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Absolute Frequency Measurements of Methanol from 1.5 to 6.5 THz

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Frequencies of 445 CH_3OH rotational transitions between 1.5 and 6.5 THz have been measured with an accuracy of one part in 10^9. The far-infrared radiation used for the measurements was generated from the radiation of two CO_2 lasers using a MIM diode as a nonlinear mixer. The high resolution and sensitivity of the spectrometer also enabled us to observe a series of forbidden Q-branch transitions ($\Delta n = 1$ and $\Delta K = 0$) for $J = 12$ to 26.

I. INTRODUCTION

We used a tunable far-infrared (FIR) spectrometer to measure the frequencies of 445 methanol absorption lines from 1.5 to 6.5 THz (50 to 216 cm^{-1}). Linecenters have been determined with a typical 1σ accuracy of ±20 kHz. The high accuracy, large number of lines, and broad spectral coverage provide an excellent calibration standard for the FIR.

The spectra of methanol in the FIR and infrared region have been extensively studied using Fourier transform spectroscopy (FTS) (*1–5*) and tunable far-infrared (TuFIR) spectroscopy (*6, 7*). In the FTS experiments, several thousand spectral lines have been observed in a single measurement, but the resolution was limited to about 50 MHz and the frequency was accurate to about 2 MHz (*1*). This limitation on the absolute accuracy is from diffraction corrections of the frequency calibration lines. In the TuFIR experiments, only a few lines at a time were measured, but with resolution and frequency accuracy limited by the Doppler linewidth.

II. EXPERIMENTAL DETAILS

Details of the TuFIR spectrometer have been given in previous works (*8–10*), so only an outline of the method is given here. Figure 1 shows a schematic of the experimental setup. Three radiations (two from CO_2 lasers and one from a microwave source) are mixed in a metal–insulator–metal (MIM) diode to generate FIR radiation of frequency

$$\nu_{FIR} = |\nu_I - \nu_{II}| \pm \nu_{MW}, \tag{1}$$

where ν_{FIR} is the generated far-infrared frequency, ν_I and ν_{II} are the laser frequencies, and ν_{MW} is the microwave frequency. The MIM diode consists of a 25-μm diameter tungsten wire contacting the polished surface of a cobalt rod. Both laser beams are focused on the point contact by a 17-mm focal length zinc selenide lens. The generated FIR radiation is reflected by a right-angle rooftop reflector positioned one wavelength away from the $2\frac{1}{4}$ wavelength long antenna; it is then collimated by a 30-mm focal length off-axis section of a parabolic mirror.

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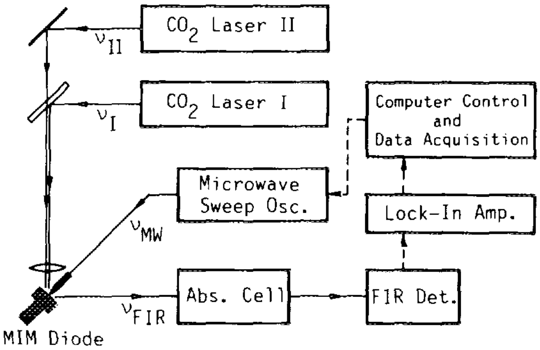

FIG. 1. Block diagram of the tunable far-infrared spectrometer.

For most of the measurements, a 0.12-m long absorption cell was used; however, a 0.60-m cell was used to observe the forbidden Q-branch lines. Both cells were 20 mm in diameter and incorporated polypropylene windows. Methanol pressure was about 20 Pa (150 mTorr) to reduce any pressure broadening or saturation broadening effects. The FIR radiation was detected by a germanium–gallium, photoconductive detector for wavenumbers higher than 70 cm^{-1}. For lower wavenumbers a gallium-doped germanium bolometer was used.

The frequency of each CO_2 laser was stabilized to the saturated fluorescence signal at 4.3 μm in a low-pressure, external CO_2 cell. For most of the present measurements, both of the CO_2 lasers oscillated in the regular bands of normal CO_2. For measurements between 170 and 190 cm^{-1}, one of the lasers oscillated on a 10-μm hot-band transition, while for measurements greater than 190 cm^{-1}, one CO_2 laser was operated in the 10-μm regular band of $^{13}CO_2$.

III. RESULTS

The criterion for selecting the spectral lines to be measured was not rigorous. We sought relatively strong spectral lines in the absorption spectrum chart of Moruzzi *et al.* (*1*) at a rate of one line for every wavenumber. When several strong lines appeared in the scanning range of the microwave frequency, two or three lines were measured. As a result, the number of observed lines is more than 400.

A spectrum near 6 THz is shown in Fig. 2. The CO_2 laser lines were $R_{II}(26)$ of $^{12}CO_2$ and $P_I(36)$ of $^{13}CO_2$. The lower trace is a 4-GHz wide survey scan. A narrower scan of a single absorption line is shown in the upper trace. The lower trace contains signals from both the positive and the negative sideband; they are easily distinguished because they differ in phase by π. The single absorption line shown in the upper trace is assigned as $Q(1, 1-; 7) \leftarrow (0, 2-; 7)\,A$. Each spectral lineshape was fitted, using a program designed by K. Chance (*11*), to a theoretical Voigt profile to obtain the transition center frequency.

The transitions are represented by the notation

$$(n', K'; J') \leftarrow (n'', K''; J'')\ \text{Symm}, \qquad (2)$$

where the primed quantum numbers specify the upper state of the transition, and the double-primed numbers the lower state (*1*). The number n is the torsional vibration quantum number; J, the total angular momentum; and K, its projection along the

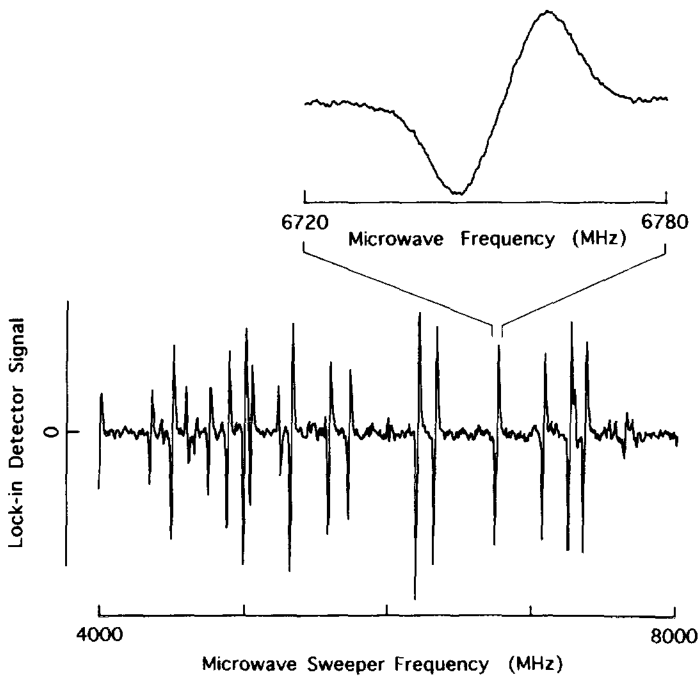

FIG. 2. A survey scan of the methanol spectra near 6 THz (lower trace), and a narrower scan of a single transition (upper trace). The CO_2 laser lines were $R_{II}(26)$ of $^{12}CO_2$ and $P_I(36)$ of $^{13}CO_2$. The frequency of the microwave sweeper is shown on the horizontal axis.

internal rotation axis. "Symm" stands for the symmetry. All of our measured transitions are in the ground vibrational state, so the vibrational state assignment is not given. As discussed in Ref. (*1*), both the $E1$ and $E2$ symmetries in previous papers are labeled by the common notation E. A state belonging to $E1$ symmetry has a positive K value, and that belonging to $E2$ symmetry has a negative K value. Some A states exhibit K doubling; the state involved in the transition is denoted by a plus or minus sign after the K value.

