5	30	f	4	4	31	f	39.03237	1
5	3	47	e	4	2	48	e	37.24312	−8	6	4	60	e	5	3	61	e	39.04860	0
3	3	19	e	2	2	18	e	37.26001	8	3	3	29	e	2	2	28	e	39.07503	10
3	3	75	e	2	2	75	f	37.27504	−20	6	6	61	f	5	5	62	f	39.09600	4
2	2	50	e	1	1	49	e	37.29071	6	2	0	22	e	1	1	23	e	39.10545	−2
3	1	30	f	2	0	30	e	37.31384	2	3	1	54	f	2	0	54	e	39.15135	−4

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
5	5	29	e	4	4	30	e	39.15839	−3	4	4	48	e	3	3	48	f	40.43087	8
3	1	17	e	2	0	16	e	39.16375	5	4	2	46	e	3	1	46	f	40.44450	3
2	2	58	e	1	1	57	e	39.18636	11	6	6	48	e	5	5	49	e	40.45144	2
6	6	60	e	5	5	61	e	39.19428	−12	4	2	27	f	3	1	27	e	40.45911	2
4	4	5	f	3	3	5	e	39.21394	12	4	2	48	e	3	1	48	f	40.49021	3
4	4	6	e	3	3	6	f	39.22014	2	3	1	25	e	2	0	24	e	40.52863	10
4	4	7	f	3	3	7	e	39.22744	0	6	4	45	f	5	3	46	f	40.54353	−16
4	4	9	f	3	3	9	e	39.24526	1	4	2	29	f	3	1	29	e	40.55700	10
4	4	10	e	3	3	10	f	39.25581	8	6	6	47	f	5	5	48	f	40.56256	9
3	3	30	f	2	2	29	f	39.25953	−3	2	0	12	e	1	1	13	e	40.56768	−10
4	4	11	f	3	3	11	e	39.26723	−2	4	2	52	e	3	1	52	f	40.58197	5
5	5	28	f	4	4	29	f	39.28554	5	4	4	51	f	3	3	51	e	40.58956	3
4	4	13	f	3	3	13	e	39.29350	5	3	3	37	e	2	2	36	e	40.60882	−2
4	4	15	f	3	3	15	e	39.32382	−2	3	1	68	f	2	0	68	e	40.61994	1
4	4	16	e	3	3	16	f	39.34054	−5	4	2	54	e	3	1	54	f	40.62755	−2
3	1	56	f	2	0	56	e	39.34490	−2	5	1	39	e	4	0	40	e	40.72632	14
4	4	17	f	3	3	17	e	39.35842	1	5	3	17	e	4	2	18	e	40.74488	−3
4	4	18	e	3	3	18	f	39.37726	−1	5	5	17	e	4	4	18	e	40.74956	−19
5	5	27	e	4	4	28	e	39.41353	−5	4	4	54	e	3	3	54	f	40.75469	10
4	4	20	e	3	3	20	f	39.41816	2	4	2	33	f	3	1	33	e	40.77254	−7
4	4	21	f	3	3	21	e	39.44013	−2	6	6	45	f	5	5	46	f	40.78752	3
4	4	22	e	3	3	22	f	39.46317	−3	3	3	38	f	2	2	37	f	40.79751	8
4	4	23	f	3	3	23	e	39.48733	1	4	4	55	f	3	3	55	e	40.81475	7
4	4	24	e	3	3	24	f	39.51246	1	4	2	64	e	3	1	64	f	40.84553	−12
4	4	25	f	3	3	25	e	39.53870	2	3	1	70	f	2	0	70	e	40.85024	16
5	3	26	f	4	2	27	f	39.56154	−8	2	0	10	e	1	1	11	e	40.86494	16
4	4	26	e	3	3	26	f	39.56592	1	4	4	56	e	3	3	56	f	40.87095	10
5	1	47	e	4	0	48	e	39.57017	3	6	6	44	e	5	5	45	e	40.90154	9
4	4	27	f	3	3	27	e	39.59427	3	4	2	7	f	3	1	6	f	40.90718	15
6	4	54	e	5	3	55	e	39.61823	−4	4	2	68	e	3	1	68	f	40.92473	−10
4	4	28	e	3	3	28	f	39.62359	2	4	4	57	f	3	3	57	e	40.93363	−2
3	3	32	f	2	2	31	f	39.63753	3	4	2	70	e	3	1	70	f	40.96202	−9
4	4	29	f	3	3	29	e	39.65403	2	4	4	11	f	3	3	10	f	40.97216	−3
4	4	30	e	3	3	30	f	39.68548	7	3	3	39	e	2	2	38	e	41.00388	7
4	4	31	f	3	3	31	e	39.71802	5	4	4	59	f	3	3	59	e	41.05693	3
4	4	33	f	3	3	33	e	39.78624	10	3	1	72	f	2	0	72	e	41.08486	0
4	4	34	e	3	3	34	f	39.82172	3	6	4	40	e	5	3	41	e	41.10541	−8
4	2	10	e	3	1	10	f	39.84438	−5	6	6	42	e	5	5	43	e	41.13217	−10
6	4	51	f	5	3	52	f	39.90626	−22	4	4	12	e	3	3	11	e	41.13969	−3
6	6	53	f	5	5	54	f	39.91070	2	4	2	39	f	3	1	39	e	41.14582	−4
4	4	37	f	3	3	37	e	39.93533	21	5	5	14	f	4	4	15	f	41.17026	9
4	2	20	e	3	1	20	f	39.94750	−6	4	0	48	e	3	1	49	e	41.17834	9
5	3	23	e	4	2	24	e	39.95363	−4	4	4	61	f	3	3	61	e	41.18464	20
3	1	62	f	2	0	62	e	39.95896	9	6	4	39	f	5	3	40	f	41.21735	−1
4	2	13	f	3	1	13	e	39.96440	1	4	4	62	e	3	3	62	f	41.24464	10
4	4	5	f	3	3	4	f	39.98883	−3	6	6	41	f	5	5	42	f	41.24921	8
4	2	24	e	3	1	24	f	40.00540	−2	4	2	41	f	3	1	41	e	41.28332	−4
4	2	26	e	3	1	26	f	40.03749	−5	4	4	63	f	3	3	63	e	41.31634	6
4	4	40	e	3	3	40	f	40.05757	−1	3	1	74	f	2	0	74	e	41.32424	9
4	4	41	f	3	3	41	e	40.10099	3	6	4	38	e	5	3	39	e	41.33538	−4
4	2	30	e	3	1	30	f	40.10757	−4	4	0	46	e	3	1	47	e	41.35177	−8
6	4	49	f	5	3	50	f	40.11496	9	6	6	40	e	5	5	41	e	41.36700	3
6	6	51	f	5	5	52	f	40.12393	−14	4	4	64	e	3	3	64	f	41.37747	13
4	2	19	f	3	1	19	e	40.13539	−6	3	3	41	e	2	2	40	e	41.40352	12
2	2	62	e	1	1	61	e	40.16518	8	4	2	43	f	3	1	43	e	41.42735	1
3	1	64	f	2	0	64	e	40.17418	−1	4	2	10	e	3	1	9	e	41.43553	−4
4	4	43	f	3	3	43	e	40.19023	2	2	0	6	e	1	1	7	e	41.46274	−10
3	3	35	e	2	2	34	e	40.21851	3	4	4	14	e	3	3	13	e	41.47805	15
4	2	36	e	3	1	36	f	40.22522	−6	6	6	39	f	5	5	40	f	41.48565	−11
4	4	44	e	3	3	44	f	40.23582	2	4	2	11	f	3	1	10	f	41.55080	−2
4	2	38	e	3	1	38	f	40.26732	6	7	7	67	e	6	6	68	e	41.56180	−11
4	0	60	e	3	1	61	e	40.29421	1	4	2	45	f	3	1	45	e	41.57770	−6
6	4	47	f	5	3	48	f	40.32730	4	3	1	31	e	2	0	30	e	41.58576	10
4	4	46	e	3	3	46	f	40.33129	9	6	6	38	e	5	5	39	e	41.60546	−6
4	2	42	e	3	1	42	f	40.35442	6	4	4	15	f	3	3	14	f	41.64847	−8
4	2	25	f	3	1	25	e	40.36802	2	4	4	68	e	3	3	68	f	41.65536	11
4	4	47	f	3	3	47	e	40.38147	7	2	2	68	e	1	1	67	e	41.66939	−5
3	1	66	f	2	0	66	e	40.39459	1	6	4	35	f	5	3	36	f	41.68697	−2
4	2	44	e	3	1	44	f	40.39930	16	4	0	42	e	3	1	43	e	41.71991	−4
3	3	36	f	2	2	35	f	40.40649	4	6	6	37	f	5	5	38	f	41.72622	−2

