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High-Resolution Infrared Spectra of Water Vapor ν_2 Band of $H_2{}^{18}O$

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The ν_2 band of $H_2{}^{18}O$ occurring in the region 5–7.5 μ was recorded with a high-resolution vacuum infrared spectrograph and an analysis was presented of the rotational structure observed; comparison of the ground state (000) energy levels determined from the ν_2 band with those derived earlier by Fraley, Rao, and Jones from the ν_1 and ν_3 bands at 2.7 μ was of assistance in this analysis. Values for the energy levels of the first excited state (010) were evaluated.

INTRODUCTION AND EXPERIMENTAL DETAILS

In a previous investigation, Fraley, Rao, and Jones (*1*) reported the measurement and analysis of the rotational structure observed in the ν_1 and ν_3 bands of $H_2{}^{18}O$ occurring in the near infrared at 2.5–3.0 μ region. A few of the ground-state energy levels derived from these bands have been found to be consistent with the recent work by Powell and Johnson (*2*) who observed, in the laboratory, microwave absorption by $H_2{}^{18}O$ at 5.33 cm. The 0.194-cm^{-1} energy-level difference between the 6_{16} and 5_{23} levels in the ground state obtained by Fraley, Rao, and Jones compares well with the measurement of 0.188 cm^{-1} (5625.147 MHz; $c = 2.9979250 \times 10^{10}$ cm per sec was used for the conversion of Hz to cm per sec) by Powell and Johnson considering that the basic infrared observational data had an estimated accuracy of about ± 0.005 cm^{-1}. The interest in this energy-level difference is due to the detection of the emission from the 6_{16}–5_{23} rotational transition in the $H_2{}^{16}O$ molecule from sources in the galaxy (*3*).

The ν_2 band of $H_2{}^{18}O$ has now been recorded employing a 3.5-m Littrow-type vacuum infrared spectrograph equipped with a liquid helium cooled Ge:Hg detector. In the best regions of the grating, a working spectral resolution of about 0.04 cm^{-1} was achieved.

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INTERPRETATION AND RESULTS

Notation

Each energy level is labeled by the set of quantum numbers J, K_{-1}, k_{+1} (written also in the form $J_{K_{-1}K_{+1}}$), K_{-1} and K_{+1} being the limiting prolate and oblate symmetric top quantum numbers. The ν_2 band of water vapor is a B-type band, the change in the dipole moment being along the axis of intermediate moment of inertia (I_b). For such a band the selection rules governing the rotational transitions are:

$$\Delta J = 0, \pm 1 \quad \text{and} \quad ee \leftrightarrow oo \quad \text{and} \quad eo \leftrightarrow oe$$

where the symbols e and o stand for even and odd, respectively; the first of the two letters ee, oo, eo or oe refers to K_{-1} and the second letter refers to K_{+1}. For example, "eo" means that the K_{-1} value is even and the K_{+1} value is odd. These selection rules imply that

$$\Delta K_{-1} = \pm 1, \pm 3, \pm 5 \cdots ; \quad \text{and} \quad \Delta K_{+1} = \pm 1, \pm 3, \pm 5 \cdots .$$

The strong lines are those for which ΔK_{-1} or ΔK_{+1} changes only by ± 1. A few

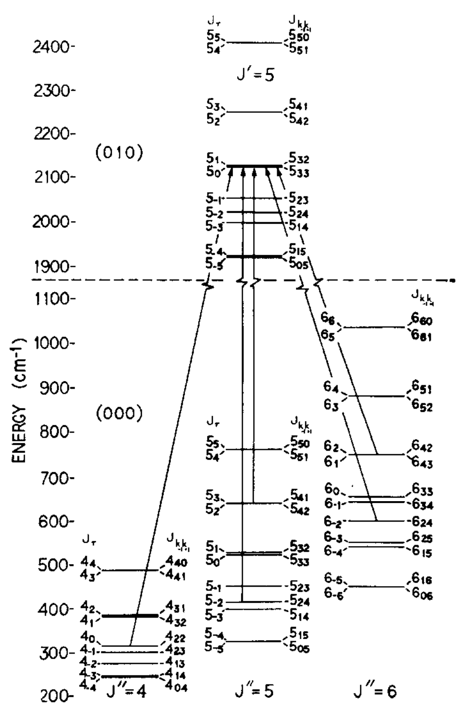


FIG. 1. Schematic energy-level diagram displaying possible transitions to the 5_{33} level of the ν_2 band of water vapor.

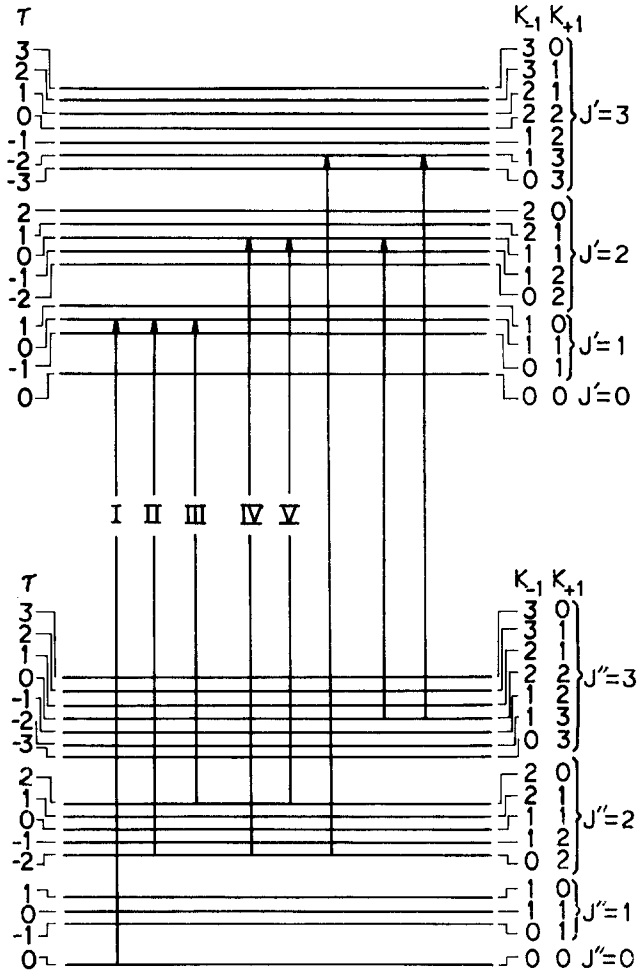


FIG. 2. Schematic energy-level diagram illustrating the procedure for the analysis of the ν_2 band of water vapor.

transitions have been assigned to ΔK_{-1} and ΔK_{+1} changing by ± 3; however, these are much weaker. An illustration of the application of these selection rules is displayed in the energy level diagram shown in Fig. 1. The transitions indicated in this figure have the common upper state which can be designated either as 5_{33} or as 5_0 . The 5_{33} notation gives the $J'_{K_{-1}K_{+1}}$ values for this level; i.e., in this case $J' = 5$ and $K'_{-1} = 3$ and $K'_{+1} = 3$. The notation 5_0 has been used to give the $J_\tau{}'$ values where $\tau = (K'_{-1} - K'_{+1})$. In other words, here we are concerned with $J' = 5$ and $\tau = (3 - 3) = 0$. Although this is only a schematic representation, irregular spacings of energy levels are shown to illustrate why the water vapor spectrum presents a complex structure.

Analysis

The procedure adopted in the analysis of the rotational structure observed in the ν_2 fundamental of $H_2{}^{18}O$ is discussed below briefly.

First, an approximate value of 1590 cm^{-1} was calculated (*4*) for the band center of the ν_2 band of $H_2{}^{18}O$. In the energy-level diagram shown in Fig. 2 this represents the energy difference between the 0_{00} level of the ground state and 0_{00} level of the first excited vibrational state. Transitions from the ground state 0_{00} to the lowest levels 0_{00} and 1_{01} of the first excited vibrational state are not allowed in view of the selection rules applicable. The first allowed transition takes place from the ground state 0_{00} to the 1_{11} level of the excited vibrational state. As a result, to begin with, we should search for the $1_{11} \leftarrow 0_{00}$ transition. An approximate value for this transition can be calculated by adding to 1590 cm^{-1} the energy difference between the 0_{00} and the 1_{11} levels of the upper state. This particular energy difference has been evaluated to be 36 cm^{-1} on the basis of a rigid rotor calculation.[2] This leads to a value $1590 + 36 = 1626$ cm^{-1} for the transition $1_{11} \leftarrow 0_{00}$. A search has been made for this line in the wavenumber region included between 1621 and 1631 cm^{-1}. As may be noticed from Fig. 3 which reproduces the $H_2\,^{18}O$ spectrum in this region, one finds about ten lines (outside of the $H_2\,^{16}O$ lines appearing in the background), any one of which can belong to the transition we are seeking. In determining which of these lines is due to the transition $1_{11} \leftarrow 0_{00}$, the following information is useful.

By examining again the energy-level diagram (Fig. 2) it is readily noticed that transitions marked II and III originate in the ground-state energy levels 2_{02} and 2_{20} and have the common upper-state level 1_{11}. From the wavenumbers of each of the lines observed in the region 1621–1631 cm^{-1}, the ground-state energy values for the 2_{02} and 2_{20} levels given by Fraley, Rao, and Jones (*1*) have been subtracted to arrive at possible values for the transitions labeled II and III in the energy-level diagram. An examination of the spectrum shows that, for the line with serial number 492 in Fig. 3, we can locate lines close to the predicted positions of transitions II and III. It is also clear from the energy-level diagram in Fig. 2 that two other transitions can originate from the 2_{02} and 2_{20} levels of the ground state and they have the common upper-state level 2_{11}. These are labeled IV and V in this figure. Again, by using the rigid rotor approximation it is possible to evaluate the approximate spectral region for the transitions labeled IV and V; then we search for a pair of lines in this region having a $\Delta\nu = 64.853$ cm^{-1}.[3] In this manner, identifications have been made of the different transitions in the ν_2 band. The ground-state combination relations of the type shown in Fig. 1 and the agreement between the values for the ground-state energy levels determined

[2] The A, B, and C values for $H_2\,^{18}O$ used in this calculation were estimated from a knowledge of the corresponding values for $H_2\,^{16}O$, using an isotopic substitution in the expressions for the principal moments of inertia of a water vapor type molecule.