Table I lists the measured frequencies, wavenumbers, and assignments of the 445 methanol transitions. The 1σ uncertainty in the frequency is given in parentheses. It is a quadrature sum of the uncertainty from the fit to the Voigt profile and the 11-kHz uncertainty inherent in the synthesized FIR frequency (*12*). The wavenumbers listed in Table I are calculated from the measured frequencies using 299 792 458 m/sec for the speed of light. The assignment of each transition is from Moruzzi *et al.* (*1*, *5*). Often, a single line in the FTS spectrum is observed as several resolved lines in the TuFIR spectrometer. In such a case, the calculated frequencies of Moruzzi *et al.* were used to assign these transitions. When there were several (or no) candidates for the assignment, the corresponding column in Table I was left blank.

Moruzzi *et al.* (*1*) observed a series of forbidden $\Delta K = 0$, $\Delta n = 1$, Q-branch lines around 184.2 cm^{-1}. These lines are assigned as $Q(1, 9; J) \leftarrow (0, 9; J)\,A$. Frequencies of the lines corresponding to $J = 12$ to 26 were measured in this work and are included in Table I.

IV. CONCLUSION

Over 400 methanol rotational transitions between 1.5 and 6.5 THz have been measured with a tunable FIR spectrometer. Linecenters have been determined to typically

TABLE I

Frequencies, Wavenumbers, and Assignments of Measured Methanol Lines

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT	(n',K';J') ←	(n",K";J")	Symm
1	1 486 099.075 (13)	49.570 929 3	R	(0, -3;15)	(0, -2;14)	E
2	1 489 019.057 (16)	49.668 329 4	R	(0, -4;20)	(0, -3;19)	E
3	1 489 338.421 (16)	49.678 982 3	R	(0, 4;10)	(0, 3; 9)	E
4	1 489 380.743 (13)	49.680 394 0	R	(0, 5; 6)	(0, 4; 5)	A
5	1 497 412.006 (73)	49.948 288 1				
6	1 498 783.634 (18)	49.994 040 7				
7	1 514 036.613 (16)	50.502 825 3				
8	1 525 231.310 (13)	50.876 240 2	R	(0, -5;16)	(0, -4;15)	E
9	1 526 021.893 (13)	50.902 611 2				
10	1 549 690.799 (13)	51.692 120 9	R	(0, 6; 8)	(0, 5; 7)	A
11	1 553 041.187 (25)	51.803 877 8				
12	1 553 048.628 (20)	51.804 126 0				
13	1 564 395.621 (16)	52.182 621 0				
14	1 581 394.716 (13)	52.749 649 8	P	(0, 14;19)	(0, 13;20)	A
15	1 584 767.041 (18)	52.862 138 4	R	(0, -4;22)	(0, -3;21)	E
16	1 593 189.664 (16)	53.143 086 9				
17	1 621 814.845 (13)	54.097 920 1	R	(0, -5;18)	(0, -4;17)	E
18	1 633 493.450 (13)	54.487 476 5	R	(0, 4;13)	(0, 3;12)	E
19	1 634 298.377 (13)	54.514 325 9	R	(0, 5; 9)	(0, 4; 8)	A
20	1 652 763.812 (18)	55.130 266 6	R	(0, 4+;21)	(0, 3+;20)	A
21	1 654 722.221 (13)	55.195 592 0	R	(0, 5;17)	(0, 4;16)	E
22	1 698 971.062 (24)	56.671 574 5	R	(0, 4-;22)	(0, 3-;21)	A
23	1 729 095.433 (18)	57.676 415 4	R	(0, 4;15)	(0, 3;14)	E
24	1 730 782.864 (18)	57.732 702 0	R	(0, 5;11)	(0, 4;10)	A
25	1 755 279.958 (18)	58.549 837 1	R	(0, -3;21)	(0, -2;20)	E
26	1 755 953.739 (16)	58.572 312 0	R	(1, 5; 8)	(1, 4; 7)	E
27	1 757 773.250 (13)	58.633 004 4	R	(1, 6;16)	(1, 5;15)	A
28	1 767 085.301 (34)	58.943 621 0				
29	1 785 565.322 (22)	59.560 048 1	R	(0, 7;15)	(0, 6;14)	A
30	1 788 354.417 (13)	59.653 082 3	R	(0, -6; 9)	(0, -5; 8)	E
31	1 798 177.709 (20)	59.980 752 1	R	(0, 5;20)	(0, 4;19)	E
32	1 799 560.070 (65)	60.026 862 7	R	(0, 4+;24)	(0, 3+;23)	A
33	1 815 241.369 (24)	60.549 934 5	R	(0, -5;22)	(0, -4;21)	E
34	1 815 254.167 (75)	60.550 361 4	R	(1, -2;38)	(1, -2;37)	E
35	1 817 752.415 (13)	60.633 694 0	Q	(2, 6;32)	(2, 5;32)	A
36	1 827 113.684 (27)	60.945 952 3	R	(0, 5;13)	(0, 4;12)	A
37	1 845 802.300 (24)	61.569 337 4				
38	1 845 857.518 (13)	61.571 179 3	R	(0, 5;21)	(0, 4;20)	E
39	1 857 152.626 (22)	61.947 943 5	P	(2, 6;11)	(1, 7;12)	E
40	1 857 692.010 (24)	61.965 935 4	P	(1, 0+; 3)	(1, 1+; 4)	A
41	1 881 455.071 (20)	62.758 585 8	R	(1, -2;21)	(1, -3;20)	E
42	1 881 601.345 (13)	62.763 465 0	R	(0, 7;17)	(0, 6;16)	A
43	1 893 458.859 (18)	63.158 989 1	R	(0, 5;22)	(0, 4;21)	E

Note. All transitions are in the ground electronic and vibrational state. The 1σ uncertainty in the last digits is listed in parentheses.

