High-Resolution Infrared Emission Spectrum of Strontium Monofluoride

P. Colarusso, B. Guo, K.-Q. Zhang, and P. F. Bernath

Centre for Molecular Beams and Laser Chemistry, Department of Chemistry, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

The high-resolution infrared spectrum of gas-phase SrF was obtained in emission with a Fourier transform spectrometer. Approximately 1400 rotational lines from the 1–0 to the 8–7 bands were measured in the $X^2\Sigma^+$ ground state of the major isotopomer, ^{88}SrF. The Dunham coefficients $Y_{l,m}$ have been derived from a combined fit of the infrared transitions with microwave transitions that have been previously reported in the literature. © 1996 Academic Press, Inc.

INTRODUCTION

The first quantum mechanical interpretations of the band spectra of SrF date back at least to the 1920s (1, 2). Subsequent reports identified electronic bands in emission spectra from carbon arcs and discharges (3, 4) as well as in absorption spectra (3, 5). In these early studies, the analysis was limited to the vibrational structure because the electronic spectra of SrF are extremely congested.

The first rotational analysis of SrF was reported by Barrow and Beale in 1967; they recorded and analyzed the high-resolution spectrum of the 0–0 band of the $F^2\Sigma^+ - X^2\Sigma^+$ transition (6). This work was followed by several laser spectroscopic experiments. Steimle *et al.* recorded and analyzed the (0, 0), (1, 1), and (2, 2) bands of the $B^2\Sigma^+ - X^2\Sigma^+$ transition (7). The same electronic transition was studied at sub-Doppler resolution using intermodulation fluorescence spectroscopy (8) as well as polarization spectroscopy (9). The (1, 0) and (2, 1) bands of the $A^2\Pi - X^2\Sigma^+$ transition were studied by laser excitation of SrF in a low-pressure flame (10); more recently, the (0, 0) band has been studied using molecular beam techniques (11). Nitsch *et al.* used optical–optical double resonance to investigate the $F^2\Sigma^+$ and $G^2\Pi$ states via the intermediate $B^2\Sigma^+$ state (12).

The spectra of SrF have also been studied in the microwave and millimeter-wave regions. Domaille *et al.* used microwave optical double resonance in order to measure several pure rotational transitions of ^{88}SrF in the $X^2\Sigma^+$ state (13). Schütze-Pahlmann and co-workers obtained the rotational spectrum of ^{88}SrF using millimeter-wave absorption; they determined some of the Dunham coefficients as well as spin–rotation constants (14). Childs and co-workers determined the spin–rotation constants and the isotropic and anisotropic hyperfine constants for ^{88}SrF and ^{86}SrF (15). The hyperfine structure of ^{87}SrF in the ground state has been

investigated by Azuma and co-workers (16). The dipole moments of the $X^2\Sigma^+$ ground state as well as the $A^2\Pi$ and $B^2\Sigma^+$ excited states of ^{88}SrF have been determined using Stark measurements (17, 18).

Recently, our laboratory has investigated the infrared emission spectra of MgF (19), CaF (20), and BaF (21). In this study, we report the analysis of the infrared emission spectrum of SrF.

EXPERIMENTAL DETAILS

Gas-phase SrF was produced by reacting a mixture of Sr metal and SrF₂ in a high-temperature furnace. The reactant

TABLE 1
Molecular Constants for ^{88}SrF (in cm^{-1})*

| v	T_v	B_v	$10^7 D_v$	$10^{14} H_v$
0	0.000000	0.249759414(28)	2.49758(42)	-2.81(36)
1	497.572685(90)	0.248212724(29)	2.49963(41)	-2.82(35)
2	990.78397(12)	0.246670524(31)	2.50159(40)	-2.74(33)
3	1479.66537(19)	0.24513291(11)	2.50343(42)	-2.61(32)
4	1964.24814(24)	0.24360004(14)	2.50509(43)	-2.47(31)
5	2444.56424(29)	0.24207212(18)	2.50682(46)	-2.22(31)
6	2920.64527(35)	0.24054887(25)	2.50779(55)	-2.31(34)
7	3392.52334(41)	0.23903047(30)	2.50841(61)	-2.38(36)
8	3860.23005(48)	0.23751709(33)	2.50894(65)	-2.39(36)

*One standard deviation is provided in parentheses.
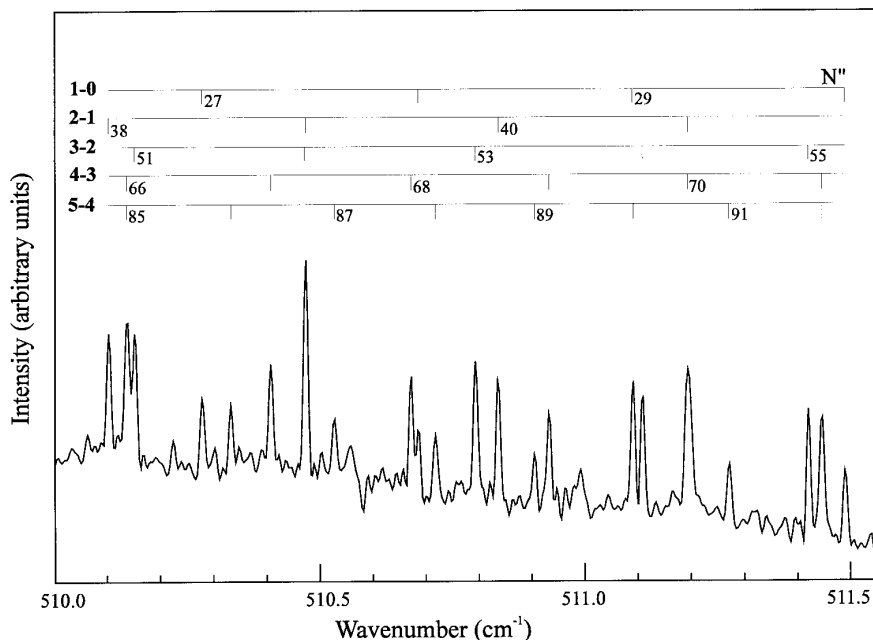
FIG. 1. A portion of the emission spectrum of SrF. The *R*-branch lines of the 1−0 to the 5−4 vibrational bands are marked along with the *N″* values.

mixture was placed in the center of an alumina tube containing a carbon liner. The center portion of the tube was housed in the furnace, which was heated to 1650°C at a rate of 5°/min. The alumina tube was sealed with KRS-5 win-

dows at both ends. In order to avoid deposition on the windows, 30 Torr of argon was introduced into the tube. The infrared emission was directed from one end of the tube into a port of a Bruker IFS 120 HR Fourier transform spectrometer. The emission spectrum of SrF was recorded at a resolution of 0.01 cm^{-1} with a helium-cooled Si:B detector over the spectral region ranging from 350 to 750 cm^{-1}.

