VIBRATION-ROTATION BANDS OF AsH_3 IN THE 2μ REGION

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ABSTRACT

The vibration-rotation bands of AsH_3 in the 2μ region have tentatively been analyzed. The resonance effect, especially the ν_1 and the ν_3 bands for the K-type doubling and the Giant ℓ-type doubling in the 4μ region have been described briefly. Some new combination difference relations in obtaining ground state constants from a perpendicular band have also been presented.

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VIBRATION-ROTATION BANDS OF AsH_3 IN THE 2μ REGION

I. INTRODUCTION

It seems from a preliminary investigation that there is a possibility of laser action from an AsH_3-N_2 system. However, aside from other problems that might arise we must first of all have enough information on the molecular potential so that vibrational levels can be predicted to see if there is indeed a level close to that of N_2 ($v_2 = 1$).

Arsine (AsH_3) is a pyramidal-type molecule similar to ammonia with the three hydrogen atoms forming the base of the pyramid and the As atom located at the apex. There are four fundamental vibration-rotation bands, two of which (designated as ν_1 and ν_3) occur in the region of 5μ and the other two (designated as ν_2 and ν_4) are doubly degenerate and are observed in the region of 10μ. All four fundamental bands plus some overtones have been studied in a series of reports by McConaghie and Nielsen[1,2,3,4] in 1948 with very low resolution.

In the past thirty years or so, many interesting features of the symmetric top molecule have been discovered. The inversion doubling in NH_3 has been studied in considerable details both experimentally[5,6,7,8] and theoretically.[9,10] The Coriolis interaction which splits the degenerate vibrational levels was first realized by Teller and Tisza[11] in 1932. More recently, due to the availability of high resolution spectrometers the higher order interaction of two different vibrations due to Coriolis forces have been observed, namely the Giant ℓ-type doubling and the K-type doubling. The theoretical developments are due to Nielsen[12] and Hoffman[13] respectively.

We shall report here the first clear observation of K-type doubling in a symmetric top molecule and the first observation of Giant ℓ-type doubling in the ν_3 band of AsH_3. These doublings have been observed through the transitions of ${}^{R}P(J, K)$ and ${}^{P}R(J, K)$. We have also been able to derive some new combination difference relations by utilizing these transistions to obtain ground state molecular constants from a perpendicular band.

In the 2μ region there are three possible bands which lie close together. These are the $2\nu_1$, a parallel band of species A, $\nu_1 + \nu_3$, a doubly degenerate perpendicular band of species E, and $2\nu_3$, a triply degenerate band of species A + A + E. Owing to the complex appearance of the spectrum, they have been only tentatively analyzed and we have not been able to obtain all the molecular constants.

II. K-TYPE DOUBLING IN THE ν_3 BAND

The doublets of ${}^PP(J, 3)$ and ${}^PR(J, 3)$ transitions are indicated in the partial spectrum presented in Fig. 1. It can be seen from an energy level diagram that the spacing between the doublets ${}^PP(J, 3)$ and ${}^PR(J-2, 3)$ should be equal if these splittings are due to the resonance effect of K-type doubling between ν_1 and ν_3. The experimental finding which is given below indicates that this is indeed the case.

TABLE I
OBSERVED K-TYPE DOUBLING SPLITTINGS

	${}^PP(8, 3)$, ${}^PR(6, 3)$	${}^PP(9, 3)$, ${}^PR(7, 3)$	${}^PP(10, 3)$, ${}^PR(8, 3)$	${}^PP(11, 3)$, ${}^PR(9, 3)$
$\Delta\nu$ (cm^{-1})	0.115 , 0.090	0.173 , 0.174	0.275 , 0.261	0.402 , 0.388

This doubling was indicated in the ν_4 ${}^RR(J, 3)$ transitions of PH_3 molecule in Hoffman's work.[13] He found that the matrix elements which will split K = 2 and K = 4 A + A levels are the following.

(1)
$$\langle v_s - 1, v_t, \ell_t, K | H^{(2)}/\hbar c | v_s, v_t - 1, \ell_t \mp, K \pm 2 \rangle$$
$$= \langle v_s, v_t - 1, \ell_t \mp 1, K \pm 2 | H^{(2)}/\hbar c | v_s - 1, v_t, \ell_t, K \rangle$$
$$= \gamma [v_s(v_s \pm \ell_t)]^{\frac{1}{2}} [(J \mp K)(J \mp K - 1)(J \pm K + 1)(J \pm K + 2)]^{\frac{1}{2}} \quad .$$

In the case of ${}^PP(J, 3)$ transitions the following determinant governs the splittings

(2)
$$\begin{vmatrix} -\Delta + E & [J(J+1)]^{\frac{1}{2}}\alpha & [J(J+1)(J+2)(J-1)]^{\frac{1}{2}}\gamma \\ [J(J+1)]^{\frac{1}{2}}\alpha & 1 + E + J(J+1)\beta & 0 \\ [J(J+1)(J+2)(J-1)]^{\frac{1}{2}}\gamma & 0 & -2 + E \end{vmatrix} = 0 \quad .$$