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT (n',K';J')	← (n",K";J")	Symm
44	1 914 297.521 (18)	63.854 092 1	R (2, 4;40)	(2, 4;39)	A
45	1 929 580.294 (16)	64.363 870 5	R (0, 7;18)	(0, 6;17)	A
46	1 940 976.384 (28)	64.744 003 1	R (0, 5;23)	(0, 4;22)	E
47	1 941 184.802 (27)	64.750 955 2	P (2, 5;22)	(2, 6;23)	E
48	1 962 550.047 (13)	65.463 623 1	R (0, 7;10)	(0, 6; 9)	E
49	1 999 452.210 (13)	66.694 546 7	R (0, -8;15)	(0, -7;14)	E
50	2 009 258.012 (20)	67.021 633 1	R (0, -5;26)	(0, -4;25)	E
51	2 010 788.695 (16)	67.072 691 2	R (0, 7;11)	(0, 6;10)	E
52	2 011 956.763 (16)	67.111 653 7	R (0, 4;21)	(0, 3;20)	E
53	2 031 161.066 (22)	67.752 240 3	Q (1, 3-;13)	(1, 2+;13)	A
54	2 033 703.330 (24)	67.837 041 1	Q (1, 3-;18)	(1, 2+;18)	A
55	2 066 892.203 (31)	68.944 102 8			
56	2 066 913.140 (31)	68.944 801 1			
57	2 082 967.960 (24)	69.480 332 3	R (0, 5;26)	(0, 4;25)	E
58	2 095 311.922 (16)	69.892 082 5	R (0, -8;17)	(0, -7;16)	E
59	2 114 634.133 (22)	70.536 602 1	R (0, 5;19)	(0, 4;18)	A
60	2 126 115.622 (13)	70.919 583 4	R (0, 6;20)	(0, 5;19)	A
61	2 143 180.110 (13)	71.488 793 4	R (0, -8;18)	(0, -7;17)	E
62	2 155 416.225 (13)	71.896 946 3	R (0, 7;14)	(0, 6;13)	E
63	2 173 833.452 (18)	72.511 278 9			
64	2 175 002.124 (13)	72.550 261 6	R (1, 3; 3)	(1, 2; 2)	A
65	2 203 594.631 (13)	73.504 004 9	R (0, 7;15)	(0, 6;14)	E
66	2 207 187.809 (13)	73.623 860 4	R (1, -4;10)	(1, -3; 9)	E
67	2 216 892.936 (13)	73.947 588 6	R (0, 8;13)	(0, 7;12)	A
68	2 216 900.908 (18)	73.947 854 6	R (0, 7;24)	(0, 6;23)	A
69	2 232 072.042 (18)	74.453 909 1	P (2, 5;16)	(2, 6;17)	E
70	2 246 322.232 (13)	74.929 244 3	R (1, 6;27)	(1, 5;26)	A
71	2 268 778.477 (13)	75.678 304 0	R (0, 6;23)	(0, 5;22)	A
72	2 280 437.216 (13)	76.067 197 7	P (2, 5;15)	(2, 6;16)	E
73	2 292 909.196 (20)	76.483 218 1	R (1, 3;25)	(1, 4;24)	E
74	2 303 946.363 (13)	76.851 378 4	R (1, -4;12)	(1, -3;11)	E
75	2 307 134.880 (13)	76.957 735 9	R (0, 9;16)	(0, 8;15)	E
76	2 322 163.410 (13)	77.459 033 7	R (0, -9;13)	(0, -8;12)	E
77	2 334 197.647 (13)	77.860 452 6	R (0, -8;22)	(0, -7;21)	E
78	2 354 993.107 (13)	78.554 114 5			
79	2 355 013.431 (13)	78.554 792 4	Q (1, -1;19)	(1, 0;19)	E
80	2 355 616.819 (10)	78.574 919 3	R (1, 2; 2)	(1, 1; 1)	E
81	2 380 377.924 (18)	79.400 860 8			
82	2 381 827.871 (13)	79.449 225 9	R (0, -8;23)	(0, -7;22)	E
83	2 396 147.740 (13)	79.926 885 3	Q (1, -1;35)	(1, 0;35)	E
84	2 409 486.822 (10)	80.371 829 2	R (0, 8;17)	(0, 7;16)	A
85	2 419 937.556 (13)	80.720 428 1	Q (2, 7;17)	(1, 8;17)	A
86	2 420 409.088 (13)	80.736 156 7			
87	2 420 929.421 (13)	80.753 513 2	Q (2, 7;21)	(1, 8;21)	A
88	2 424 572.902 (16)	80.875 046 6	Q (2, 7;25)	(1, 8;25)	A
89	2 453 081.083 (10)	81.825 977 2	R (0, 8;14)	(0, 7;13)	E

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT (n',K';J')	← (n",K";J")	Symm
90	2 470 030.216 (13)	82.391 339 4	R (0, 11;11)	(0, 10;10)	A
91	2 492 327.446 (16)	83.135 094 9	R (0, 7;21)	(0, 6;20)	E
92	2 505 723.371 (13)	83.581 934 9	R (0, 8;19)	(0, 7;18)	A
93	2 518 059.651 (13)	83.993 428 9	R (0, 11;12)	(0, 10;11)	A
94	2 530 714.750 (13)	84.415 557 6	R (0, 10;15)	(0, 9;14)	E
95	2 531 719.826 (47)	84.449 083 3	P (3, 9;22)	(2, 10;23)	A
96	2 548 575.761 (13)	85.011 336 8	R (1, 2; 6)	(1, 1; 5)	E
97	2 549 240.741 (13)	85.033 518 1	R (0, 8;16)	(0, 7;15)	E
98	2 551 160.986 (18)	85.097 570 6	R (0, 6-;29)	(0, 5-;28)	A
99	2 551 173.339 (18)	85.097 982 7	R (0, 6+;29)	(0, 5+;28)	A
100	2 562 557.864 (16)	85.477 729 5	R (0, -9;18)	(0, -8;17)	E
101	2 566 054.951 (16)	85.594 379 8	R (0, 11;13)	(0, 10;12)	A
102	2 593 446.076 (13)	86.508 049 4	R (0, 9;22)	(0, 8;21)	E
103	2 597 255.700 (13)	86.635 124 8	R (0, 8;17)	(0, 7;16)	E
104	2 604 442.470 (13)	86.874 849 6	R (0, -6;26)	(0, -5;25)	E
105	2 606 330.971 (10)	86.937 843 2	R (0, 10;16)	(0, 9;15)	A
106	2 606 569.116 (13)	86.945 786 9	R (0, 9;12)	(0, 8;11)	A
107	2 624 891.758 (16)	87.556 964 4			
108	2 626 661.509 (13)	87.615 997 0	R (0, 10;17)	(0, 9;16)	E
109	2 657 592.361 (13)	88.647 739 1	R (1, 3-;13)	(1, 2-;12)	A
110	2 657 768.433 (13)	88.653 612 3	R (1, 3+;13)	(1, 2+;12)	A
111	2 658 622.048 (13)	88.682 085 8	R (0, -9;20)	(0, -8;19)	E
112	2 661 937.306 (16)	88.792 670 9	R (0, 11;15)	(0, 10;14)	A
113	2 684 491.745 (13)	89.545 006 0	Q (1,-14;16)	(0,-15;16)	E
114	2 688 164.260 (13)	89.667 507 9	R (1, -1; 7)	(1, 0; 6)	E
115	2 698 128.098 (13)	89.999 865 8	R (0, 8+;23)	(0, 7+;22)	A
116	2 713 790.926 (10)	90.522 321 5	R (0,-10;10)	(0, -9; 9)	E
117	2 727 700.626 (10)	90.986 299 1	R (0,-12;13)	(0,-11;12)	E
118	2 751 013.116 (13)	91.763 920 1	R (0, 9;15)	(0, 8;14)	A
119	2 752 477.138 (13)	91.812 754 6	P (2, 3;18)	(1, 4;19)	A
120	2 754 358.536 (13)	91.875 511 3	R (1, 3-;15)	(1, 2-;14)	A
121	2 754 648.500 (13)	91.885 183 4			
122	2 754 677.156 (13)	91.886 139 3			
123	2 761 995.453 (13)	92.130 251 4	R (0,-10;11)	(0, -9;10)	E
124	2 784 304.909 (13)	92.874 414 8	R (0,-11;13)	(0,-10;12)	E
125	2 784 758.840 (13)	92.889 556 3	R (1, -1; 9)	(1, 0; 8)	E
126	2 789 645.501 (16)	93.052 557 7	P (2, 6;10)	(2, 7;11)	A
127	2 805 465.306 (13)	93.580 249 6	R (0, 11;18)	(0, 10;17)	A
128	2 806 131.503 (13)	93.602 471 6	P (2, 1+;16)	(2, 0+;17)	A
129	2 810 181.286 (13)	93.737 557 8	R (0,-10;12)	(0, -9;11)	E
130	2 810 686.419 (13)	93.754 407 2	P (2, -1;13)	(1, -2;14)	E
131	2 818 250.225 (13)	94.006 708 6	R (0, 10;21)	(0, 9;20)	E
132	2 823 435.084 (13)	94.179 656 9	R (0,-12;15)	(0,-11;14)	E
133	2 838 227.821 (13)	94.673 089 5	R (1, 2;12)	(1, 1;11)	E
134	2 842 427.037 (10)	94.813 160 3	R (0, 8;26)	(0, 7;25)	A
135	2 851 320.353 (13)	95.109 809 4	R (1, 3-;17)	(1, 2-;16)	A