RESULTS AND ANALYSIS

While Sr has five naturally occurring isotopes (^{84}SrF (0.56%), (^{86}Sr (9.86%), ^{87}SrF (7.00%), and ^{88}SrF (82.58%)) (22), only ^{88}SrF was detected in this experiment. The line positions were measured using Brault's PC-DECOMP, a computer program that fits a spectral lineshape to a Voigt lineshape function. Spin−rotation splitting was not resolved. HF lines, which were present in the spectrum as an impurity, were used in the absolute calibration of the ^{88}SrF spectrum (23). The line positions were organized into different bands using an in-house program based on the Loomis−Wood technique. The 1−0 and 2−1 bands were assigned using combination differences based on the data reported by Steimle *et al.* (7). The line positions were then fit to the standard energy level expression

$$F_{v,N} = T_v + B_v N(N + 1) - D_v[N(N + 1)]^2$$
$$+ H_v[N(N + 1)]^3. \qquad [1]$$

The preliminary constants were used to assign the next few

TABLE 2
Dunham Coefficients of ^{88}SrF*

Dunham Coefficient	Value (cm^{-1})
Y_{01}	0.250534383(25)
$10^7 Y_{02}$	-2.49586(33)
$10^{14}Y_{03}$	-3.30(25)
Y_{10}	501.96496(13)
$10^3 Y_{11}$	-1.551101(17)
$10^{10}Y_{12}$	-2.423(17)
Y_{20}	-2.204617(37)
$10^6 Y_{21}$	2.1850(58)
$10^{11}Y_{22}$	1.029(23)
$10^3 Y_{30}$	5.2815(28)
$10^8 Y_{31}$	1.518(44)

*One standard deviation is provided in parentheses.

TABLE 3
Observed and Calculated Transition Wavenumbers (in cm^{-1})

N'	N''	Observed	O-C[1]	N'	N''	Observed	O-C	N'	N''	Observed	O-C
						$v = 1 - 0$					
2	3	496.0657	0.6	37	38	476.4711	0.2	68	69	456.1719	−0.8
5	6	494.5292	−0.3	38	39	475.8585	0.3	69	70	455.4779	3.9
6	7	494.0107	−1.0	40	41	474.6241	−0.2	70	71	454.7730	0.4
8	9	492.9660	−0.6	41	42	474.0036	0.5	71	72	454.0694	1.0
10	11	491.9063	−3.0	42	43	473.3779	−1.1	72	73	453.3627	1.1
11	12	491.3755	−0.7	44	45	472.1221	−0.2	73	74	452.6512	−1.0
14	15	489.7566	−2.0	45	46	471.4902	0.5	74	75	451.9385	−1.6
15	16	489.2129	−0.6	47	48	470.2176	1.6	75	76	451.2262	0.8
16	17	488.6655	0.2	48	49	469.5756	0.5	76	77	450.5077	−0.2
18	19	487.5610	1.1	49	50	468.9307	−0.5	77	78	449.7905	2.6
19	20	487.0028	0.1	50	51	468.2845	0.0	78	79	449.0666	1.4
20	21	486.4421	−0.5	51	52	467.6349	−0.2	79	80	448.3394	−0.4
22	23	485.3161	2.7	52	53	466.9829	0.1	80	81	447.6117	−0.2
23	24	484.7439	−0.5	53	54	466.3281	0.3	81	82	446.8794	−1.9
24	25	484.1722	−0.3	54	55	465.6709	0.8	82	83	446.1480	0.0
25	26	483.5976	0.1	55	56	465.0087	−0.8	83	84	445.4136	1.3
26	27	483.0196	−0.1	57	58	463.6798	−0.3	84	85	444.6735	−0.3
27	28	482.4389	0.0	58	59	463.0110	−0.3	86	87	443.1884	−0.8
28	29	481.8552	0.1	59	60	462.3400	0.3	87	88	442.4435	0.5
29	30	481.2691	0.6	60	61	461.6658	0.5	91	92	439.4339	1.5
30	31	480.6794	0.4	61	62	460.9885	0.2	92	93	438.6746	1.2
32	33	479.4904	−0.7	62	63	460.3068	−1.7	93	94	437.9133	1.5
33	34	478.8931	0.2	63	64	459.6257	−0.3	96	97	435.6127	0.9
34	35	478.2911	−0.6	64	65	458.9406	−0.1	99	100	433.2886	−0.3
35	36	477.6876	−0.1	65	66	458.2529	0.2	100	101	432.5088	−0.8
36	37	477.0805	−0.3	66	67	457.5624	0.2				
4	3	499.5396	−0.3	48	47	517.8004	0.1	89	88	528.9233	1.1
5	4	500.0245	0.5	49	48	518.1413	0.2	90	89	529.1188	0.1
6	5	500.5024	−2.5	50	49	518.4784	−0.1	91	90	529.3110	−0.5
7	6	500.9772	−5.4	51	50	518.8118	−0.7	92	91	529.5003	−0.3
8	7	501.4581	0.9	52	51	519.1422	−0.8	93	92	529.6864	0.4
9	8	501.9283	−0.3	53	52	519.4690	−1.2	94	93	529.8669	−0.9
10	9	502.3964	−0.5	54	53	519.7934	−0.6	95	94	530.0460	0.1
11	10	502.8640	1.9	55	54	520.1140	−0.3	96	95	530.2209	0.5
12	11	503.3242	0.1	56	55	520.4316	0.3	97	96	530.3914	0.4
13	12	503.7845	1.6	57	56	520.7445	−0.2	98	97	530.5579	−0.1
14	13	504.2379	−0.7	58	57	521.0544	−0.2	99	98	530.7212	−0.2
15	14	504.6886	−2.5	59	58	521.3609	−0.4	100	99	530.8812	0.3
16	15	505.1400	−0.4	60	59	521.6652	0.8	101	100	531.0378	0.9
17	16	505.5856	−0.9	61	60	521.9642	0.2	102	101	531.1888	−0.2
18	17	506.0290	−0.5	62	61	522.2601	−0.1	103	102	531.3377	0.3
21	20	507.3394	0.4	63	62	522.5533	0.4	104	103	531.4817	−0.4
22	21	507.7685	−0.5	64	63	522.8426	0.5	105	104	531.6236	0.5
23	22	508.1927	−3.1	65	64	523.1280	0.2	106	105	531.7621	1.9
24	23	508.6196	0.1	66	65	523.4095	−0.5	108	107	532.0243	1.0
25	24	509.0375	−2.3	67	66	523.6890	0.2	109	108	532.1494	0.2

[1] Observed − Calculated (in $\times 10^3$ cm^{-1}).