[3] This value of $\Delta\nu$ represents the energy difference (in cm^{-1}) between the ground state levels 2_{02} and 2_{20} as obtained by Fraley, Rao and Jones (*1*).

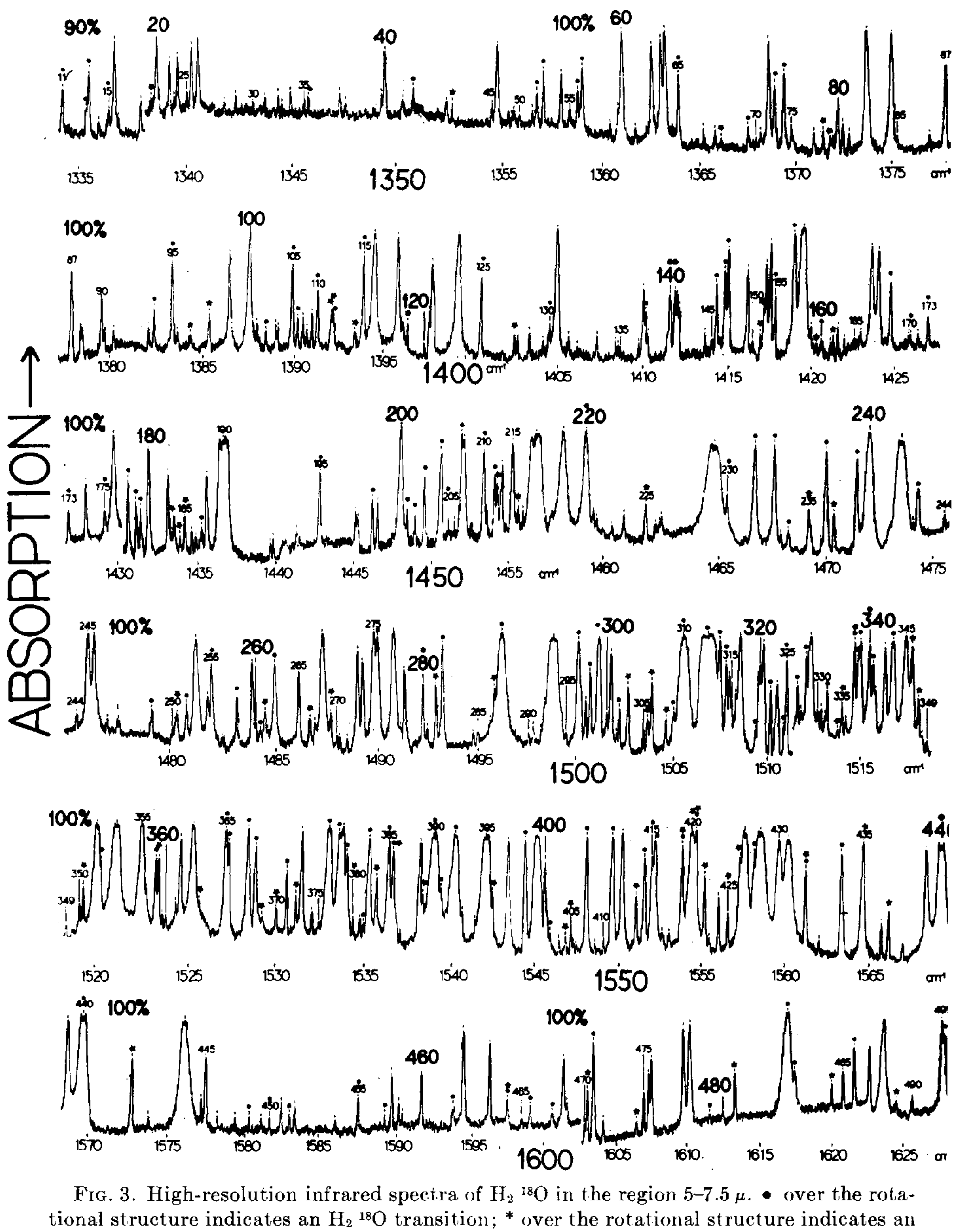
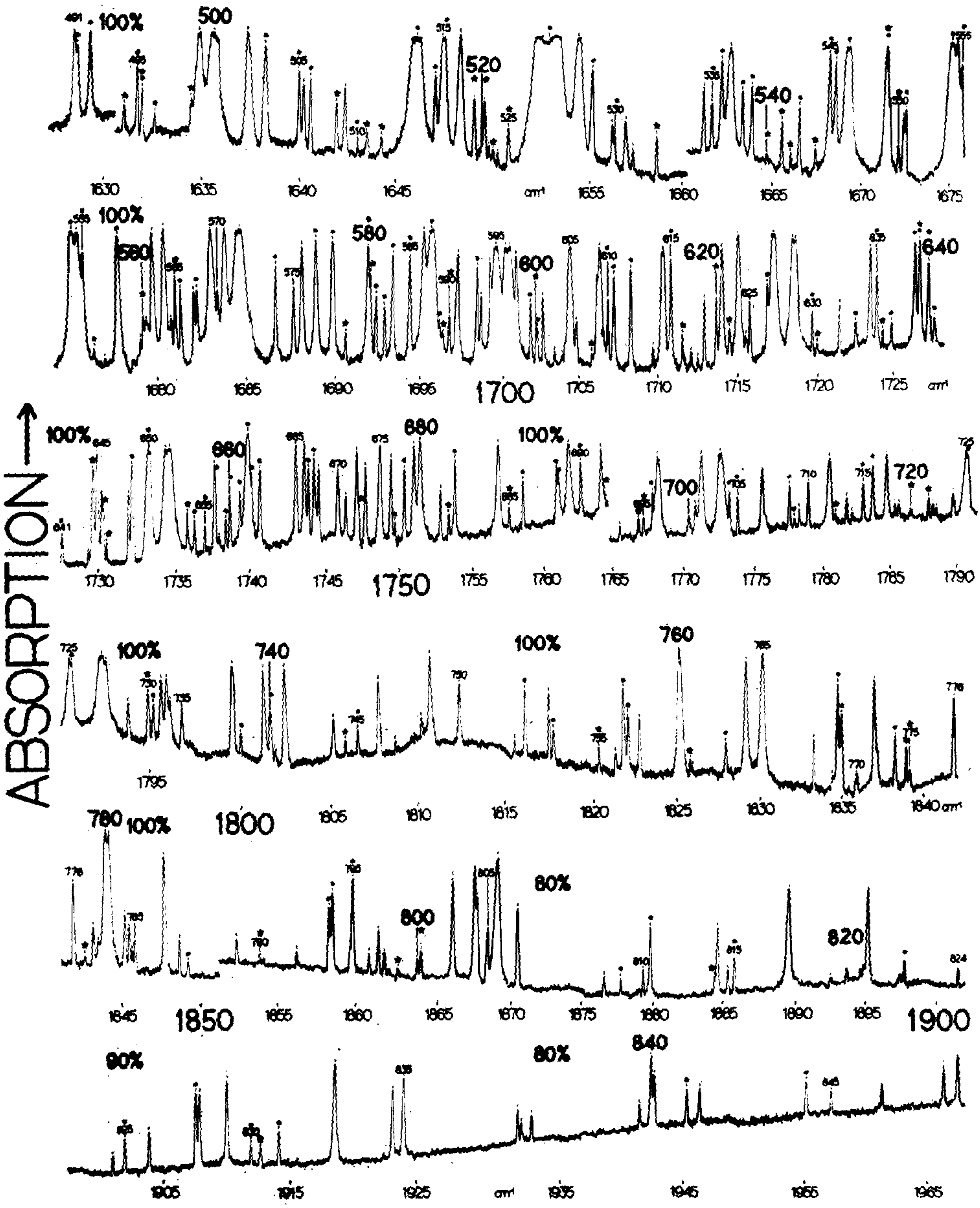


FIG. 3. High-resolution infrared spectra of $H_2\,^{18}O$ in the region 5–7.5 μ. • over the rotational structure indicates an $H_2\,^{18}O$ transition; * over the rotational structure indicates an $H_2\,^{17}O$ transition. All others are due to $H_2\,^{16}O$.



ABSORPTION
100%
500
520
540
580
600
620
640
660
680
700
720
740
760
780
800
820
840
80%
90%
1700
1750
1800
1850
1900

Fig. 3 (Cont.)

