

THE RAMAN SPECTRA OF SOME ORGANIC LIQUIDS UNDER HIGH DISPERSION AND RESOLVING POWER.

(Benzene, Toluene, Phenol, Chlorobenzene, Pyridine and Cyclohexane.)

By R. ANANTHAKRISHNAN.

(From the Department of Physics, Indian Institute of Science, Bangalore.)

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1. Introduction.

THE use of spectrographs of high dispersion and resolving power in the study of Raman spectra is obviously of great interest and importance from the point of view of the elucidation of the fine structure of some of the lines appearing in them, and the precision measurement of their wave-numbers. The chief difficulty in all such work is of course the extremely long duration of exposure required to get well-exposed photographs. Although this difficulty can be overcome to a certain extent by the use of high speed photographic plates and intense sources of illumination, the proper choice of the spectrograph is also an important matter for consideration. A new spectrograph which has been recently added to the Physics Laboratory of the Institute was found to be particularly suited for this type of work. It was therefore thought worth while to examine the Raman spectra of a few substances with this instrument.

2. Experimental.

The spectrograph was of Littrow model with glass optical parts, and was supplied by the firm of Adam Hilger Ltd. The prisms (one 60° and the other 30°) were of large size giving a resolving power of about 3 cm.^{-1} in the region between $\lambda 4046$ and $\lambda 4358$. The dispersion in the region $\lambda 4358$ was about 10 \AA/mm. The instrument combined fairly good light gathering power with a high degree of optical perfection.

The experimental technique was the same as that described by the author on a previous occasion,¹ the quartz mercury arc being put in direct contact with a water mantle enveloping the Raman tube with concave metallic reflectors above and below. The slit width in all experiments was 50μ as it was found that further diminution of it failed to bring out any additional spectral details (so far as the present work was concerned), and resulted only

¹ R. Ananthakrishnan, *Proc. Ind. Acad. Sci., A*, 1935, 2, 452.

in a general loss of intensity necessitating longer exposures. The illumination was so powerful, and the experimental conditions so good that a very intense spectrum of benzene could be obtained in 24 hours. Longer exposures did not reveal any additional features. Ilford golden isozennith plates with special backing were employed for photographing the spectra; an iron arc comparison spectrum was photographed at the centre of the Raman spectrum on all the plates.

3. Results.

The plates were measured on a Hilger Cross-slide micrometer and the frequency shifts of the Raman lines were determined using linear interpolation from the nearest iron arc lines. In the case of sharp lines the results are correct to $\pm 1 \text{ cm}^{-1}$. The 992 line of benzene and its satellites were measured several times with the greatest care, and the results in this case are probably correct to $\pm 0.5 \text{ cm}^{-1}$. The complete classification of the spectra of the substances studied in the interval between $\lambda 4046$ and $\lambda 5100$ is given at the end of the paper. (Tables I to VI.)

(1) *Benzene*.—The Raman spectrum of this substance has formed the subject of investigation by several workers from diverse standpoints. The complete literature on the subject would be too lengthy, and reference may be made to Sirkar's bibliography of the Raman effect.² We may mention in particular the careful work of Dr. Krishnamurti,³ and the more recent and elaborate investigation of Grassmann and Weiler.⁴ The latter authors have reported many new lines of feeble intensity, all of which, however, could not be confirmed in the present work, probably because of the lack of sensitivity of the plates employed in the spectral regions concerned. In Table VII we have given our results side by side with those of the above-mentioned authors. The infra-red absorption frequencies in the last column are taken from Coblentz's book. A surprisingly close coincidence is noticed between the Raman and infra-red frequencies, but whether this coincidence is one of principle or merely accidental is a disputed point.

Placzek⁵ has pointed out that the interpretation of the benzene spectrum is confronted with great difficulties. If we take the plane regular hexagonal model of the benzene molecule, then it follows from symmetry considerations that all Raman frequencies should be inactive in the infra-red and *vice versa*.

² S. C. Sirkar, *Ind. Jour. Phys.*, 1932, 7, 431; S. C. Sirkar and D. Chakravarty, *Ind. Jour. Phys.*, 1935, 9, 553.

³ P. Krishnamurti, *Ind. Jour. Phys.*, 1931, 6, 543.

⁴ P. Grassmann and J. Weiler, *Z. f. Phys.*, 1933, 86, 321.

⁵ G. Placzek, *Leipziger Vorträge*, 1931, S 71.

E. B. Wilson,⁶ however, has expressed the view that in so far as infra-red data are lacking in precision, the coincidence of Raman and infra-red frequencies cannot be asserted with certainty "to establish a result contrary to all other evidence".

The normal vibrations of the benzene molecule have been worked out by E. B. Wilson⁷ who has ascribed to it twenty distinct fundamental frequencies. Of these, seven are Raman-active, four infra-red-active, while the nine remaining fundamentals are completely inactive. Wilson's assignment of the fundamental frequencies⁸ is as given below:—

Raman-active	Infra-red-active
$\nu_1 = 991 \text{ cm.}^{-1}$	$\nu_{11} = 1040 \text{ cm.}^{-1}$
$\nu_2 = 3060$	$\nu_{18} = 660$
$\nu_6 = 605$	$\nu_{19} = 1480$
$\nu_{10} = 1178$	$\nu_{20} = 3080$

"The remaining lines and bands which are nearly all much weaker than those assigned to fundamentals are to be considered as overtones and combinations from this viewpoint." It might be remarked that the classification does not account for the strong infra-red absorption frequency at 1183 whose coincidence with the Raman frequency 1178 has been pointed out by Dr. Placzek⁹ as a result incompatible with the usually accepted plane model of the benzene ring with a centre of symmetry. Similarly, the origin of the Raman line at 2949 cm.^{-1} which is perhaps stronger than the line at 1178 is also not quite clear. As has been pointed out by Grassmann and Weiler,¹⁰ it might probably be the octave of the strong infra-red absorption frequency 1480. The strange coincidence of the Raman frequency 2949 of benzene with the C-H frequency observed in the case of aliphatics, as well as its disappearance in the monosubstituted benzene derivatives, has, however, been a great puzzle.¹¹

⁶ E. B. Wilson, *Phys. Rev.*, 1934, **46**, 146.

⁷ E. B. Wilson, *Phys. Rev.*, 1934, **45**, 706.

⁸ E. B. Wilson, *Phys. Rev.*, 1934, **46**, 146.

⁹ G. Placzek, *Quantenmechanik der Materie und Strahlung*, Teil II, S 235.

¹⁰ P. Grassmann and J. Weiler, *Loc. cit.*

¹¹ See K. W. F. Kohlrausch, *Der Smekal-Raman Effekt*, p. 225.