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
4	2	12	e	3	1	11	e	41.78182	−2	6	6	26	e	5	5	27	e	43.11780	−7
4	4	70	e	3	3	70	f	41.80044	12	3	1	49	e	2	2	50	e	43.17904	−11
3	3	43	e	2	2	42	e	41.80782	16	6	4	23	f	5	3	24	f	43.19525	1
3	1	78	f	2	0	78	e	41.81543	−15	4	4	87	f	3	3	87	e	43.24159*	54
4	4	16	e	3	3	15	e	41.82021	−2	6	6	25	f	5	5	26	f	43.25020	4
6	6	36	e	5	5	37	e	41.84786	−8	7	7	50	f	6	6	51	f	43.32273	0
7	7	64	f	6	6	65	f	41.85311	−9	6	4	22	e	5	3	23	e	43.32790	13
4	2	13	f	3	1	12	f	41.87687	4	7	5	46	f	6	4	47	f	43.32790	−10
4	2	49	f	3	1	49	e	41.89752	−15	5	1	21	e	4	0	22	e	43.35681	−14
4	0	40	e	3	1	41	e	41.91394	−19	5	3	4	f	4	2	4	e	43.37733	−2
3	1	33	e	2	0	32	e	41.94433	12	5	3	7	e	4	2	7	f	43.39716	2
4	4	72	e	3	3	72	f	41.94962*	19	4	4	25	f	3	3	24	f	43.41193	3
2	0	60	e	1	1	60	f	41.98063	12	4	2	65	f	3	1	65	e	43.42366	−9
2	0	54	e	1	1	54	f	42.02436	7	5	3	10	f	4	2	10	e	43.42713	9
2	0	48	e	1	1	48	f	42.08595	2	5	5	7	e	4	4	7	f	43.43449	0
2	0	46	e	1	1	46	f	42.10930	9	7	7	49	e	6	6	50	e	43.43449	−17
4	0	38	e	3	1	39	e	42.11471	−12	5	5	10	f	4	4	10	e	43.46115	−2
7	7	61	e	6	6	62	e	42.15279	−1	5	3	13	e	4	2	13	f	43.46628	5
2	0	42	e	1	1	42	f	42.15833	−4	5	5	11	e	4	4	11	f	43.47192	−13
4	4	18	e	3	3	17	e	42.16675	5	5	5	14	f	4	4	14	e	43.51061	1
6	4	31	f	5	3	32	f	42.17303	−11	5	3	16	f	4	2	16	e	43.51702	1
2	0	40	e	1	1	40	f	42.18376	−3	5	3	17	e	4	2	17	f	43.53375	−16
4	4	75	f	3	3	75	e	42.19870	12	5	5	16	f	4	4	16	e	43.54123	−1
2	0	38	e	1	1	38	f	42.20949	3	4	2	23	f	3	1	22	f	43.54771	−1
2	0	36	e	1	1	36	f	42.23532	15	5	3	20	f	4	2	20	e	43.59978	−2
4	2	53	f	3	1	53	e	42.24263	−6	5	3	21	e	4	2	21	f	43.61857	−3
2	0	34	e	1	1	34	f	42.26062	−12	5	5	21	e	4	4	21	f	43.63518	6
2	0	32	e	1	1	32	f	42.28593	0	4	2	67	f	3	1	67	e	43.64116	−6
6	4	30	e	5	3	31	e	42.29787	3	5	3	22	f	4	2	22	e	43.64804	−14
3	1	35	e	2	0	34	e	42.30585	8	7	7	47	e	6	6	48	e	43.66140	9
2	0	30	e	1	1	30	f	42.31062	3	5	3	23	e	4	2	23	f	43.66719	−5
2	0	28	e	1	1	28	f	42.33460	7	7	5	43	e	6	4	44	e	43.66719	−2
2	0	26	e	1	1	26	f	42.35752	−8	4	0	24	e	3	1	25	e	43.69055	9
7	5	55	e	6	4	56	e	42.36529	1	5	3	25	e	4	2	25	f	43.72003	3
2	0	24	e	1	1	24	f	42.37953	−9	5	5	25	e	4	4	25	f	43.72806	4
2	0	22	e	1	1	22	f	42.40059	12	5	5	26	f	4	4	26	e	43.75368	−2
3	3	46	f	2	2	45	f	42.40431	4	5	3	26	f	4	2	26	e	43.75912	−4
2	0	18	e	1	1	18	f	42.43817	6	5	5	28	f	4	4	28	e	43.80805	0
2	0	16	e	1	1	16	f	42.45466	−1	3	1	45	e	2	2	46	e	43.84991	1
7	7	58	f	6	6	59	f	42.46079	5	5	5	30	f	4	4	30	e	43.86629	−5
2	0	12	e	1	1	12	f	42.48288	12	5	5	32	f	4	4	32	e	43.92855	−5
2	0	8	e	1	1	8	f	42.50364	4	5	1	17	e	4	0	18	e	43.95092	−9
2	0	6	e	1	1	6	f	42.51126	11	5	3	33	e	4	2	33	f	43.97123	7
6	4	28	e	5	3	29	e	42.54909	7	7	5	40	f	6	4	41	f	44.01510	10
7	7	57	e	6	6	58	e	42.56533	9	5	5	35	e	4	4	35	f	44.02953	17
7	5	53	e	6	4	54	e	42.57238	10	5	3	34	f	4	2	34	e	44.03996	−5
4	4	80	e	3	3	80	f	42.58564	−12	5	3	35	e	4	2	35	f	44.04372	8
6	6	30	e	5	5	31	e	42.59825	−9	5	5	36	f	4	4	36	e	44.06482	−10
4	2	57	f	3	1	57	e	42.61242	5	3	3	54	f	2	2	53	f	44.07889	6
3	3	47	e	2	2	46	e	42.63028	7	4	2	71	f	3	1	71	e	44.09308	−14
3	1	37	e	2	0	36	e	42.67043	14	5	5	37	e	4	4	37	f	44.10140	−7
6	4	27	f	5	3	28	f	42.67597	9	7	5	39	e	6	4	40	e	44.13307	5
4	4	21	f	3	3	20	f	42.69433	16	5	5	38	f	4	4	38	e	44.13898	−2
6	6	29	f	5	5	30	f	42.72666	−13	4	4	29	f	3	3	28	f	44.14597	−15
4	0	32	e	3	1	33	e	42.75456	−7	5	5	39	e	4	4	39	f	44.17749	−2
5	1	25	e	4	0	26	e	42.76683	−10	3	1	43	e	2	2	44	e	44.18576	−3
7	7	55	e	6	6	56	e	42.77709	6	4	0	20	e	3	1	21	e	44.19172	6
7	5	51	e	6	4	52	e	42.78304	−25	5	3	38	f	4	2	38	e	44.21119	−4
3	3	48	f	2	2	47	f	42.81675	14	5	5	40	f	4	4	40	e	44.21699	−4
3	1	51	e	2	2	52	e	42.84483	14	4	2	27	f	3	1	26	f	44.23515	6
6	6	28	e	5	5	29	e	42.85614	−5	7	7	42	f	6	6	43	f	44.24415	−2
4	2	18	e	3	1	17	e	42.86064	7	5	5	41	e	4	4	41	f	44.25749	−3
7	7	54	f	6	6	55	f	42.88409	−22	5	5	42	f	4	4	42	e	44.29901	1
4	4	84	e	3	3	84	f	42.92721	−17	5	3	40	f	4	2	40	e	44.30482	−4
4	0	30	e	3	1	31	e	42.98000	2	4	4	30	e	3	3	29	e	44.33238	8
6	6	27	f	5	5	28	f	42.98646	−9	5	5	43	e	4	4	43	f	44.34162	17
7	7	53	e	6	6	54	e	42.99251	−2	5	5	44	f	4	4	44	e	44.38484	−7
7	5	49	e	6	4	50	e	42.99832	3	4	2	26	e	3	1	25	e	44.38860	11
4	2	61	f	3	1	61	e	43.00618	−5	5	3	42	f	4	2	42	e	44.40397	−3
7	5	48	f	6	4	49	f	43.10665	−24	5	5	45	e	4	4	45	f	44.42936	3