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT (n',K';J')	← (n",K";J")	Symm
136	2 853 222.815 (13)	95.173 268 7	R (0, 11;19)	(0, 10;18)	A
137	2 871 225.459 (13)	95.773 772 2	R (0,-12;16)	(0,-11;15)	E
138	2 872 484.180 (16)	95.815 758 6	Q (1, 9;18)	(1, 8;18)	E
139	2 886 284.715 (18)	96.276 094 9	P (2, 6; 8)	(2, 7; 9)	A
140	2 886 583.411 (27)	96.286 058 4	P (1, 7; 9)	(1, 6;10)	A
141	2 911 288.055 (16)	97.110 116 6	Q (2, -5;13)	(1, -6;13)	E
142	2 913 896.308 (13)	97.197 118 5			
143	2 924 889.692 (10)	97.563 818 4	R (0, 11;11)	(0, 10;10)	E
144	2 928 213.963 (13)	97.674 704 1	R (0,-11;16)	(0,-10;15)	E
145	2 943 132.206 (13)	98.172 323 1	R (0, 9;19)	(0, 8;18)	A
146	2 949 382.445 (13)	98.380 808 7	R (1, 3+;19)	(1, 2+;18)	A
147	2 955 522.714 (13)	98.585 626 0	P (2, 3+;14)	(1, 4-;15)	A
148	2 986 785.331 (16)	99.628 434 6	R (0, 8;29)	(0, 7;28)	A
149	2 987 463.522 (13)	99.651 056 7	R (0, 10;24)	(0, 9;23)	A
150	2 998 309.573 (16)	100.012 842 0	R (1, 3+;20)	(1, 2+;19)	A
151	3 002 711.695 (13)	100.159 681 0	R (0,-10;16)	(0, -9;15)	E
152	3 031 919.819 (13)	101.133 959 1	R (1, 2;16)	(1, 1;15)	E
153	3 046 104.029 (27)	101.607 093 4	R (1, 3-;21)	(1, 2-;20)	A
154	3 047 949.805 (27)	101.668 661 9	Q (2, 5;21)	(2, 6;21)	E
155	3 075 190.111 (18)	102.577 300 7	R (1, -1;15)	(1, 0;14)	E
156	3 086 728.894 (13)	102.962 193 1	R (0, 9;22)	(0, 8;21)	A
157	3 098 831.232 (13)	103.365 883 6	R (0,-10;18)	(0, -9;17)	E
158	3 101 336.601 (20)	103.449 453 7	P (2, -1; 7)	(1, -2; 8)	E
159	3 110 933.621 (27)	103.769 575 9	P (1, 9;11)	(0, 10;12)	A
160	3 115 027.902 (13)	103.906 146 4	R (1, 10;12)	(1, 9;11)	A
161	3 117 413.534 (13)	103.985 722 5	R (0, 11;15)	(0, 10;14)	E
162	3 128 067.477 (84)	104.341 099 8	P (2, 0+;13)	(1, 1-;14)	A
163	3 129 119.908 (18)	104.376 205 1	R (1, 2;18)	(1, 1;17)	E
164	3 146 850.284 (13)	104.967 626 8	R (0,-10;19)	(0, -9;18)	E
165	3 149 818.056 (13)	105.066 621 0	P (2, -1; 6)	(1, -2; 7)	E
166	3 162 451.907 (13)	105.488 040 9	R (1, 10;13)	(1, 9;12)	A
167	3 177 841.194 (13)	106.001 372 3	R (1, 2;19)	(1, 1;18)	E
168	3 180 827.540 (24)	106.100 986 0	R (1, 0+;23)	(1, 1+;22)	A
169	3 182 107.196 (13)	106.143 670 8	R (0, 9;24)	(0, 8;23)	A
170	3 194 840.231 (10)	106.568 399 1	R (0,-10;20)	(0, -9;19)	E
171	3 195 409.406 (41)	106.587 384 7	R (1, 3+;24)	(1, 2+;23)	A
172	3 213 572.234 (13)	107.193 231 5	R (0, 11;17)	(0, 10;16)	E
173	3 214 575.232 (13)	107.226 687 9	R (0,-11;22)	(0,-10;21)	E
174	3 229 625.557 (13)	107.728 712 7	R (0, 9;25)	(0, 8;24)	A
175	3 246 728.052 (13)	108.299 190 5	P (2, -1; 4)	(1, -2; 5)	E
176	3 257 321.507 (16)	108.652 550 1	R (1, 10;15)	(1, 9;14)	A
177	3 261 626.216 (13)	108.796 139 8	R (0, 11;18)	(0, 10;17)	E
178	3 276 945.708 (13)	109.307 143 0	R (0, 9;26)	(0, 8;25)	A
179	3 290 728.084 (13)	109.766 873 6	R (0,-10;22)	(0, -9;21)	E
180	3 309 663.628 (13)	110.398 495 3	R (0, 11;19)	(0, 10;18)	E
181	3 314 889.912 (16)	110.572 825 4	Q (2, 6;21)	(2, 7;21)	A