TABLE 3—*Continued*

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
26	25	509.4575	0.5	68	67	523.9635	−0.5	110	109	532.2719	0.7
27	26	509.8708	0.0	69	68	524.2359	0.1	111	110	532.3889	−0.7
28	27	510.2814	0.0	70	69	524.5031	−0.9	112	111	532.5034	−0.7
29	28	510.6888	0.1	71	70	524.7696	1.0	113	112	532.6149	0.1
30	29	511.0931	0.3	72	71	525.0296	−0.1	114	113	532.7216	−0.1
31	30	511.4926	−1.1	73	72	525.2877	0.4	116	115	532.9244	0.2
32	31	511.8913	0.1	74	73	525.5413	−0.1	118	117	533.1134	2.1
33	32	512.2837	−1.8	75	74	525.7925	0.6	119	118	533.1995	0.5
34	33	512.6769	0.5	76	75	526.0388	0.0	120	119	533.2831	0.1
35	34	513.0636	−0.5	77	76	526.2818	−0.4	121	120	533.3656	2.5
36	35	513.4477	−0.7	78	77	526.5220	0.0	122	121	533.4385	−0.8
37	36	513.8294	0.0	79	78	526.7582	0.0	123	122	533.5138	2.1
38	37	514.2069	−0.2	80	79	526.9896	−1.2	124	123	533.5814	1.2
39	38	514.5818	0.3	81	80	527.2193	−0.6	125	124	533.6449	0.0
40	39	514.9553	2.7	82	81	527.4451	−0.3	127	126	533.7608	−1.6
41	40	515.3204	0.1	83	82	527.6665	−0.7	130	129	533.9135	4.0
42	41	515.6852	0.5	84	83	527.8851	−0.3	131	130	533.9493	−1.5
43	42	516.0444	−1.2	85	84	528.1010	0.9	132	131	533.9860	−2.1
44	43	516.4038	0.5	86	85	528.3115	0.5	133	132	534.0190	−2.5
45	44	516.7578	0.2	87	86	528.5185	0.1	138	137	534.1302	1.1
46	45	517.1085	−0.1	88	87	528.7216	−0.5	140	139	534.1425	−2.0
47	46	517.4556	−0.5								
						v = 2 − 1					
3	4	491.2070	−0.1	38	39	471.6227	−1.3	69	70	451.3512	−0.1
4	5	490.7039	5.6	39	40	471.0130	1.1	70	71	450.6531	−0.6
5	6	490.1877	1.1	40	41	470.3970	0.0	71	72	449.9544	1.1
8	9	488.6337	0.7	41	42	469.7791	−0.1	72	73	449.2502	−0.1
9	10	488.1116	2.4	42	43	469.1593	0.7	73	74	448.5452	0.5
10	11	487.5820	−0.2	43	44	468.5351	0.0	74	75	447.8369	0.5
11	12	487.0521	−0.2	45	46	467.2799	0.0	75	76	447.1259	0.4
12	13	486.5190	−0.3	46	47	466.6485	0.6	76	77	446.4123	0.5
14	15	485.4452	0.9	47	48	466.0137	0.5	77	78	445.6953	−0.3
15	16	484.9017	−0.7	48	49	465.3755	−0.2	78	79	444.9761	−0.7
16	17	484.3574	0.0	49	50	464.7359	0.5	79	80	444.2552	−0.1
17	18	483.8100	0.6	50	51	464.0925	0.1	80	81	443.5324	1.2
18	19	483.2588	0.3	51	52	463.4466	0.1	81	82	442.8044	−0.1
19	20	482.7056	1.0	52	53	462.7970	−0.8	83	84	441.3442	0.9
20	21	482.1477	0.0	53	54	462.1464	0.0	84	85	440.6093	0.5
21	22	481.5895	1.6	54	55	461.4908	−1.4	85	86	439.8752	3.5
22	23	481.0256	0.4	55	56	460.8342	−1.1	86	87	439.1329	0.8
23	24	480.4594	0.0	56	57	460.1753	−0.3	87	88	438.3889	−0.9
24	25	479.8904	−0.3	57	58	459.5118	−1.3	88	89	437.6442	−0.8
25	26	479.3214	2.2	58	59	458.8473	−0.6	89	90	436.8950	−2.6
26	27	478.7447	0.0	59	60	458.1795	−0.5	91	92	435.3939	−1.3
27	28	478.1676	0.4	60	61	457.5094	0.1	92	93	434.6420	1.9
28	29	477.5849	−1.9	61	62	456.8356	−0.3	93	94	433.8832	0.6
29	30	477.0033	−0.2	62	63	456.1586	−1.2	94	95	433.1219	−0.5
31	32	475.8295	1.2	63	64	455.4779	−3.1	95	96	432.3582	−1.6
32	33	475.2381	1.8	64	65	454.7987	−0.7	96	97	431.5930	−1.7

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TABLE 3—*Continued*

N′	N″	Observed	O-C	N′	N″	Observed	O-C	N′	N″	Observed	O-C
33	34	474.6417	0.2	65	66	454.1151	−0.1	99	100	429.2847	0.7
34	35	474.0441	0.4	66	67	453.4287	0.5	100	101	428.5092	0.4
35	36	473.4429	−0.2	67	68	452.7400	1.4	104	105	425.3827	−0.3
36	37	472.8390	−0.6	68	69	452.0446	−1.8	109	110	421.4171	−3.1
37	38	472.2331	−0.1								
3	2	494.6823	0.4	46	45	512.6147	0.4	90	89	524.5174	1.2
4	3	495.1661	0.1	47	46	512.9591	−0.1	91	90	524.7075	0.7
5	4	495.6465	−0.4	48	47	513.3006	−0.1	92	91	524.8934	−0.4
6	5	496.1252	0.5	49	48	513.6390	0.1	93	92	525.0773	0.4
7	6	496.5993	−0.2	50	49	513.9739	0.3	94	93	525.2559	−0.6
8	7	497.0719	0.9	51	50	514.3052	0.3	95	94	525.4331	0.7
9	8	497.5409	1.4	52	51	514.6292	−3.7	96	95	525.6049	0.2
10	9	498.0043	−0.5	53	52	514.9553	−2.2	97	96	525.7728	−0.4
11	10	498.4678	0.9	54	53	515.2788	0.2	98	97	525.9372	−0.9
12	11	498.9251	−0.9	55	54	515.5963	−0.1	99	98	526.0987	−0.6
13	12	499.3859	4.1	56	55	515.9108	0.1	100	99	526.2562	−0.5
14	13	499.8350	0.5	57	56	516.2218	0.2	101	100	526.4102	−0.3
15	14	500.2845	0.5	58	57	516.5292	0.2	102	101	526.5610	0.4
16	15	500.7351	4.7	59	58	516.8329	−0.2	103	102	526.7063	−0.6
17	16	501.1726	−1.0	60	59	517.1336	−0.1	104	103	526.8494	0.0
18	17	501.6143	0.7	61	60	517.4311	0.3	105	104	526.9896	1.4
19	18	502.0519	1.5	62	61	517.7241	−0.3	106	105	527.1229	−0.5
20	19	502.4837	−0.2	63	62	518.0137	−0.8	107	106	527.2557	0.9
21	20	502.9146	0.3	64	63	518.3036	2.3	108	107	527.3823	−0.1
22	21	503.3419	0.3	65	64	518.5843	−0.2	109	108	527.5071	0.8
23	22	503.7663	0.8	67	66	519.1422	1.7	110	109	527.6271	0.8
24	23	504.1873	1.1	68	67	519.4130	−0.3	111	110	527.7424	−0.2
25	24	504.5995	−4.2	69	68	519.6823	−0.3	112	111	527.8550	−0.1
26	25	505.0180	0.0	70	69	519.9478	−0.5	113	112	527.9626	−1.3
27	26	505.4261	−2.9	71	70	520.2106	0.1	114	113	528.0702	1.4
28	27	505.8368	0.0	72	71	520.4692	−0.1	115	114	528.1705	0.5
29	28	506.2413	0.0	73	72	520.7242	−0.3	116	115	528.2689	1.6
30	29	506.6423	−0.3	74	73	520.9759	−0.1	117	116	528.3622	1.4
31	30	507.0407	0.1	75	74	521.2237	−0.5	118	117	528.4507	0.2
32	31	507.4359	0.7	76	75	521.4683	−0.4	119	118	528.5358	−0.7
33	32	507.8263	−0.5	77	76	521.7091	−0.6	120	119	528.6205	2.0
34	33	508.2147	−0.2	78	77	521.9476	0.4	121	120	528.7003	3.6
35	34	508.5997	0.0	79	78	522.1814	0.4	122	121	528.7718	0.8
36	35	508.9808	−0.5	80	79	522.4116	0.3	123	122	528.8418	0.3
37	36	509.3593	−0.3	81	80	522.6376	−0.4	124	123	528.9075	−0.7
38	37	509.7324	−2.1	82	81	522.8614	0.3	126	125	529.0308	0.9
39	38	510.1061	−0.1	83	82	523.0800	−0.7	127	126	529.0829	−2.1
40	39	510.4759	1.4	84	83	523.2966	0.0	128	127	529.1357	−0.4
41	40	510.8389	−0.6	85	84	523.5097	0.8	129	128	529.1813	−2.1
42	41	511.1975	−3.6	86	85	523.7179	0.3	130	129	529.2271	0.3
43	42	511.5595	0.0	87	86	523.9226	−0.2	131	130	529.2661	−0.1
44	43	511.9140	−0.4	88	87	524.1237	−0.5	134	133	529.3602	−0.9
45	44	512.2661	0.1	89	88	524.3224	0.4	135	134	529.3856	0.8