According to Wilson,¹² the doublet at 1600 cm.⁻¹ in the Raman spectrum of benzene is to be explained on the basis of quantum-mechanical resonance (as in the case of CCl_4) because the sum $\nu_1 + \nu_6 = 1596$ cm.⁻¹ falls between the members of the doublet ν_8 . He has also pointed out that additional evidence in support of this view is provided by the Raman spectra of benzene derivatives. "In nearly all of these a single line occurs near 1600 cm.⁻¹; in none of them is a doublet reported. This is in harmony with the fact that the accidental degeneracy $\nu_1 + \nu_6 \sim \nu_8$ is not nearly so close as in benzene." The above statement appears to have been made from an insufficient knowledge of the experimental data. To illustrate this point, we give below the following table:—

Substance	Frequencies and relative intensities		
C_6H_6	606 (5)	992.5 (10)	1584 (3), 1605 (2)
$\text{C}_6\text{H}_5\text{CH}_3$	622 (4b)	1005 (10s)	1588 (2), 1606 (3), 1630 (0)
$\text{C}_6\text{H}_5\text{Cl}$	615 (3)	1003 (10s)	1565 (0), 1584 (4)
$\text{C}_6\text{H}_5\text{OH}$	620 (4)	1001 (10)	1595 (5), 1605 (5)
$\text{C}_6\text{H}_5\text{N}$	602 (1)	990 (10)	1570 (2), 1579 (2), 1594 (1)

The structure of the benzene molecule has been the theme of a recent note in *Nature* by Angus, Bailey, Ingold, Leckie, Raisin, Thompson and Wilson¹³ who have investigated the Raman and infra-red spectra of hexadeutero-benzene. Coincident frequencies are found in this case also, though not so many as in the case of benzene. These authors therefore believe that these are not coincidences of principle, but are accidental, and come to the conclusion that no real objection remains against the usually accepted structure of the benzene molecule.

Further discussion of the Raman spectrum of benzene is postponed to the next section.

(2) *Toluene*.—The Raman spectrum of this substance has been studied under high dispersion by Howlett¹⁴ and also by Mesnage.¹⁵ More recently,

¹² E. B. Wilson, *Phys. Rev.*, 1934, **46**, 146.

¹³ W. R. Angus, C. R. Bailey, C. K. Ingold, A. H. Leckie, C. G. Raisin, J. W. Thompson and C. L. Wilson, *Nature*, 1935, **136**, 680.

¹⁴ L. E. Howlett, *Canad. Jour. Res.*, 1931, **5**, 572.

¹⁵ P. L. Mesnage, *Jour. de Phys.*, 1931, **2**, 403.

Kohlrausch¹⁶ has made a systematic reinvestigation of the Raman spectra of benzene derivatives. The Raman frequencies are given in Table VIII. The infra-red absorption maxima are given in the last column. Here again, we find many frequencies common to the Raman and infra-red absorption spectra. A number of new Raman lines have been found in the region between $\Delta\nu = 1200$ and 1500 cm.^{-1} , some of which correspond to the infra-red frequencies present in this interval.

(3) *Phenol*.—The Raman frequencies of this substance obtained in the present investigation are given along with those reported by Kohlrausch¹⁷ in Table IX. Several new frequencies have been found, and some of the lines previously reported as broad have been found to be doublets: *e.g.*, 1162 (5b), 1599 (7b), and 3060 (12b). The broad diffuse band at 3524 cm.^{-1} , also reported by Kohlrausch is to be attributed to the O—H oscillation.

(4) *Chlorobenzene*.—Murray and Andrews¹⁸ have made a detailed study of the Raman spectrum of C_6H_5Cl and have reported several new lines. Many of these are confirmed by the present work. The Raman frequencies and infra-red absorption maxima are given in Table X.

(5) *Pyridine*.—Krishnamurti¹⁹ has made a detailed study of the Raman spectrum of pyridine and has reported several new frequencies. Very recently Kohlrausch and Pongratz²⁰ have studied the Raman spectrum of this substance. Unfortunately, the latter authors have overlooked the work of Krishnamurti, so that not only those frequencies which they report as new, but several other frequencies not obtained by them are contained in Krishnamurti's paper. The present work confirms almost all the frequencies reported by Krishnamurti and also shows that some of these frequencies are actually doublets. The results are given in Table XI. The remarkable coincidence between the Raman and infra-red absorption frequencies may be seen from the table.

(6) *Cyclohexane*.—A careful investigation of the Raman spectrum of this substance has been made by Krishnamurti²¹ whose results along with those of the author are given in Table XII. The line $\Delta\nu = 992$ (0) arises most probably from a trace of benzene impurity. The line $\Delta\nu = 695$ (0) reported by Krishnamurti is not confirmed as the corresponding line is not

¹⁶ K. W. F. Kohlrausch and A. Pongratz, *Sitz. der Kais. Acad. Wiss.*, 1933, 142, 637.

¹⁷ K. W. F. Kohlrausch and A. Pongratz, *Loc. cit.*

¹⁸ J. M. Murray and D. H. Andrews, *Jour. Chem. Phys.*, 1933, 1, 402.

¹⁹ P. Krishnamurti, *Ind. Jour. Phys.*, 1931, 6, 543.

²⁰ K. W. F. Kohlrausch and A. Pongratz, *Ber. der Deut. Chem. Ges.*, 1934, 67, 1465.

²¹ P. Krishnamurti, *Ind. Jour. Phys.*, 1931, 6, 543.

observed by 4046 excitation. It would seem that the line in question is really the 802 line excited by λ 4339 and not 695 coming from λ 4358. Between $\Delta\nu = 2852$ 2922 cm.⁻¹ Krishnamurti has reported a continuous background and a line at 2889. In the present work three lines 2870, 2888 and 2898 are observed in this region.

4. *The Carbon Isotope and the Fine Structure of the 992 Line of Benzene.*

The fine structure of the Raman line 992 cm.⁻¹ of benzene has been investigated by Weiler,²² Howlett,²³ Mesnage,²⁴ L. and E. Bloch,²⁵ Grassmann and Weiler,²⁶ Specchia and Scandurra²⁷ and more recently by Bhagavantam.²⁸ The following table gives a collective summary of the results of various investigators:—

Author	Frequencies and Relative Intensities					
J. Weiler (1931) ..	982 (1)		992.0 (4)			
L. E. Howlett (1931) ..	980.3 (5)	983.9 (5)	992.2 (10)	998.5 (5)	1005.3 (0)	
P. L. Mesnage (1931) ..	981.2 (2)		992.4 (10)			
L. and E. Bloch (1933) ..	978.5 (0)	983.8 (2)	992.2 (20)	999.0 (1)	1006.0 (0)	
P. Grassmann and J. Weiler (1933) ..	979 (1)	984 (2)	992.5 (15)	(999)	1005	(1)
O. Specchia and G. Scandurra (1935) ..	977	984	992		1002	
S. Bhagavantam (1935) ..		985 (1)	992.2 (20)			
R. Ananthakrishnan (1935) ..	979 ($\frac{1}{2}$)	984 (1)	992.5 (10)	998 (1)	1006	($\frac{1}{2}$)

A little consideration will show that the results of the different workers are not really discordant except in so far as the visual estimates of the relative intensities are concerned. The latter remark applies especially to

²² J. Weiler, *Z. f. Phys.*, 1931, **69**, 586.

²³ L. E. Howlett, *Loc. cit.*

²⁴ P. L. Mesnage, *Loc. cit.*

²⁵ L. and E. Bloch, *C.R.*, 1933, **196**, 1787.

²⁶ P. Grassmann and J. Weiler, *Loc. cit.*

²⁷ O. Specchia and G. Scandurra, *N. Cimento*, 1935, **12**, 129.

²⁸ S. Bhagavantam, *Proc. Ind. Acad. Sci.*, A, 1935, **2**, 86.