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT (n',K';J')	← (n",K";J")	Symm
182	3 314 926.685 (13)	110.574 052 0	R (0,-13;14)	(0,-12;13)	E
183	3 315 477.237 (13)	110.592 416 5	Q (2, 6;20)	(2, 7;20)	A
184	3 324 050.580 (70)	110.878 392 4	R (0, 9;27)	(0, 8;26)	A
185	3 324 618.018 (13)	110.897 320 1	R (1, 2;22)	(1, 1;21)	E
186	3 324 820.330 (18)	110.904 068 5	P (2, 0+; 9)	(1, 1-;10)	A
187	3 352 288.835 (13)	111.820 319 2	R (1, 10;17)	(1, 9;16)	A
188	3 379 980.417 (13)	112.744 011 0	Q (1, 7;19)	(1, 6;19)	A
189	3 381 638.507 (13)	112.799 318 9	Q (1, 6;18)	(1, 5;18)	E
190	3 388 791.397 (13)	113.037 913 6	Q (1, 6;16)	(1, 5;16)	E
191	3 389 623.099 (10)	113.065 656 2	Q (1, 7;22)	(1, 6;22)	A
192	3 393 114.673 (13)	113.182 122 6	R (0, 12;19)	(0, 11;18)	E
193	3 405 690.330 (16)	113.601 601 3	R (0, 11;21)	(0, 10;20)	E
194	3 410 916.112 (13)	113.775 914 7	R (0,-13;16)	(0,-12;15)	E
195	3 419 317.597 (22)	114.056 158 0	P (1, -7;15)	(0, -8;16)	E
196	3 421 191.011 (13)	114.118 648 4	R (0, 14;14)	(0, 13;13)	E
197	3 421 205.241 (16)	114.119 123 1			
198	3 422 255.869 (16)	114.154 168 2	R (0, 11;31)	(0, 10;30)	A
199	3 441 755.059 (13)	114.804 591 2	R (0, 12;19)	(0, 11;18)	A
200	3 446 760.919 (13)	114.971 568 7	P (2, 3; 4)	(1, 4; 5)	A
201	3 453 680.955 (13)	115.202 396 3	R (0, 11;22)	(0, 10;21)	E
202	3 453 703.029 (55)	115.203 132 6			
203	3 458 884.783 (13)	115.375 977 3	R (0,-13;17)	(0,-12;16)	E
204	3 469 661.994 (13)	115.735 466 4	P (1, -7;14)	(0, -8;15)	E
205	3 472 563.965 (13)	115.832 265 7	R (1, 2;25)	(1, 1;24)	E
206	3 484 697.589 (13)	116.236 999 8	Q (2, -1;19)	(1, -2;19)	E
207	3 484 734.307 (10)	116.238 224 6	Q (2, -1;15)	(1, -2;15)	E
208	3 485 377.150 (10)	116.259 667 5	Q (2, -1;21)	(1, -2;21)	E
209	3 485 494.117 (10)	116.263 569 1	Q (2, -1;12)	(1, -2;12)	E
210	3 485 814.021 (10)	116.274 240 0	Q (2, -1;11)	(1, -2;11)	E
211	3 485 814.035 (10)	116.274 240 5	Q (2, -1;11)	(1, -2;11)	E
212	3 485 951.499 (13)	116.278 825 8	Q (2, -1;22)	(1, -2;22)	E
213	3 508 701.376 (18)	117.037 680 0	P (2, 4;10)	(1, 5;11)	A
214	3 511 377.343 (13)	117.126 940 6	R (1, -5;12)	(1, -4;11)	E
215	3 524 236.390 (13)	117.555 872 3	Q (2, 2;19)	(1, 3;19)	E
216	3 537 772.464 (31)	118.007 387 1	R (0, 12;21)	(0, 11;20)	A
217	3 547 317.577 (13)	118.325 777 8	R (0, 13;16)	(0, 12;15)	A
218	3 549 620.024 (13)	118.402 579 2	R (0, 11;24)	(0, 10;23)	E
219	3 550 479.188 (18)	118.431 237 8			
220	3 550 499.580 (16)	118.431 918 0			
221	3 552 114.858 (13)	118.485 797 9	R (1, -8; 8)	(1, -7; 7)	E
222	3 572 016.081 (16)	119.149 631 2	R (1, 2;27)	(1, 1;26)	E
223	3 574 871.402 (24)	119.244 874 5	P (2, 4;19)	(1, 3;20)	A
224	3 574 899.434 (22)	119.245 809 5	Q (3, 8;18)	(2, 9;18)	E
225	3 585 743.451 (31)	119.607 527 0	P (2, 0;12)	(2, -1;13)	E
226	3 585 773.983 (20)	119.608 545 4	R (0, 12;22)	(0, 11;21)	A
227	3 590 697.777 (58)	119.772 785 5	R (1, 10;22)	(1, 9;21)	A

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT (n',K';J')	← (n",K";J")	Symm
228	3 595 273.739 (28)	119.925 423 2	R (0, 13;17)	(0, 12;16)	A
229	3 607 936.912 (28)	120.347 821 2	R (1, -5;14)	(1, -4;13)	E
230	3 626 229.172 (60)	120.957 985 3	P (1, 11;15)	(1, 10;16)	A
231	3 637 998.735 (13)	121.350 575 6	Q (2, 1-; 2)	(2, 0+; 2)	A
232	3 639 529.601 (24)	121.401 639 8	Q (2, 1-; 6)	(2, 0+; 6)	A
233	3 672 254.202 (27)	122.493 215 0	R (1, 2;29)	(1, 1;28)	E
234	3 672 610.453 (18)	122.505 098 3	Q (2, 1-;29)	(2, 0+;29)	A
235	3 672 962.382 (13)	122.516 837 4	Q (2, 3;17)	(1, 4;17)	A
236	3 673 007.319 (59)	122.518 336 3	Q (1, 9;23)	(0, 10;23)	A
237	3 677 727.019 (18)	122.675 768 5	Q (2, 3;15)	(1, 4;15)	A
238	3 686 360.391 (13)	122.963 746 8	Q (2, 3; 8)	(1, 4; 8)	A
239	3 704 562.830 (16)	123.570 914 8	R (1, -5;16)	(1, -4;15)	E
240	3 705 596.645 (13)	123.605 399 2	R (1, 7; 7)	(1, 6; 6)	A
241	3 707 308.429 (18)	123.662 498 2	P (2, 1;14)	(2, 2;15)	E
242	3 718 976.393 (13)	124.051 699 6	P (1, -7; 9)	(0, -8;10)	E
243	3 737 530.379 (16)	124.670 593 9	R (1, 6; 7)	(1, 5; 6)	E
244	3 740 640.137 (25)	124.774 324 3	R (1, 9;18)	(1, 8;17)	E
245	3 752 903.118 (22)	125.183 373 3	R (1, -5;17)	(1, -4;16)	E
246	3 753 808.554 (33)	125.213 575 4	R (1, 7; 8)	(1, 6; 7)	A
247	3 768 367.779 (31)	125.699 218 9	P (1, -7; 8)	(0, -8; 9)	E
248	3 780 407.796 (30)	126.100 830 6	P (2, 2;15)	(2, 3;16)	A
249	3 786 685.863 (13)	126.310 244 4	R (0, 13;21)	(0, 12;20)	A
250	3 788 888.232 (16)	126.383 707 5	P (2, 3;16)	(1, 2;17)	E
251	3 821 767.095 (30)	127.480 428 3	Q (2, 0+;26)	(1, 1+;26)	A
252	3 824 732.449 (25)	127.579 341 9	R (2, -1; 7)	(1, -2; 6)	E
253	3 825 801.589 (40)	127.615 004 5	R (0, 12;27)	(0, 11;26)	A
254	3 833 544.867 (20)	127.873 292 5	R (1, 9;20)	(1, 8;19)	E
255	3 833 570.753 (13)	127.874 156 0	R (1, 6; 9)	(1, 5; 8)	E
256	3 837 696.521 (13)	128.011 776 8			
257	3 838 029.695 (20)	128.022 890 3	P (2, 3;15)	(1, 2;16)	E
258	3 848 978.712 (16)	128.388 110 2	R (2, -4;32)	(2, -5;31)	E
259	3 861 570.336 (37)	128.808 121 5	P (3, 4;17)	(2, 5;18)	E
260	3 871 884.032 (41)	129.152 149 4	Q (1, 8;16)	(0, 9;16)	E
261	3 873 832.453 (20)	129.217 141 7	R (0, 12;28)	(0, 11;27)	A
262	3 887 102.945 (60)	129.659 797 7	P (2, 3;14)	(1, 2;15)	E
263	3 890 036.017 (16)	129.757 634 4	R (1, -8;15)	(1, -7;14)	E
264	3 898 820.262 (22)	130.050 645 3	R (1, 7;11)	(1, 6;10)	A
265	3 901 102.774 (18)	130.126 781 7	P (2, 1;10)	(2, 2;11)	E
266	3 915 710.787 (77)	130.614 052 6	R (2, 5;18)	(2, 6;17)	E
267	3 917 100.620 (37)	130.660 412 4	P (1, 6;14)	(0, 7;15)	A
268	3 928 892.771 (16)	131.053 756 2			
269	3 929 747.581 (33)	131.082 269 6	R (0, 13;24)	(0, 12;23)	A
270	3 936 061.700 (36)	131.292 886 0	P (3, -3;14)	(2, -4;15)	E
271	3 936 105.557 (28)	131.294 348 9	P (2, 3;13)	(1, 2;14)	E
272	3 938 305.042 (16)	131.367 715 8	P (1, 5;15)	(0, 6;16)	A
273	3 938 594.928 (13)	131.377 385 4	R (1, -8;16)	(1, -7;15)	E