TABLE 3—*Continued*

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
						$v = 3 - 2$					
3	4	486.8884	−1.0	36	37	468.6299	0.0	66	67	449.3267	0.8
5	6	485.8753	0.0	37	38	468.0284	1.5	67	68	448.6390	−1.0
6	7	485.3624	−1.1	38	39	467.4217	0.5	69	70	447.2613	1.1
7	8	484.8491	0.3	39	40	466.8163	3.7	70	71	446.5669	0.6
8	9	484.3317	0.5	40	41	466.2010	0.0	71	72	445.8697	0.0
9	10	483.8100	−0.3	41	42	465.5869	0.1	72	73	445.1709	0.4
10	11	483.2862	−0.4	42	43	464.9698	0.2	73	74	444.4679	−0.8
11	12	482.7606	0.7	43	44	464.3480	−1.7	74	75	443.7656	1.4
12	13	482.2300	0.0	44	45	463.7274	0.5	75	76	443.0578	0.8
13	14	481.6973	0.0	45	46	463.1017	0.3	76	77	442.3460	−1.3
14	15	481.1608	−0.8	46	47	462.4731	0.2	77	78	441.6350	0.1
15	16	480.6216	−1.2	47	48	461.8428	0.9	78	79	440.9194	−0.5
16	17	480.0836	2.5	48	49	461.2078	0.0	80	81	439.4812	−0.9
17	18	479.5389	2.5	49	50	460.5704	−0.8	81	82	438.7585	−0.8
19	20	478.4383	0.2	50	51	459.9317	0.1	82	83	438.0336	−0.2
20	21	477.8839	−0.6	51	52	459.2898	0.5	83	84	437.3061	0.2
21	22	477.3284	0.5	52	53	458.6442	−0.1	84	85	436.5747	−0.6
22	23	476.7679	−0.5	54	55	457.3467	0.9	85	86	435.8422	0.0
23	24	476.2062	0.1	55	56	456.6910	−1.5	86	87	435.1063	−0.1
24	25	475.6408	0.1	56	57	456.0367	0.3	88	89	433.6269	−0.3
25	26	475.0727	0.3	57	58	455.3772	−0.3	89	90	432.8851	1.2
26	27	474.5016	0.3	58	59	454.7159	−0.1	90	91	432.1370	−1.0
27	28	473.9274	0.3	59	60	454.0532	1.4	93	94	429.8844	−0.5
28	29	473.3493	−0.8	60	61	453.3849	0.2	94	95	429.1260	−2.8
30	31	472.1884	1.0	61	62	452.7154	0.3	95	96	428.3685	−1.6
31	32	471.6022	0.6	62	63	452.0446	2.0	96	97	427.6079	−1.2
32	33	471.0130	0.0	63	64	451.3688	1.4	101	102	423.7667	0.7
33	34	470.4217	0.2	64	65	450.6898	0.2	103	104	422.2121	0.7
34	35	469.8275	0.3	65	66	450.0097	0.7	104	105	421.4312	0.8
35	36	469.2306	0.6								
3	2	490.3468	4.0	46	45	508.1529	0.5	87	86	519.3592	−1.1
4	3	490.8238	0.0	47	46	508.4944	−0.2	88	87	519.5591	−0.4
5	4	491.3035	1.8	48	47	508.8331	−0.4	89	88	519.7548	−0.3
6	5	491.7750	−1.4	49	48	509.1692	0.2	90	89	519.9478	0.6
7	6	492.2518	3.6	50	49	509.5012	0.1	91	90	520.1355	0.0
8	7	492.7181	1.4	51	50	509.8298	−0.1	92	91	520.3197	−0.5
9	8	493.1859	3.8	52	51	510.1550	−0.2	93	92	520.5016	0.3
10	9	493.6465	2.0	53	52	510.4759	−1.3	94	93	520.6775	−1.2
12	11	494.5596	−0.1	54	53	510.7963	0.5	95	94	520.8535	1.1
14	13	495.4613	−1.0	55	54	511.1111	0.1	96	95	521.0228	0.3
15	14	495.9094	0.5	56	55	511.4232	0.4	97	96	521.1884	−0.6
16	15	496.3563	4.0	57	56	511.7305	−0.6	98	97	521.3510	−0.6
17	16	496.7920	−0.5	58	57	512.0359	0.0	99	98	521.5112	0.5
18	17	497.2320	2.4	59	58	512.3375	0.0	100	99	521.6652	−0.9
19	18	497.6628	−0.7	60	59	512.6351	−0.4	101	100	521.8177	0.0
20	19	498.0937	−0.5	61	60	512.9302	0.1	102	101	521.9642	−1.5
21	20	498.5219	1.8	62	61	513.2211	−0.1	103	102	522.1107	0.7

TABLE 3—*Continued*

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
22	21	498.9464	0.4	63	62	513.5092	0.3	104	103	522.2492	−1.2
23	22	499.3661	−0.9	64	63	513.7930	−0.1	105	104	522.3876	0.3
24	23	499.7870	2.1	65	64	514.0743	0.3	106	105	522.5203	0.0
25	24	500.2000	0.4	66	65	514.3515	0.3	107	106	522.6493	−0.4
26	25	500.6107	−0.3	68	67	514.8955	0.2	108	107	522.7761	0.8
27	26	501.0197	0.5	69	68	515.1615	−0.6	109	108	522.8960	−1.1
28	27	501.4238	−0.3	70	69	515.4247	−0.8	111	110	523.1280	−1.6
29	28	501.8243	−1.6	71	70	515.6852	−0.1	112	111	523.2410	0.8
31	30	502.6194	−0.1	72	71	515.9412	−0.4	113	112	523.3473	0.3
32	31	503.0115	0.1	73	72	516.1944	0.0	114	113	523.4497	−0.2
33	32	503.3999	−0.2	74	73	516.4442	0.5	115	114	523.5497	0.5
34	33	503.7845	−1.0	75	74	516.6893	−0.1	116	115	523.6448	0.2
35	34	504.1676	0.0	76	75	516.9325	1.0	117	116	523.7356	−0.6
36	35	504.5465	0.1	77	76	517.1704	0.2	118	117	523.8247	0.7
37	36	504.9218	−0.1	78	77	517.4049	−0.4	119	118	523.9068	−1.2
38	37	505.2942	0.1	79	78	517.6367	−0.1	120	119	523.9891	0.9
39	38	505.6624	−0.6	80	79	517.8644	−0.4	121	120	524.0629	−1.7
40	39	506.0290	0.3	81	80	518.0895	0.2	122	121	524.1369	−0.1
41	40	506.3913	0.3	83	82	518.5271	−0.2	123	122	524.2059	0.1
42	41	506.7501	0.2	84	83	518.7406	−0.3	124	123	524.2691	−1.5
43	42	507.1056	0.1	85	84	518.9508	−0.2	127	126	524.4424	0.4
44	43	507.4577	−0.1	86	85	519.1580	0.6	129	128	524.5400	3.1
45	44	507.8064	−0.3								