Howlett's intensity estimates of the satellites which are certainly far too high. As regards the frequencies themselves, it might be pointed out that 982 and 981.2 reported by Weiler and Mesnage respectively may be regarded as the mean of the two frequencies 979 and 984, the separation being not observed by them, probably on account of the insufficient resolving power of the instruments employed. The 1002 lines reported by Specchia and Scandurra is perhaps the mean of 998 and 1006. The line at 998 cm.⁻¹ is just resolved from the main line at 992.5 and appears as a wing to the latter. Such a wing to the total symmetric vibration Raman line of CCl_4 has been recently reported by the author.²⁹ A microphotometric study of the intensity distribution in the wing in these two cases would appear to be of great interest in view of the recent work of Bhagavantam, Weiler and others on the distribution of intensity in the rotational wings accompanying the Rayleigh line in the case of liquids.

The author's findings regarding the fine structure of the 992 line of benzene stands in good agreement with that of Grassmann and Weiler, L. E. Howlett and L. and E. Bloch. In view of this, the remark of Bhagavantam³⁰ that "the failure to record the other components, *viz.*, 980.3, 999, etc., in the present investigation is very significant..... A possible explanation is that they have arisen from traces of impurities such as toluene, etc.," does not seem to be justified. The fact that Bhagavantam could record only the strongest satellite was probably because either the duration of exposure or the resolving power of the instrument employed was insufficient.

As is well known, the Raman line 992.5 cm.⁻¹ in the case of benzene, corresponds to the symmetrical expansion and contraction of the benzene ring. Following the original suggestion of Gerlach,³¹ Grassmann and Weiler, Specchia and Scandurra, and Bhagavantam have attributed the strong satellite at 984 cm.⁻¹ to the vibration of the benzene nucleus in which one of the six carbon atoms is the heavier isotope C_{13} . The satellites of lesser intensity are, in the opinion of Grassmann and Weiler, to be interpreted as combinatorial tones. In order to investigate the matter more thoroughly, these authors undertook polarisation measurements and found that the satellite at 984 is polarised to the same extent as the principal line at 992.5. However, they were unable to draw any conclusions as regards the state of polarisation of the other satellites since these could not be recorded in the polarisation experiments on account of their feeble intensity.

²⁹ R. Ananthakrishnan, *Loc. cit.*

³⁰ S. Bhagavantam, *Loc. cit.*

³¹ W. Gerlach, *Ber. d. Bayr. Akad. d. Wiss.*, 1932, 1, 39.

Following Bhagavantam, we can calculate to a first order of approximation the change in frequency that would be produced if one of the six carbon atoms of the benzene nucleus were to be replaced by the isotope C_{13} . If the symmetrical expansion of the benzene ring C_6^{12} has got the frequency 992.5, the corresponding frequency for the ring $C_5^{12}C^{13}$ works out easily as 986, provided it be assumed that the introduction of the heavier isotope does not appreciably affect the symmetry character of the ring. The deviation between the observed frequency 984 and the calculated frequency 986 appears to be too great to attribute it to an error in measurement.

The abundance ratio of the carbon isotopes C^{12} and C^{13} as given by different workers is very divergent. The recent estimate of Aston³² gives the most probable value ratio of abundance as $C^{13} : C^{12} :: 1 : (140 \pm 14)$. As Bhagavantam has pointed out, this ratio gives for the expected satellite an intensity which is roughly 1/23rd of the intensity of the main line. Although too much emphasis cannot be laid on visual estimates of intensity, it appears from the photographs that the relative intensity of the satellite at 984 is greater than this value.

We shall now consider a little more closely the Raman spectra of the monosubstituted derivatives of benzene. It is well known that a number of the Raman lines of benzene occur also in its monoderivatives with practically the same frequency and degree of depolarisation. These frequencies have therefore their origin presumably in the vibrations of the carbon ring. In the case of benzene these frequencies have the following values :

$\Delta\nu = 606, 992, 1176, 1600$ (double) and 3060 (double). Of these $\Delta\nu = 992 \text{ cm.}^{-1}$ is of special interest for reasons already pointed out. In the monoderivatives of benzene the corresponding line has a slightly higher

Substance	Frequency and Relative Intensities				
C_6H_6	979 (½)	984 (1)	992.5 (10)	998 (1) (wing)	1006 (½)
$C_6H_5CH_3$	978 (½)		993 (½)		1005 (10)
C_6H_5Cl		989 (0)		1003 (1)	1013 (00)
C_6H_5OH		991 (00)		1001 (10)	1013 (0) (wing)
C_5H_5N	979 (0)	990 (10)			

³² F. W. Aston, *Proc. Roy. Soc., A*, 1935, **149**, 396.

frequency, and the present investigation shows that in all cases it is accompanied by faint satellites.

The faint companion to the shorter wave-length side of the strong line is in all cases very sharp but its frequency and relative intensity do not seem to bear any simple relation to those of the main line. Its relative intensity is greatest in the case of toluene and least in the case of phenol.

Structure of the Raman line 802 cm.⁻¹ of cyclohexane.—As in the case of the 992.5 line of benzene, the 802 line of cyclohexane represents the frequency of the symmetric expansion and contraction of the puckered carbon ring which forms the nucleus of this molecule. Bhagavantam³³ has reported an "unresolved blackening" to the shorter wave-length side of this line, which, however, is not confirmed by the present work. It seems desirable to point out the remarkable dissimilarity in the structure of the Raman line corresponding to the symmetrical vibration in the case of benzene and cyclohexane. An enlargement of these two lines excited by λ 4047 is reproduced in the Plate. The 802 line of cyclohexane is quite sharp and is completely free from wings and satellites. If the satellite at 984 cm.⁻¹ in the case of benzene is to be attributed to the nucleus C₅¹² C¹³, we ought to expect a similar satellite with the same relative intensity and a frequency shift of 796.7 cm.⁻¹ in the case of cyclohexane. The fact that there is not even the faintest trace of such a satellite, when taken together with other difficulties already pointed out, renders it highly improbable that the 984 satellite of benzene has its origin in the carbon isotope.

5. Conclusion.

The present investigation shows that there exists a fundamental difference between the structure of the 992 line of benzene and the corresponding line in the case of its monosubstituted derivatives. How far it is correct to interpret the satellites of the 992.5 line of benzene as well as many of the less intense lines in its Raman spectrum as over- and combinational tones remains an open question. That the benzene problem is beset with several difficulties has been already emphasised. It may be that many of these difficulties as well as the fine structure of the 992 line itself are all intimately connected with the constitution of the benzene ring which is still a problem not completely understood.

The author wishes to express his respectful thanks to Professor Sir C. V. Raman for his kind interest and suggestions in the course of the present work.

³³ S. Bhagavantam, *Loc. cit.*

Summary.