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
4	0	18	e	3	1	19	e	44.45032	10	8	8	50	e	7	7	51	e	46.09168	11
5	3	45	e	4	2	45	f	44.46002	14	3	3	63	e	2	2	62	e	46.11200	21
5	5	46	f	4	4	46	e	44.47476	0	7	7	27	e	6	6	28	e	46.13190	−1
7	5	36	f	6	4	37	f	44.49272	−4	5	5	74	f	4	4	74	e	46.14548	7
5	5	7	e	4	4	6	e	44.52689	5	7	5	23	e	6	4	24	e	46.15460	7
3	1	47	e	2	0	46	e	44.53564	12	5	3	17	e	4	2	16	e	46.17204	−2
5	1	13	e	4	0	14	e	44.54956	5	3	1	31	e	2	2	32	e	46.19646	8
5	3	47	e	4	2	47	f	44.55322	9	5	5	17	e	4	4	16	e	46.21026	−13
4	2	29	f	3	1	28	f	44.58295	12	5	5	75	e	4	4	75	f	46.21780	−17
7	7	39	e	6	6	40	e	44.60503	1	4	4	40	e	3	3	39	e	46.25016	3
6	6	15	f	5	5	16	f	44.62552	−19	3	3	64	f	2	2	63	f	46.26500	17
5	5	50	f	4	4	50	e	44.66639	11	2	0	24	e	1	1	23	e	46.27339	10
5	5	8	f	4	4	7	f	44.69081	2	7	5	22	f	6	4	23	f	46.28935	9
4	4	32	e	3	3	31	e	44.70779	14	5	5	76	f	4	4	76	e	46.29423	10
7	7	38	f	6	6	39	f	44.72731	14	8	8	48	e	7	7	49	e	46.32139	18
5	3	51	e	4	2	51	f	44.74873	13	5	3	18	f	4	2	17	f	46.34512	2
3	1	46	f	2	2	47	f	44.76279	11	5	5	77	e	4	4	77	f	46.36810	−24
4	2	28	e	3	1	27	e	44.78571	4	5	5	18	f	4	4	17	f	46.38406	−5
5	3	9	e	4	2	8	e	44.81199	11	7	5	21	e	6	4	22	e	46.42487	−11
5	5	53	e	4	4	53	f	44.82012	−5	4	2	36	e	3	1	35	e	46.43051	1
5	5	54	f	4	4	54	e	44.87347	−7	4	4	41	f	3	3	40	f	46.44716	−7
4	4	33	f	3	3	32	f	44.89690	12	3	1	57	e	2	0	56	e	46.46647	9
3	1	49	e	2	0	48	e	44.91666	−2	3	1	29	e	2	2	30	e	46.52901	−17
5	5	55	e	4	4	55	f	44.92770	0	7	7	24	f	6	6	25	f	46.53446	0
4	2	31	f	3	1	30	f	44.93324	−3	8	8	46	e	7	7	47	e	46.55455	13
3	3	58	f	2	2	57	f	44.94110	8	5	5	19	e	4	4	18	e	46.55879	−3
5	3	55	e	4	2	55	f	44.95503	5	2	0	26	e	1	1	25	e	46.59564	−14
5	3	10	f	4	2	9	f	44.97787	2	5	5	80	f	4	4	80	e	46.60342	10
5	5	10	f	4	4	9	f	45.02165	3	5	3	72	f	4	2	72	e	46.63222	18
5	5	57	e	4	4	57	f	45.03922	6	4	4	42	e	3	3	41	e	46.64612	12
4	4	34	e	3	3	33	e	45.08728	17	6	4	7	f	5	3	7	e	46.68852	20
7	5	31	e	6	4	32	e	45.11217	0	5	3	20	f	4	2	19	f	46.69759	6
5	3	54	f	4	2	54	e	45.12106	12	6	4	9	f	5	3	9	e	46.70575	−2
5	3	11	e	4	2	10	e	45.14538	13	5	5	20	f	4	4	19	f	46.73452	2
5	3	59	e	4	2	59	f	45.17087	2	6	4	12	e	5	3	12	f	46.73957	−7
7	7	34	f	6	6	35	f	45.22508	7	5	1	8	f	4	0	8	e	46.74407	15
7	5	30	f	6	4	31	f	45.23906	5	6	4	13	f	5	3	13	e	46.75288	−10
4	0	12	e	3	1	13	e	45.25674	1	6	4	14	e	5	3	14	f	46.76732	−2
5	5	61	e	4	4	61	f	45.27381	−1	6	4	15	f	5	3	15	e	46.78264	−11
4	4	35	f	3	3	34	f	45.27842	15	8	8	44	e	7	7	45	e	46.79110	−12
4	2	33	f	3	1	32	f	45.28654	14	6	4	16	e	5	3	16	f	46.79896	−19
2	0	18	e	1	1	17	e	45.31611	1	7	7	22	f	6	6	23	f	46.80753	10
5	5	62	f	4	4	62	e	45.33529	6	6	4	18	e	5	3	18	f	46.83508	2
7	7	33	e	6	6	34	e	45.35177	−3	4	4	43	f	3	3	42	f	46.84514	9
5	5	12	f	4	4	11	f	45.35647	9	6	4	21	f	5	3	21	e	46.89664	−2
3	3	60	f	2	2	59	f	45.37831	6	5	5	84	f	4	4	84	e	46.92838	25
5	3	58	f	4	2	58	e	45.40945	2	6	4	23	f	5	3	23	e	46.94294	10
4	4	36	e	3	3	35	e	45.47075	7	7	5	17	e	6	4	18	e	46.97755	−12
7	5	28	f	6	4	29	f	45.49582	17	6	4	25	f	5	3	25	e	46.99306	−8
5	3	65	e	4	2	65	f	45.50861	−16	5	5	85	e	4	4	85	f	47.00811	−10
3	1	40	f	2	2	41	f	45.51871	1	6	4	26	e	5	3	26	f	47.01964	1
5	3	60	f	4	2	60	e	45.56352	1	6	6	8	e	5	5	8	f	47.05875	3
5	5	66	f	4	4	66	e	45.58952	−9	6	6	9	f	5	5	9	e	47.06725	4
2	0	20	e	1	1	19	e	45.63366	13	5	1	22	f	4	0	22	e	47.10269	−7
4	2	35	f	3	1	34	f	45.64233	10	7	5	16	f	6	4	17	f	47.11840	10
3	3	61	e	2	2	60	e	45.65957	5	6	6	14	e	5	5	14	f	47.12367	−11
4	4	37	f	3	3	36	f	45.66398	14	4	0	14	e	3	1	14	f	47.17382	−3
3	1	53	e	2	0	52	e	45.68672	6	4	0	16	e	3	1	16	f	47.17947	5
5	5	14	f	4	4	13	f	45.69504	−1	4	0	18	e	3	1	18	f	47.18596	−2
3	1	38	f	2	2	39	f	45.77702	−2	6	6	18	e	5	5	18	f	47.18596	−3
5	5	69	e	4	4	69	f	45.78998	−3	4	0	20	e	3	1	20	f	47.19345	−16
3	3	62	f	2	2	61	f	45.81951	−2	4	0	24	e	3	1	24	f	47.21258	8
5	3	15	e	4	2	14	e	45.82524	−8	4	4	45	f	3	3	44	f	47.24679*	−13
7	5	25	e	6	4	26	e	45.88804	1	4	0	30	e	3	1	30	f	47.25192	9
2	0	22	e	1	1	21	e	45.95265	7	4	0	32	e	3	1	32	f	47.26837	−5
4	2	34	e	3	1	33	e	46.01122	−1	4	0	38	e	3	1	38	f	47.33099	5
7	5	24	f	6	4	25	f	46.02080	2	6	4	36	e	5	3	36	f	47.34199	0
5	5	16	f	4	4	15	f	46.03778	14	5	1	28	f	4	0	28	e	47.35134	3
4	4	39	f	3	3	38	f	46.05356	6	7	7	18	f	6	6	19	f	47.36435	−8
3	1	55	e	2	0	54	e	46.07547	14	4	0	42	e	3	1	42	f	47.38500	−7