TABLE I

ENERGY LEVELS OF THE GROUND STATE (000) AND THE FIRST EXCITED STATE (010) OF $H_2{}^{18}O$ (cm^{-1})

KEY TO COLUMNS:

(1) Values for the energy levels of the ground state (000) derived from the ν_2 band (this work)

(2) Values for the energy levels of the ground state (000) derived from the ν_1 and ν_3 bands (Fraley, Rao and Jones, 1969)

(3) Column #2 minus column #1

(4) Values for the energy levels of the first excited state (010)

J	K_{-1}	K_{+1}	000 (1)	000 (2)	000 (3)	010 (4)
0	0	0	0	0	0	1588.275
1	0	1	23.759	.756	-0.003	1612.025
1	1	1	36.747	.751	+0.004	1628.062
1	1	0	42.023	.024	+0.001	1633.644
2	0	2	69.944	.932	-0.012	1658.330
2	1	2	78.988	.995	+0.007	1670.045
2	1	1	94.790	.790	0.000	1686.745
2	2	1	133.482	.479	-0.003	1734.222
2	2	0	134.784	.785	+0.001	1735.442
3	0	3	136.344	.344	0.000	1725.034
3	1	3	141.581	.576	-0.005	1732.261
3	1	2	172.891	.887	-0.004	1765.406
3	2	2	204.764	.762	-0.001	1805.578
3	2	1	210.799	.800	+0.001	1811.291
3	3	1	282.093	.093	0.000	1897.461
3	3	0	282.305	.304	-0.001	1897.624
4	0	4	221.234	.237	+0.003	1810.207
4	1	4	223.833	.830	-0.003	1814.092
4	1	3	274.793	.811	+0.018	1868.260
4	2	3	298.622	.629	+0.007	1899.614
4	2	2	314.461	.460	-0.001	1914.879
4	3	2	379.293	.293	0.000	1994.708
4	3	1	380.702	.700	-0.002	1995.877
4	4	1	482.638	.632	-0.006	2117.001
4	4	0	482.672	.660	-0.012	2117.027
5	0	5	324.034	.026	-0.008	1913.040
5	1	5	325.216	.194	-0.024	1914.939
5	1	4	398.384	.371	-0.013	1993.277
5	2	4	414.176	.177	+0.001	2015.455
5	2	3	445.155	.160	+0.005	2045.923
5	3	3	500.594	.604	+0.010	2116.160
5	3	2	505.745	.726	-0.019	2120.462
5	4	2	604.564	.549	-0.015	2238.991
5	4	1	604.797	.796	-0.001	2239.145
5	5	1		733.708		
5	5	0		733.712		
6	0	6	444.861	.848	-0.013	2033.484
6	1	6	445.364	.354	-0.010	2034.826
6	1	5	541.169	.183	+0.014	2138.100
6	2	5	550.456	.447	-0.009	2152.219
6	2	4	601.252	.246	-0.006	2202.986
6	3	4	645.377	.377	0.000	2261.220
6	3	3	658.623	.601	-0.022	2272.699
6	4	3	751.046	.031	-0.015	2385.570
6	4	2	752.214	.195	-0.019	2386.385
6	5	2	880.079	.100	+0.021	
6	5	1	880.121	.146	+0.025	
6	6	1	1033.495	.548	+0.053	
6	6	0	1033.495	.548	+0.053	
7	0	7	583.757	.767	+0.010	2171.758
7	1	7	583.973	.972	-0.001	2172.163
7	1	6	701.692	.697	+0.005	2300.796
7	2	6	706.608	.608	0.000	2308.901
7	2	5	780.441	.428	-0.013	2384.035
7	3	5	812.746	.753	+0.007	2429.143
7	3	4	839.564	.561	-0.003	2453.037
7	4	4	921.927	.908	-0.019	2556.668
7	4	3	925.688	.698	+0.010	2559.311
7	5	3	1051.010	.036	+0.026	
7	5	2	1051.308	.334	+0.026	
8	0	8	740.947	.940	-0.007	2327.869
8	1	8	741.009	.013	+0.004	2328.065
8	1	7	879.482	.481	-0.001	2480.517
8	2	7	881.895	.902	+0.007	2484.893
8	2	6	980.227	.230	+0.003	2586.669
8	3	6	1001.709	.718	+0.009	2618.910
8	3	5	1047.314	.317	+0.003	2661.610
8	4	5	1116.620	.635	+0.015	2751.426
8	4	4	1126.437	.433	-0.004	2758.088
8	5	4		1246.319		
8	5	3		1247.234		
9	0	9	916.261			2502.001
9	1	9	916.341			2502.058
9	1	8	1074.777	.779	+0.002	2677.268
9	2	8	1075.922	.932	+0.010	2679.523
9	2	7	1198.187	.194	+0.007	2808.289
9	3	7	1211.190			2829.750
9	3	6	1279.830	.822	-0.008	2894.676

TABLE II

MEASUREMENTS AND ASSIGNMENTS OF THE $H_2\,^{18}O$ SPECTRUM IN THE 5–7.5 μ REGION

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J''	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1329.278							3	20	*
1329.909	8	3	5	9	4	6	4	40	0 16
1330.090							5	10	*
1332.294	7	0	7	7	3	4	6	10	0 18
1332.473							7	10	*
1332.595							8	10	**
1332.750	7	2	5	7	5	2	9	30	0 16
1333.642							10	10	*
1334.306	6	4	3	7	5	2	11	40	0 18
1335.378	6	4	2	7	5	3	12	20	0 18
1335.495	6	3	4	7	4	3	13	60	0 18
1336.003							14	10	*
1336.423	7	3	4	8	4	5	15	20	0 18
	6	5	2	7	6	1			0 16
1336.672	6	5	1	7	6	2	16	80	0 16
1336.879							17	10	*
1337.901							18	30	**
1338.306	7	3	4	8	4	5	19	20	0 17
1338.548	6	4	3	7	5	2	20	80	0 16
1338.667							21	20	**
1339.146	6	6	0	7	7	1	22	60	**
	6	6	1	7	7	0			0 16
1339.391							23	10	*
1339.519	6	4	2	7	5	3	24	60	0 16
1339.952							25	10	*
1340.170	7	3	4	8	4	5	26	70	0 16
1340.474	6	3	4	7	4	3	27	80	0 16
1341.796							28	10	*
1342.295							29	10	*
1343.108							30	10	*
1343.674							31	10	*
1344.306							32	10	*
1344.457							33	10	**
1344.903							34	10	*
1345.531							35	10	**
1345.728	3	0	3	4	3	2	36	10	0 18
1347.210							37	20	*
1347.465							38	10	*
1349.210							39	20	*
1349.382	3	0	3	4	3	2	40	70	0 16
1350.240							41	20	*
1350.747	6	3	3	7	4	4	42	20	0 18
1352.371							43	10	*
1352.659	6	3	3	7	4	4	44	10	0 17
1354.584							45	10	*
1354.843	6	3	3	7	4	4	46	70	0 16
1355.453							47	10	*
1355.612							48	10	
1355.729							49	10	*
1355.993							50	10	*
1356.637							51	10	**
1356.829	5	2	4	6	3	3	52	30	0 18
1357.160	5	5	1	6	6	0	53	50	0 18
	5	5	0	6	6	1			0 18
1358.034	11	1	11	12	0	12	54	50	0 16
	11	0	11	12	1	12			0 16
1358.472							55	20	*
1358.870	5	4	2	6	5	1	56	30	0 18
1359.076	5	4	1	6	5	2	57	50	0 18
1360.512							58	10	*
1360.886							59	20	*
1361.082	5	5	1	6	6	0	60	90	0 16
	5	5	0	6	6	1			0 16
1361.796							61	10	
1362.604	5	2	4	6	3	3	62	80	0 16
1363.077	5	4	2	6	5	1	63	80	0 16
1363.262	5	4	1	6	5	2	64	90	0 16
1363.947	5	3	3	6	4	2	65	50	0 18
1365.302							66	20	*
1365.867							67	20	*
1366.173	5	3	3	6	4	2	68	10	0 17
1367.583	9	2	7	10	3	8	69	20	0 18
1367.979							70	10	
1368.208							71	10	*
1368.625	5	3	3	6	4	2	72	80	0 16
1368.937	4	1	4	5	2	3	73	50	0 18
1369.418	5	3	2	6	4	3	74	70	0 18
1369.833							75	20	*
1370.995							76	10	*
1371.477	5	3	2	6	4	3	77	10	0 17
1371.845	4	1	4	5	2	3	78	10	0 17
1372.019							79	10	**
1372.259							80	40	**
1372.529							81	20	**
1372.866							82	10	*
1373.763	5	3	2	6	4	3	83	90	0 16
1375.084	4	1	4	5	2	3	84	90	0 16
1375.436							85	10	**
1377.174							86	10	*
1378.011	10	0	10	11	1	11	87	70	0 16
	10	1	10	11	0	11			0 16
1378.496	7	1	6	7	4	3	88	20	0 16
1378.594							89	20	*
1379.580	8	2	6	9	3	7	90	50	0 16
1379.739	2	0	2	3	3	1	91	20	0 16
1380.228	6	0	6	6	3	3	92	10	0 16
1382.059							93	10	**
1382.336	7	2	5	8	3	6	94	30	0 18
1383.332	4	4	1	5	5	0	95	70	0 18
	4	4	0	5	5	1			0 18
1383.602							96	10	*
1384.306	7	2	5	8	3	6	97	10	0 17
1385.316	4	4	1	5	5	0	98	30	0 17
	4	4	0	5	5	1			0 17
1386.483	7	2	5	8	3	6	99	80	0 16
1387.528	4	4	0	5	5	1	100	90	0 16
	4	4	1	5	5	0			0 16
1387.968							101	20	*
1388.479	9	1	8	10	2	9	102	10	0 18
1389.007	6	1	5	6	4	2	103	20	0 16
1389.132							104	20	*
1389.912	4	3	2	5	4	1	105	70	0 18
1390.228	6	2	4	7	3	5	106	20	0 18
1390.518	5	1	4	5	4	1	107	20	0 16
1390.755							108	10	**
1391.027	11	0	11	11	1	10	109	20	0 16
1391.328	4	3	1	5	4	2	110	40	0 18
	9	2	8	10	1	9			0 18
1392.073	4	3	2	5	4	1	111	20	0 17
1392.147	6	2	4	7	3	5	112	30	0 17
1392.250	9	1	9	10	0	10	113	20	0 18
	9	0	9	10	1	10			0 18
1393.450	4	3	1	5	4	2	114	10	0 17
1393.885	4	2	3	5	3	2	115	70	0 18
1394.472	4	3	2	5	4	1	116	90	0 16

Isotopic Species:

016 indicates $H_2\,^{16}O$;

017 indicates $H_2\,^{17}O$; and

018 indicates $H_2\,^{18}O$

* indicates HDO identified by N. M. Gailar and F. P. Dickey, *J. Mol. Spectrosc.* **4,** 1 (1960).