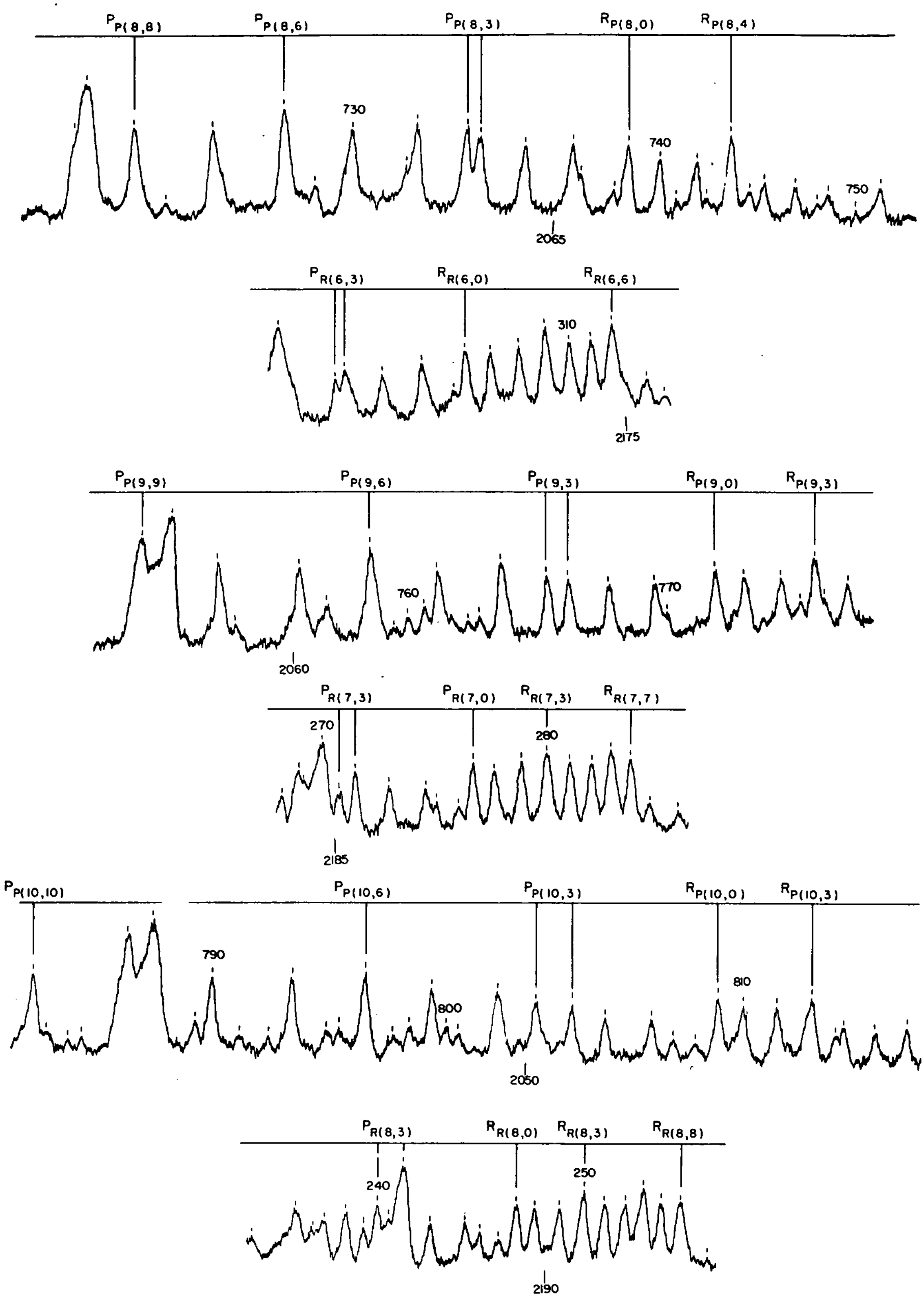

Fig. 1. K-type doubling and Giant ℓ-type doubling in ν_3 of AsH_3.

To determine the parameter γ associated with K-type doubling, one could first employ the second order perturbation technique to obtain an approximate value of γ. Then by iteration one would eventually arrive at a best value for γ which, in this case, comes out to be 1.91×10^{-2} cm^{-1}. These results are tabulated in Table II.

TABLE II
OBSERVED AND CALCULATED $^{P}P(J,3)$ SPLITTINGS

	$^{P}P(8,3)$	$^{P}P(9,3)$	$^{P}P(10,3)$	$^{P}P(11,3)$	$^{P}P(12,3)$	$^{P}P(13,3)$	$^{P}P(14,3)$	$^{P}P(15,3)$
Observed (cm^{-1})	0.115	0.174	0.275	0.402	0.614	0.832	0.995	1.174
Calculated (cm^{-1})	0.114	0.200	0.285	0.416	0.632	0.775	1.002	1.252

III. COMBINATION DIFFERENCE RELATIONS AND THE GIANT ℓ-TYPE DOUBLING

The most desirable way of obtaining the ground state constants is to use certain combination relations in which the perturbation in the upper state energy levels is not involved. Therefore, in the past the ground state constants are obtained from parallel bands since the upper state of a parallel band is nondegenerate. However, if the transitions of $^{P}R(J,K)$ and $^{R}P(J,K)$ are observed in a perpendicular band one can obtain some combination difference relations which only involve the ground state levels. The fact that each pair of the transitions $[^{R}P(J+2,K), ^{R}R(J,K)]$ and $[^{P}R(J-2,K), ^{P}P(J,K)]$ do have a common upper state energy level leads to the following relations.

$$(3) \qquad \frac{^{R}R(J-1,K) - {}^{R}P(J+1,K)}{2J+1} = 2B'' - 4D_J''(J^2+J+1) - 2D_{JK}''K^2$$

$$\frac{^{P}R(J-1,K) - {}^{P}P(J+1,K)}{2J+1} = 2B'' - 4D_J''(J^2+J+1) - 2D_{JK}''K^2 \quad .$$

The ground state constants obtained from ν_3 (⊥) band by using the relations given by Eq. (3) and that obtained from ν_2 (∥) band are very close as can be seen in Table III.