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
8	8	39	*f*	7	7	40	*f*	47.39899	7	2	0	42	*e*	1	1	41	*e*	49.25249	−5
6	6	28	*e*	5	5	28	*f*	47.40748	7	3	1	71	*e*	2	0	70	*e*	49.26448*	−23
6	6	29	*f*	5	5	29	*e*	47.43473	1	5	3	34	*f*	4	2	33	*f*	49.27858	−6
6	4	40	*e*	5	3	40	*f*	47.49899	−18	3	1	12	*f*	2	2	13	*f*	49.38646	−2
6	6	32	*e*	5	5	32	*f*	47.52226	−3	4	0	14	*e*	3	1	13	*e*	49.43045	−3
4	0	50	*e*	3	1	50	*f*	47.53062	16	3	1	11	*e*	2	2	12	*e*	49.46523*	32
5	1	32	*f*	4	0	32	*e*	47.54675	−11	5	3	35	*e*	4	2	34	*e*	49.50131	1
6	6	33	*f*	5	5	33	*e*	47.55335	−1	4	4	56	*e*	3	3	55	*e*	49.53185	6
5	3	25	*e*	4	2	24	*e*	47.60461	−2	8	6	18	*e*	7	5	19	*e*	49.54994	19
6	4	43	*f*	5	3	43	*e*	47.63178	9	6	4	18	*e*	5	3	17	*e*	49.64630	5
6	4	44	*e*	5	3	44	*f*	47.67235	6	5	5	36	*f*	4	4	35	*f*	49.67722	15
6	6	37	*f*	5	5	37	*e*	47.68701	−1	5	1	19	*e*	4	0	18	*e*	49.68245	1
4	2	42	*e*	3	1	41	*e*	47.71787	11	7	5	11	*e*	6	4	11	*f*	49.72298	13
6	6	39	*f*	5	5	39	*e*	47.75949	3	4	4	57	*f*	3	3	56	*f*	49.74319	9
5	1	36	*f*	4	0	36	*e*	47.76517	−3	7	5	14	*f*	6	4	14	*e*	49.76073	1
5	5	26	*f*	4	4	25	*f*	47.80906	10	8	8	21	*f*	7	7	22	*f*	49.77206	4
6	4	47	*f*	5	3	47	*e*	47.81963	0	4	0	16	*e*	3	1	15	*e*	49.77507	10
3	1	21	*e*	2	2	22	*e*	47.84882	−2	7	5	16	*f*	6	4	16	*e*	49.79079	−2
4	0	62	*e*	3	1	62	*f*	47.86902	−8	6	6	17	*f*	5	5	16	*f*	49.83822	5
6	6	42	*e*	5	5	42	*f*	47.87502	−14	7	5	19	*e*	6	4	19	*f*	49.84330	9
5	1	38	*f*	4	0	38	*e*	47.88271	13	5	5	37	*e*	4	4	36	*e*	49.86921	4
8	8	35	*f*	7	7	36	*f*	47.90127	6	5	3	37	*e*	4	2	36	*e*	49.89541	9
2	0	34	*e*	1	1	33	*e*	47.90550	4	7	5	22	*f*	6	4	22	*e*	49.90430	−4
6	6	43	*f*	5	5	43	*e*	47.91556	−4	8	8	20	*e*	7	7	21	*e*	49.91240	6
6	4	49	*f*	5	3	49	*e*	47.92013	10	7	5	23	*e*	6	4	23	*f*	49.92652	−12
8	6	30	*e*	7	5	31	*e*	47.92650	−7	2	0	46	*e*	1	1	45	*e*	49.94307	13
6	6	44	*e*	5	5	44	*f*	47.95687	−9	4	4	58	*e*	3	3	57	*e*	49.96055	11
3	3	71	*e*	2	2	70	*e*	47.97073	−14	7	5	25	*e*	6	4	25	*f*	49.97410	−7
5	3	27	*e*	4	2	26	*e*	47.97445	8	6	6	18	*e*	5	5	17	*e*	50.01219	12
5	5	27	*e*	4	4	26	*e*	47.99150	7	7	5	27	*e*	6	4	27	*f*	50.02546	−9
6	6	45	*f*	5	5	45	*e*	47.99930	2	7	5	30	*f*	6	4	30	*e*	50.10978	−9
6	4	51	*f*	5	3	51	*e*	48.02478	3	7	5	34	*f*	6	4	34	*e*	50.23573	−7
6	6	46	*e*	5	5	46	*f*	48.04252	0	7	7	8	*f*	6	6	8	*e*	50.24303	2
3	1	65	*e*	2	0	64	*e*	48.05304	3	7	7	9	*e*	6	6	9	*f*	50.25123	6
8	6	28	*e*	7	5	29	*e*	48.18766	−1	5	5	39	*e*	4	4	38	*e*	50.25622	−4
4	2	49	*f*	3	1	48	*f*	48.20845	10	7	7	12	*f*	6	6	12	*e*	50.28102	−5
6	6	50	*e*	5	5	50	*f*	48.22495	14	5	1	23	*e*	4	0	22	*e*	50.32736	−6
2	0	36	*e*	1	1	35	*e*	48.23837	−2	7	5	37	*e*	6	4	37	*f*	50.34018	−17
6	4	55	*f*	5	3	55	*e*	48.24754	13	7	7	17	*e*	6	6	17	*f*	50.34904	1
5	1	44	*f*	4	0	44	*e*	48.26591	5	7	7	19	*e*	6	6	19	*f*	50.38253	−1
8	8	31	*f*	7	7	32	*f*	48.41793	9	7	7	20	*f*	6	6	20	*e*	50.40064	−1
6	6	54	*e*	5	5	54	*f*	48.42215	13	7	5	39	*e*	6	4	39	*f*	50.41479	−5
6	4	11	*f*	5	3	10	*f*	48.44562	9	7	7	21	*e*	6	6	21	*f*	50.41963	−5
6	4	59	*f*	5	3	59	*e*	48.48811	3	7	7	22	*f*	6	6	22	*e*	50.43948	−11
5	3	30	*f*	4	2	29	*f*	48.52132	2	5	3	40	*f*	4	2	39	*f*	50.44292	−6
2	0	38	*e*	1	1	37	*e*	48.57383	4	7	7	25	*e*	6	6	25	*f*	50.50472	−7
6	6	57	*f*	5	5	57	*e*	48.57972	2	4	2	61	*f*	3	1	60	*f*	50.51288	10
4	2	51	*f*	3	1	50	*f*	48.58584	16	7	7	26	*f*	6	6	26	*e*	50.52831	−1
4	2	46	*e*	3	1	45	*e*	48.59829	4	6	4	23	*f*	5	3	22	*f*	50.53414	−10
6	6	10	*e*	5	5	9	*e*	48.64693	−4	6	6	21	*f*	5	5	20	*f*	50.53946	15
4	0	10	*e*	3	1	9	*e*	48.75632	−13	3	1	63	*e*	2	2	63	*f*	50.59629	−7
6	4	64	*e*	5	3	64	*f*	48.76639	15	7	7	29	*e*	6	6	29	*f*	50.60453	18
6	4	13	*f*	5	3	12	*f*	48.78353	1	5	1	25	*e*	4	0	24	*e*	50.65154	12
6	6	61	*f*	5	5	61	*e*	48.80303	9	7	7	32	*f*	6	6	32	*e*	50.68846	−5
6	6	11	*f*	5	5	10	*f*	48.81442	8	7	7	35	*e*	6	6	35	*f*	50.78081	5
5	1	52	*f*	4	0	52	*e*	48.84306	−11	3	1	51	*e*	2	2	51	*f*	50.79404	5
6	4	65	*f*	5	3	65	*e*	48.88380	−40	7	7	36	*f*	6	6	36	*e*	50.81325	−6
8	8	27	*f*	7	7	28	*f*	48.94886	7	4	4	62	*e*	3	3	61	*e*	50.82998	−5
6	4	14	*e*	5	3	13	*e*	48.95411	8	7	7	38	*f*	6	6	38	*e*	50.88113	2
4	2	53	*f*	3	1	52	*f*	48.96589	18	7	7	39	*e*	6	6	39	*f*	50.91639	3
8	6	22	*e*	7	5	23	*e*	48.99358	−4	3	1	41	*e*	2	2	41	*f*	50.96117	−3
5	1	54	*f*	4	0	54	*e*	48.99805	−2	7	7	42	*f*	6	6	42	*e*	51.02737	−12
3	3	76	*f*	2	2	75	*f*	49.01916	2	7	7	43	*e*	6	6	43	*f*	51.06627	−6
8	8	26	*e*	7	7	27	*e*	49.08359	−17	6	6	24	*e*	5	5	23	*e*	51.07479	−10
5	3	33	*e*	4	2	32	*e*	49.11224	−2	6	4	26	*e*	5	3	25	*e*	51.07924	−4
3	1	13	*e*	2	2	14	*e*	49.14526	15	7	5	54	*f*	6	4	54	*e*	51.09619	−14
6	6	13	*f*	5	5	12	*f*	49.15187	−2	7	7	46	*f*	6	6	46	*e*	51.18824	3
5	1	56	*f*	4	0	56	*e*	49.15685	6	4	0	24	*e*	3	1	23	*e*	51.20430	−5
6	6	67	*f*	5	5	67	*e*	49.16558	−3	5	3	44	*f*	4	2	43	*f*	51.23736	3
6	6	68	*f*	5	5	68	*e*	49.22916	−14	5	5	44	*f*	4	4	43	*f*	51.24079	12