** indicate HDO and High J $H_2\,^{16}O$ transitions along with lines belonging to the "hot" band ($2\nu_2 - \nu_2$)—See D. M. Gates, R. F. Calfee, D. W. Hansen and W. S. Benedict, National Bureau of Standards (U.S.), Monograph 71, (1964).

The $H_2\,^{17}O$ lines were identified using the empirical formula

$$[\nu(H_2\,^{16}O) - \nu(H_2\,^{17}O)]/[\nu(H_2\,^{16}O) - \nu(H_2\,^{18}O)] = 0.529,$$

as was previously noted by Fraley, Rao, and Jones (*1*)

TABLE II—*Continued*

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J"	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
	6	2	4	7	3	5			0 16
	9	1	8	10	2	9			0 16
1395.805	4	3	1	5	4	2	117	90	0 16
1396.093							118	30	**
1396.383	4	2	3	5	3	2	119	30	0 17
1397.323							120	10	*
1397.589							121	40	**
1397.750	9	0	9	10	1	10	122	70	0 16
1397.829	9	1	9	10	0	10	123	60	0 16
1399.199	4	2	3	5	3	2	124	90	0 16
1400.544	5	2	3	6	3	4	125	60	0 18
1402.645	5	2	3	6	3	4	126	10	0 17
1402.812							127	10	*
1403.465	9	3	7	10	2	8	128	20	0 16
1404.254							129	10	*
1404.606	8	1	7	9	2	8	130	20	0 18
1404.995	5	2	3	6	3	4	131	90	0 16
1407.303							132	10	*
1408.407							133	10	*
1408.542							134	10	**
1408.666							135	10	**
1409.749							136	10	**
1409.973	8	1	7	9	2	8	137	50	0 16
1410.122	8	2	7	9	1	8	138	30	0 18
1410.282							139	10	*
1411.528	10	1	10	10	2	9	140	50	0 16
	8	0	8	9	1	9			0 18
1411.824	8	1	8	9	0	9	141	50	0 18
1411.959	5	0	5	5	3	2	142	50	0 16
1412.086							143	40	**
1413.649							144	10	*
1414.056							145	10	*
1414.287	4	2	2	5	3	3	146	50	0 18
1414.788	3	3	1	4	4	0	147	60	0 18
1414.985	3	3	0	4	4	1	148	80	0 18
1416.087	8	2	7	9	1	8	149	70	0 16
1416.470							150	10	
1416.928	3	3	1	4	4	0	151	10	0 17
1417.122	3	3	0	4	4	1	152	40	0 17
1417.253	8	0	8	9	1	9	153	70	0 16
1417.493	8	1	8	9	0	9	154	80	0 16
1417.797	3	1	3	4	2	2	155	40	0 18
1418.927	4	2	2	5	3	3	156	90	0 16
	7	1	6	8	2	7			0 18
1419.441	3	3	1	4	4	0	157	90	0 16
	3	3	0	4	4	1			0 16
1419.992							158	10	*
1420.346	3	1	3	4	2	2	159	10	0 17
1420.721	8	3	6	9	2	7	160	10	0 18
1421.194							161	10	*
1421.365	7	1	6	8	2	7	162	10	0 17
1421.642							163	20	*
1422.040							164	10	*
1422.689							165	10	*
1423.031							166	10	*
1423.701	3	1	3	4	2	2	167	90	0 16
1424.112	7	1	6	8	2	7	168	90	0 16
1424.871	3	2	2	4	3	1	169	60	0 18
1426.023							170	10	*
1426.124	9	1	9	9	2	8	171	10	0 18
1426.606							172	10	**
1427.227	9	0	9	9	1	8	173	20	0 18
1428.277	8	3	6	9	2	7	174	50	0 16
1429.423	7	2	6	8	1	7	175	20	0 18
1429.942	3	2	2	4	3	1	176	90	0 16
1430.745	7	0	7	8	1	8	177	60	0 18
1431.235	7	1	7	8	0	8	178	40	0 18
1431.520	6	1	5	7	2	6	179	40	0 18
1432.001	9	1	9	9	2	8	180	80	0 16
	3	2	1	4	3	2			0 18
1433.206	9	0	9	9	1	8	181	60	0 16
1433.443	7	0	7	8	1	8	182	20	0 17
1433.622	4	0	4	4	3	1	183	30	0 16
1433.948	7	1	7	8	0	8	184	10	0 17
1434.270	3	2	1	4	3	2	185	30	0 17
1434.683							186	20	*
1434.946							187	10	**
1435.312	9	4	6	10	3	7	188	20	0 18
1435.653	7	2	6	8	1	7	189	60	0 16
1436.745	7	0	7	8	1	8	190	90	0 16
	7	1	7	8	0	8			0 16
	6	1	5	7	2	6			0 16
	3	2	1	4	3	2			0 16
1439.716							191	10	*
1439.896							192	10	*
1441.351							193	10	**
1441.559							194	10	**
1442.825	5	1	4	6	2	5	195	60	0 18
	3	0	3	3	3	0			0 18
1445.105							196	30	**
1445.254							197	30	**
1446.160	8	1	8	8	2	7	198	40	0 18
1446.486	3	0	3	3	3	0	199	40	0 16
1447.954	5	1	4	6	2	5	200	90	0 16
1448.387	8	0	8	8	1	7	201	20	0 18
1448.902	7	3	5	8	2	6	202	10	0 18
1449.512	6	0	6	7	1	7	203	40	0 18
1450.563	6	2	5	7	1	6	204	70	0 18
1451.082	6	1	6	7	0	7	205	20	0 18
1451.465							206	20	*
1451.923	2	2	1	3	3	0	207	90	0 18
1452.036	8	1	8	8	2	7	208	90	0 16
1452.570							209	10	*
1453.357	2	2	0	3	3	1	210	80	0 18
	2	2	1	1	0	1			0 18
1453.568							211	30	*
1454.086	4	1	3	5	2	4	212	60	0 18
1454.256	2	2	1	3	3	0	213	50	0 17
1454.573	8	0	8	8	1	7	214	70	0 16
1455.301	6	0	6	7	1	7	215	90	0 16
1455.664	2	2	0	3	3	1	216	30	0 17
1455.981							217	30	*
1456.791	6	1	6	7	0	7	218	90	0 16
	2	2	1	3	3	0			0 16
1458.265	2	2	0	3	3	1	219	90	0 16
1459.262	4	1	3	5	2	4	220	90	0 16
	2	1	2	3	2	1			0 18
1459.598							221	20	**
1459.757							222	10	*
1460.431							223	10	*
1460.941							224	20	*
1461.914	2	1	2	3	2	1	225	30	0 17
1462.544							226	10	*
1462.628							227	10	**
1462.680							228	10	**
1464.922	2	1	2	3	2	1	229	90	0 16

TABLE II—*Continued*

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J"	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1465.542	7	1	7	7	2	6	230	40	0 18
1466.783	3	1	2	4	2	3	231	90	0 18
1467.674	5	0	5	6	1	6	232	90	0 18
1467.989							233	10	**
1468.333	9	2	8	9	3	7	234	10	0 18
1469.269	3	1	2	4	2	3	235	40	0 17
1469.374							236	10	*
1470.068	5	1	5	6	0	6	237	80	0 18
	7	0	7	7	1	6			0 18
1470.425	5	0	5	6	1	6	238	40	0 17
1471.486	7	1	7	7	2	6	239	80	0 16
	8	4	5	9	3	6			0 18
1472.052	3	1	2	4	2	3	240	90	0 16
1473.525	5	0	5	6	1	6	241	90	0 16
1474.106							242	20	**
1474.321	9	2	8	9	3	7	243	50	0 16
	5	2	4	6	1	5			0 18
1475.604							244	10	*
1476.142	5	1	5	6	0	6	245	90	0 16
1476.429	7	0	7	7	1	6	246	90	0 16
1477.022							247	10	*
1477.528							248	10	**
1479.083	9	1	8	9	2	7	249	20	0 18
1480.240							250	20	**
1480.324							251	30	*
1480.771	6	3	4	7	2	5	252	30	0 18
1481.243	5	2	4	6	1	5	253	90	0 16
1481.794	8	4	5	9	3	6	254	30	0 16
1481.982	2	1	1	3	2	2	255	70	0 18
1482.434	9	1	8	9	2	7	256	10	0 17
1482.553							257	10	
1483.178	8	2	7	8	3	6	258	40	0 18
1483.931							259	70	**
1484.106							260	20	*
1484.305	6	1	6	6	2	5	261	10	0 18
1484.504	2	1	1	3	2	2	262	30	0 17
1484.651							263	10	**
1484.974	4	0	4	5	1	5	264	70	0 18
1486.166	9	1	8	9	2	7	265	60	0 16
1486.731	6	1	6	6	2	5	266	20	0 17
1486.981							267	20	*
1487.354	2	1	1	3	2	2	268	90	0 16
1487.731	4	0	4	5	1	5	269	20	0 17
1488.031							270	10	*
1488.199							271	10	**
1488.545							272	10	*
1489.050	8	2	7	8	3	6	273	80	0 16
1489.301	6	3	4	7	2	5	274	70	0 16
1489.851	6	1	6	6	2	5	275	90	0 16
1490.038	4	1	4	5	0	5	276	90	0 18
1490.824	4	0	4	5	1	5	277	90	0 16
1491.237							278	40	*
1491.386							279	60	**
1492.314	6	0	6	6	1	5	280	50	0 18
1492.532							281	10	*
1492.969	4	1	4	5	0	5	282	50	0 17
1493.277	1	1	1	2	2	0	283	80	0 18
1494.871							284	10	*
1495.090							285	10	**
1495.685							286	10	*
1495.897	1	1	1	2	2	0	287	50	0 17
1496.255	4	1	4	5	0	5	288	90	0 16
	7	2	6	7	3	5			0 18