$$v = 4 - 3$$

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
1	2	483.5976	−1.6	36	37	464.4520	0.3	65	66	445.9349	0.4
3	4	482.6021	−1.4	37	38	463.8523	0.1	66	67	445.2542	−0.7
6	7	481.0883	1.3	39	40	462.6445	−0.1	67	68	444.5713	−1.5
7	8	480.5740	−1.4	40	41	462.0370	0.4	68	69	443.8892	1.2
8	9	480.0612	0.4	41	42	461.4264	0.6	69	70	443.2003	−0.2
11	12	478.4994	0.3	42	43	460.8127	0.5	70	71	442.5099	−0.5
12	13	477.9730	0.5	43	44	460.1959	0.2	71	72	441.8184	0.8
13	14	477.4444	1.5	44	45	459.5762	−0.2	72	73	441.1217	−0.5
17	18	475.2942	−0.6	45	46	458.9545	0.2	74	75	439.7238	0.4
18	19	474.7512	0.8	46	47	458.3298	0.3	75	76	439.0195	−0.6
19	20	474.2043	1.3	47	48	457.7018	−0.1	76	77	438.3122	−2.0
20	21	473.6508	−1.9	48	49	457.0716	0.2	77	78	437.6055	−0.2
21	22	473.0999	0.4	50	51	455.8016	−0.7	78	79	436.8950	0.5
22	23	472.5431	−0.2	51	52	455.1631	−0.5	79	80	436.1798	−1.1
23	24	471.9853	1.2	52	53	454.5213	−0.8	80	81	435.4651	0.6
24	25	471.4232	1.1	53	54	453.8777	−0.1	82	83	434.0247	0.7
25	26	470.8563	−0.8	54	55	453.2307	−0.2	83	84	433.3006	0.6
26	27	470.2894	0.2	56	57	451.9273	−1.4	84	85	432.5741	0.8
27	28	469.7182	−0.2	57	58	451.2728	−0.7	85	86	431.8438	−0.3
28	29	469.1440	−0.8	58	59	450.6149	−0.7	88	89	429.6411	−0.1
29	30	468.5689	0.7	59	60	449.9544	−0.5	92	93	426.6696	1.3
30	31	467.9894	0.6	60	61	449.2913	−0.3	94	95	425.1644	−2.2
31	32	467.4063	−0.1	61	62	448.6266	1.1	96	97	423.6547	−0.4

TABLE 3—*Continued*

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
33	34	466.2333	0.2	62	63	447.9546	−2.2	97	98	422.8968	1.3
34	35	465.6422	0.0	63	64	447.2856	0.3	98	99	422.1351	1.6
35	36	465.0485	0.2								
3	2	486.0337	−1.6	48	47	504.3984	−0.2	87	86	514.8311	−0.1
6	5	487.4588	−1.0	49	48	504.7314	−0.2	88	87	515.0286	0.5
7	6	487.9257	−2.8	50	49	505.0620	1.0	89	88	515.2216	0.0
8	7	488.3928	−1.3	51	50	505.3873	0.1	90	89	515.4107	−0.7
9	8	488.8569	0.3	52	51	505.7092	−0.8	91	90	515.5963	−1.2
10	9	489.3163	0.4	53	52	506.0290	−0.4	92	91	515.7804	0.3
12	11	490.2251	−0.1	54	53	506.3452	−0.2	93	92	515.9589	−0.1
14	13	491.1224	0.5	55	54	506.6582	0.1	94	93	516.1337	−0.6
15	14	491.5657	0.1	56	55	506.9687	1.4	96	95	516.4732	−0.6
17	16	492.4429	−0.5	57	56	507.2724	−0.7	97	96	516.6381	0.0
19	18	493.3066	−1.9	58	57	507.5752	−0.2	99	98	516.9564	0.6
20	19	493.7366	0.3	59	58	507.8744	0.0	100	99	517.1085	−0.6
21	20	494.1601	−0.8	60	59	508.1699	0.0	101	100	517.2589	0.3
22	21	494.5831	0.7	61	60	508.4620	−0.1	102	101	517.4049	0.3
23	22	495.0005	−0.1	62	61	508.7509	0.2	103	102	517.5465	−0.3
24	23	495.4147	−0.9	63	62	509.0375	1.5	104	103	517.6845	−0.8
25	24	495.8282	0.8	64	63	509.3179	0.2	105	104	517.8204	0.3
26	25	496.2360	0.0	65	64	509.5967	0.7	106	105	517.9508	−0.3
27	26	496.6415	0.2	66	65	509.8708	−0.1	107	106	518.0759	−2.6
28	27	497.0442	0.7	67	66	510.1406	−1.6	108	107	518.2008	−1.3
29	28	497.4430	0.6	68	67	510.4101	0.0	109	108	518.3193	−2.7
30	29	497.8378	−0.3	69	68	510.6748	0.2	110	109	518.4380	−0.1
31	30	498.2310	0.5	70	69	510.9350	−0.5	111	110	518.5499	−0.7
32	31	498.6191	−0.5	71	70	511.1975	4.6	112	111	518.6594	0.2
33	32	499.0053	−0.2	72	71	511.4483	1.5	113	112	518.7632	−0.8
34	33	499.3859	−2.3	73	72	511.6970	−0.3	114	113	518.8646	−0.6
35	34	499.7669	−0.7	74	73	511.9445	0.3	115	114	518.9631	0.7
36	35	500.1433	−0.3	75	74	512.1872	−0.3	116	115	519.0562	0.2
37	36	500.5165	0.0	76	75	512.4289	1.6	118	117	519.2337	2.0
38	37	500.8858	−0.1	77	76	512.6645	0.8	119	118	519.3146	0.7
39	38	501.2515	−0.7	78	77	512.8958	−0.7	121	120	519.4690	2.3
40	39	501.6143	−0.8	79	78	513.1253	−0.4	122	121	519.5383	0.8
41	40	501.9750	0.4	80	79	513.3519	0.6	124	123	519.6695	2.1
42	41	502.3313	0.3	81	80	513.5737	0.2	125	124	519.7244	−2.2
43	42	502.6840	0.1	82	81	513.7930	1.0	131	130	520.0044	3.4
44	43	503.0348	1.3	83	82	514.0067	−0.4	133	132	520.0631	1.8
45	44	503.3800	0.2	84	83	514.2180	−0.5	134	133	520.0852	−0.5
46	45	503.7223	−0.5	85	84	514.4262	0.0	137	136	520.1355	0.1
47	46	504.0619	−0.5	86	85	514.6292	−1.2	138	137	520.1473	3.2