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
7	5	10	*f*	6	4	9	*f*	51.28441	−6	8	6	37	*f*	7	5	37	*e*	53.04757	−14
5	1	29	*e*	4	0	28	*e*	51.30217	4	6	6	35	*f*	5	5	34	*f*	53.10946	0
3	1	6	*f*	2	2	6	*e*	51.35521	−14	4	0	34	*e*	3	1	33	*e*	53.11377	10
3	1	10	*f*	2	2	10	*e*	51.37405	2	8	8	12	*e*	7	7	12	*f*	53.13240	9
7	7	51	*e*	6	6	51	*f*	51.40917	−5	8	6	41	*f*	7	5	41	*e*	53.19369	−6
7	5	60	*f*	6	4	60	*e*	51.42940	−10	8	8	17	*f*	7	7	17	*e*	53.19813	12
6	6	26	*e*	5	5	25	*e*	51.43671	17	7	7	18	*f*	6	6	17	*f*	53.20839	2
6	4	28	*e*	5	3	27	*e*	51.44752	−10	8	8	21	*f*	7	7	21	*e*	53.26639	7
7	5	11	*e*	6	4	10	*e*	51.45231	−4	8	8	22	*e*	7	7	22	*f*	53.28545	−13
7	7	52	*f*	6	6	52	*e*	51.45605	−5	4	4	73	*f*	3	3	72	*f*	53.29469	6
5	3	45	*e*	4	2	44	*e*	51.52251	2	6	6	36	*e*	5	5	35	*e*	53.29990	−1
3	1	26	*f*	2	2	26	*e*	51.54244	−5	8	6	44	*e*	7	5	44	*f*	53.31277	−12
7	5	62	*f*	6	4	62	*e*	51.54824	−5	7	5	22	*f*	6	4	21	*f*	53.36244	9
4	0	26	*e*	3	1	25	*e*	51.57495	−1	8	8	26	*e*	7	7	26	*f*	53.37131	−5
3	1	30	*f*	2	2	30	*e*	51.61019	0	7	7	19	*e*	6	6	18	*e*	53.38351	6
6	6	27	*f*	5	5	26	*f*	51.61895	19	8	8	29	*f*	7	7	29	*e*	53.44499	14
5	1	31	*e*	4	0	30	*e*	51.62862	−10	8	6	48	*e*	7	5	48	*f*	53.48449	−3
3	1	32	*f*	2	2	32	*e*	51.64832	4	8	8	32	*e*	7	7	32	*f*	53.52630	11
2	0	56	*e*	1	1	55	*e*	51.72876	−4	8	6	49	*f*	7	5	49	*e*	53.52955	−15
3	1	36	*f*	2	2	36	*e*	51.73339	−3	8	8	33	*f*	7	7	33	*e*	53.55506	2
6	6	28	*e*	5	5	27	*e*	51.80189	0	8	6	50	*e*	7	5	50	*f*	53.57537*	−43
6	4	30	*e*	5	3	29	*e*	51.82011	10	5	1	43	*e*	4	0	42	*e*	53.60096	−3
3	1	40	*f*	2	2	40	*e*	51.83118	−3	8	8	35	*f*	7	7	35	*e*	53.61533	−2
7	7	60	*f*	6	6	60	*e*	51.86314	7	8	8	37	*f*	7	7	37	*e*	53.67900	−14
3	1	42	*f*	2	2	42	*e*	51.88520	6	6	6	38	*e*	5	5	37	*e*	53.68354	0
7	7	61	*e*	6	6	61	*f*	51.91776	−16	8	6	8	*e*	7	5	7	*e*	53.69541	13
7	5	68	*f*	6	4	68	*e*	51.92808	4	8	8	38	*e*	7	7	38	*f*	53.71226	−7
4	4	67	*f*	3	3	66	*f*	51.93357	28	8	8	39	*f*	7	7	39	*e*	53.74626	−13
4	0	28	*e*	3	1	27	*e*	51.95112	3	8	6	54	*e*	7	5	54	*f*	53.76884*	−43
5	1	33	*e*	4	0	32	*e*	51.95613	10	8	8	40	*e*	7	7	40	*f*	53.78135	3
7	5	14	*f*	6	4	13	*f*	51.96183	6	8	8	42	*e*	7	7	42	*f*	53.85381	4
7	7	62	*f*	6	6	62	*e*	51.97366	0	8	8	45	*f*	7	7	45	*e*	53.96878	−14
7	7	63	*e*	6	6	63	*f*	52.03016	−11	6	6	40	*e*	5	5	39	*e*	54.07070	−10
5	5	48	*f*	4	4	47	*f*	52.04537	2	8	8	49	*f*	7	7	49	*e*	54.13466	15
3	1	48	*f*	2	2	48	*e*	52.06874	15	8	8	50	*e*	7	7	50	*f*	54.17789	−17
2	0	58	*e*	1	1	57	*e*	52.09775	3	8	8	55	*f*	7	7	55	*e*	54.40866	3
7	7	65	*e*	6	6	65	*f*	52.14614	0	4	4	78	*e*	3	3	77	*e*	54.47347	−8
4	4	68	*e*	3	3	67	*e*	52.16538	10	8	8	57	*f*	7	7	57	*e*	54.50692	10
6	6	30	*e*	5	5	29	*e*	52.17084	−7	5	5	60	*f*	4	4	59	*f*	54.55012	−7
7	7	12	*f*	6	6	11	*f*	52.17669	−2	5	3	59	*e*	4	2	58	*e*	54.57531	−9
6	4	32	*e*	5	3	31	*e*	52.19650	7	7	7	26	*f*	6	6	25	*f*	54.63377	0
5	5	49	*e*	4	4	48	*e*	52.24877	−16	4	4	79	*f*	3	3	78	*f*	54.69098	26
4	2	62	*e*	3	1	61	*e*	52.25585	5	8	6	14	*e*	7	5	13	*e*	54.70833	−1
7	7	67	*e*	6	6	67	*f*	52.26552	1	6	4	45	*f*	5	3	44	*f*	54.73733	7
5	1	35	*e*	4	0	34	*e*	52.28402	2	6	6	44	*e*	5	5	43	*e*	54.85626	7
7	5	16	*f*	6	4	15	*f*	52.30607	−11	5	1	51	*e*	4	0	50	*e*	54.92271	5
4	0	30	*e*	3	1	29	*e*	52.33286	2	5	3	62	*f*	4	2	61	*f*	54.97394	6
7	7	13	*e*	6	6	12	*e*	52.34638	−4	7	5	31	*e*	6	4	30	*e*	55.01085	8
6	6	31	*f*	5	5	30	*f*	52.35693	15	8	8	12	*e*	7	7	11	*e*	55.03871	−11
8	6	14	*e*	7	5	14	*f*	52.49361	−9	4	2	74	*e*	3	1	73	*e*	55.08464	4
8	6	15	*f*	7	5	15	*e*	52.50753	−8	6	4	47	*f*	5	3	46	*f*	55.14280	4
8	6	16	*e*	7	5	16	*f*	52.52248	2	7	7	29	*e*	6	6	28	*e*	55.18291	2
8	6	17	*f*	7	5	17	*e*	52.53815	−8	8	8	13	*f*	7	7	12	*f*	55.20893	−12
6	6	32	*e*	5	5	31	*e*	52.54363	5	7	7	30	*f*	6	6	29	*f*	55.36765	−4
8	6	18	*e*	7	5	18	*f*	52.55504	10	5	3	63	*e*	4	2	62	*e*	55.49669	−18
8	6	20	*e*	7	5	20	*f*	52.59110	−2	6	6	48	*e*	5	5	47	*e*	55.65608	7
4	4	70	*e*	3	3	69	*e*	52.61888	26	8	8	16	*e*	7	7	15	*e*	55.72500	9
8	6	22	*e*	7	5	22	*f*	52.63082	−18	5	5	66	*f*	4	4	65	*f*	55.85325	0
5	5	51	*e*	4	4	50	*e*	52.65899	11	6	6	49	*f*	5	5	48	*f*	55.85840	19
8	6	24	*e*	7	5	24	*f*	52.67449	−9	8	8	17	*f*	7	7	16	*f*	55.89849	−9
8	6	25	*f*	7	5	25	*e*	52.69787	11	6	4	51	*f*	5	3	50	*f*	55.96515	6
7	7	74	*f*	6	6	74	*e*	52.71087	8	8	6	22	*e*	7	5	21	*e*	56.11043	7
6	6	33	*f*	5	5	32	*f*	52.73124	−5	5	1	59	*e*	4	0	58	*e*	56.24461	−11
8	6	27	*f*	7	5	27	*e*	52.74692	5	5	5	68	*f*	4	4	67	*f*	56.29498	−7
8	6	28	*e*	7	5	28	*f*	52.77277	−4	7	5	38	*f*	6	4	37	*f*	56.34564	2
7	7	75	*e*	6	6	75	*f*	52.77783	−5	4	0	50	*e*	3	1	49	*e*	56.48880	4
6	6	34	*e*	5	5	33	*e*	52.91992	−1	5	5	69	*e*	4	4	68	*e*	56.51817	24
8	6	34	*e*	7	5	34	*f*	52.94788	8	7	5	39	*e*	6	4	38	*e*	56.54015	6
8	6	36	*e*	7	5	36	*f*	53.01339	−10	6	6	53	*f*	5	5	52	*f*	56.67597	−1
7	7	17	*e*	6	6	16	*e*	53.03422	2	7	7	37	*e*	6	6	36	*e*	56.68590	7

TABLE I. (*continued*).