TABLE III
GROUND STATE CONSTANTS OBTAINED
FROM ν_2 AND ν_3

	ν_2	ν_3
$B''(cm^{-1})$	3.7512	3.7510
$D''_J(cm^{-1})$	9.4×10^{-5}	9.3×10^{-5}
$D''_{JK}(cm^{-1})$	-1.16×10^{-4}	-1.20×10^{-4}

In addition, these ${}^PR(J,K)$, ${}^RP(J,K)$ transitions provide the relations

(4) $$ {}^RR(J-1,0) + {}^RP(J,0) = 2[\nu_0 - A' + B'] + 4[A'(1-\zeta) - B'] + 2(B' - B'' - D'_J + D''_J + \tfrac{1}{2}q)J^2 - 2(D'_J - D''_J)J^4 $$

and

(5) $$ \frac{{}^RR(J,0) - {}^RP(J,0)}{2J+1} = (2B'+q) - 4D'_J(J^2+J+1) $$

which can be used in obtaining better values for the parameter q of the Giant ℓ-type doubling as well as the band center.

The following matrix element which give rise to Giant ℓ-type doubling has been derived by Nielsen.[12]

(6) $$\langle v_s-1, v_t, \ell_t, K | H^{(1)\prime}/\hbar c | v_s, v_t-1, \ell_t \pm 1, K \pm 1 \rangle$$

$$= \langle v_s, v_t-1, \ell_t \pm 1, K \pm 1 | H^{(1)\prime}/\hbar c | v_s-1, v_t, \ell_t, K \rangle$$

$$= \frac{1}{2} \frac{\omega_s + \omega_t}{(\omega_s \omega_t)^{\frac{1}{2}}} [v_s(v_t \mp \ell_t)]^{\frac{1}{2}} [(J \mp K)(J \pm K + 1)]^{\frac{1}{2}}$$

$$(\zeta^x_{st} B_e) \quad .$$

The effect of these matrix elements is to split the K=1 upper state levels. However, owing to its selection rule, only one transition of the split levels is allowed. Therefore the appearance of this effect on the spectrum is the shift of ${}^R R(J, 0)$ and ${}^R P(J, 0)$ transitions. These shifts can be seen in Fig. 1.

IV. VIBRATION-ROTATION BAND IN THE 2μ REGION

The spectrum in this region is shown in Fig. 2. One can see that it is complex and puzzling as far as a complete analysis is concerned. As already mentioned in the introduction, there are three possible bands which lie very close to each other. For the convenience of the following discussion we shall list them again.

$2\nu_1$: a parallel band of species A

$\nu_1 + \nu_3$: a doubly degenerate perpendicular band of species E

$2\nu_3$: a triply degenerate band of species A+A+E which has two components, one of which is a parallel band of species A, while the other is a doubly degenerate perpendicular band of species E. We shall designate them as $2\nu_3(\parallel)$ and $2\nu_3(\perp)$ respectively.

From the theoretical point of view, one sees first of all that Fermi type resonance can occur between the parallel component of the $2\nu_3$ band and the parallel band of $2\nu_1$ through the cubic anharmonic force constants in the molecular potential. However, the perpendicular component of the $2\nu_3$ band and the perpendicular band $\nu_1 + \nu_3$ can give rise to Fermi type resonance only through very high order anharmonic terms. Therefore the observation of this effect is very unlikely. Secondly, according to John's rule all three bands will be coupled through Coriolis force.