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J"	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1496.564							289	50	*
1497.635							290	10	*
1497.900							291	10	*
1498.397							292	10	**
1498.574							293	30	**
1498.814	1	1	1	2	2	0	294	90	0 16
	6	0	6	6	1	5			0 16
1499.507							295	10	*
1500.168	1	1	0	2	2	1	296	90	0 18
1500.549	9	3	7	9	4	6	297	30	0 16
1500.777	5	1	5	5	2	4	298	60	0 18
1501.204	3	0	3	4	1	4	299	90	0 18
	4	2	3	5	1	4			0 18
1501.646							300	20	**
1501.847	7	2	6	7	3	5	301	80	0 16
1502.173							302	10	**
1502.289	8	3	6	8	4	5	303	30	0 18
1502.728	1	1	0	2	2	1	304	50	0 17
1503.533							305	10	**
1503.739	5	1	5	5	2	4	306	20	0 17
1503.944	7	2	5	6	5	2	307	60	0 16
	3	0	3	4	1	4			0 17
1504.704	4	2	3	5	1	4	308	20	0 17
1505.056	8	4	5	8	5	4	309	20	0 18
1505.619	1	1	0	2	2	1	310	90	0 16
	5	4	1	5	5	0			0 18
	5	4	2	5	5	1			0 18
	6	4	3	6	5	2			0 18
	7	4	4	7	5	3			0 18
1506.964	5	1	5	5	2	4	311	90	0 16
	3	0	3	4	1	4			0 16
	6	2	5	6	3	4			0 18
1507.455	7	3	5	7	4	4	312	90	0 18
	8	1	7	8	2	6			0 16
	8	3	6	8	4	5			0 16
1507.813	7	5	3	7	6	2	313	70	0 16
1507.987	8	5	4	8	6	3	314	60	0 16
	7	4	3	7	5	2			0 18
1508.114							315	30	**
1508.325							316	40	**
1508.558	4	2	3	5	1	4	317	90	0 16
1509.402	7	4	4	8	3	5	318	20	0 18
1509.544	8	4	5	8	5	4	319	60	0 16
1509.626	5	4	2	5	5	1	320	70	0 16
1509.801	6	4	3	6	5	2	321	90	0 16
	5	4	1	5	5	0			0 16
	7	4	4	7	5	3			0 16
1510.186	6	3	4	6	4	3	322	50	0 18
1510.519	6	4	2	6	5	1	323	60	0 16
	7	6	1	7	7	0			0 16
1510.906	8	4	4	8	5	3	324	30	0 18
1511.028	3	1	3	4	0	4	325	80	0 18
1511.600	5	3	3	5	4	2	326	40	0 18
1511.792							327	10	*
1512.070	4	3	2	4	4	1	328	70	0 18
1512.287	7	3	5	7	4	4	329	90	0 16
	6	2	5	6	3	4			0 16
	7	4	3	7	5	2			0 16
1512.694							330	10	**
1512.881							331	10	*
1513.096							332	10	*
1513.196	4	3	1	4	4	0	333	30	0 18
1513.817	5	3	3	5	4	2	334	10	0 17

TABLE II—*Continued*

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J''	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1514.049	3	1	3	4	0	4	335	20	O 17
1514.263	4	3	2	4	4	1	336	20	O 17
1514.668	5	0	5	5	1	4	337	90	O 18
1514.872	5	2	4	5	3	3	338	80	O 18
1514.974	6	3	4	6	4	3	339	90	O 16
	5	3	3	6	2	4			O 18
1515.465	4	1	4	4	2	3	340	90	O 18
1515.665	5	3	2	5	4	1	341	70	O 18
1515.776	8	4	4	8	5	3	342	50	O 16
1516.295	5	3	3	5	4	2	343	90	O 16
1516.724	4	3	2	4	4	1	344	90	O 16
	2	0	2	3	1	3			O 18
1517.433	3	1	3	4	0	4	345	90	O 16
1517.765	4	3	1	4	4	0	346	90	O 16
	5	3	2	5	4	1			O 17
	5	0	5	5	1	4			O 17
1518.183	4	1	4	4	2	3	347	40	O 17
1518.399							348	10	*
1518.666							349	10	*
1519.355	7	4	4	8	3	5	350	30	O 16
1519.566	2	0	2	3	1	3	351	40	O 17
1520.224	5	3	2	5	4	1	352	90	O 16
	5	2	4	5	3	3			O 16
1520.460	4	2	3	4	3	2	353	50	O 18
	6	3	3	6	4	2			O 18
	7	1	6	7	2	5			O 18
1521.281	5	0	5	5	1	4	354	90	O 16
	4	1	4	4	2	3			O 16
1522.690	2	0	2	3	1	3	355	90	O 16
1523.373							356	10	*
1523.492	3	2	2	3	3	1	357	60	O 18
1523.632	5	3	3	6	2	4	358	60	O 16
	7	1	6	7	2	5			O 17
1523.863							359	10	*
1524.050							360	10	*
1524.558							361	10	*
1524.813	6	3	3	6	4	2	362	80	O 16
1525.496	4	2	3	4	3	2	363	90	O 16
1525.880	3	2	2	3	3	1	364	10	O 17
1527.329	7	1	6	7	2	5	365	90	O 16
	7	3	4	7	4	3			O 18
1527.499	3	1	3	3	2	2	366	80	O 18
1528.565	3	2	2	3	3	1	367	90	O 16
	9	2	7	9	3	6			O 18
1528.983	3	2	1	3	3	0	368	80	O 18
1529.385	7	3	4	7	4	3	369	10	O 17
1530.193	3	1	3	3	2	2	370	20	O 17
1530.781	3	2	2	4	1	3	371	60	O 18
1531.321	3	2	1	3	3	0	372	30	O 17
1531.636	7	3	4	7	4	3	373	90	O 16
1532.233	4	0	4	3	3	1	374	20	O 16
1532.639							375	10	*
1533.161	3	1	3	3	2	2	376	90	O 16
	1	0	1	2	1	2			O 18
1533.715	2	1	2	3	0	3	377	90	O 18
1533.923	3	2	1	3	3	0	378	90	O 16
1534.170	4	2	2	4	3	1	379	70	O 18
1534.555	3	2	2	4	1	3	380	20	O 17
1534.943							381	20	**
1535.140	8	3	5	8	4	4	382	10	O 18
1535.436	9	2	7	9	3	6	383	90	O 16
	4	0	4	4	1	3			O 18
1535.879	1	0	1	2	1	2	384	50	O 17
1536.549	2	1	2	2	2	1	385	90	O 18
1536.829	6	1	5	6	2	4	386	80	O 18
	2	1	2	3	0	3			O 17
1537.828	6	0	6	5	3	3	387	10	O 16
1538.290	3	2	2	4	1	3	388	90	O 16
1538.491	4	0	4	4	1	3	389	40	O 17
1539.073	1	0	1	2	1	2	390	90	O 16
	4	2	2	4	3	1			O 16
	8	3	5	8	4	4			O 16
	8	2	6	8	3	5			O 18
	2	1	2	2	2	1			O 17
1539.514	9	3	6	9	4	5	391	40	O 18
1540.274	2	1	2	3	0	3	392	90	O 16
	5	2	3	5	3	2			O 18
1540.773							393	20	*
1541.530							394	10	*
1542.097	4	0	4	4	1	3	395	90	O 16
	2	1	2	2	2	1			O 16
1542.525	5	2	3	5	3	2	396	40	O 17
1543.488	6	1	5	6	2	4	397	90	O 16
1544.442	9	3	6	9	4	5	398	90	O 16
	7	2	5	7	3	4			O 18
	6	2	4	6	3	3			O 18
1545.162	5	2	3	5	3	2	399	90	O 16
1545.659	8	2	6	8	3	5	400	70	O 16
1545.796							401	40	*
1545.962	6	4	3	7	3	4	402	10	O 18
1546.505							403	10	*
1546.870	6	2	4	6	3	3	404	10	O 17
1547.207	7	2	5	7	3	4	405	20	O 17
1547.341							406	10	
1547.527							407	10	**
1548.117	5	1	4	5	2	3	408	90	O 18
1548.639							409	10	**
1549.142							410	10	
1549.626	6	2	4	6	3	3	411	90	O 16
	4	3	2	5	2	3			O 18
1550.233	7	2	5	7	3	4	412	90	O 16
1551.062	5	1	4	5	2	3	413	40	O 17
1551.529	0	0	0	1	1	1	414	70	O 18
1551.960	2	1	1	2	2	0	415	70	O 18
1552.130	3	0	3	3	1	2	416	90	O 18
1552.993	7	1	6	6	4	3	417	10	O 16
1553.099							418	10	**
1553.799	4	1	3	4	2	2	419	80	O 18
	4	3	2	5	2	3			O 17
1554.330	5	1	4	5	2	3	420	90	O 16
	0	0	0	1	1	1			O 17
1554.590	3	1	2	3	2	1	421	90	O 18
	2	1	1	2	2	0			O 17
1555.152	3	0	3	3	1	2	422	60	O 17
1555.464	8	4	4	9	3	7	423	10	O 16
1556.028	6	4	3	7	3	4	424	40	O 16
1556.577	4	1	3	4	2	2	425	30	O 17
1557.291	3	1	2	3	2	1	426	80	O 17
1557.550	2	1	1	2	2	0	427	90	O 16
	0	0	0	1	1	1			O 16
1558.152	1	1	1	2	0	2	428	80	O 18
1558.497	4	3	2	5	2	3	429	90	O 16
	3	0	3	3	1	2			O 16
1559.696	4	1	3	4	2	2	430	90	O 16
1560.249	3	1	2	3	2	1	431	90	O 16
1561.331	2	2	1	3	1	2	432	70	O 18