v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C	v'	l'	J'	p'	v''	l''	J''	p''	Obs.	O−C
6	4	55	*f*	5	3	54	*f*	56.80236	5	8	8	39	*f*	7	7	38	*f*	59.93556	−2
8	6	26	*e*	7	5	25	*e*	56.83307	−13	5	5	84	*f*	4	4	83	*f*	59.96140	−19
7	7	38	*f*	6	6	37	*f*	56.87763	0	7	5	56	*f*	6	4	55	*f*	59.98684	23
6	6	54	*e*	5	5	53	*e*	56.88267	1	6	6	69	*f*	5	5	68	*f*	60.08939	24
5	3	69	*e*	4	2	68	*e*	56.91897	−11	8	6	44	*e*	7	5	43	*e*	60.26382	12
4	0	52	*e*	3	1	51	*e*	56.94156	−1	7	7	55	*e*	6	6	54	*e*	60.27027	0
8	6	27	*f*	7	5	26	*f*	57.01617	0	7	5	58	*f*	6	4	57	*f*	60.40934	−5
8	6	28	*e*	7	5	27	*e*	57.19998	−6	7	7	56	*f*	6	6	55	*f*	60.47755	2
6	4	57	*f*	5	3	56	*f*	57.22656	18	8	8	42	*e*	7	7	41	*e*	60.51778	4
8	8	25	*f*	7	7	24	*f*	57.31899	4	5	5	87	*e*	4	4	86	*e*	60.67883	5
7	5	43	*e*	6	4	42	*e*	57.32738	20	7	7	57	*e*	6	6	56	*e*	60.68562	−1
6	6	57	*f*	5	5	56	*f*	57.50803	−1	8	8	43	*f*	7	7	42	*f*	60.71346	0
5	5	74	*f*	4	4	73	*f*	57.64265	7	7	5	61	*e*	6	4	60	*e*	61.05266	12
7	7	43	*e*	6	6	42	*e*	57.84960	−6	8	8	46	*e*	7	7	45	*e*	61.30548	−9
8	8	28	*e*	7	7	27	*e*	57.86569	0	7	7	60	*f*	6	6	59	*f*	61.31520	20
6	4	60	*e*	5	3	59	*e*	57.89436	3	8	6	50	*e*	7	5	49	*e*	61.47108	9
3	1	40	*f*	2	2	39	*f*	57.96688	9	7	5	63	*e*	6	4	62	*e*	61.48484	−11
8	6	33	*f*	7	5	32	*f*	58.13307	17	7	7	61	*e*	6	6	60	*e*	61.52669	22
6	6	61	*f*	5	5	60	*f*	58.35430	1	8	8	48	*e*	7	7	47	*e*	61.70449	3
7	5	49	*e*	6	4	48	*e*	58.53579	10	4	0	72	*e*	3	1	71	*e*	61.90973	1
3	1	44	*f*	2	2	43	*f*	58.68528	−10	7	5	66	*f*	6	4	65	*f*	62.13607	1
7	5	51	*e*	6	4	50	*e*	58.94617	24	7	7	64	*f*	6	6	63	*f*	62.16596	6
8	8	34	*e*	7	7	33	*e*	58.98197	−11	8	6	55	*f*	7	5	54	*f*	62.50102	−6
7	7	49	*e*	6	6	48	*e*	59.04446	−10	7	7	66	*f*	6	6	65	*f*	62.59638	3
8	8	35	*f*	7	7	34	*f*	59.17104	−6	8	8	56	*e*	7	7	55	*e*	63.33276	0
7	7	50	*f*	6	6	49	*f*	59.24683	11	8	6	60	*e*	7	5	59	*e*	63.55287	4
8	6	39	*f*	7	5	38	*f*	59.28205	22	8	8	61	*f*	7	7	60	*f*	64.37670	−11
7	7	51	*e*	6	6	50	*e*	59.44978	6	8	8	62	*e*	7	7	61	*e*	64.58791	−11
8	6	40	*e*	7	5	39	*e*	59.47661	17	8	8	65	*f*	7	7	64	*f*	65.22641	−2
7	7	52	*f*	6	6	51	*f*	59.65359	0	8	8	67	*f*	7	7	66	*f*	65.65603	4
4	0	64	*e*	3	1	63	*e*	59.82116	2	8	8	68	*e*	7	7	67	*e*	65.87200	4

if C_3O_2 is assumed to be bent, v_7 in the abscissa of Fig. 5 becomes K_a and the curves A, B and C then represent the evolution of the effective B constant with K_a in the ground level, the $v_7^{\text{bend}} = 1$ level and $v_7^{\text{bend}} = 2$ level, respectively. For a "true" bent molecule, Fig. 5 would then show three nearly horizontal lines because B is not expected to depend strongly on K_a within a given vibrational level. Clearly, C_3O_2 is also far from this case. In a fit of the spectrum of carbon suboxide to a symmetric or asymmetric rotor model, this situation will give rise to abnormally large centrifugal distortion constants.

B. Linear model

We have fitted the lines corresponding to transitions between all the l sublevels of the vibrational levels characterized by v_7 ranging from 0 to 3, observed on the far infrared and microwave spectra,[2] using the usual model describing the energy level structure associated with a degenerate bending mode of a linear molecule including l-type doubling and l-type resonance. Despite the fact that such a model cannot describe the energy levels structure of C_3O_2 better than the effective model, such an approach is of interest because the constants should have greater physical significance because the l-type doubling and resonance interaction is taken properly into account. The matrix elements used here were taken from the work of Pliva,[19] Winnewisser and Winnewisser,[20] and Yamada *et al.*[21] Those actually used in the present work are as follows (only the constants actually fitted here are entered into the expressions):

Diagonal elements

$$\langle v_7 l_7 J | H | v_7 l_7 J \rangle = \omega_7^0 v_7 + x_{77}^0 v_7^2 + y_{777}^0 v_7^3 + z_{7777} v_7^4 + g_{77}^0 l_7^2 + y_7 l_7^4 + (B_v + \gamma^{77} l_7^2 + \gamma^{7777} l_7^4)(M - l^2) - (D_v + \beta^{77} l_7^2 + \beta^{7777} l_7^4)(M - l^2)^2 + (H_v + \delta^{77} l_7^2 + \delta^{7777} l_7^4)(M - l^2)^3 + L_v (M - l^2)^4 + N_v (M - l^2)^5, \quad (4)$$

with

$$M = J(J+1), \quad (5)$$

$$B_v = B_0 - \alpha_7^0 v_7 + \gamma_{77}^0 v_7^2 + \gamma_{777} v_7^3, \quad (6)$$

$$D_v = D_0 + \beta_7^0 v_7 + \beta_{77}^0 v_7^2 + \beta_{777} v_7^3, \quad (7)$$

$$H_v = H_0 + \delta_7^0 v_7 + \delta_{77}^0 v_7^2 + \delta_{777} v_7^3, \quad (8)$$

$$L_v = L_0 + \epsilon_7^0 v_7 + \epsilon_{77}^0 v_7^2 + \epsilon_{777} v_7^3, \quad (9)$$

$$N_v = N_0 + \eta_7^0 v_7 + \eta_{77}^0 v_7^2. \quad (10)$$

TABLE II. Effective constants (in cm^{-1})[a] for levels in the ν_7 manifold of the ground electronic state of carbon suboxide.

Constant	Ground state	$\nu_7^1(\Pi_u)$	$2\nu_7^0(\Sigma_g^+)$
E_v	0.0	18.255 807 33(22)	60.701 304(29)
B	0.075 564 187 8(63)	0.076 311 984 0(64)	0.076 261 474(49)
$D\times10^{-7}$	0.387 179(38)	0.331 567(39)	0.075 09(22)
$H\times10^{-12}$	0.714 86(95)	0.393 96(98)	0.219 6(31)
$L\times10^{-17}$	−0.101 9(10)	−0.289(11)	−0.744(19)
$N\times10^{-22}$	0.374(56)	−0.631(58)	
$q_B\times10^{-3}$		0.408 900 88(60)	
$q_D\times10^{-8}$		0.923 809(77)	
$q_H\times10^{-12}$		0.168 0(33)	
$q_L\times10^{-17}$		−0.132 2(55)	
$q_N\times10^{-22}$		−0.265(32)	

Constant	$2\nu_7^2(\Delta_g)$	$3\nu_7^1(\Pi_u)$	$3\nu_7^3(\Phi_g)$
E_v	46.105 721 14(36)	97.218 787(27)	80.617 572 00(75)
B	0.076 939 708 4(63)	0.076 951 180(48)	0.077 504 353 5(60)
$D\times10^{-7}$	0.331 414(38)	0.176 50(22)	0.322 291(34)
$H\times10^{-12}$	0.150 08(92)	0.213 2(26)	0.157 08(78)
$L\times10^{-17}$	0.260 9(75)		−0.031 7(67)
$N\times10^{-22}$			
$q_B\times10^{-3}$	0.000 023 21(87)	0.522 457(30)	
$q_D\times10^{-8}$	−0.394 00(14)	0.538 2(17)	0.000 462(29)
$q_H\times10^{-12}$	0.297 42(70)	−0.058 5(23)	0.073 85(13)
$q_L\times10^{-17}$	−0.868(15)		0.304 3(18)
$q_N\times10^{-22}$	−1.17(11)		