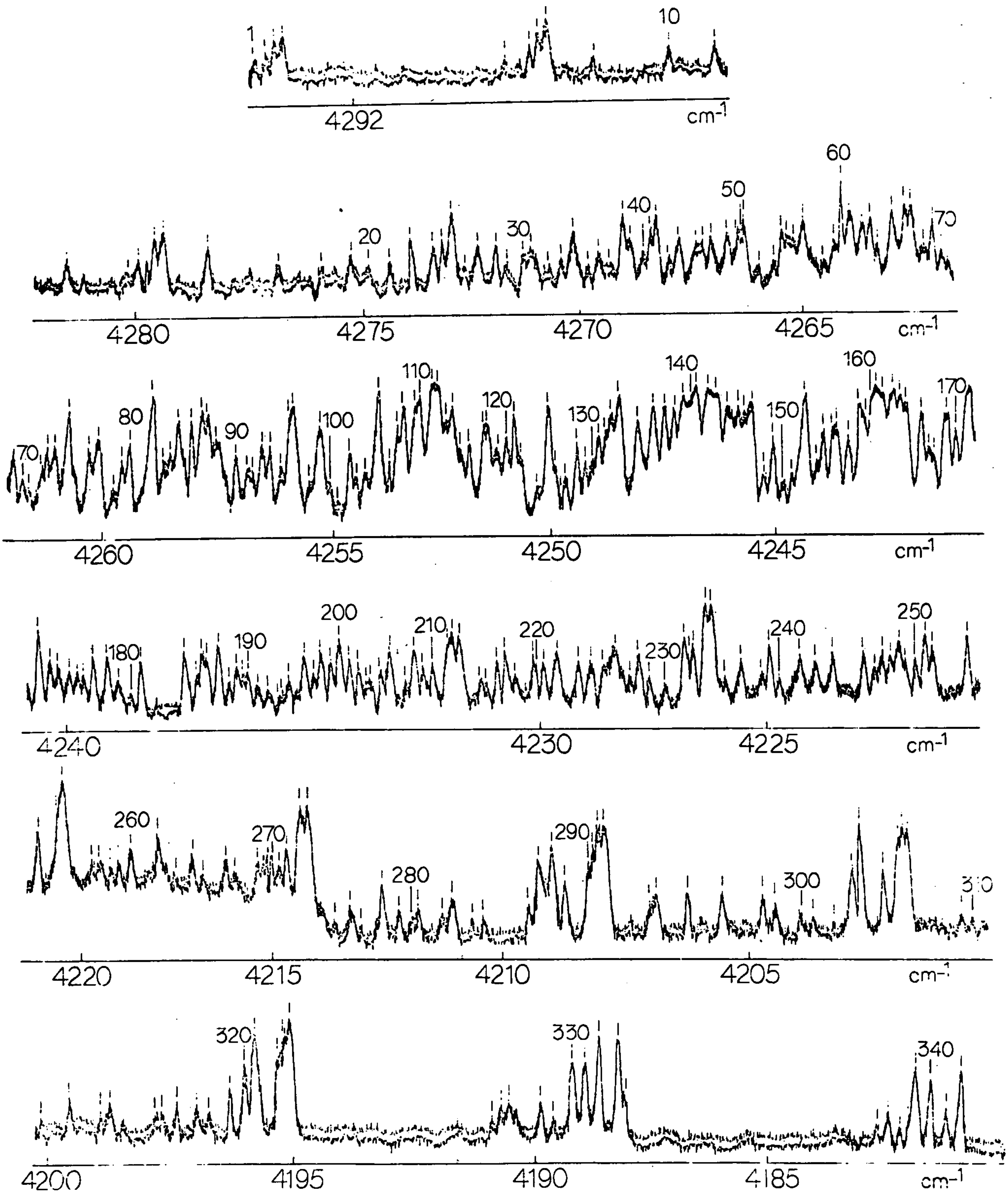

Fig. 2. Absorption spectrum of AsH_3 in the 2μ region.

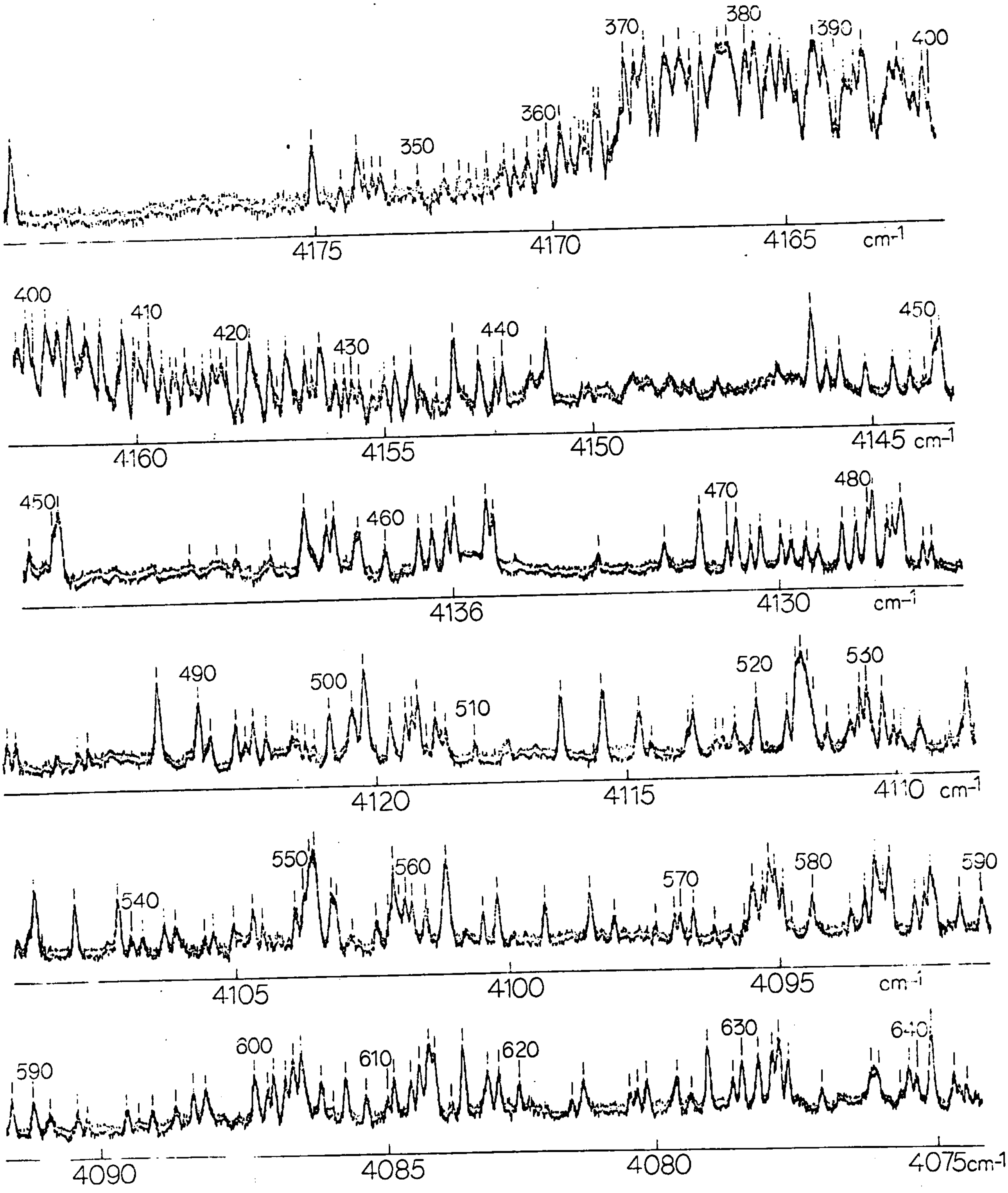
350
360
370
380
390
400
4175
4170
4165 cm-1
400
410
420
430
440
450
4160
4155
4150
4145 cm-1
450
460
470
480
4136
4130 cm-1
490
500
510
520
530
4120
4115
4110 cm-1
540
550
560
570
580
590
4105
4100
4095 cm-1
590
600
610
620
630
640
4090
4085
4080
4075cm-1