A detailed study of the Raman spectra of benzene, toluene, phenol, chlorobenzene, pyridine and cyclohexane has been made with a spectrograph of high dispersion and resolving power. Several faint lines have been observed in the Raman spectra of these substances many of which agree with those reported by previous workers, and some of which are reported for the first time. The Raman spectrum of phenol in particular shows several new features. A careful study has been made of the fine structure of the 992 line of benzene, and it is found to consist of four satellites in addition to the main line at 992.5 cm.^{-1} . The frequencies and relative intensities are: 979 ($\frac{1}{2}$), 984 (1), 992.5 (10), 998 (1), 1006 ($\frac{1}{2}$). The corresponding Raman line (802 cm.^{-1}) in the case of cyclohexane shows no fine structure. The possibility of the 984 satellite of benzene arising from the carbon isotope C^{13} has been discussed, and several difficulties are pointed out which render it difficult to attribute such an origin to this satellite. The study of the Raman spectrum of the monoderivatives as well as of pyridine shows that the intense Raman line which corresponds to the symmetrical expansion and contraction of the nucleus is in all cases accompanied by a faint companion to the shorter wave-length side. The frequency and relative intensity of this satellite, however, seem to bear no unique relation to those of the main line. It is concluded that the peculiar structure of the 992 line of benzene is probably connected with the constitution of the benzene ring.

Note on chemicals.—The benzene employed in the present work was the "Kahlbaum" variety for the determination of molecular weight. No special purification was therefore considered necessary excepting the usual process of vacuum distillation to remove suspended motes. Toluene, pyridine and chlorobenzene were subjected to preliminary fractionation in a rectifying column, and the middle fractions distilling at constant boiling point were used in the experiment. Phenol was available in the pure crystalline state, while cyclohexane was taken from a bottle labelled "pure" and supplied by the firm of Theodor Schucardt.

The duration of exposure varied from 24 hours in the case of benzene and chlorobenzene to 48 hours in the case of toluene, pyridine and phenol. Cyclohexane gave a very clear and intense Raman spectrum with a continuous exposure of 80 hours. It may be interesting to add that phenol was a supercooled liquid at 25°C . during the time of exposure.

The notation employed in the accompanying Tables is as follows and is taken from Kohlrausch's well-known book:—

Exciting line Å	Notation	Wave Number (cm. ⁻¹)
4358.34	<i>e</i>	22938
4347.50	<i>f</i>	22995
4339.24	<i>g</i>	23039
4108	<i>h</i>	24335
4077.84	<i>i</i>	24516
4046.56	<i>k</i>	24705.4
3984	<i>l</i>	25098
3906	<i>m</i>	25592
3663	<i>o</i>	27293
3655	<i>p</i>	27353
3650	<i>q</i>	27388

Diffuse lines of zero intensity whose assignments are not quite certain are indicated by an interrogation mark. An asterisk against some of the frequencies indicates that the corresponding lines show a doublet structure.

The abbreviations employed in the Tables have the following significance :—

s = sharp ; *b* = broad ; *d* = diffuse ; *vb* = very broad.

Anti-Stokes lines are indicated by a bar placed over the corresponding frequencies.

TABLE I. Raman Spectrum of Benzene.

No.	ν	Int.	Assignment	No.	ν	Int.	Assignment
1	19874	3	$e-3064$	37	22535	1d	$\{ e-403$
2	19890	1	$e-3048$	38	23100	2	$m-3057$
3	19988	0	$e-2950$	39	23121	3	$k-1605$
4	21333	2	$\{ e-1605$	40	23230	0	$k-1584$
			$\{ i-3188$	41	23260	0	$k-1475$
5	21353	3	$\{ e-1585$	42	23302	$\frac{1}{2}d$	$k-1445$
			$\{ i-3167$				$k-1403$
6	21392	0	$f-1603$	43	23341	1d	$\{ h-992$
7	21412	0	$f-1583$	44	23383	0d	$\{ i-1175$
8	21454	3	$\{ e-1484$	45	23435	0d	$o-3910?$
			$\{ i-3062$	46	23480	0d	$p-3918?$
9	21468	$\frac{1}{2}$	$i-3041$	47	23523.5	6	$q-3908?$
10	21493	00	$e-1445$	48	23532	2	$i-992.5$
11	21518	1	$k-3187$	49	23544	$\frac{1}{2}$	$\{ i-984$
12	21541	$\frac{1}{2}$	$\{ e-1397$	50	23670	$\frac{1}{2}$	$\{ k-1173$
			$\{ k-3164$				$e-606$
13	21566	$\frac{1}{2}$	$i-2950$	51	23699.4	$\frac{1}{2}$	$\{ i-846$
14	21589	00	$i-2927$	52	23707.6	2	$k-1035$
15	21642	8	$k-3063$	53	23712.6	15	$k-1006$
16	21657	4	$k-3048$	54	23721.4	2	$k-997.8$
17	21756	5	$k-2949$	55	23726	1	$k-992.8$
18	21762	2	$e-1176$	56	23855	1d	$k-984$
19	21777	0bd	$k-2928$	57	23905	$\frac{1}{2}$	$k-979.4$
20	21820	0	$f-1175$	58	23930	1	$k-850$
21	21862	00	$g-1177$	59	24009	00d	$k-800$
22	21904	0	$e-1034$	60	24099	5b	$\{ e-992$
23	21933	0	$e-1005$	61	24125	1d	$\{ k-775$
24	21945.2	10	$e-992.8$	62	24165	2	$k-686$
25	21954	1	$e-984$	63	24185	0	$\{ k-606$
26	21959	0	$e-979$	64	24201	4	$o-3194$
27	22003.5	3	$f-991.8$	65	24228	5b	$o-3168$
28	22047	2	$g-992$	66	24242	1	$p-3188$
29	22088*	2	$\{ e-850$	67	24286	8	$p-3168$
			$\{ k-2617$	68	24305	1	$q-3187$
30	22136	0	$e-802$	69			$o-3065$
31	22158	$\frac{1}{2}$	$\{ e-780$	70			$q-3160$
			$\{ k-2547$	71			$o-3051$
32	22248*	$\frac{1}{2}$	$\{ e-690$	72			$p-3067$
			$\{ k-2457$				$p-3048$
33	22331	5	$e-607$	73			$k-400$
34	22388	0	$f-607$	74			$q-3063$
35	22413	0	$k-2292$	75			$o-2949$
36	22438	0	$g-601$	76			$p-2949$
				77			$q-2950$
				78			

402(1d), 606(5), 688($\frac{1}{2}$), 778(0), 801(0), 850(2), 979($\frac{1}{2}$), 984(1), 992.5(10), 998(1), 1006($\frac{1}{2}$), 1035(0), 1175(2), 1400($\frac{1}{2}$), 1445(0), 1480(0), 1584(3), 1605(2), 2292(0), 2457($\frac{1}{2}$), 2547($\frac{1}{2}$), 2617(0), 2928(0d), 2949(5), 3048(4), 3064(8), 3164($\frac{1}{2}$), 3187(1), (3910)(0d).

TABLE II.
Raman Spectrum of Toluene.