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT (n',K';J')	← (n",K";J")	Symm
274	3 987 271.048 (16)	133.001 045 9	R (1, -8;17)	(1, -7;16)	E
275	3 996 017.994 (20)	133.292 812 7	R (1, 7;13)	(1, 6;12)	A
276	4 019 701.781 (31)	134.082 818 8	R (2, 1+; 8)	(2, 0+; 7)	A
277	4 022 962.611 (44)	134.191 588 3	P (2, 2;10)	(2, 3;11)	A
278	4 023 106.075 (45)	134.196 373 8	R (1, 6;13)	(1, 5;12)	E
279	4 036 082.039 (40)	134.629 205 3	R (1, -8;18)	(1, -7;17)	E
280	4 044 851.534 (16)	134.921 724 2	R (1, 7;14)	(1, 6;13)	A
281	4 081 734.393 (42)	136.152 004 0	P (3, -3;11)	(2, -4;12)	E
282	4 093 878.861 (31)	136.557 099 8	R (1, 7;15)	(1, 6;14)	A
283	4 099 502.664 (30)	136.744 689 7	R (2, 0+; 6)	(1, 1-; 5)	A
284	4 109 154.350 (57)	137.066 635 3	Q (2, -4;22)	(1, -5;22)	E
285	4 111 651.424 (34)	137.149 928 7	R (2, -1;13)	(1, -2;12)	E
286	4 132 123.482 (18)	137.832 803 1	Q (2, -4; 7)	(1, -5; 7)	E
287	4 132 596.531 (25)	137.848 582 3	Q (2, -4; 6)	(1, -5; 6)	E
288	4 134 182.916 (25)	137.901 498 4	R (1, -8;20)	(1, -7;19)	E
289	4 144 254.406 (16)	138.237 447 1	P (2, -2;13)	(1, -1;14)	E
290	4 147 076.598 (13)	138.331 585 3	R (2, 0+; 7)	(1, 1-; 6)	A
291	4 178 727.817 (68)	139.387 356 3	P (3, -3; 9)	(2, -4;10)	E
292	4 183 510.955 (30)	139.546 904 6	R (1, -8;21)	(1, -7;20)	E
293	4 209 385.181 (13)	140.409 975 9	Q (2, 0;20)	(2, -1;20)	E
294	4 232 757.045 (25)	141.189 577 4	R (1, 10;10)	(1, 9; 9)	E
295	4 233 049.571 (40)	141.199 335 0	R (1, -8;22)	(1, -7;21)	E
296	4 237 443.852 (20)	141.345 912 4	P (1, 5; 9)	(0, 6;10)	A
297	4 261 394.326 (25)	142.144 814 3	R (0, 13;31)	(0, 12;30)	A
298	4 264 976.035 (13)	142.264 287 2	P (2, 2; 5)	(2, 3; 6)	A
299	4 275 615.310 (13)	142.619 175 2	P (3, -3; 7)	(2, -4; 8)	E
300	4 277 444.466 (20)	142.680 189 3	P (2, 3; 6)	(1, 2; 7)	E
301	4 292 508.895 (16)	143.182 684 6	R (1, 7;19)	(1, 6;18)	A
302	4 301 741.515 (13)	143.490 651 6	R (2, 1+;14)	(2, 0+;13)	A
303	4 324 017.265 (16)	144.233 690 7	P (3, -3; 6)	(2, -4; 7)	E
304	4 336 234.919 (13)	144.641 227 7	P (1, 5; 7)	(0, 6; 8)	A
305	4 339 959.047 (28)	144.765 451 3	P (2, -2; 9)	(1, -1;10)	E
306	4 352 122.664 (20)	145.171 185 9	P (1, -3;10)	(0, -4;11)	E
307	4 366 640.724 (18)	145.655 456 2	P (3, 5; 8)	(2, 6; 9)	A
308	4 393 727.705 (16)	146.558 980 6	R (1, 7;21)	(1, 6;20)	A
309	4 401 719.065 (18)	146.825 543 7	P (1, -3; 9)	(0, -4;10)	E
310	4 401 852.776 (22)	146.830 003 8	R (2, 3;15)	(1, 4;14)	A
311	4 405 909.219 (31)	146.965 312 2	R (2, 0; 4)	(2, -1; 3)	E
312	4 427 203.919 (33)	147.675 626 9	Q (2, 1;19)	(2, 2;19)	E
313	4 428 751.360 (38)	147.727 244 0	Q (2, 1;16)	(2, 2;16)	E
314	4 436 646.798 (64)	147.990 607 5	R (2, 2;19)	(1, 3;18)	E
315	4 451 191.154 (16)	148.475 755 0	P (1, -3; 8)	(0, -4; 9)	E
316	4 477 612.889 (22)	149.357 089 2	R (2, 0+;14)	(1, 1-;13)	A
317	4 493 807.787 (20)	149.897 292 8	R (2, 3;17)	(1, 4;16)	A
318	4 524 542.348 (18)	150.922 487 4	R (2, 0+;15)	(1, 1-;14)	A
319	4 550 672.494 (16)	151.794 095 3	Q (2, 2;15)	(2, 3;15)	A