TABLE II—*Continued*

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J"	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
	1	1	1	2	0	2			0 17
1562.134							433	10	*
1563.555	2	0	2	2	1	1	434	80	0 18
1564.879	1	1	1	2	0	2	435	90	0 16
	2	2	1	3	1	2			0 17
1566.033	7	4	3	8	3	6	436	30	0 16
1566.497	2	0	2	2	1	1	437	40	0 17
1567.428							438	10	
1568.985	2	2	1	3	1	2	439	90	0 16
1569.879	2	0	2	2	1	1	440	90	0 16
	1	0	1	1	1	0			0 18
1572.948	6	3	3	7	2	6	441	70	0 16
	1	0	1	1	1	0			0 17
1573.957							442	10	*
1576.195	1	0	1	1	1	0	443	90	0 16
1577.281	7	3	4	8	2	7	444	20	0 16
1577.583	5	3	2	6	2	5	445	60	0 16
1578.331	7	1	7	6	2	4	446	10	0 16
1579.486							447	10	**
1580.363	5	4	2	6	3	3	448	10	0 18
1581.331							449	10	
1581.738	4	3	1	5	2	4	450	10	0 18
1582.469	6	4	2	7	3	5	451	20	0 16
1583.004	3	3	1	4	2	2	452	10	0 18
1583.359							453	10	**
1585.988							454	10	**
1587.474	3	2	1	4	1	4	455	30	0 18
1589.234	6	1	6	5	2	3	456	10	0 18
1589.709	4	3	1	5	2	4	457	50	0 16
1590.158	5	4	2	6	3	3	458	20	0 16
1590.399							459	10	**
1591.678	3	3	1	4	2	2	460	50	0 16
1593.842	2	2	0	3	1	3	461	20	0 18
1594.502	3	2	1	4	1	4	462	80	0 16
1596.262	4	2	2	5	1	5	463	70	0 16
	6	1	6	5	2	3			0 16
1597.492	2	2	0	3	1	3	464	20	0 17
	3	1	3	2	2	0			0 18
1598.447							465	10	*
1599.008	3	3	0	4	2	3	466	20	0 18
1600.509	5	1	5	4	2	2	467	10	0 18
1601.210	2	2	0	3	1	3	468	70	0 16
1601.454	7	5	2	8	4	5	469	20	0 16
1602.725							470	10	**
1602.889	5	4	1	6	3	4	471	40	0 16
	3	3	0	4	2	3			0 17
1603.317	3	1	3	2	2	0	472	80	0 16
	4	1	4	3	2	1			0 18
1603.988							473	10	*
1606.215	4	1	4	3	2	1	474	10	0 17
1606.722	5	2	3	6	1	6	475	30	0 16
1607.062	5	1	5	4	2	2	476	50	0 16
1607.255	3	3	0	4	2	3	477	60	0 16
1609.442	4	1	4	3	2	1	478	80	0 16
1609.881	1	1	0	1	0	1	479	90	0 18
1612.181							480	10	**
1613.091	1	1	0	1	0	1	481	50	0 17
1616.723	1	1	0	1	0	1	482	90	0 16
	2	1	1	2	0	2			0 18
1617.290	4	2	3	3	3	0	483	40	0 18
1619.985	2	1	1	2	0	2	484	30	0 17
1620.788	4	4	1	5	3	2	485	40	0 16
1621.593	2	0	2	1	1	1	486	60	0 18
1622.602	4	2	3	3	3	0	487	60	0 16
1623.566	2	1	1	2	0	2	488	90	0 16
1624.526	2	0	2	1	1	1	489	10	0 17
1625.661	4	4	0	5	3	3	490	20	0 16
1627.854	2	0	2	1	1	1	491	90	0 16
1628.033	1	1	1	0	0	0	492	70	0 18
1629.063	3	1	2	3	0	3	493	90	0 18
1631.319	1	1	1	0	0	0	494	20	0 17
1631.923	3	1	2	2	2	1	495	70	0 18
1632.165	9	2	8	8	3	5	496	50	0 18
	3	1	2	3	0	3			0 17
1632.788	4	2	2	3	3	1	497	20	0 18
1634.562	3	1	2	2	2	1	498	20	0 17
1634.961	1	1	1	0	0	0	499	90	0 16
1635.655	3	1	2	3	0	3	500	90	0 16
1637.505	3	1	2	2	2	1	501	90	0 16
1637.680	4	2	2	3	3	1	502	60	0 16
1638.294	5	3	3	4	4	0	503	60	0 16
1638.406	3	2	1	3	1	2	504	80	0 18
1640.086	4	2	2	4	1	3	505	70	0 18
1640.306	5	2	4	4	3	1	506	60	0 16
1640.647	2	2	0	2	1	1	507	60	0 18
1641.970	3	2	1	3	1	2	508	40	0 17
1642.381	5	3	2	4	4	1	509	50	0 16
1643.061	7	2	5	8	1	8	510	10	0 18
1643.526	4	2	2	4	1	3	511	20	0 17
1644.271	2	2	0	2	1	1	512	10	0 17
1646.061	3	2	1	3	1	2	513	90	0 16
	2	1	2	1	0	1			0 18
	3	0	3	2	1	2			0 18
1647.029	4	1	3	4	0	4	514	60	0 18
1647.397	4	2	2	4	1	3	515	90	0 16
1647.534	5	2	3	5	1	4	516	90	0 18
1648.317	2	2	0	2	1	1	517	90	0 16
1649.035	3	0	3	2	1	2	518	40	0 17
1649.290							519	10	*
1649.417							520	10	**
1649.580	2	1	2	1	0	1	521	40	0 17
1649.822							522	10	**
1650.042	4	1	3	4	0	4	523	10	0 17
1650.293							524	10	**
1650.842	5	2	3	5	1	4	525	30	0 17
1652.860	3	0	3	2	1	2	526	90	0 16
	6	2	5	5	3	2			0 16
	2	1	2	1	0	1			0 16
	4	1	3	4	0	4			0 16
	6	4	2	5	5	1			0 18
1654.507	5	2	3	5	1	4	527	90	0 16
1655.232	2	2	1	2	1	2	528	70	0 18
1656.304	6	4	3	5	5	0	529	30	0 16
1656.431	6	3	4	5	4	1	530	20	0 18
1657.011	6	4	2	5	5	1	531	40	0 16
	7	2	6	6	3	3			0 16
1657.415							532	20	**
1658.807	2	2	1	2	1	2	533	30	0 17
1661.374	6	3	4	5	4	1	534	60	0 16
1661.819	6	2	4	6	1	5	535	50	0 18
1662.342	3	1	3	2	0	2	536	90	0 18
1662.807	2	2	1	2	1	2	537	90	0 16
1663.492	4	1	3	3	2	2	538	70	0 18
1664.009	3	2	2	3	1	3	539	70	0 18
1664.848	6	2	4	6	1	5	540	10	0 17
1665.664	3	1	3	2	0	2	541	40	0 17

TABLE II—*Continued*

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J"	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1666.208	4	1	3	3	2	2	542	20	O 17
1666.633	5	2	3	4	3	2	543	50	O 18
1667.565	3	2	2	3	1	3	544	20	O 17
1668.285	6	2	4	6	1	5	545	90	O 16
	6	3	3	5	4	2			O 18
1668.620	4	0	4	3	1	3	546	80	O 18
1669.329	4	1	3	3	2	2	547	90	O 16
	3	1	3	2	0	2			O 16
	5	1	4	5	0	5			O 18
1671.496	5	2	3	4	3	2	548	90	O 16
	6	3	3	6	2	4			O 18
	3	2	2	3	1	3			O 16
1671.691	4	0	4	3	1	3	549	50	O 17
1672.193	5	1	4	5	0	5	550	20	O 17
1672.475	6	3	3	5	4	2	551	50	O 16
1672.597	7	3	4	7	2	5	552	50	O 18
1675.174	4	0	4	3	1	3	553	90	O 16
	5	3	2	5	2	3			O 18
1675.532	5	1	4	5	0	5	554	90	O 16
1675.767	4	2	3	4	1	4	555	80	O 18
1676.326	3	3	1	4	0	4	556	10	O 18
1676.940							557	10	
1677.751	4	1	4	3	0	3	558	90	O 18
1679.103	7	5	2	6	6	1	559	10	O 16
1679.265	4	2	3	4	1	4	560	20	O 17
	5	3	2	5	2	3			O 17
1679.415	4	3	2	5	0	5	561	10	O 16
1679.819	6	3	3	6	2	4	562	90	O 16
1680.465	7	3	4	7	2	5	563	90	O 16
1680.867	7	4	4	6	5	1	564	20	O 16
1681.092	4	1	4	3	0	3	565	60	O 17
1681.411	4	3	1	4	2	2	566	50	O 18
	8	3	5	8	2	6			O 18
1682.182	7	3	5	6	4	2	567	50	O 16
1682.341	7	2	5	7	1	6	568	50	O 18
1683.181	4	2	3	4	1	4	569	90	O 16
1683.533	7	4	3	6	5	2	570	50	O 16
1683.988	5	3	2	5	2	3	571	90	O 16
1684.827	4	1	4	3	0	3	572	90	O 16
1685.511	3	3	1	4	0	4	573	40	O 16
1686.827	3	3	0	3	2	1	574	70	O 18
1687.882	8	3	5	8	2	6	575	50	O 16
1688.374	7	2	5	7	1	6	576	80	O 16
1689.198	5	0	5	4	1	4	577	90	O 18
1690.158	4	3	1	4	2	2	578	80	O 16
	5	2	4	5	1	5			O 18
1690.899	3	3	0	3	2	1	579	20	O 17
1692.201	2	2	1	1	1	0	580	90	O 18
1692.361	5	0	5	4	1	4	581	70	O 17
1692.697	3	3	1	3	2	2	582	50	O 18
1693.239	6	1	5	6	0	6	583	40	O 18
1693.701	5	1	5	4	0	4	584	80	O 18
1694.657	5	1	4	4	2	3	585	80	O 18
1695.457	3	3	0	3	2	1	586	90	O 16
1695.935	5	0	5	4	1	4	587	90	O 16
	4	3	2	4	2	3			O 18
1696.481	9	3	6	9	2	7	588	30	O 18
1696.674	3	3	1	3	2	2	589	10	O 17
1697.039	5	1	5	4	0	4	590	30	O 17
1697.510	5	2	4	5	1	5	591	90	O 16
1698.691	2	2	0	1	1	1	592	80	O 18
1698.957	8	3	6	7	4	3	593	50	O 16
1699.581	6	1	5	6	0	6	594	80	O 16