No.	ν	Int.	Assignment	No.	ν	Int.	Assignment
1	19980	3b	$e-3058$	46	23206	0	$k-1499$
2	20018	2	$e-2920$	47	23250	0d	$k-1455$
3	21315	0	$e-1623$	48	23272	0d	$k-1433$
4	21331	3	$e-1607$	49	23304	1s	$i-1213$
5	21350	2	$e-1588$	50	23324	3	$k-1401$
6	21387	00	$f-1608$	51	23357	0d	$k-1381$
7	21406	00	$f-1599$	52	23390	0d	$i-1159$
8	21460	2b	$i-3056$	53	23423	0d	$k-1315$
9	21484	0	$e-1454$	54	23457	1	$k-1282$
10	21503	0	$e-1435$	55	23485	1	$e-519$
11	21534	$\frac{1}{2}s$	$e-1404$	56	23494	6s	$i-1031$
12	21555	2s	$e-1383$	57	23510	4s	$k-1211$
13	21597	$\frac{1}{2}b$	$i-2919$	58	23524	1	$i-1006$
14	21634	6b	$k-3071$	59	23548	2	$k-1181$
15	21645	8	$k-3060$	60	23672	8s	$k-1157$
16	21668	4b	$k-3037$	61	23699	10s	$k-1033$
17	21703	$\frac{1}{2}$	$k-3002$	62	23711	$\frac{1}{2}s$	$k-1006$
18	21725	6s	$e-1213$	63	23722	0	$k-993$
19	21756	1	$e-1182$	64	23728	1	$e-784$
20	21783	6b	$\{ e-1155$ $k-2922$	65	23811	0b	$i-788$
21	21837	$3vb$	$k-2868$	66	23865	0b	$k-977$
22	21909	8s	$e-1029$	67	23895	0b	$k-894$
23	21933	10s	$e-1005$	68	23917	0b	$k-840$
24	21945	$\frac{1}{2}s$	$e-993$	69	23941	10s	$i-621$
25	21960	$\frac{1}{2}$	$e-978$	70	23969	0	$k-810$
26	21968	0	$f-1027$	71	23975	0	$k-788$
27	21989	$\frac{1}{2}s$	$f-1006$	72	23993	$\frac{1}{2}s$	$e-1003$
28	22009	00	$g-1030$	73	24084	0	$e-1031$
29	22034	0	$g-1005$	74	24124	4b	$k-730$
30	22040	0b	$e-898$	75	24182	0b	$k-621$
31	22095	0b	$e-843$	76	24220	6s	$k-581?$
32	22122	0b	$e-816$	77	24234	3	$k-523$
33	22150	9s	$e-788$	78	24255	6	$o-3073$
34	22205	$\frac{1}{2}$	$\{ e-733$ $f-790$	79	24284	1d	$o-3059$
35	22250	0	$g-789$	80	24296	4	$o-3038$
36	22314	3	$e-624$	81	24139	6	$p-3069$
37	22415	5	$e-523$	82	24350	5b	$o-3057$
38	22470	$\frac{1}{2}$	$f-525$	83	24370	4b	$q-3034$
39	22537	$0vb$	$m-3055$	84	24382	$\frac{1}{2}$	$q-3038$
40	22604	$\frac{1}{2}$	$e-334$	85	24429	6b	$p-3003$
41	22670	0	$m-2922$	86	24465	6b	$o-2933$
42	22720	6b	$e-218$	87	24470	6b	$q-3006$
43	23099	3	$k-1606$	88	24470	6b	$p-2924$
44	23118	1	$k-1587$	89	24470	6b	$q-2933$
45	23153	1b	$e-215$				

218 (6b), 334 ($\frac{1}{2}$), 523 (5), (581) (0), 622 (4b), 730 (0), 788 (10), 813 (0b), 842 (0b), 896 (0b), 978 ($\frac{1}{2}$), 993 ($\frac{1}{2}$), 1005 (10s), 1030 (8s), 1157 (2), 1181 (1), 1212 (6s), 1282 (0), 1315 (0), 1348 (0), 1381 (2), 1402 (0), 1434 (0), 1455 (0), 1499 (0), 1588 (2), 1606 (3), 1630 (0), 2868 (3vb), 2922 (6b), 3002 ($\frac{1}{2}$), 3037 (4b), 3058 (8), 3070 (6b).

TABLE III.
Raman Spectrum of Phenol.

No.	ν	Int.	Assignment	No.	ν	Int.	Assignment
1	19879	3b	$e-3059$	40	22530	0bd	$m-3062$
2	21171	0bd	$k-3524$	41	22696	5b	$e-242$
3	21332	5	$e-1606$	42	23100	5	$k-1605$
4	21342	5	$e-1596$	43	23111	5	$k-1594$
5	21394*	00b	$f-1601$	44	23179	2b	$e-241$
6	21441	$\frac{1}{2}$	$e-1497$	45	23206	0	$k-1499$
7	21455	2b	$i-3061$	46	23241	0	$k-1464$
8	21505*	0bd	$k-3200$	47	23280	00	$k-1425$
9	21555	00d	$k-3150$	48	23345	0	$i-1171$
10	21620*	$\frac{1}{2}$	$k-3085$	49	23360	0	$i-1156$
		(wing)		50	23449	2b	$k-1256$
11	21641	8	$k-3064$	51	23473	0	$e-535$
12	21654	5	$k-3051$	52	23490	1	$i-1026$
13	21688	2b	$e-1250$	53	23515	3	$i-1001$
14	21714	$\frac{1}{2}$ b	$k-3017$	54	23535	3	$k-1170$
15	21740	00b	$f-1255$	55	23550	3	$k-1155$
16	21768	4s	$e-1170$	56	23592	0	$k-1113$
17	21784	3s	$e-1154$	57	23634	1	$k-1071$
18	21825	0	$\{e-1113^2$	58	23678	8	$k-1027$
19	21840	00	$\{f-1170$		23693	0	$\{e-755$
20	21866	1s	$f-1155$	59			$\{k-1012$
21	21911	8s	$e-1072$	60	23704	10	$k-1001$
22	21923	0	$e-1015$	61	23715	00	$k-990$
		(wing)		62	23754	0	$e-816$
23	21937	10	$e-1001$	63	23766	00	$i-750$
24	21947	00	$e-991$	64	23830	0bd	$p-3520$
25	21968	0	$f-1027$	65	23877	3	$i-623$
26	21994	$\frac{1}{2}$ s	$f-1001$				$\{k-828$
27	22040	0	$g-999$	66	23893	8	$k-812$
28	22107	4	$e-831$	67	23918	0b	$k-787$
29	22125	8	$e-813$	68	23950	2b	$k-755$
30	22153	0d	$e-785$	69	23982	$\frac{1}{2}$	$i-534$
31	22181	3b	$\{e-757$	70	24000	00d	$k-705$
32	22227	00d	$f-814$	71	24085	4	$k-620$
33	22273	00d	$g-812$	72	24114	0d	$k-591$
34	22319	5s	$e-665$	73	24171	4b	$k-534$
35	22349	00	$e-619$	74	24199	$\frac{1}{2}$	$k-506$
36	22377	00	$e-589$	75	24230	4b	$o-3063$
37	22407	4	$f-618$	76	24270	$\frac{1}{2}$	$i-246$
38	22430	1	$e-531$	77	24289	6b	$p-3062$
39	22460	0	$e-508$	78	24324	6	$q-3064$
			$f-530$	79	24462	4b	$k-243$

243 (5b), 507 ($\frac{1}{2}$), 532 (4), 590 (0), 620 (4), 655 (00d), 756 (3), 787 (0b), 812 (8), 830 (3), 991 (0), 1001 (10), 1013 (0), 1027 (8s), 1072 (1), (1113) (0), 1155 (3s), 1170 (4s), 1253 (2b), (1425) (00), 1464 (0), 1498 ($\frac{1}{2}$), 1595 (5), 1605 (5), 3017 ($\frac{1}{2}$ b), 3051 (5), 3064 (8), 3035 ($\frac{1}{2}$) (3150) (00d), 3200 (0bd), 3524 (0vb).