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm⁻¹)	ASSIGNMENT (n',K';J') ← (n",K";J") Symm
320	4 551 164.858 (16)	151.810 518 8	Q (2, 2;14) (2, 3;14) A
321	4 559 501.011 (13)	152.088 582 9	P (2, 5;15) (2, 4;16) A
322	4 584 390.672 (13)	152.918 812 7	R (2, 3;19) (1, 4;18) A
323	4 609 380.951 (13)	153.752 398 6	Q (2, 3;15) (1, 2;15) E
324	4 611 155.399 (16)	153.811 587 8	Q (2, 3;13) (1, 2;13) E
325	4 625 560.409 (22)	154.292 087 3	R (2, 1+;21) (2, 0+;20) A
326	4 653 771.352 (16)	155.233 103 0	R (1, 7;26) (1, 6;25) A
327	4 658 094.988 (16)	155.377 324 0	Q (3, -3;14) (2, -4;14) E
328	4 685 774.257 (34)	156.300 605 0	
329	4 711 149.046 (16)	157.147 016 9	Q (1, 5;15) (0, 6;15) A
330	4 714 898.256 (22)	157.272 077 1	Q (1, 5;13) (0, 6;13) A
331	4 743 235.327 (13)	158.217 300 0	Q (2, -5;13) (1, -4;13) E
332	4 747 720.028 (18)	158.366 893 5	Q (2, -5; 7) (1, -4; 7) E
333	4 773 886.612 (13)	159.239 716 8	P (2, 1-;12) (1, 0+;13) A
334	4 776 669.036 (13)	159.332 528 5	P (1, 5; 8) (0, 6; 9) E
335	4 798 086.136 (16)	160.046 926 1	Q (3, 5;12) (2, 6;12) A
336	4 805 829.110 (28)	160.305 203 9	Q (2, -2;23) (1, -1;23) E
337	4 808 670.073 (13)	160.399 968 2	R (2, 3; 4) (1, 2; 3) E
338	4 809 348.182 (16)	160.422 587 5	Q (2, -2;21) (1, -1;21) E
339	4 817 399.763 (16)	160.691 159 3	Q (2, -2;15) (1, -1;15) E
340	4 818 417.734 (16)	160.725 115 2	Q (2, -2;14) (1, -1;14) E
341	4 831 812.611 (18)	161.171 920 2	Q (1, -6;20) (0, -7;20) E
342	4 864 903.365 (24)	162.275 708 9	R (2, 1; 9) (2, 2; 8) E
343	4 865 624.712 (33)	162.299 770 5	Q (1, -3;19) (0, -4;19) E
344	4 874 787.440 (61)	162.605 406 2	P (1, 5; 6) (0, 6; 7) E
345	4 877 294.558 (25)	162.689 034 6	Q (1, -3;14) (0, -4;14) E
346	4 886 600.050 (18)	162.999 432 4	R (2, 4; 7) (1, 3; 6) A
347	4 888 271.160 (28)	163.055 174 7	Q (1, -3; 6) (0, -4; 6) E
348	4 898 892.893 (16)	163.409 477 5	R (2, 0+;23) (1, 1-;22) A
349	4 908 012.334 (61)	163.713 669 3	P (3, -2;21) (3, -3;22) E
350	4 921 390.276 (30)	164.159 909 5	R (2, -2; 2) (1, -1; 1) E
351	4 942 645.309 (16)	164.868 901 0	P (1, 2; 4) (0, 3; 5) A
352	4 952 411.436 (37)	165.194 664 0	R (2, 3; 7) (1, 2; 6) E
353	4 976 967.797 (18)	166.013 776 0	P (3, 1;16) (2, 0;17) E
354	4 989 726.743 (16)	166.439 368 6	R (2, -5; 5) (1, -4; 4) E
355	5 008 402.608 (16)	167.062 328 4	R (2, 1;12) (2, 2;11) E
356	5 017 465.685 (13)	167.364 640 1	R (2, -2; 4) (1, -1; 3) E
357	5 043 812.909 (24)	168.243 488 9	P (3, 0;16) (2, 1;17) E
358	5 056 152.578 (27)	168.655 096 0	R (2, 1;13) (2, 2;12) E
359	5 077 277.209 (25)	169.359 737 8	R (2, 4;11) (1, 3;10) A
360	5 133 068.320 (16)	171.220 729 0	R (2, -5; 8) (1, -4; 7) E
361	5 143 135.593 (16)	171.556 537 1	R (2, 3;11) (1, 2;10) E
362	5 166 554.427 (38)	172.337 705 3	R (1,-12;15) (1,-11;14) E
363	5 177 664.177 (18)	172.708 286 6	R (2, 2;13) (2, 3;12) A
364	5 208 814.302 (27)	173.747 343 0	R (2, -2; 8) (1, -1; 7) E
365	5 238 036.664 (18)	174.722 096 0	R (2, 3;13) (1, 2;12) E