Constant	$4\nu_7^0(\Sigma_g^+)$	$4\nu_7^2(\Delta_g)$	$4\nu_7^4(\Gamma_g)$
E_v	144.298 403(53)	137.258 853(36)	120.366 598(17)
B	0.077 288 80(11)	0.077 556 791(57)	0.078 027 664(17)
$D\times10^{-7}$	−0.079 75(52)	0.316 38(20)	0.319 442(58)
$H\times10^{-12}$	−0.113 4(67)		0.138 62(71)
$L\times10^{-17}$		3.950(41)	
$q_B\times10^{-3}$			
$q_D\times10^{-8}$		−2.243 1(25)	
$q_H\times10^{-12}$		0.418(13)	
$q_L\times10^{-17}$		−7.39(17)	0.125 8(16)

Constant	$5\nu_7^1(\Pi_u)$	$5\nu_7^3(\Phi_u)$	$5\nu_7^5(H_u)$
E_v	191.059 865(88)	181.017 919(48)	164.488 013(31)
B	0.077 791 67(21)	0.078 107 125(90)	0.078 521 310(40)
$D\times10^{-7}$	0.092 6(14)	0.302 91(43)	0.320 42(14)
$H\times10^{-12}$	0.161(27)	0.045 4(55)	0.127 8(14)
$L\times10^{-17}$			
$q_B\times10^{-3}$	0.670 50(19)		
$q_D\times10^{-8}$	0.457(19)		
$q_H\times10^{-12}$	−0.753(42)	0.582 4(29)	
$q_L\times10^{-17}$		1.131(65)	

Constant	$6\nu_7^4(\Gamma_g)$	$6\nu_7^6(I_g)$	$7\nu_7^5(H_u)$
E_v	228.232 460(59)	212.393 491(47)	278.610 940(70)
B	0.078 619 93(11)	0.078 992 093(80)	0.079 104 99(14)
$D\times10^{-7}$	0.306 21(55)	0.323 98(39)	0.312 53(74)
$H\times10^{-12}$	0.070 3(73)	0.128 8(56)	0.084(10)
$L\times10^{-17}$			
$q_B\times10^{-3}$			
$q_D\times10^{-8}$			
$q_H\times10^{-12}$	−0.011 2(39)		
$q_L\times10^{-17}$	1.594(90)		

Constant	$7\nu_7^7(J_u)$	$8\nu_7^6(I_g)$	$8\nu_7^8(K_g)$
E_v	263.652 975(57)	331.894 006(87)	317.936 631(72)
B	0.079 444 40(10)	0.079 568 67(20)	0.079 881 59(14)
$D\times10^{-7}$	0.327 75(48)	0.320 2(12)	0.332 26(69)
$H\times10^{-12}$	0.111 0(65)	0.105(21)	0.083 1(99)
$L\times10^{-17}$			

[a] Error estimates (1σ) are given in parentheses in units of the last figure quoted.

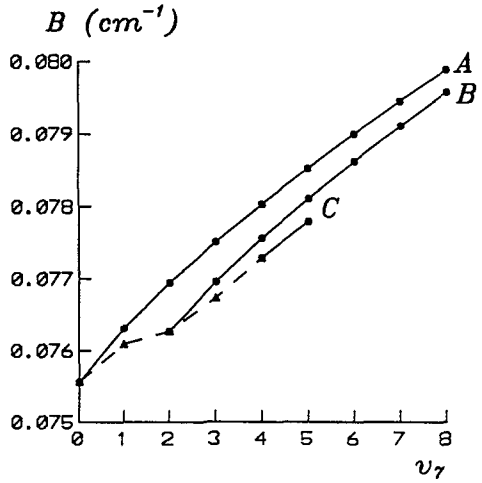

FIG. 5. Evolution of the effective B constant derived using the model described in Sec. IV A (solid curves) and of the B_v constant derived with the linear model described in Sec. IV B (dashed curve) with the vibrational quantum number v_7 associated with the ν_7 quasilinear bending mode. Solid curves A, B, and C correspond, respectively, to the l sublevels having $l_7 = v_7$, $l_7 = v_7 - 2$ and $l_7 = v_7 - 4$.

Off-diagonal elements $\Delta l_7 = \pm 2$

$$\langle v_7 l_7 J | H | v_7 l_7 \pm 2 J \rangle = \tfrac{1}{4} q_7 \{(v_7 \mp l_7)(v_7 \pm l_7 + 2)\}^{1/2} f(l, l \pm 2), \quad (11)$$

with

$$f(l, l \pm 2) = \{[M - l(l \pm 1)][M - (l \pm 1)(l \pm 2)]\}^{1/2}, \quad (12)$$

$$q_7 = q_7^0 + q_7^J M + q_7^{JJ} M^2 + q_7^{JJJ} M^3 + (q_{77} + q_{77}^J M + q_{77}^{JJ} M^2) v_7. \quad (13)$$

Off-diagonal elements $\Delta l_7 = \pm 4$

$$\langle v_7 l_7 J | H | v_7 l_7 \pm 4 J \rangle = \tfrac{1}{16} \rho_7 \{(v_7 \mp l_7 - 2)(v_7 \mp l_7) \times (v_7 \pm l_7 + 2)(v_7 \pm l_7 + 4)\}^{1/2} \times f(l, l \pm 2) f(l \pm 2, l \pm 4), \quad (14)$$

with

$$\rho_7 = \rho_7^0 + \rho_7^J M + \rho_7^{JJ} M^2 + \rho_7^{JJJ} M^3 + (\rho_{77} + \rho_{77}^J M + \rho_{77}^{JJ} M^2) v_7. \quad (15)$$

The Hamiltonian matrix was built with these elements using the phase convention defined by Watson in Ref. 22 together with the e/f parity labeling of the levels defined by Brown *et al.*[23]

Using this approach, we have been able to fit the 511 far infrared lines belonging to the bands 1^1–0^0, 2^2–1^1, 3^1–2^0, 3^3–2^2, 2^0–1^1, and 3^1–2^2 appearing in Table I together with 212 microwave lines measured by Karyakin *et al.*[2] in the first four bands with a standard deviation of 0.000 09 cm^{-1} for the far infrared lines and 0.000 001 1 cm^{-1} (33 kHz) for the microwave lines. The values obtained for the constants appearing in the Eqs. (4)–(15) are given in Table III. The evolution of B_v with v_7 ranging from 0 to 4 is also shown in Fig. 5 (dashed line).

As one can see by comparison with the matrix elements given in Refs. 19, 20, and 21, we have had to add extra terms in the expansion of the rotational constants and in the expression of the l-type doubling and resonance constants q_7 and ρ_7 in order to fit the data to the experimental precision. In fact, comparison between Tables II and III, as far as the number of constants needed to fit this set of data to experimental precision is concerned, shows that we needed nearly

TABLE III. Constants (in cm^{-1}) derived in the linear model for levels with $v_7 = 0$ to 3.

Constant	Value[a]	Constant	Value[a]
ω_7^0	10.907 615 4(36)	η_7^0	$-0.034\,4(63)\times10^{-21}$
x_{77}^0	13.846 414(16)	η_{77}	$-0.029\,7(28)\times10^{-21}$
y_{777}^0	−2.062 444 4(36)	γ^{77}	$0.236\,574(16)\times10^{-3}$
g_{77}^0	−4.698 069 6(92)	γ^{7777}	$-0.167\,430(11)\times10^{-4}$
y_7	0.262 291 68(60)	β^{77}	$0.532\,75(71)\times10^{-8}$
B_0	0.075 564 220 7(90)	β^{7777}	$-0.425\,02(51)\times10^{-9}$
α_7^0	$-0.927\,259\,2(72)\times10^{-3}$	δ^{77}	$0.444\,8(81)\times10^{-13}$
γ_{77}^0	$-0.509\,240(29)\times10^{-3}$	δ^{7777}	$-0.429\,5(59)\times10^{-14}$
γ_{777}	$0.109\,947\,6(69)\times10^{-3}$	q_7^0	$0.408\,920\,39(47)\times10^{-3}$
D_0	$0.387\,568(79)\times10^{-7}$	q_7^J	$-0.924\,067(52)\times10^{-8}$
β_7^0	$-0.032\,741(37)\times10^{-7}$	q_7^{JJ}	$0.169\,38(17)\times10^{-12}$
β_{77}^0	$-0.100\,47(13)\times10^{-7}$	q_7^{JJJ}	$-0.164\,4(18)\times10^{-17}$
β_{777}	$0.028\,609(31)\times10^{-7}$	q_{77}	$-0.737\,744(89)\times10^{-4}$
H_0	$0.731\,1(28)\times10^{-12}$	q_{77}^J	$0.320\,73(51)\times10^{-8}$
δ_7^0	$-0.320\,60(80)\times10^{-12}$	q_{77}^{JJ}	$-0.622\,8(67)\times10^{-13}$
δ_{77}^0	$-0.078\,5(16)\times10^{-12}$	ρ_7^0	$0.675\,05(75)\times10^{-8}$
δ_{777}	$0.039\,90(42)\times10^{-12}$	ρ_7^J	$-0.427\,4(45)\times10^{-12}$
L_0	$-0.130\,6(44)\times10^{-16}$	ρ_7^{JJ}	$0.163\,4(62)\times10^{-16}$
ϵ_7^0	$0.063\,4(10)\times10^{-16}$	ρ_7^{JJJ}	$-0.243\,9(79)\times10^{-21}$
ϵ_{77}^0	$0.010\,45(81)\times10^{-16}$	ρ_{77}	$-0.315\,12(75)\times10^{-8}$
ϵ_{777}	$-0.005\,31(19)\times10^{-16}$	ρ_{77}^J	$0.201\,9(46)\times10^{-12}$
N_0	$0.221(26)\times10^{-21}$	ρ_{77}^{JJ}	$-0.722(63)\times10^{-17}$

[a] Error estimates (1σ) are given in parentheses in units of the last figure quoted.

the same number of constants for each approach (44 with the linear model and 46 with the effective one). This seems to be due to the fact that we have tried to fit the spectrum of carbon suboxide with a linear model that does not take any account of the quasilinearity.