TABLE IV.
Raman Spectrum of Chlorobenzene.

No.	ν	Int.	Assignment	No.	ν	Int.	Assignment
1	19870	2b	<i>e</i> —3066	38	23336	0	<i>k</i> —1369
2	21353	3	<i>e</i> —1585	39	23358	1	<i>e</i> —420
3	21373	0	<i>e</i> —1565	40	23384	0	<i>k</i> —1321
4	21413	00	<i>f</i> —1582	41	23410	0	<i>k</i> —1295?
5	21448	2	<i>i</i> —3068	42	23435	$\frac{1}{2}$	<i>i</i> —1081
6	21492	0	<i>e</i> —1446	43	23493	1s	<i>i</i> —1023
7	21542	1	<i>k</i> —3163	44	23514	2s	<i>i</i> —1002
8	21564	0	{ <i>e</i> —1374 <i>k</i> —3141	45	23531	$\frac{1}{2}$	<i>k</i> —1174
9	21616	0	<i>e</i> —1322	46	23548	1	<i>k</i> —1157
10	21637	10b	<i>k</i> —3068	47	23585	$\frac{1}{2}$	<i>k</i> —1120
11	21677	0	<i>k</i> —3028	48	23622	5	<i>k</i> —1083
12	21697	0	<i>k</i> —3008	49	23638	0	<i>e</i> —700
13	21760	0	<i>e</i> —1178	50	23681	8	<i>k</i> —1024
14	21780	$\frac{1}{2}$	<i>e</i> —1158	51	23692	00	<i>k</i> —1013
15	21815	0	<i>e</i> —1123	52	23702	10s	<i>k</i> —1003
16	21853	4	<i>e</i> —1085	53	23715	0s	<i>k</i> —990
17	21914	6s	<i>e</i> —1024	54	23780	0	<i>k</i> —925
18	21925	00	<i>e</i> —1013	55	23815	$\frac{1}{2}$	<i>i</i> —701
19	21935	10s	<i>e</i> —1003	56	23874	0	<i>k</i> —831
20	21949	0s	<i>e</i> —989	57	23904	0	<i>i</i> —612
21	21971	0s	<i>f</i> —1024	58	23917	00	<i>k</i> —788
22	21993	$\frac{1}{2}s$	<i>f</i> —10 ⁰ 2	59	23941	0s	<i>e</i> —1003
23	22015	00	<i>g</i> —1024	60	23961	0	{ <i>e</i> —1023 <i>k</i> —744
24	22037	0	<i>g</i> —1002	61	24002	6	<i>k</i> —702
25	22108	0	<i>e</i> —830	62	24090	3	<i>k</i> —615
26	22148	00	<i>e</i> —790	63	24127	0	<i>o</i> —3166
27	22198	0	<i>e</i> —740	64	24193	0	<i>p</i> —3160
28	22236	5s	<i>e</i> —702	65	24223	6b	<i>o</i> —3070
29	22295	0	<i>f</i> —700	66	24264	0	<i>o</i> —3029
30	22335	3	<i>e</i> —615	67	42284	10b	{ <i>k</i> —421 <i>p</i> —3069
31	22518	6	<i>e</i> —420	68	24318	10	<i>q</i> —3070
32	22643	3	<i>e</i> —295	69	24364	$\frac{1}{2}d$	<i>q</i> —3024
33	22742	6b	<i>e</i> —196	70	24387	$\frac{1}{2}$	<i>q</i> —3001
34	23121	5	<i>k</i> —1584	71	24407	2	<i>k</i> —298
35	23132	4	<i>e</i> —194	72	22435	$\frac{1}{2}$	<i>k</i> —270?
36	23239	$\frac{1}{2}$	<i>e</i> —301				
37	23265	0	<i>k</i> —1440				

196 (6b), (270) ($\frac{1}{2}$), 295 (2), 420 (6), 615 (3), 702 (6), 742 (0), 790 (0), 830 (0), (925) (0),
989 (0s), 1003 (10s), 1013 (00), 1024 (7), 1084 (5), 1121 ($\frac{1}{2}$), 1158 ($\frac{1}{2}$), 1176 ($\frac{1}{2}$), (1295) (0),
1321 (0), 1372 (0), 1443 (0), 1565 (0), 1584 (4), 3008 (5), 3028 (0), 3068 (10b), 3140 (0),
3165 (1).

TABLE V.
 Raman Spectrum of Pyridine.

No.	ν	Int.	Assignment	No.	ν	Int.	Assignment
1	19884	1½	<i>e</i> —3054	32	22561	00	<i>e</i> —377?
2	21345	½	<i>e</i> —1593	33	23111	1	<i>k</i> —1594
3	21359	2	<i>e</i> —1579	34	23125	2	<i>k</i> —1580
4	21367	2	<i>e</i> —1571	35	23136	2	<i>k</i> —1569
5	21416*	00	<i>i</i> —1579	36	23220	1	<i>k</i> —1485
6	21461	1	<i>e</i> —3055	37	23303	0	<i>i</i> —1213
7	21494	0	<i>k</i> —1444?	38	23488*	5	{ <i>i</i> —1028
8	21533	½	<i>k</i> —3172	39	23525	4s	{ <i>k</i> —1217
9	21563	1½	<i>k</i> —3142	40	23560	0d	<i>k</i> —1145
10	21615	½	<i>k</i> —3090	41	23591	0d	<i>e</i> —653
11	21642	½	<i>k</i> —3063	42	23647	0	<i>k</i> —1058
12	21652	8b	<i>k</i> —3053	43	23667	0	<i>k</i> —1038
13	21671	½	<i>k</i> —3034	44	23677	10s	<i>k</i> —1028
14	21680	½	<i>k</i> —3025	45	23716	10s	<i>k</i> —989
15	21719.	3	{ <i>e</i> —1219	46	23726	0	<i>k</i> —979
			{ <i>k</i> —2986	47	23763	0	<i>k</i> —942
16	21754	1	<i>k</i> —2951	48	23827	½	<i>k</i> —878
17	21797*	½d	{ <i>e</i> —1141	49	23871	00	<i>i</i> —645
			{ <i>k</i> —2908				
18	21834	0d	<i>k</i> —2871	50	23906	0	<i>k</i> —799
19	21882	0	<i>e</i> —1056	51	23930	0	<i>e</i> —992
20	21897	0	<i>e</i> —1041	52	23968	00	<i>e</i> —1030
21	21909	10s	<i>e</i> —1029	53	24052	3	<i>k</i> —653
22	21948	10s	<i>e</i> —990	54	24103	½	<i>k</i> —602
23	21959	0	<i>e</i> —979	55	24158*	0	<i>o</i> —3073
24	21966	0	<i>f</i> —1029	56	24238	5b	<i>o</i> —3055
25	22006	½	<i>f</i> —989	57	24265*	0	<i>o</i> —3028
			{ <i>e</i> —891	58	24285	0	<i>p</i> —3068
26	22047*	½	{ <i>g</i> —992	59	24298	6b	{ <i>k</i> —407
			{ <i>k</i> —2658				{ <i>p</i> —3055
27	22256	0	<i>k</i> —2449	60	24318	0	<i>q</i> —3070
28	22286	3	<i>e</i> —652	61	24335	6b	<i>q</i> —3053
29	22335	1	{ <i>e</i> —603	62	24356	0	<i>q</i> —3032
			{ <i>k</i> —2370	63	24367	0	<i>q</i> —3021
30	22385	0	<i>e</i> —553?	64	24399	1	<i>p</i> —2954
31	22536	1	<i>e</i> —402	65	24436	1½	<i>q</i> —2952