TABLE 3—*Continued*

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
						v = 5 − 4					
4	5	477.8531	3.3	32	33	462.6602	−0.6	58	59	446.5469	0.4
5	6	477.3448	−2.6	33	34	462.0751	−1.0	59	60	445.8914	1.9
6	7	476.8458	3.8	34	35	461.4908	2.3	60	61	445.2297	−0.2
7	8	476.3329	−0.7	35	36	460.8970	−1.1	61	62	444.5713	3.8
9	10	475.3098	2.1	36	37	460.3068	1.9	62	63	443.9022	−0.2
10	11	474.7902	−0.1	37	38	459.7081	−0.8	63	64	443.2349	0.2
11	12	474.2677	−2.1	38	39	459.1103	0.5	64	65	442.5663	2.0
12	13	473.7489	2.4	39	40	458.5094	1.2	65	66	441.8909	−0.2
13	14	473.2196	−0.5	40	41	457.9032	−0.4	67	68	440.5392	2.2
14	15	472.6900	−0.7	41	42	457.2963	0.1	68	69	439.8566	0.6
16	17	471.6227	−0.4	42	43	456.6840	−2.1	69	70	439.1707	−1.5
17	18	471.0859	1.0	43	44	456.0741	1.0	70	71	438.4858	−0.1
18	19	470.5419	−1.8	44	45	455.4580	0.7	71	72	437.7962	−0.7
19	20	470.0007	1.2	45	46	454.8392	0.4	72	73	437.1060	0.7
20	21	469.4518	−0.7	46	47	454.2176	0.1	74	75	435.7124	−1.8
21	22	468.9026	0.1	47	48	453.5936	0.3	75	76	435.0137	−1.0
22	23	468.3499	0.4	48	49	452.9675	1.1	76	77	434.3126	0.0
23	24	467.7957	2.0	49	50	452.3369	0.0	77	78	433.6085	0.6
24	25	467.2353	0.3	50	51	451.7048	0.4	78	79	432.9015	0.9
25	26	466.6736	0.3	51	52	451.0693	0.1	79	80	432.1900	−0.8
26	27	466.1086	−0.1	52	53	450.4323	1.0	81	82	430.7641	0.8
27	28	465.5407	−0.6	53	54	449.7905	−0.2	85	86	427.8782	0.7
28	29	464.9698	−1.1	54	55	449.1478	0.5	88	89	425.6868	0.4
29	30	464.3987	1.0	55	56	448.5014	0.2	89	90	424.9520	0.9
30	31	463.8211	−0.5	56	57	447.8514	−0.9	93	94	421.9835	−0.6
31	32	463.2466	4.0								
7	6	483.6406	−0.1	46	45	499.3255	0.0	86	85	510.1406	3.9
8	7	484.1061	2.8	47	46	499.6619	−0.5	87	86	510.3352	0.1
9	8	484.5623	−0.5	48	47	499.9961	0.0	88	87	510.5298	−0.2
10	9	485.0190	−0.1	49	48	500.3262	−0.2	89	88	510.7207	−0.5
11	10	485.4718	−0.6	50	49	500.6515	−1.9	90	89	510.9076	−1.3
12	11	485.9224	−0.1	51	50	500.9772	0.2	91	90	511.0931	0.2
13	12	486.3664	−3.1	52	51	501.2972	0.0	92	91	511.2739	0.6
14	13	486.8129	−0.4	53	52	501.6143	0.2	93	92	511.4483	−1.8
15	14	487.2527	−1.4	54	53	501.9283	0.8	94	93	511.6235	0.3
16	15	487.6947	3.0	56	55	502.5439	−0.4	95	94	511.7923	−0.5
17	16	488.1263	0.2	57	56	502.8472	−0.4	96	95	511.9588	0.1
18	17	488.5619	4.6	58	57	503.1475	0.1	97	96	512.1201	−0.8
19	18	488.9825	−2.9	59	58	503.4438	−0.1	98	97	512.2837	4.2
20	19	489.4089	−1.5	60	59	503.7368	−0.2	99	98	512.4289	−5.4
21	20	489.8322	0.0	61	60	504.0270	0.4	100	99	512.5859	0.3
22	21	490.2498	−0.9	62	61	504.3132	0.3	101	100	512.7330	−0.2
23	22	490.6702	4.1	63	62	504.5995	3.9	102	101	512.8770	−0.1
24	23	491.0789	0.6	64	63	504.8749	−0.1	103	102	513.0171	−0.2
25	24	491.4891	1.9	65	64	505.1509	0.1	104	103	513.1539	0.1
26	25	491.8924	−0.6	66	65	505.4261	2.8	105	104	513.2869	0.3
27	26	492.2966	1.0	67	66	505.6924	0.2	106	105	513.4159	0.2

TABLE 3—*Continued*

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
28	27	492.6947	−0.2	68	67	505.9578	0.1	107	106	513.5393	−1.8
29	28	493.0906	−0.4	69	68	506.2197	0.0	108	107	513.6635	0.8
30	29	493.4835	−0.4	70	69	506.4738	−4.5	109	108	513.7790	−1.7
31	30	493.8734	−0.1	71	70	506.7330	−0.3	110	109	513.8934	−1.5
32	31	494.2609	1.0	72	71	506.9857	0.7	111	110	514.0067	1.2
33	32	494.6429	−0.2	73	72	507.2328	−0.2	112	111	514.1117	−0.5
34	33	495.0184	−4.6	74	73	507.4776	0.1	113	112	514.2180	2.8
35	34	495.3997	0.0	75	74	507.7188	0.2	114	113	514.3176	3.3
36	35	495.7733	0.3	76	75	507.9540	−2.1	115	114	514.4100	0.1
37	36	496.1429	−0.2	77	76	508.1927	2.5	116	115	514.5016	0.1
38	37	496.5094	−0.5	78	77	508.4205	−0.2	119	118	514.7541	0.2
39	38	496.8736	0.2	79	78	508.6483	0.7	120	119	514.8311	0.6
40	39	497.2320	−1.6	80	79	508.8713	0.2	124	123	515.1002	1.6
41	40	497.5902	−0.3	81	80	509.0911	0.2	125	124	515.1615	5.4
42	41	497.9448	0.7	82	81	509.3068	−0.4	126	125	515.2098	0.1
43	42	498.2940	−0.5	83	82	509.5192	−0.7	127	126	515.2606	1.0
44	43	498.6421	0.7	84	83	509.7324	3.3	128	127	515.3054	−0.1
45	44	498.9851	−0.1								

<div align="center">v = 6 − 5</div>

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
4	5	473.6204	−9.8	32	33	458.5321	0.2	55	56	444.4533	0.6
6	7	472.6248	−3.8	34	35	457.3658	−0.6	56	57	443.8065	−1.0
7	8	472.1221	−1.2	35	36	456.7785	−0.9	57	58	443.1583	−1.3
9	10	471.1013	−2.4	36	37	456.1902	0.6	58	59	442.5099	1.0
12	13	469.5532	1.2	37	38	455.5980	1.1	59	60	441.8552	−0.4
13	14	469.0276	−1.1	38	39	455.0001	−1.4	61	62	440.5392	−1.6
14	15	468.5017	−1.0	39	40	454.4037	0.5	62	63	439.8752	−4.3
16	17	467.4388	−2.6	40	41	453.7998	−2.3	63	64	439.2147	−0.8
17	18	466.9072	0.7	41	42	453.1986	0.4	64	65	438.5481	−0.7
19	20	465.8277	0.1	43	44	451.9826	0.6	65	66	437.8791	−0.3
20	21	465.2843	0.6	44	45	451.3688	−0.9	66	67	437.2032	−4.2
21	22	464.7359	−1.2	45	46	450.7560	1.3	67	68	436.5315	−1.1
22	23	464.1891	1.7	46	47	450.1354	−1.4	68	69	435.8538	−1.6
23	24	463.6340	−0.8	47	48	449.5164	0.1	69	70	435.1734	−2.0
24	25	463.0794	0.1	48	49	448.8949	2.0	70	71	434.4911	−1.8
25	26	462.5213	0.3	49	50	448.2672	0.4	71	72	433.8077	0.1
26	27	461.9613	1.5	50	51	447.6386	0.7	72	73	433.1219	2.1
27	28	461.3938	−1.8	51	52	447.0058	−0.6	73	74	432.4288	−0.6
29	30	460.2592	0.4	52	53	446.3724	0.4	76	77	430.3431	0.7
30	31	459.6857	−0.3	53	54	445.7349	−0.1	77	78	429.6411	−0.6
31	32	459.1103	0.0								
2	1	477.0376	−2.9	41	40	493.2373	−1.4	79	78	504.2028	0.2
3	2	477.5146	−0.8	42	41	493.5880	−1.7	80	79	504.4230	−0.7
4	3	477.9925	5.2	43	42	493.9373	0.0	81	80	504.6413	−0.1
6	5	478.9217	−0.2	44	43	494.2803	−1.5	82	81	504.8559	0.5
8	7	479.8431	−1.1	45	44	494.6228	0.0	83	82	505.0620	−4.0
9	8	480.3019	1.2	46	45	494.9656	5.1	84	83	505.2722	−0.8
10	9	480.7544	0.2	47	46	495.2949	−0.1	85	84	505.4761	−0.2
11	10	481.2057	1.3	48	47	495.6266	0.6	86	85	505.6771	0.9