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J"	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1699.936	2	2	1	1	1	0	595	90	O 16
1700.462	5	1	4	4	2	3	596	90	O 16
1700.794	5	1	5	4	0	4	597	90	O 16
1701.137	3	3	1	3	2	2	598	80	O 16
1701.984	5	3	3	5	2	4	599	40	O 18
	7	3	4	6	4	3			O 18
1702.298	2	2	0	1	1	1	600	30	O 17
1702.392	6	2	4	5	3	3	601	30	O 18
1702.747	9	3	6	9	2	7	602	50	O 16
1703.437	8	5	4	7	6	1	603	10	O 16
1703.982							604	10	**
1704.452	4	3	2	4	2	3	605	90	O 16
	6	2	4	5	3	3			O 17
1704.853	8	4	5	7	5	2	606	30	O 16
1705.873	5	3	3	5	2	4	607	10	O 17
1706.165	7	3	4	6	4	3	608	70	O 16
1706.349	2	2	0	1	1	1	609	90	O 16
	8	6	2	7	7	1			O 16
1706.832	6	2	5	6	1	6	610	60	O 18
1707.213	6	2	4	5	3	3	611	70	O 16
	8	2	6	8	1	7			O 18
1708.269	6	0	6	5	1	5	612	80	O 18
	8	4	4	7	5	3			O 18
1709.659	9	3	7	8	4	4	613	10	O 16
1710.271	5	3	3	5	2	4	614	90	O 16
	6	2	5	6	1	6			O 17
1710.780	3	2	2	2	1	1	615	90	O 18
	6	1	6	5	0	5			O 18
	6	3	4	6	2	5			O 18
1711.515	6	0	6	5	1	5	616	20	O 17
1712.041	8	4	4	7	5	3	617	10	O 16
1712.503							618	10	**
1712.920	8	2	6	8	1	7	619	50	O 16
1713.665	6	1	6	5	0	5	620	50	O 17
1714.029	6	2	5	6	1	6	621	90	O 16
1714.485	3	2	2	2	1	1	622	30	O 17
1715.150	6	0	6	5	1	5	623	90	O 16
1715.603							624	20	**
1715.842	9	4	5	9	3	6	625	40	O 16
1717.001	7	1	6	7	0	7	626	50	O 18
1717.403	6	1	6	5	0	5	627	90	O 16
1718.592	3	2	2	2	1	1	628	90	O 16
1718.784	6	3	4	6	2	5	629	90	O 16
1719.762	7	4	3	7	3	4	630	30	O 18
1720.049	7	1	6	7	0	7	631	10	O 17
1721.531	8	4	4	8	3	5	632	40	O 16
1722.538	7	3	5	7	2	6	633	20	O 18
1723.483	7	1	6	7	0	7	634	90	O 16
1723.915	6	1	5	5	2	4	635	70	O 18
1724.292	7	4	3	7	3	4	636	10	O 17
1724.922	7	2	6	7	1	7	637	20	O 18
1726.396	7	0	7	6	1	6	638	90	O 18
1726.728	4	2	3	3	1	2	639	90	O 18
	6	1	5	5	2	4			O 17
1727.298	7	1	7	6	0	6	640	80	O 18
1727.759	6	4	2	6	3	3	641	20	O 18
1729.443							642	10	**
1729.768	7	4	3	7	3	4	643	80	O 16
	7	0	7	6	1	6			O 17
1730.052	6	1	5	5	2	4	644	90	O 16
1730.352	7	3	5	7	2	6	645	70	O 16
1730.457	4	2	3	3	1	2	646	50	O 17
1730.638	7	1	7	6	0	6	647	30	O 17

TABLE II—*Continued*

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J"	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1732.063	7	2	6	7	1	7	648	60	O 16
1732.302	3	2	1	2	1	2	649	80	O 18
1733.397	7	0	7	6	1	6	650	90	O 16
	5	4	1	5	3	2			O 18
	9	2	7	9	1	8			O 18
1734.557	4	2	3	3	1	2	651	90	O 16
1734.561	7	1	7	6	0	6	652	90	O 16
1735.856	3	2	1	2	1	2	653	30	O 17
1736.327	4	4	0	4	3	1	654	20	O 18
1737.017	8	3	6	8	2	7	655	20	O 18
1737.630	6	4	2	6	3	3	656	70	O 16
1737.700	4	4	1	4	3	2	657	60	O 18
1737.956							658	10	
1738.381	5	4	2	5	3	3	659	20	O 18
1738.665	7	2	5	6	3	4	660	40	O 18
1739.329	9	2	7	9	1	8	661	50	O 16
	8	1	7	8	0	8			O 18
1739.841	3	2	1	2	1	2	662	90	O 16
	8	3	5	7	4	4			O 18
1740.121	6	4	3	6	3	4	663	60	O 18
1740.653	5	2	4	4	1	3	664	70	O 18
1743.057	5	4	1	5	3	2	665	90	O 16
1743.622	7	2	5	6	3	4	666	90	O 16
1743.896	8	0	8	7	1	7	667	70	O 18
	8	2	7	8	1	8			O 18
	7	4	4	7	3	5			O 18
1744.299	8	1	8	7	0	7	668	80	O 18
1744.595	8	3	6	8	2	7	669	70	O 16
1745.781	4	4	0	4	3	1	670	80	O 16
1746.297	8	1	7	8	0	8	671	50	O 16
1747.087	4	4	1	4	3	2	672	90	O 16
1747.241	8	0	8	7	1	7	673	40	O 17
1747.717	5	4	2	5	3	3	674	80	O 16
1748.663	5	2	4	4	1	3	675	90	O 16
1749.410	6	4	3	6	3	4	676	80	O 16
1749.711	8	4	5	8	3	6	677	20	O 18
1750.334	7	1	6	6	2	5	678	70	O 18
1750.995	8	0	8	7	1	7	679	90	O 16
1751.429	8	1	8	7	0	7	680	90	O 16
1752.818	7	4	4	7	3	5	681	50	O 16
1753.401	7	1	6	6	2	5	682	20	O 17
1753.822	6	2	5	5	1	4	683	80	O 18
	9	3	7	9	2	8			O 18
1756.818	7	1	6	6	2	5	684	90	O 16
1757.595	6	2	5	5	1	4	685	20	O 17
1758.578	8	4	5	8	3	6	686	60	O 16
	9	4	6	9	3	7			O 18
1760.989	9	0	9	8	1	8	687	70	O 18
	9	1	8	9	0	9			O 18
	9	3	7	9	2	8			O 16
1761.121	9	1	9	8	0	8	688	60	O 18
	3	3	0	3	0	3			O 18
1761.835	6	2	5	5	1	4	689	90	O 16
1762.673	3	3	1	2	2	0	690	80	O 18
	9	2	8	9	1	9			O 18
1764.156	3	3	0	2	2	1	691	90	O 18
1764.355	9	1	9	8	0	8	692	30	O 17
	9	0	9	8	1	8			O 17
1765.387							693	10	**
1766.745	3	3	1	2	2	0	694	10	O 17
1767.100	3	3	0	2	2	1	695	10	O 17
1767.734	7	2	6	6	1	5	696	50	O 18
1767.924	9	1	8	9	0	9	697	50	O 16
1768.109	9	0	9	8	1	8	698	90	O 16
1768.306	9	1	9	8	0	8	699	90	O 16
1770.377	9	2	8	9	1	9	700	20	O 16
1770.877	3	3	0	3	0	3	701	30	O 16
1771.296	3	3	1	2	2	0	702	90	O 16
1772.716	3	3	0	2	2	1	703	90	O 16
1773.296	4	2	2	3	1	3	704	60	O 18
1773.898	8	2	6	7	3	5	705	50	O 18
	8	1	7	7	2	6			O 18
1775.633	7	2	6	6	1	5	706	80	O 16
1777.710	10	0	10	9	1	9	707	50	O 18
	10	1	10	9	0	9			O 18
1778.038	9	3	6	8	4	5	708	10	O 18
1778.432							709	20	**
1779.116	8	2	6	7	3	5	710	60	O 16
	10	3	8	10	2	9			O 16
1780.673	4	2	2	3	1	3	711	90	O 16
	8	1	7	7	2	6			O 16
1781.150	10	0	10	9	1	9	712	10	O 17
	10	1	10	9	0	9			O 17
1781.963	9	3	6	8	4	5	713	30	O 16
1782.378							714	10	**
1783.190	8	2	7	7	1	6	715	50	O 18
1783.907	4	3	1	4	0	4	716	80	O 16
	4	3	2	3	2	1			O 18
1784.948	10	0	10	9	1	9	717	90	O 16
	10	1	10	9	0	9			O 16
1785.567							718	20	**
1785.871							719	20	**
1786.860	8	2	7	7	1	6	720	10	O 17
1788.029	4	3	2	3	2	1	721	30	O 17
1788.371							722	20	**
1788.611	10	1	9	10	0	10	723	10	O 16
1789.875							724	30	**
1790.947	8	2	7	7	1	6	725	90	O 16
1791.074	4	3	1	3	2	2	726	90	O 18
1792.644	4	3	2	3	2	1	727	90	O 16
1792.948	7	5	2	7	4	3	728	90	O 16
1794.057							729	40	**
1795.109	6	5	1	6	4	2	730	50	O 16
	4	3	1	3	2	2			O 17
1795.369	9	1	8	8	2	7	731	40	O 18
1795.801	5	5	0	5	4	1	732	70	O 16
1796.101	5	5	1	5	4	2	733	70	O 16
	6	5	2	6	4	3			O 16
1796.311	7	5	3	7	4	4	734	40	O 16
1796.924	8	5	4	8	4	5	735	40	O 16
1799.622	4	3	1	3	2	2	736	90	O 16
1800.041	9	2	8	8	1	7	737	20	O 18
1801.337	11	0	11	10	1	10	738	80	O 16
	11	1	11	10	0	10			O 16
1801.660							739	50	
1801.690	5	3	3	4	2	2	740	50	O 18
1801.959							741	10	**
1802.484	9	1	8	8	2	7	742	80	O 16
1805.153	5	3	2	5	0	5	743	40	O 16
1805.898	5	3	3	4	2	2	744	10	O 17
1806.575	9	2	7	8	3	6	745	20	O 18
1807.700	9	2	8	8	1	7	746	70	O 16
1808.669	11	1	10	11	0	11	747	10	O 16
1810.127							748	20	**
1810.621	5	3	3	4	2	2	749	90	O 16
1812.281	9	2	7	8	3	6	750	60	O 16