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm⁻¹)	ASSIGNMENT (n',K';J')	← (n",K";J")	Symm
366	5 241 206.883 (58)	174.827 843 2	P (3, 2+; 9)	(2, 1-;10)	A
367	5 266 640.867 (16)	175.676 229 6	R (2, 4;15)	(1, 3;14)	A
368	5 268 264.939 (28)	175.730 402 8	P (1, 1; 6)	(0, 2; 7)	E
369	5 285 357.444 (30)	176.300 547 4	R (2, 3;14)	(1, 2;13)	E
370	5 298 811.890 (28)	176.749 339 4	P (3, 2-; 8)	(2, 1+; 9)	A
371	5 331 699.080 (22)	177.846 337 9	Q (2, 5; 9)	(2, 4; 9)	A
372	5 332 585.608 (20)	177.875 909 3	R (2, 3;15)	(1, 2;14)	E
373	5 334 618.939 (42)	177.943 734 0	P (1, 0; 9)	(0, 1;10)	E
374	5 364 312.563 (18)	178.934 206 6	Q (2, 1+;20)	(1, 0+;20)	A
375	5 374 113.554 (28)	179.261 132 5	Q (2, 1+;17)	(1, 0+;17)	A
376	5 377 002.390 (24)	179.357 493 7	Q (2, 1+;16)	(1, 0+;16)	A
377	5 394 982.963 (18)	179.957 261 1	Q (2, 1+; 7)	(1, 0+; 7)	A
378	5 397 103.274 (22)	180.027 987 0	Q (2, 1+; 5)	(1, 0+; 5)	A
379	5 408 524.504 (53)	180.408 958 3	P (1, 2+; 9)	(0, 1-;10)	A
380	5 409 566.271 (41)	180.443 707 9	P (1, 2-;10)	(0, 1+;11)	A
381	5 452 283.794 (40)	181.868 611 1	R (1,-12;21)	(1,-11;20)	E
382	5 463 414.253 (20)	182.239 883 2	R (2, -6;12)	(2, -5;11)	E
383	5 483 088.710 (28)	182.896 152 4	P (1, 0; 6)	(0, 1; 7)	E
384	5 493 515.546 (22)	183.243 954 3	R (2, -2;14)	(1, -1;13)	E
385	5 494 811.421 (66)	183.287 180 0	Q (1, 9;26)	(0, 9;26)	A
386	5 496 111.529 (27)	183.330 546 9	R (2, 1-; 2)	(1, 0+; 1)	A
387	5 497 947.933 (113)	183.391 802 8	Q (1, 9;25)	(0, 9;25)	A
388	5 500 989.829 (145)	183.493 269 5	Q (1, 9;24)	(0, 9;24)	A
389	5 501 011.880 (164)	183.494 005 0	R (2, 4;20)	(1, 3;19)	A
390	5 503 905.605 (219)	183.590 529 3	Q (1, 9;23)	(0, 9;23)	A
391	5 506 637.840 (85)	183.681 666 9	Q (1, 9;22)	(0, 9;22)	A
392	5 509 191.171 (80)	183.766 836 8	Q (1, 9;21)	(0, 9;21)	A
393	5 511 497.827 (56)	183.843 778 6			
394	5 513 737.245 (138)	183.918 477 5	Q (1, 9;19)	(0, 9;19)	A
395	5 515 766.248 (31)	183.986 157 8	Q (1, 9;18)	(0, 9;18)	A
396	5 516 416.550 (34)	184.007 849 5	Q (2, 4;10)	(2, 3;10)	E
397	5 516 745.747 (58)	184.018 830 4	Q (2, 4; 9)	(2, 3; 9)	E
398	5 517 608.415 (41)	184.047 605 9	Q (1, 9;17)	(0, 9;17)	A
399	5 519 284.299 (63)	184.103 507 3	Q (1, 9;16)	(0, 9;16)	A
400	5 520 800.678 (225)	184.154 088 3	Q (1, 9;15)	(0, 9;15)	A
401	5 522 133.924 (365)	184.198 560 6	Q (1, 9;14)	(0, 9;14)	A
402	5 523 374.941 (73)	184.239 956 5	Q (1, 9;13)	(0, 9;13)	A
403	5 524 446.359 (158)	184.275 695 1	Q (1, 9;12)	(0, 9;12)	A
404	5 550 177.314 (44)	185.133 987 4	P (1, 1+; 8)	(0, 2-; 9)	A
405	5 550 561.017 (69)	185.146 786 3	P (1, -2;14)	(0, -3;15)	E
406	5 567 154.391 (25)	185.700 281 7	R (2, 3;20)	(1, 2;19)	E
407	5 595 283.868 (49)	186.638 580 1	Q (2, 6;14)	(1, 5;14)	E
408	5 605 907.532 (28)	186.992 947 4	Q (1, 1; 7)	(0, 2; 7)	E
409	5 606 489.726 (36)	187.012 367 3	Q (2, -9;16)	(1, -8;16)	E
410	5 625 937.594 (27)	187.661 078 3	Q (2, -3; 7)	(2, -2; 7)	E
411	5 660 142.177 (84)	188.802 020 4	R (2, 3;22)	(1, 2;21)	E

TABLE I—*Continued*

No	FREQUENCY (MHz)	WAVENUMBER (cm^{-1})	ASSIGNMENT (n',K';J') ←	(n",K";J") Symm
412	5 669 398.998 (84)	189.110 794 7	R (2, 5; 7)	(2, 4; 6) A
413	5 703 472.089 (46)	190.247 350 7	Q (2, 8;15)	(1, 7;15) A
414	5 704 335.534 (44)	190.276 152 1	Q (2, 8;14)	(1, 7;14) A
415	5 721 027.483 (18)	190.832 935 6	Q (3, 2-;11)	(2, 1-;11) A
416	5 733 557.611 (52)	191.250 895 7	Q (3, 2+;12)	(2, 1+;12) A
417	5 751 260.664 (50)	191.841 406 0	P (1, -2;10)	(0, -3;11) E
418	5 751 995.230 (93)	191.865 908 4	Q (1, 2-;26)	(0, 1-;26) A
419	5 773 016.859 (66)	192.567 114 5	Q (1, 2-;24)	(0, 1-;24) A
420	5 774 733.609 (58)	192.624 379 1	R (2, -2;20)	(1, -1;19) E
421	5 786 617.501 (66)	193.020 783 1	Q (1, 0;21)	(0, 1;21) E
422	5 815 174.243 (37)	193.973 333 5	Q (1, 0;11)	(0, 1;11) E
423	5 816 832.026 (53)	194.028 631 2	Q (1, 0;10)	(0, 1;10) E
424	5 830 427.638 (46)	194.482 132 0	P (1, 5+;24)	(0, 4-;25) A
425	5 849 088.943 (51)	195.104 606 1	Q (1, 2-;16)	(0, 1-;16) A
426	5 862 512.530 (31)	195.552 368 8	Q (3, 0;15)	(2, 1;15) E
427	5 863 217.788 (25)	195.575 893 6	Q (3, 0;14)	(2, 1;14) E
428	5 882 956.028 (38)	196.234 290 5	R (2, 1-;10)	(1, 0+; 9) A
429	5 893 679.627 (49)	196.591 991 2	R (2, 6; 6)	(1, 5; 5) E
430	5 893 965.857 (49)	196.601 538 8	R (1, 2+;15)	(0, 3-;14) A
431	5 914 979.079 (25)	197.302 464 5	Q (1, 2-; 4)	(0, 1-; 4) A
432	5 928 016.495 (61)	197.737 345 8		
433	5 928 074.011 (59)	197.739 264 4		
434	5 929 343.060 (36)	197.781 595 3		
435	5 929 385.347 (34)	197.783 005 8		
436	5 953 477.972 (25)	198.586 649 3	Q (1, 1+;18)	(0, 2+;18) A
437	5 967 613.992 (33)	199.058 176 2	Q (2, 7; 8)	(1, 6; 8) E
438	5 968 287.887 (25)	199.080 654 9	Q (2, 7;21)	(1, 6;21) E
439	5 989 361.199 (30)	199.783 584 9	Q (1, 1-; 7)	(0, 2-; 7) A
440	6 001 364.217 (34)	200.183 962 5	P (1, 0; 2)	(0, -1; 3) E
441	6 036 471.069 (60)	201.355 001 0	Q (3, 3; 7)	(3, 4; 7) E
442	6 036 524.268 (50)	201.356 775 6	R (2, 6; 9)	(1, 5; 8) E
443	6 038 646.026 (34)	201.427 549 8	R (1, 1; 9)	(0, 2; 8) E
444	6 486 008.401 (31)	216.349 952 4	R (1, 0;14)	(0, 1;13) E
445	6 486 084.311 (46)	216.352 484 5	P (1, 1-; 5)	(0, 0+; 6) A

20 kHz (1σ). These measurements make methanol an excellent molecule for FIR frequency and wavelength calibration.

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