Fig. 2. (Cont.)

Hence the K = 1, 2, 4 upper state levels of $\nu_1 + \nu_3$ band will split through the interactions with both $2\nu_1$ and the parallel component of the $2\nu_3$. However, there is no direct interaction between $2\nu_1$ and $2\nu_3(\perp)$ as one can easily see from the matrix elements given by Eqs. (1) and (6). Nonetheless, splitting of some of the levels of $2\nu_3(\perp)$ will be possible through $\nu_1 + \nu_3$, namely the K=2, 4, 5 levels, and K=3, and will be shifted. From group theory consideration, the $2\nu_3(\perp)$ upper state rotational levels have the species given in Table IV in which p is any integer.

TABLE IV
SYMMETRY OF THE ROTATIONAL LEVELS
OF $2\nu_3(\perp)$

K=0	K=3p	K=3p+2		K=3p-2	
E	E + E	$\ell = 2$	$A_1 + A_1$	$\ell = -2$	$A_1 + A_1$
		$\ell = -2$	E	$\ell = 2$	E

Accordingly, the splitting of K=2, 5 levels will be seen at $^RR(J, 1)$ and $^RR(J, 4)$ transitions respectively and that of K=4 level will be seen at $^PP(J, 5)$ transitions. These predicted splittings are not clearly snown in the spectrum except perhaps in the one instance of $^PP(8, 5)$ and $^PP(9, 5)$ which correspond to line numbers (541, 542) and (567, 568) in Fig. 2.

In assigning the rotational quantum numbers we have found Eq. (3) to be extremely useful since the ground state constants are known from the analysis of the fundamental bands. Table V gives all the lines that are tentatively identified.

It appears from the spectrum there is another band whose band center is around 4247 cm^{-1}.

V. CONCLUSIONS

The detailed analysis of the four fundamental bands of AsH_3, their spectra and frequencies can be obtained in Reference 14. Table VI gives the molecular constants from this analysis. The vibration-rotation band in the 2μ region whose frequencies are given in Table VII is far from being completely analyzed. The author believes that further theoretical study must be done before thorough analysis can be attempted.

From the analysis of the four fundamentals of AsH_3, it seems that the K-type doubling as well as the Giant ℓ-type doubling can be observed more readily in ν_3 than ν_4 because of the fact that the K structure of ν_1 which lies very close to ν_3 does not spread out as does that of ν_2 so that the rotational lines of ν_3 are left clean. It is therefore interesting to further confirm the findings of this work by studying the ν_1 and ν_3 vibration-rotation bands of similar molecules, namely PH_3.

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TABLE V
ASSIGNED TRANSITIONS OF THE VIBRATION-ROTATION BANDS OF AsH_3 IN THE 2μ REGION