The constants listed in Table III clearly show that the vibrational and rotational energy level structure of the ν_7 manifold in the ground electronic state of carbon suboxide is far from that of a linear molecule. Indeed, the vibrational constant ω_7^0 is actually *smaller* than the first order anharmonic constant x_{77}^0 and the second order anharmonic constant y_{777}^0 is about an order of magnitude larger than in a normal linear molecule such as acetylene in its ground electronic state.[18] Moreover, the vibration–rotation interaction constants determined for each rotational constant B_v to N_v are of about the same order of magnitude. For example, the vibration–rotation interaction constants α_7^0, γ_{77}^0, and γ_{777} associated to B_v are all of the order of 10^{-4} cm^{-1}. When considering the *l*-type doubling and resonance constants q_7 and ρ_7, similar comments can be made. Indeed, q_7 shows an unusual dependance on the bending quantum number v_7, i.e., the ratio q_{77}/q_7^0 is up to thirty times greater than what is found for other linear molecules (see for example Refs. 18 and 24). Concerning ρ_7, it seems that this is the first time that a J dependance has had to be invoked in that matrix element in order to fit the data to experimental precision.[25]

We have also tried to include in this fit lines corresponding to transitions involving the *l* sublevels of the $v_7 = 4$ vibrational level but it was not possible to achieve convergence, probably because it involved too many strongly correlated constants.

C. Bent model

It is tempting to compare the ability of the linear model to fit the energy level structure of the ground state of carbon suboxide to that of a bent model. For this purpose, we have fitted separately to both models the vibrational energy and the B values of the levels characterized by $v_7 = l_7$, with v_7 ranging from 0 to 12 for the energies E_v and up to $v_7 = 8$ for the B values because these data were not available above that level. The values for E_v and B were taken from Table II for $v_7 = 0$ to 8 and from Table VII of Ref. 6 for $v_7 = 9$ to 12 (E_v values only). For simplicity in this comparison, we have not taken any account of the *l*-resonance effects in the linear model nor of the asymmetry of the molecule in the bent model.

In the following, we will only consider the value of the standard deviation obtained for each fit and not the parameters determined because only the former are of interest in this discussion.

The fit of the vibrational energies to the linear model has been performed using an expression corresponding to the first four terms appearing in Eq. (4). With all four parameters fitted, the overall standard deviation obtained was 0.4 cm^{-1}. In a similar manner, the B values were adjusted to Eq. (6) with B_0 constrained to the value obtained for the ground level and given in Table II. Allowing the three anharmonicity parameters to vary, the standard deviation obtained was 1.2×10^{-5} cm^{-1}.

When carbon suboxide is considered as being bent, the levels mentioned above correspond to $K = 0$ to 12 of the ground vibrational state. The energies were fitted to the following expression, which is Watson's Hamiltonian for a symmetric top molecule[26] where only the terms relevant for this comparison have been considered

$$\begin{aligned} E(J,K) &= \langle JK|{}^{W}H|JK\rangle \\ &= B_0J(J+1) + (A-B_0)K^2 - \Delta_{JK}J(J+1)K^2 \\ &\quad - \Delta_K K^4 + H_{KJ}J(J+1)K^4 + H_K K^6 \\ &\quad + L_{KKJ}J(J+1)K^6 + L_K K^8. \end{aligned} \tag{16}$$

Since $J = 0$ for the levels being considered, the terms involving J vanish leaving the four parameters $(A - B_0)$, Δ_K, H_K, and L_K. The overall standard deviation obtained, when these were fitted, was 7.2 cm^{-1}.

We have also fitted the vibrational energies to a bent model using the method of the Borel approximation. The Borel approximation consists of a rearrangement of Watson's Hamiltonian for symmetric and asymmetric top molecules in order to remove its divergence, which is especially important for molecules in which the effects of centrifugal distortion are large (see for example Refs. 27 and 28). The rearranged Hamiltonian for a symmetric top molecule, including the terms up to J^8 is [Eqs. (1) of Ref. 28],

$${}^{B}H^{(8)} = \int_0^\infty e^{-x} \cdot \frac{u_0^2u_2 - u_1^2u_0 + (2u_0u_1u_2 - u_0^2u_3 - u_1^3)x}{u_0u_2 - u_1^2 + (u_2u_1 - u_0u_3)x + (u_1u_3 - u_2^2)x^2}\,dx, \tag{17}$$

with

$$u_0 = B_0J^2 + (A - B_0)J_z^2, \tag{18}$$

$$u_1 = -\Delta_{JK}J^2J_z^2 - \Delta_K J_z^4, \tag{19}$$

$$u_2 = \tfrac{1}{2}\{H_{KJ}J^2J_z^4 + H_K J_z^6\}, \tag{20}$$

$$u_3 = \tfrac{1}{6}\{L_{KKJ}J^2J_z^6 + L_K J_z^8\}. \tag{21}$$

In these expressions, we have again only considered the terms relevant for the present comparison. The eight parameters appearing in Eqs. (18)–(21) are the same as those involved in Eq. (16). The fit of the vibrational energies to this model, allowing the four parameters $(A - B_0)$, Δ_K, H_K, and L_K to vary led to an overall standard deviation of 1.4 cm^{-1}.

The B values were also fitted to the two bent models, using the following expression:

$$B = \frac{E(J=1,K) - E(J=0,K)}{2}, \tag{22}$$

where the $E(J,K)$ were taken from Eq. (16) or Eq. (17) depending on whether Watson's Hamiltonian or the rearranged Hamiltonian were considered. Due to simplifications occurring because of the energy difference appearing in Eq. (22), B can be shown to depend only on the four parameters B_0, Δ_{JK}, H_{KJ}, and L_{KKJ} when Watson's Hamiltonian is used. However in the case of the rearranged Hamiltonian, B still depends on the 8 parameters appearing in Eqs. (18)–(21) because of the nonlinearity of that Hamiltonian. So in order to fit the B values using that model, the constants $(A - B_0)$,

TABLE IV. Values of the overall standard deviation (in cm^{-1}) obtained for the fits of the vibrational energies E_v and B values of levels in the ν_7 manifold with $v_7 = l_7$ using three different models.

Model	E_v	B
Bent (Watson)	7.2	3.4×10^{-4}
Bent (rearranged)	1.4	2.5×10^{-5}
Linear	0.4	1.2×10^{-5}

Δ_K, H_K, and L_K which do not involve a J dependance, were held fixed to the values determined in the energy levels fit described in the previous paragraph. Just as was done with the linear model, B_0 was constrained in the two fits to the B value obtained for the ground level and given in Table II. With the three centrifugal distortion constants fitted, the overall standard deviation obtained with Watson's Hamiltonian was 3.4×10^{-4} cm^{-1} while that obtained with the rearranged Hamiltonian was 2.5×10^{-5} cm^{-1}.

The results of this comparison are summarized in Table IV. They clearly show that the rearrangement of Watson's Hamiltonian in the bent model leads to a significant improvement in the standard deviation (a factor of 5 for the fit of the energy of the levels, a factor of nearly 14 when fitting the B values). However, neither bent model can represent the data as well as the linear model. As a consequence, we have not investigated the bent model any further.

V. CONCLUSION

This study presents an analysis of the far infrared spectrum of carbon suboxide recorded at high resolution in the region from 15 to 130 cm^{-1}. It has been possible to make rotational analyses of bands involving levels with up to 8 quanta in the ν_7 quasilinear bending mode. Constants have been derived in two ways, each combining our data together with data obtained from the microwave spectrum recorded by Karyakin *et al.*[2] The first fit was to effective parameters. The constants determined for the levels 5^3, 5^5 and those involving $v_7 = 6$, 7, and 8 are new and the constants obtained for the levels with $v_7 = 0$ to 4 and the 5^1 level have been significantly improved. The new set of experimental data is now being used to extend the analysis of the spectrum of carbon suboxide in the region of the ν_6 fundamental around 540 cm^{-1} which was started by Jensen and Johns.[8] The second fit did not include all the data at higher vibrational quantum numbers but used a realistic model to describe l-doubling and l-resonance effects. In this way we have hoped to generate parameters with greater physical significance than the effective parameters of the first fit.

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