TABLE 3—*Continued*

N'	N''	Observed	O-C	N'	N''	Observed	O-C	N'	N''	Observed	O-C
12	11	481.6545	2.9	49	48	495.9545	0.8	87	86	505.8743	1.8
13	12	482.0942	−1.5	50	49	496.2778	−0.3	88	87	506.0652	0.0
14	13	482.5360	−0.7	51	50	496.5993	0.1	89	88	506.2553	1.0
15	14	482.9738	−0.7	52	51	496.9168	0.0	90	89	506.4383	−1.5
16	15	483.4109	1.7	53	52	497.2320	0.8	91	90	506.6228	1.1
17	16	483.8410	0.4	54	53	497.5409	−1.2	92	91	506.7996	−0.4
18	17	484.2704	1.3	55	54	497.8499	0.2	94	93	507.1458	0.0
19	18	484.6924	−1.9	56	55	498.1559	2.1	95	94	507.3133	0.1
20	19	485.1153	−1.0	57	56	498.4549	0.3	96	95	507.4776	0.6
21	20	485.5351	−0.2	58	57	498.7522	0.1	97	96	507.6416	4.4
22	21	485.9500	−0.9	59	58	499.0462	0.1	98	97	507.7928	−1.0
23	22	486.3664	2.8	60	59	499.3387	2.0	100	99	508.0942	−1.7
24	23	486.7731	0.2	61	60	499.6244	0.5	101	100	508.2422	0.7
25	24	487.1776	−1.4	62	61	499.9075	−0.2	102	101	508.3860	2.7
26	25	487.5820	0.0	63	62	500.1870	−1.0	103	102	508.5217	0.1
27	26	487.9804	−1.4	64	63	500.4657	0.8	105	104	508.7865	−0.4
28	27	488.3777	−0.6	65	64	500.7351	−3.2	106	105	508.9168	2.7
29	28	488.7723	0.6	66	65	501.0088	0.4	107	106	509.0375	−0.1
30	29	489.1619	0.1	67	66	501.2756	0.6	108	107	509.1567	−0.6
31	30	489.5480	−0.7	68	67	501.5391	1.0	109	108	509.2720	−1.4
32	31	489.9341	1.8	69	68	501.7983	0.5	110	109	509.3863	0.6
33	32	490.3117	−1.1	70	69	502.0519	−2.1	111	110	509.5012	6.9
34	33	490.6906	0.7	71	70	502.3053	−1.3	112	111	509.5967	−2.5
35	34	491.0650	1.1	72	71	502.5570	1.1	113	112	509.7001	−0.2
36	35	491.4341	−0.4	73	72	502.8020	0.4	114	113	509.7982	0.5
37	36	491.8019	0.0	75	74	503.2834	0.7	115	114	509.8890	−2.3
38	37	492.1654	−0.6	76	75	503.5190	1.1	116	115	509.9784	−2.9
39	38	492.5270	0.1	77	76	503.7505	0.8	117	116	510.0684	1.1
40	39	492.8804	−4.1	78	77	503.9777	−0.2	119	118	510.2267	−1.6
						v = 7 − 6					
4	5	469.4518	9.5	30	31	455.5834	1.6	49	50	444.2268	−1.4
6	7	468.4509	4.0	31	32	455.0100	0.4	50	51	443.6019	−1.1
8	9	467.4388	−0.7	32	33	454.4347	0.2	51	52	442.9758	0.9
9	10	466.9278	−3.6	33	34	453.8579	1.4	52	53	442.3460	1.8
11	12	465.9048	−1.4	34	35	453.2754	−0.4	54	55	441.0745	0.0
12	13	465.3938	4.7	35	36	452.6912	−0.9	57	58	439.1506	0.9
13	14	464.8683	−0.8	36	37	452.1064	0.7	58	59	438.5028	0.1
14	15	464.3480	1.9	37	38	451.5136	−2.8	59	60	437.8534	0.3
15	16	463.8211	0.9	38	39	450.9255	1.1	60	61	437.2032	2.5
18	19	462.2233	−1.5	39	40	450.3287	−0.8	61	62	436.5471	1.4
19	20	461.6869	−0.2	40	41	449.7309	−1.0	62	63	435.8894	1.4
20	21	461.1474	0.8	41	42	449.1312	−0.3	63	64	435.2321	4.5
22	23	460.0585	1.8	42	43	448.5288	0.5	64	65	434.5664	1.7
23	24	459.5118	4.4	43	44	447.9220	−0.3	65	66	433.9006	1.6
24	25	458.9545	−0.7	44	45	447.3141	0.6	66	67	433.2309	0.2
25	26	458.4002	0.0	45	46	446.7013	−0.7	67	68	432.5596	−0.1
26	27	457.8433	1.0	46	47	446.0876	0.0	68	69	431.8851	−1.1
27	28	457.2813	−0.1	47	48	445.4721	1.5	72	73	429.1672	1.4
28	29	456.7167	−1.0	48	49	444.8514	0.7	73	74	428.4775	−1.6