Serial No.	Transition	Serial No.	Transition	Serial No.	Transition
213	R(9, K)	328	$^{P}R(2,1)$	494, 495	$^{P}P(6,3)$
235	R(8, K)	330	$^{R}R(2,0)$	501	$^{R}P(6,0)$
255	R(7, K)	331	$^{R}R(2,1)$	502	$^{R}P(6,1)$
274	R(6, K)	332	$^{R}R(2,2)$	503	$^{R}P(6,2)$
294	R(5, K)	337	$^{P}R(1,1)$	504	$^{R}P(6,3)$
308	R(4, K)	339	$^{R}R(1,0)$	511	$^{P}P(7,7)$
325	R(3, K)	340	$^{R}R(1,1)$	512	$^{P}P(7,6)$
333	R(2, K)	343	$^{R}R(0.0)$	513	$^{P}P(7,5)$
342	R(1, K)	406	$^{P}P(1,1)$	516	$^{P}P(7,4)$
345	R(0, 0)	437	$^{P}P(2,2)$	520	$^{P}P(7,3)$
410	P(1, 0)	438	$^{P}P(2,1)$	521	$^{P}P(7,2)$
442	P(2, K)	440	$^{R}P(2,0)$	526	$^{P}P(7,1)$
451	P(3, K)	443	$^{P}P(3,3)$	536	$^{P}P(8,8)$
465	P(4, K)	445	$^{P}P(3,2)$	537	$^{P}P(8,7)$
485	P(5, K)	446	$^{P}P(3,1)$	538	$^{P}P(8,6)$
506	P(6, K)	447	$^{R}P(3,0)$	541	$^{P}P(8,5)$
530	P(7, K)	448	$^{R}P(3,1)$	544	$^{P}P(8,4)$
557	P(8, K)	456	$^{P}P(4,4)$	546	$^{P}P(8,3)$
583	P(9, K)	458	$^{P}P(4,3)$	550	$^{P}P(8,2)$
613	P(10, K)	459	$^{P}P(4,2)$	562	$^{P}P(9,9)$
267	$^{R}R(6,0)$	460	$^{P}P(4,1)$	564	$^{P}P(9,8)$
278	$^{P}R(5,5)$	461	$^{P}R(4,0)$	565	$^{P}P(9,7)$
281	$^{P}R(5,4)$	462	$^{P}R(4,1)$	564	$^{P}P(9,6)$
283	$^{P}R(5,3)$	464	$^{P}R(4,2)$	585	$^{P}P(10,10)$
286	$^{R}R(5,0)$	469	$^{P}P(5,5)$	588	$^{P}P(10,9)$
297	$^{P}R(4,4)$	471	$^{P}P(5,4)$	590	$^{P}P(10,8)$
298	$^{P}R(4,3)$	473	$^{P}P(5,3)$	592	$^{P}P(10,7)$
300	$^{P}R(4,2)$	474	$^{P}P(5,2)$	594	$^{P}P(10,6)$
303	$^{R}R(4,0)$	476	$^{P}P(5,1)$	608	$^{P}P(11,11)$
307	$^{R}R(4,4)$	478	$^{R}P(5,0)$	612	$^{P}P(11,10)$
317	$^{P}R(3,2)$	479	$^{R}P(5,1)$	617	$^{P}P(11,9)$
320	$^{R}R(3,0)$	480	$^{R}P(5,2)$	620	$^{P}P(11,8)$
321	$^{R}R(3,1)$	481	$^{R}P(5,3)$	621	$^{P}P(11,7)$
322	$^{R}R(3,2)$	489	$^{P}P(6,6)$		
323	$^{R}R(3,3)$	490	$^{P}P(6,5)$		
327	$^{P}R(2,2)$	492	$^{P}P(6,4)$		

TABLE VI

MOLECULAR CONSTANTS FOR AsH_3 (in cm^{-1})

	Ground State	ν_1	ν_2	ν_3	ν_4	$2\nu_1$	$2\nu_3$
B	3.7513	3.7108	3.5848	3.7153	3.886	3.639	3.688
D_J	9.4×10^{-5}	1.10×10^{-4}	-1.13×10^{-4}	0.86×10^{-4}		-3.6×10^{-4}	
D_{JK}	-1.18×10^{-4}		3.71×10^{-4}	-2.19×10^{-4}			
D_K	1.58×10^{-4}			2.05×10^{-4}			
A	3.4866			3.4273	3.571		
$D_K' - D_K''$			-2.66×10^{-4}				
$A' - A''$			0.0243				- .0433
$(1-\zeta)A$				3.5076	5.088		3.477
q				-7.0×10^{-4}	0.061		
γ				1.91×10^{-2}			
ν_1		2115.191					
ν_2			906.736				
ν_3				2126.402			
ν_4					999.409		
$2\nu_1$						4167.01	
$2\nu_3$			1				

TABLE VII
MEASURED FREQUENCIES OF AsH_3 BANDS
IN THE 2μ REGION

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No	Wave No. (in vacc. cm^{-1})
1		36	4269.53
2		37	
3	4292.34	38	4268.99
4	4292.15	39	4268.84
5	4286.83	40	4268.54
6	4286.53	41	4268.38
7	4286.29	42	4268.25
8	4286.11	43	4267.98
9	4285.92	44	4267.75
10	4283.06	45	4267.38
11	4282.03	46	4267.25
12	4280.18	47	4267.05
13	4279.92	48	4266.68
14	4279.70	49	4266.42
15	4279.52	50	4266.30
16	4278.52	51	4266.22
17	4276.91	52	4265.90
18	4275.95	53	4265.55
19	4275.31	54	4265.35
20	4274.91	55	4265.25
21	4274.44	56	4265.09
22	4273.88	57	4264.90
23	4273.63	58	4264.46
24	4273.17	59	4264.21
25	4272.96	60	4264.03
26	4272.67	61	4263.79
27	4272.37	62	4263.53
28	4271.97	63	4263.36
29	4271.75	64	4263.22
30	4271.37	65	4262.88
31	4271.21	66	4262.60
32	4270.70	67	4262.46
33	4270.41	68	4262.17
34	4270.13	69	4261.98
35	4269.77	70	4261.78

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})
71	4261.64	111	4252.56
72	4261.34	112	4252.48
73	4261.17	113	4252.29
74	4260.97	114	4252.15
75	4260.68	115	4251.98
76	4260.22	116	4251.78
77	4260.01	117	4251.45
78	4259.67	118	4251.38
79	4259.50	119	4251.17
80	4259.20	120	4250.96
81	4258.85	121	4250.77
82	4258.61	122	4250.64
83	4258.46	123	4250.25
84	4258.15	124	4250.03
85	4257.92	125	4249.88
86	4257.66	126	4249.67
87	4257.66	127	4249.57
88	4257.54	128	4249.30
89	4257.35	129	4249.13
90	4256.95	130	4248.99
91	4256.69	131	4248.82
92	4256.59	132	4248.67
93	4256.36	133	4248.57
94	4256.22	134	4248.40
95	4255.96	135	4248.00
96	4255.75	136	4247.67
97	4255.70	137	4247.43
98	4255.35	138	4247.23
99	4255.12	139	4247.03
100	4254.92	140	4246.85
101	4254.73	141	4246.77
102	4254.47	142	4246.49
103	4254.35	143	4246.29
104	4254.14	144	4246.07
105	4253.87	145	4245.82
106	4253.54	146	4245.69
107	4253.33	147	4245.55
108	4253.19	148	4245.28
109	4252.94	149	4245.08
110	4252.86	150	4244.87