(377) (0), 402 (1), (553) (0), 602 (1), 652 (3), 799 (0), 878 (½), 942 (0), 979 (0), 990 (10), 1028 (10), 1040 (0), 1057 (0), 1143 (½), 1218 (3), (1444) (0), 1485 (1), 1570 (2), 1579 (2), 1594 (1), 2370 (0), 2449 (0), (2658) (0), 2871 (0), 2908 (0), 2951 (1), 2986 (0), 3025 (½), 3034 (½), 3054 (8b), 3063 (½), 3090 (½), 3142 (1½), 3172 (½).

TABLE VI.
Raman Spectrum of Cyclohexane.

No.	ν	Int.	Assignment	No.	ν	Int.	Assignment
1	20001	5	<i>e</i> —2937	32	22335	0	<i>e</i> —603
2	20016	5	<i>e</i> —2922	33	22352	0	<i>k</i> —2353
3	20046	1 <i>b</i>	<i>e</i> —2892	34	22512	1	<i>e</i> —426
4	20084	8	<i>e</i> —2854	35	22554	$\frac{1}{2}$	<i>e</i> —384
5	20238	0	<i>e</i> —2700	36	22654	$\frac{1}{2}d$	<i>m</i> —2938
6	20278	1	<i>e</i> —2660	37	22737	$\frac{1}{2}$	<i>m</i> —2855
7	20311	$\frac{1}{2}$	<i>e</i> —2627	38	22765	0	<i>e</i> —173?
8	20580	0	<i>e</i> —2358	39	22795	0	<i>e</i> —143?
9	21493	5 <i>b</i>	<i>e</i> —1445	40	23072	0 <i>b</i>	<i>i</i> —1444
10	21555	0 <i>d</i>	<i>f</i> —1440	41	23265	5 <i>b</i>	<i>k</i> —1440
11	21578	4	<i>i</i> —2938	42	23319	0 <i>d</i>	<i>e</i> —381
12	21591	4	{ <i>e</i> —1347 <i>i</i> —2925	43	23357	1	{ <i>e</i> —419 <i>k</i> —1348
13	21662	6	<i>i</i> —2854	44	23440	5	<i>k</i> —1265
14	21672	6	<i>e</i> —1266	45	23487	1	<i>i</i> —1029
15	21768	8	<i>k</i> —2937	46	23549	3 <i>s</i>	<i>k</i> —1156
16	21784	8	{ <i>e</i> —1154 <i>k</i> —2921	47	23676	5	<i>k</i> —1029
17	21807	2	<i>k</i> —2928	48	23714	4 <i>s</i>	<i>i</i> —802
18	21817	2	<i>k</i> —2888	49	24738	1 <i>s</i>	<i>e</i> —800
19	21835	1	<i>k</i> —2870	50	24902	10 <i>s</i>	<i>k</i> —803
20	21852	10	<i>k</i> —2853	51	24107	0 <i>b</i>	<i>k</i> —598?
21	21909	6	<i>e</i> —1029	52	24218	$\frac{1}{2}d$	<i>e</i> —1280
22	21946	0	<i>e</i> —992	53	24278	1	<i>k</i> —427
23	21962	0	<i>f</i> —1033	54	24352	8	<i>o</i> —2941
24	22009	1	<i>k</i> —2696	55	24369	8	<i>o</i> —2924
25	22014	00	<i>g</i> —1025	56	24426	8	<i>p</i> —2927
26	22040	2	<i>k</i> —2665	57	24440	7	<i>o</i> —2853
27	22071	1 <i>s</i>	<i>k</i> —2634	58	24457	8	<i>q</i> —2931
28	22100	0 <i>d</i>	<i>k</i> —2605	59	24468	8	<i>q</i> —2920
29	22136	10 <i>s</i>	<i>e</i> —802	60	24502	8	<i>p</i> —2851
30	22192	1 <i>s</i>	<i>f</i> —803	61	24537	10 <i>b</i>	<i>q</i> —2851
31	22238	$\frac{1}{2}b$	{ <i>g</i> —801 <i>k</i> —2467?	62	24591	1 <i>d</i>	<i>o</i> —2702
				63	24632	2	<i>o</i> —2661
				64	24656	2	<i>p</i> —2697

384 (1), 426 (1), (600) (0), 802 (10), 1029 (6), 1156 (3), 1265 (5), 1348 (1), 1442 (5*b*), 2353 (0), 2467 (0), 2605 (0), 2630 (1), 2662 (2), 2698 (1), 2853 (10*b*), 2870 (1), 2888 (2), 2898 (2), 2922 (8), 2937 (8).

TABLE VII.
Benzene.

Author	Krishnamurti	Grassmann and Weiler	Infra-red Absorption maxima
400 (1d)	407 (½)	404 (1d)	
606 (5)	603 (3)	606.8 (8)	
688 (½)	687 (0)	692 (1)	694
778 (0)		781 (1)	782
801 (0)	806 (0)	802 (0)	803
		824 (½)	820
850 (2)	848 (2)	849 (4d)	847
979 (½)	976 (0)	979 (1)	971
984 (1)		984 (2)	
992.5 (10)	992 (10)	992.5 (15s)	
998 (1)		(999)	
1006 (½)		1005 (1)	
1035 (0)	1029 (0)	1034 (1)	1025
1175 (2)	1178 (5)	1176 (4d)	1183
		1285 (0)	
		1326 (½)	1316
1400 (½)	1407 (0)	1403 (2)	1379
1445 (0)		1449 (0d)	
1480 (0)	1477 (0)	1480 (0)	1481
1584 (3)	1584 (3)	1585.4 (12)	1587
1605 (2)	1603 (2)	1606.4 (8)	1613
		1697 (0)	
		1827 (½)	1818
		1936 (1d)	
		1988 (½)	1968
		2030 (½)	2040
		2128 (½d)	
2272 (0)		2296 (1)	2260
		2358 (½dd)	2326
2457 (½)	2455 (½)	2455 (1)	
2547 (½)	2543 (½)	2545 (1)	
2617 (½)		2618 (2)	
		2688 (½)	2667
			2856
			2894
2928 (0d)	2928 (0)	2927 (1)	
2949 (5)	2948 (1)	2949 (4)	
3048 (4)	3046 (1)	3049 (8)	3040
3064 (8)	3063 (4)	3063.6 (12)	3074
3164 (½)	3164 (½)	3166.6 (3s)	
3187 (1)	3187 (1)	3187.4 (4s)	
		3467 (0)	
		3680 (0)	
(3910) (0)		(3916) (0)	

TABLE VIII.

Toluene.