TABLE 3—*Continued*

N′	N″	Observed	O-C[1]	N′	N″	Observed	O-C	N′	N″	Observed	O-C
5	4	474.2401	2.2	45	44	490.2954	2.6	79	78	499.7870	−3.6
8	7	475.6209	3.9	46	45	490.6290	1.1	80	79	500.0111	1.5
10	9	476.5235	2.5	47	46	490.9598	0.1	81	80	500.2257	0.7
13	12	477.8531	−0.7	48	47	491.2865	−1.8	82	81	500.4366	−0.2
14	13	478.2911	−0.7	49	48	491.6128	−0.6	84	83	500.8511	1.1
15	14	478.7260	−0.7	50	49	491.9350	−0.3	85	84	501.0503	−1.0
16	15	479.1585	0.0	51	50	492.2518	−2.0	86	85	501.2515	2.5
17	16	479.5874	0.2	52	51	492.5684	−0.5	87	86	501.4419	−1.2
18	17	480.0125	−0.1	53	52	492.8804	−0.3	88	87	501.6334	−0.2
19	18	480.4333	−1.7	54	53	493.1859	−3.2	90	89	502.0036	−0.4
20	19	480.8533	−1.0	55	54	493.4935	−0.8	91	90	502.1833	−0.6
21	20	481.2691	−1.2	56	55	493.7961	0.1	92	91	502.3603	0.2
22	21	481.6816	−1.6	57	56	494.0962	1.9	93	92	502.5312	−1.5
23	22	482.0942	1.3	58	57	494.3890	−0.3	94	93	502.7033	1.5
24	23	482.5008	1.3	59	58	494.6823	1.5	95	94	502.8640	−3.2
25	24	482.9026	−0.3	60	59	494.9656	−3.4	97	96	503.1890	1.9
26	25	483.3021	−0.9	61	60	495.2544	0.7	98	97	503.3419	0.2
27	26	483.6998	−0.2	62	61	495.5347	−0.3	99	98	503.4935	1.0
28	27	484.0937	−0.1	63	62	495.8133	0.3	100	99	503.6393	−0.5
29	28	484.4843	−0.1	64	63	496.0875	0.0	101	100	503.7845	1.1
31	30	485.2572	1.2	65	64	496.3563	−2.4	102	101	503.9229	−0.4
32	31	485.6372	0.3	66	65	496.6265	0.2	103	102	504.0619	2.3
33	32	486.0143	−0.2	67	66	496.8901	−0.4	107	106	504.5689	0.9
34	33	486.3878	−1.2	68	67	497.1509	−0.3	108	107	504.6886	2.8
35	34	486.7578	−2.4	69	68	497.4123	3.7	109	108	504.8012	1.2
36	35	487.1276	−0.6	70	69	497.6628	0.4	110	109	504.9095	−0.9
37	36	487.4914	−1.6	71	70	497.9130	0.1	111	110	505.0180	0.8
38	37	487.8534	−1.0	72	71	498.1559	−3.8	115	114	505.4072	0.2
39	38	488.2160	3.4	73	72	498.4039	0.7	118	117	505.6624	2.4
41	40	488.9185	−0.6	74	73	498.6421	−1.1	120	119	505.8102	0.2
42	41	489.2674	0.0	75	74	498.8790	−0.7	121	120	505.8743	−4.9
43	42	489.6127	0.2	76	75	499.1132	0.5	122	121	505.9431	−1.7
44	43	489.9532	−1.1	78	77	499.5676	−0.6	124	123	506.0652	0.8
						v = 8 − 7					
4	5	465.2843	−1.7	31	32	450.9415	1.3	44	45	443.2896	0.9
7	8	463.8076	9.9	32	33	450.3643	−4.2	45	46	442.6816	0.9
9	10	462.7970	6.3	33	34	449.7905	−3.4	47	48	441.4571	0.8
10	11	462.2826	0.0	35	36	448.6390	2.6	48	49	440.8403	0.3
11	12	461.7737	2.0	36	37	448.0557	2.4	53	54	437.7195	1.8
12	13	461.2575	−0.3	37	38	447.4679	0.5	56	57	435.8132	1.3
16	17	459.1754	2.7	38	39	446.8794	0.6	57	58	435.1734	2.2
17	18	458.6442	0.0	39	40	446.2855	−1.9	59	60	433.8832	1.3
19	20	457.5781	−0.1	40	41	445.6953	2.1	60	61	433.2309	−2.3
20	21	457.0419	1.0	41	42	445.0960	−0.2	61	62	432.5741	−7.8
21	22	456.4965	−4.2	42	43	444.4975	1.0	65	66	429.9474	−2.6
27	28	453.1986	−0.2	43	44	443.8892	−4.8	66	67	429.2847	−0.7
30	31	451.5136	4.5								

TABLE 3—*Continued*

N'	N''	Observed	O-C[1]	N'	N''	Observed	O-C	N'	N''	Observed	O-C
8	7	471.4232	1.7	54	53	488.8685	−0.2	93	92	498.1226	−1.7
9	8	471.8749	2.8	56	55	489.4684	−2.2	94	93	498.2940	2.7
12	11	473.2053	−0.1	57	56	489.7690	2.5	95	94	498.4549	0.3
17	16	475.3647	−0.8	58	57	490.0587	−0.3	96	95	498.6191	4.7
18	17	475.7871	−1.0	59	58	490.3468	−1.4	97	96	498.7698	−0.8
19	18	476.2062	−1.5	60	59	490.6290	−4.9	98	97	498.9251	1.9
21	20	477.0376	0.2	61	60	490.9156	−0.6	99	98	499.0727	0.7
22	21	477.4444	−3.0	62	61	491.1954	0.2	101	100	499.3661	7.1
23	22	477.8531	−1.2	63	62	491.4716	0.9	103	102	499.6365	5.1
24	23	478.2565	−1.5	64	63	491.7426	−0.3	104	103	499.7669	4.8
25	24	478.6602	1.6	65	64	492.0085	−3.2	105	104	499.8911	2.0
28	27	479.8431	1.8	66	65	492.2761	−0.8	106	105	500.0111	−1.5
29	28	480.2305	1.3	67	66	492.5383	−0.6	107	106	500.1319	−0.3
31	30	480.9943	−0.9	68	67	492.7960	−1.3	108	107	500.2489	0.6
32	31	481.3723	−1.2	69	68	493.0531	0.9	109	108	500.3607	0.1
33	32	481.7478	−0.7	70	69	493.3066	2.8	110	109	500.4657	−3.5
34	33	482.1201	−0.1	71	70	493.5524	0.5	111	110	500.5741	0.0
35	34	482.4890	0.2	72	71	493.7961	−0.5	112	111	500.6788	3.4
36	35	482.8531	−1.0	73	72	494.0382	0.5	113	112	500.7738	0.8
37	36	483.2143	−1.8	74	73	494.2803	4.8	114	113	500.8663	−0.4
38	37	483.5765	1.5	75	74	494.5099	0.2	115	114	500.9569	0.1
39	38	483.9318	1.4	76	75	494.7397	−0.8	117	116	501.1247	−1.1
40	39	484.2824	−0.3	77	76	494.9656	−2.1	118	117	501.2035	−1.2
41	40	484.6318	0.0	78	77	495.1902	−1.3	119	118	501.2756	−4.2
42	41	484.9778	0.2	79	78	495.4147	3.0	120	119	501.3474	−3.8
43	42	485.3161	−3.9	80	79	495.6266	−1.9	122	121	501.4807	−2.0
44	43	485.6579	−1.3	81	80	495.8428	1.1	123	122	501.5391	−3.6
46	45	486.3286	0.9	82	81	496.0514	0.0	125	124	501.6458	−5.7
47	46	486.6573	0.4	83	82	496.2594	1.8	127	126	501.7463	1.2
48	47	486.9837	0.8	84	83	496.4594	−0.9	128	127	501.7840	−2.2
49	48	487.3050	−0.5	86	85	496.8555	0.5	129	128	501.8243	0.7
50	49	487.6238	−1.0	87	86	497.0442	−2.8	130	129	501.8564	−0.6
51	50	487.9412	0.3	88	87	497.2320	−3.5	131	130	501.8881	1.4
52	51	488.2524	−1.1	89	88	497.4123	−8.1	132	131	501.9109	−1.6
53	52	488.5619	−0.9								

vibrational bands in an iterative procedure. In all, approximately 1400 lines were assigned from the 1–0 to the 8–7 bands. These line positions, as well as millimeter-wave data from the work of Schütze-Pahlmann and co-workers (14), were included in the final fit to Eq. [1]. Vibrational term energies and rotational constants are listed in Table 1. A portion of the emission spectrum of SrF is shown in Fig. 1.

The observed frequencies and the pure rotational data were also fit to the energy levels of the Dunham model:

$$F_{v,N} = \sum_{l,m} Y_{l,m}(v + \tfrac{1}{2})^l [N(N+1)]^m. \qquad [2]$$

The Dunham $Y_{l,m}$ constants are given in Table 2. All of the measured line positions are listed in Table 3.

In summary, infrared emission spectroscopy is an effective technique for obtaining the spectra of the alkaline earth monofluorides. The infrared emission spectrum of the major isotopomer of SrF has been analyzed and the spectroscopic constants have been presented.

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