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})	
151	4244.68	191	4236.12	
152	4244.39	192	4235.89	
153	4244.14	193	4235.64	
154	4244.02	194		
155	4243.80	195	4235.46	
156	4243.72	196	4235.12	
157	4243.47	197	4234.93	
158	4243.20	198	4234.77	
159	4243.10	199	4234.56	
160	4242.80	200	4234.38	
161	4242.74	201	4234.17	
162	4242.63	202	4233.98	
163	4242.42	203	4233.81	
164	4242.25	204	4233.75	
165	4242.11	205	4233.52	
166	4241.79	206	4233.33	
167	4241.63	207	4232.97	
168	4241.52	208	4232.80	
169	4241.24	209	4232.62	
170	4241.05	210	4232.41	
171	4240.79	211	4232.08	
172	4240.55	212	4232.00	
173	4240.38	213	4231.85	$\underset{\vee}{R}(9, K)$
174	4240.14	214	4231.39	
175	4239.98	215	4231.29	
176	4239.85	216	4231.05	
177	4239.63	217	4230.85	
178	4239.33	218	4230.66	
179	4239.11	219	4230.28	
180	4238.85	220	4230.20	
181	4238.62	221	4229.95	
182	4237.68	222	4229.67	
183	4237.43	223	4229.21	
184	4237.31	224	4228.95	
185	4237.24	225	4228.67	
186	4236.97	226	4228.46	
187	4236.75	227	4228.13	
188	4236.57	228	4227.93	
189	4236.44	229	4227.60	
190	4236.35	230	4237.28	

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})
231	4226.85	271	4214.76
232	4226.74	272	4214.62
233	4226.56	273	4214.31
234	4226.30	274	4214.15
235	4226.16	275	4213.64
236	4225.88	276	4213.29
237	4225.54	277	4213.11
238	4225.09	278	4212.63
239	4224.94	279	4212.28
240	4224.74	280	4212.02
241	4224.30	281	4211.89
242	4223.97	282	4211.39
243	4223.63	283	4211.19
244	4222.97	284	4210.68
245	4222.73	285	4210.44
246	4222.59	286	4209.49
247	4222.41	287	4209.28
248	4222.25	288	4209.02
249	4222.12	289	4208.74
250	4221.88	290	4208.25
251	4221.68	291	4208.14
252	4221.55	292	4208.04
253	4220.82	293	4207.91
254	4220.37	294	4207.00
255	4220.28	295	4206.84
256	4219.66	296	4206.21
257	4219.49	297	4205.43
258	4219.27	298	4204.59
259	4219.11	299	4204.33
260	4218.86	300	4203.81
261	4218.16	301	4203.57
262	4217.79	302	4203.13
263	4217.47	303	4202.70
264	4217.25	304	4202.49
265	4216.77	305	4202.01
266	4216.58	306	4201.71
267	4216.10	307	4201.61
268	4215.95	308	4201.53
269	4215.81	309	4200.43
270	4215.40	310	4200.21

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})
311	4199.62	351	4172.26
312	4198.96	352	4172.96
313	4198.76	353	4171.74
314	4197.83	354	4171.56
315	4197.68	355	4171.39
316	4197.41	356	4171.00
317	4196.92	357	4170.80
318	4196.65	358	4170.53
319	4196.20	359	4170.27
320	4195.92	360	4170.13
321	4195.73	361	4169.83
322	4195.19	362	4169.64
323	4195.11	363	4169.41
324	4195.02	364	4169.33
325	4190.92	365	4169.23
326	4190.74	366	4169.02
327	4190.56	367	4168.96
328	4189.92	368	4168.75
329	4189.65	369	4168.48
330	4189.27	370	4168.30
331	4189.02	371	4168.06
332	4188.76	372	4167.83
333	4188.35	373	3167.63
334	4188.22	374	4167.38
335	4183.02	375	4167.08
336	4182.79	376	4166.87
337	4182.52	377	4166.64
338	4182.35	378	4166.28
339	4182.24	379	4166.10
340	4181.93	380	4165.74
341	4181.60	381	4165.57
342	4181.32	382	4165.33
343	4175.09	383	4165.22
344	4174.50	384	4165.02
345	4174.15	385	4164.86
346	4174.00	386	4164.72
347	4173.84	387	4164.50
348	4173.68	388	4164.35
349	4173.38	389	4164.15
350	4172.80	390	4163.93