TABLE II—*Continued*

Wave Number (vac. cm^{-1})	J'	K'_{-1}	K'_{+1}	J''	K''_{-1}	K''_{+1}	Line No.	% Abs.	Isotopic Species
1815.449							751	10	**
1816.067	6	3	4	5	2	3	752	60	O 18
1817.467	12	0	12	11	1	11	753	60	O 16
	12	1	12	11	0	11			O 16
1817.729	10	2	9	9	1	8	754	30	O 18
1820.367	6	3	4	5	2	3	755	20	O 17
1821.375							756	10	**
1821.838	5	3	2	4	2	3	757	70	O 18
1822.091	5	2	3	4	1	4	758	40	O 18
1822.763	10	1	9	9	2	8	759	40	O 16
1825.244	6	3	4	5	2	3	760	90	O 16
1825.744	5	3	2	4	2	3	761	20	O 17
1825.908							762	10	**
1827.903	7	3	5	6	2	4	763	30	O 18
1829.134	5	2	3	4	1	4	764	90	O 16
1830.128	5	3	2	4	2	3	765	90	O 16
1833.283							766	40	**
1834.475							767	10	**
1834.703	4	4	1	3	3	0	768	80	O 18
1834.932	4	4	0	3	3	1	769	60	O 16
1835.909	6	3	3	6	0	6	770	20	O 16
1837.188	7	3	5	6	2	4	771	70	O 16
1837.403	3	3	1	2	0	2	772	20	O 16
1838.470	8	3	6	7	2	5	773	30	O 18
1839.171	4	4	1	3	3	0	774	20	O 17
1839.393	4	4	0	3	3	1	775	10	O 17
1842.145	11	1	10	10	2	9	776	60	O 16
1842.874	8	3	6	7	2	5	777	10	O 17
1843.398							778	30	**
1843.737							779	20	**
1844.170	4	4	1	3	3	0	780	90	O 16
1844.377	4	4	0	3	3	1	781	90	O 16
1845.355	8	6	2	8	5	3	782	40	O 16
1845.601							783	30	**
1845.787							784	10	**
1845.968							785	20	**
1847.787	8	3	6	7	2	5	786	80	O 16
1848.816							787	20	**
1849.343	9	3	7	8	2	6	788	10	O 18
1852.409	5	4	1	5	1	4	789	20	O 16
1853.895	9	3	7	8	2	6	790	10	O 17
1856.265	6	4	2	6	1	5	791	10	O 16
1858.298	5	4	2	4	3	1	792	50	O 18
1858.501	9	3	7	8	2	6	793	60	O 16
	6	3	3	5	2	4			O 18
1859.707							794	20	**
1859.868	5	4	1	4	3	2	795	70	O 18
1860.921							796	20	**
1861.532							797	30	**
1861.913							798	20	**
1862.798	5	4	2	4	3	1	799	10	O 17
1864.061							800	10	**
1864.329	5	4	1	4	3	2	801	20	O 17
1866.381	6	3	3	5	2	4	802	70	O 16
1867.848	5	4	2	4	3	1	803	80	O 16
1868.033	4	3	2	3	0	3	804	60	O 16
1868.732							805	40	**
1869.346	5	4	1	4	3	2	806	90	O 16
1870.808	10	3	8	9	2	7	807	60	O 16
1876.641	7	3	4	7	0	7	808	10	O 16
1877.782	6	2	4	5	1	5	809	10	O 18
1879.289							810	20	**
1879.792	6	4	3	5	3	2	811	50	O 18
1884.373	6	4	3	5	3	2	812	10	O 17
1884.562	6	2	4	5	1	5	813	60	O 16
1885.314							814	20	**
1885.772	6	4	2	5	3	3	815	30	O 18
1889.571	6	4	3	5	3	2	816	90	O 16
1892.607							817	10	**
1893.730							818	10	**
1894.683							819	10	**
1894.924							820	10	**
1895.199	6	4	2	5	3	3	821	80	O 16
1897.521							822	10	**
1897.849	7	4	4	6	3	3	823	20	O 18
1901.752							824	10	
1902.603	7	3	4	6	2	5	825	30	O 18
1904.355	5	3	3	4	0	4	826	30	O 16
1907.703	5	5	1	4	4	0	827	60	O 18
	5	5	0	4	4	1			O 18
1907.953	7	4	4	6	3	3	828	60	O 16
1909.958	7	3	4	6	2	5	829	70	O 16
1911.873	8	4	5	7	3	4	830	20	O 18
1912.564	5	5	1	4	4	0	831	20	O 17
	5	5	0	4	4	1			O 17
1913.935	7	4	3	6	3	4	832	30	O 18
1918.031	5	5	1	4	4	0	833	90	O 16
	5	5	0	4	4	1			O 16
1922.346	8	4	5	7	3	4	834	60	O 16
1923.164	7	4	3	6	3	4	835	80	O 16
1932.127							836	40	**
1932.378							837	20	**
1933.167							838	30	**
1941.635							839	30	**
1942.519	6	5	2	5	4	1	840	80	O 16
1942.765	6	5	1	5	4	2	841	60	O 16
1945.337	7	2	5	6	1	6	842	40	O 16
	8	4	4	7	3	5			O 18
1946.368							843	40	**
1955.006	8	4	4	7	3	5	844	40	O 16
	8	3	5	7	2	6			O 18
1957.045							845	20	**
1961.192	8	3	5	7	2	6	846	30	O 16
1966.259	7	5	3	6	4	2	847	60	O 16
1967.434	7	5	2	6	4	3	848	80	O 16

from the ν_2 band and those evaluated from the ν_1 and ν_3 bands have been of help in arriving at the final assignments.

Energy Levels

The $J\ K_{-1}\ K_{+1}$ assignments made for the rotational structure observed allow us to determine values for the rotational energy levels of the two vibrational states of the ν_2 band of $H_2{}^{18}O$. For each $J'K'_{-1}K'_{+1}$, there are several values for the upperstate energy. These values result from the addition of the appropriate ground-state energy values to the observed transitions. Since the ground-state energy levels have previously been determined by Fraley, Rao, and Jones (*1*), use has been made of their data in arriving at the upper-state energy levels. For a given $J'K'_{-1}K'_{+1}$, we have several values which should agree within experimental errors. Occasionally, it was found that some values deviated from the others more than expected. When this occurred, a careful examination was made of the original data to correct for any accidental inaccuracies in the measurement. If the discrepancies were due to the blended nature of some of the lines, the corresponding values were not used in arriving at the average wavenumbers for the energy levels. Once the average values for the upper-state energy levels were determined, the observed transitions were subtracted from them in order to arrive at the ground-state energy levels. An iteration of this type led to values for the energy levels of the upper and lower states involved in the ν_2 transitions. The results are presented in Table I. There is good agreement between the ground-state energy levels determined in the present work and the results of Fraley, Rao, and Jones based on the analysis of the ν_1 and ν_3 bands of $H_2\,^{18}O$. The basic observational data for the ν_2 band of $H_2\,^{18}O$ are given in Table II.

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REFERENCES

1. P. E. FRALEY, K. NARAHARI RAO, AND L. H. JONES, *J. Mol. Spectrosc.* **29**, 312 (1969).
2. F. X. POWELL AND D. R. JOHNSON, *Phys. Rev. Lett.* **24**, 637 (1970).
3. S. H. KNOWLES, C. H. MAYER, A. C. CHEUNG, D. M. RANK, AND C. H. TOWNES, *Science* **163**, 1055 (1969).
4. See, for example, G. Herzberg, "*Infrared and Raman Spectra of Polyatomic Molecules*," Van Nostrand, Princeton, NJ., 1945.