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})
391	4163.71	431	4155.46
392	4163.53	432	4155.22
393	4163.37	433	4154.97
394	4163.15	434	4154.74
395	4162.81	435	4154.41
396	4162.67	436	4153.91
397	4162.54	437	4153.54
398	4162.36	438	4153.04
399	4162.16	439	4152.73
400	4162.05	440	4152.56
401	4161.76	441	4151.96
402	4161.53	442	4151.62
403	4161.29	443	4146.33
404	4160.95	444	4146.04
405	4160.66	445	4145.77
406	4160.31	446	4145.27
407	4160.20	447	4144.72
408	4159.98	448	4144.38
409	4159.87	449	4144.07
410	4159.66	450	4143.88
411	4159.43	451	4143.79
412	4159.24	452	4140.24
413	4159.16	453	4140.02
414	4158.97	454	4139.62
415	4158.81	455	4139.35
416	4158.63	456	4138.96
417	4158.44	457	4138.52
418	4158.27	458	4138.38
419	4158.16	459	4137.97
420	4157.94	460	4137.39
421	4157.68	461	4136.76
422	4157.29	462	4136.49
423	4157.16	463	4136.22
424	4156.95	464	4136.07
425	4156.57	465	4135.84
426	4156.44	466	4135.71
427	4156.26	467	4133.53
428	4155.95	468	4132.23
429	4155.77	469	4131.53
430	4155.62	470	4130.98

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})
471	4130.81	511	4116.40
472	4130.52	512	4115.62
473	4130.32	513	4114.87
474	4129.91	514	4114.64
475	4129.72	515	4113.98
476	4129.43	516	4113.88
477	4129.19	517	4113.45
478	4128.73	518	4113.34
479	4128.46	519	4113.10
480	4128.22	520	4112.70
481	4128.14	521	4112.13
482	4127.77	522	4111.92
483	4127.65	523	4111.86
484	4127.49	524	4111.78
485	4127.04	525	4111.71
486	4126.87	526	4111.40
487	4125.60	527	4110.81
488	4125.33	528	4110.69
489	4124.01	530	4110.55
490	4123.27	531	4110.26
491	4122.95	532	4110.07
492	4122.48	533	4109.95
493	4122.30	534	4109.60
494	4122.15	535	4108.81
495	4121.88	536	4108.72
496	4121.41	537	4107.90
497	4121.33	538	4107.10
498	4121.16	539	4106.85
499	4121.01	540	4106.66
500	4120.72	541	4106.27
501	4120.28	542	4106.06
502	4120.05	543	4105.75
503	4119.58	544	4105.52
504	4119.30	545	4105.01
505	4119.17	546	4104.65
506	4119.05	547	4104.48
507	4118.91	548	4103.87
508	4118.73	549	4103.71
509	4118.55	550	4103.59
510	4118.01		

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})
551	4103.53	591	4091.04
552	4103.21	592	4090.47
553	4103.15	593	4090.29
554	4102.85	594	4089.61
555	4102.37	595	4089.40
556	4102.12	596	4089.16
557	5102.01	597	4088.74
558	4101.93	598	4088.41
559	4101.77	599	4088.18
560	4101.64	600	4087.32
561	4101.40	601	4087.10
562	4101.01	602	4086.99
563	4100.37	603	4086.78
564	4100.11	604	4086.64
565	4099.24	605	4086.49
566	4098.41	606	4086.14
567	4097.98	607	4085.98
568		608	4085.70
569	4096.89	609	4085.33
570	4096.80	610	4084.96
571	4096.55	611	4084.84
572	4096.18	612	4084.54
573	4095.62	613	4084.39
574	4095.47	614	4084.22
575	4095.29	615	4084.13
576	4095.17	616	4083.83
577	4095.08	617	4083.61
578	4094.93	618	4083.18
579	4094.80	619	4082.99
580	4094.40	620	4082.52
581	4093.69	621	4081.39
582	4093.45	622	4081.24
583	4093.26	623	4080.54
584	4093.13	624	4080.43
585	4093.00	625	4080.27
586	4092.56	626	4079.66
587	4092.37	627	4079.40
588	4092.26	628	4079.07
589	4091.74	629	4078.61
590	4091.33	630	4078.45

TABLE VII (Cont.)

Serial No.	Wave No. (in vacc. cm^{-1})	Serial No.	Wave No. (in vacc. cm^{-1})
631	4078.16	638	4075.64
632	4077.91	639	4075.51
633	4077.80	640	4075.37
634	4077.64	641	4075.10
635	4077.05	642	4074.71
636	4076.12	643	4074.48
637	4076.07		

REFERENCES

1. McConaghie, V.M. and Nielsen, H.H., Phys. Rev. 75, 633, (1948).

2. McConaghie, V.M. and Nielsen, H.H., Phys. Rev. 75, 633, (1949).

3. Nielsen, H.H., J. Chem. Phys. 20, 759, (1952).

4. Nielsen, H.H., J. Chem. Phys. 20, 1955 (1952).

5. Badger, R.M. and Cartwright, C.H., Phys. Rev. 33, 692, (1929).

6. Wright, N. and Randall, H.M., Phys. Rev. 44, 391, (1933).

7. Barnes, R.B., Phys. Rev. 47, 658, (1935).

8. Dennison, D.M., Rev. Mod. Phys. 12, 175, (1940).

9. Dennison, D.M. and Uhlenbech, G.E., Phys. Rev. 41, 313, (1932).

10. Garring, J.S., Ph.D. Dissertation, "High Resolution Study of the 6, 10, and 16μ Vibration-Rotation Bands of Ammonia," The Ohio State University, (1958).

11. Teller, E and Tisza, L., Z. Physik 73, 791, (1932).

12. Nielsen, H.H., Rev. Mod. Phys. 23, 90, (1951).

13. Hoffman, J.M.; Nielsen, H.H., and Rao, K.N., Zeitschrift für Elektrochemie, Band 64, Heft 5, p. 606, (1960).

14. Yin, P.K.L., Ph.D. Dissertation, "High Resolution Infrared Spectrum of Arsine," The Ohio State University, (1966).