Author	Howlett	Kohlrausch	Mesnage	Infra-red Absorption maxima
218 (6b)	216.7 (4)	217 (8b)	214.3 (F)	
334 (½)	335.0 (0)	348 (1)	341.0 (f)	
		405 (0)		
523 (5)	519.8 (5)	521 (7)	461.4 (m)	
(581) (0)			521.1 (m)	
622 (4b)	622.2 (3)	622 (4)	621.9 (m)	725.6
730 (0)		729 (1)		
788 (10)	786.7 (8)	785 (12)	785.8 (F)	769.3
813 (0b)	807.2 (0)			
842 (0b)	842.4 (0)	842 (1)		831.4
896 (0b)		892 (1)		897.1
978 (0)	968.3 (0)		977.0 (f)	943.4
993 (½s)	992.2 (3)		990.9 (m)	980.4
1005 (10s)	1001.9 (10)	1002 (12)	1003.8 (F)	
1030 (8s)	1027.7 (6)	1032 (6)	1027.1 (m)	1028
				1077
1157 (2)	1156.5 (3)	1153 (3)	1155.4 (m)	
1181 (1)	1180.3 (3)	1176 (1)	1178.5 (ff)	1170
			1187.5 (ff)	1191
1212 (6s)	1210.0 (5)	1209 (8)	1210.0 (F)	1234
1282 (0)			1253.7 (f)	1299
1315 (0)				
1348 (0)				
1381 (2)	1379.5 (2)	1377 (3)	1378.2 (m)	1379
1402 (0)				
1434 (0)		1444 (1b)	1445.2 (f)	
1455 (0)				1457
1499 (0)				1492
1588 (2)	1585.5 (2)	1580 (1)	1585.1 (m)	1550
1606 (3)	1604.7 (3)	1603 (5b)	1604.5 (F)	1613
1630 (0)	1628.5 (00)			
				1724
				1814
				1869
				1961
				2500
			2574.5 (ff)	
			2583.3 (ff)	
			2602.4 (ff)	
			2610.7 (ff)	
2868 (3vb)	2865.8 (0)	2731 (½) 2867 (3b)	2855.5 (f) 2874.6 (f)	

TABLE VIII—(Contd.)

Author	Howlett	Kohlrausch	Mesnage	Infra-red Absorption maxima
2922 (6b)	2919.9 (4)	2917 (10b)	2920.0 (F) 2978.9 (f) 3000.3 (f)	
3002 (½)	3004.4 (0)			2994
3037 (4b)	3035.4 (3)	3026 (4b)		
3058 (8)	3052.1 (5)	3055 (10vb)	3056.6 (m)	
3070 (6b)	3062.5 (4)		3059.0 (0)	
	3205.9 (0)			4150 4586 5848

TABLE IX. Phenol.

Author	Kohlrausch and Pongratz
243 (5b)	238 (7b)
507 (½)	504 (½)
532 (4)	530 (6)
590 (0)	
620 (4)	616 (5)
655 (00d)	
756 (3)	751 (3)
787 (0b)	
812 (8)	810 (10b)
830 (3)	826 (3)
	882 (00)
991 (00)	
1001 (10)	998 (12)
1013 (0)	
1027 (8s)	1025 (7)
1072 (1)	1068 (0)
(1113) (0)	
1155 (3s) }	1162 (5b)
1170 (4s) }	
1253 (2b)	1253 (4b)
(1425) (00)	
1464 (0)	
1498 (½)	
1595 (5) }	
1605 (5) }	1599 (7b)
3017 (½b)	
3051 (5) }	
3064 (8) }	
3085 (½) }	3060 (12b)
(3150) (00d)	
3200 (0bd)	
3524 (0vb)	3518 (0vb)

TABLE X.
Chlorobenzene.

Author	Murray and Andrews	Infra-red Absorption maxima
196 (6b)	198 (7)	
(270) ($\frac{1}{2}$)	275 (0)	
295 (2)	299 (2)	
420 (6)	419 (6)	
	465 (1)	
615 (3)	614 (3)	
702 (6)	703 (5)	
742 (0)	743 (1)	756
790 (0)		
830 (0)	832 (2)	820
		900
(925) (0)		943
989 (0s)		
1003 (10s)	1004 (10)	
1013 (00)		1014
1024 (7)	1023 (7)	
1084 (5)	1084 (5)	1071
1121 ($\frac{1}{2}$)	1122 (2)	1111
1158 ($\frac{1}{2}$)	1159 (3)	1149
1176 ($\frac{1}{2}$)	1174 (2)	
(1295) (0)		1250
1321 (0)	1324 (0)	1333
1372 (0)	1366 (0)	
	1402 (0)	
1443 (0)	1438 (1)	1441
	1475 (1)	1477
1565 (0)	1561 (1)	
1584 (4)	1584 (6)	1595
	2329 (0)	2326
3008 (0)	3005 (0)	
3028 (0)	3027 (0)	
3068 (10b)	3069 (10)	3068
3140 (0)	3141 (0)	
3165 (1)	3166 (0)	

TABLE XI. Pyridine.

Author	Krishnamurti	Kohlrausch and Pongratz	Infra-red Absorption maxima
(377) (0)	371 (0)		
402 (1)	403.6 (1)	401 (3)	
(553) (0)	553 (0)		
602 (1)	603 (1½)	604 (4)	
652 (3)	651.9 (3)	652 (6)	
	717 (0)		
	747 (0)		752
799 (0)	806 (0)		806.5
			840.5
			855
878 (½)	885 (1)	880 (3)	888.6
			922
942 (0)	942 (0)		950
979 (0)			
990 (10)	992 (10)	990 (15)	992.6
1028 (10)	1029.4 (10)	1028 (12)	1028
1040 (0)			
1057 (0)	1067 (1)	1066 (0)	1069
1143 (½)	1145 (1)	1144 (2)	1139
1218 (3)	1218 (3)	1207 (7)	1211
			1290
			1370
(1444) (0)	1439 (0)		1439
1485 (1)	1483 (1½)	1479 (½)	1481
1570 (2)	1571.4 (4)		
1579 (2)	1580.8 (2)	1575 (6b)	
1594 (1)	1596.7 (1)		1600
			1724
			1923
2370 (0)	2368 (½)		
2449 (0)	2455 (½)		
(2658) (0)	2651 (0)		
2871 (0)	2867 (½)		
2908 (0)	2913 (½)		
2951 (1)	2952.2 (1)	2952 (1)	
2986 (0)	2985 (½)		
3025 (½)	3024 (1)		
3034 (½)			
3054 (8b)	3054 (10)	3053 (10b)	3077
3063 (½)			
3090 (½)	3089 (½)		
3142 (1½)	3144.1 (1½)		
3172 (½)	3175 (½)		
			3390
			5848
			5883

TABLE XII.
Cyclohexane.

Author	Krishnamurti	Infra-red Absorption maxima
384 (½)	381 (½)	
426 (1)	425 (1)	
(600) (0)		
802 (10)	695 (0) 802 (10)	840
(992) (0)	(992) (0)	909
1029 (6)	1028 (8)	1042
1156 (3)	1156 (1)	
1265 (5)	1266 (5)	1220
1348 (1)	1344 (½)	1323
1442 (5b)	1444 (5)	1435
2353 (0)	2351 (0)	
2467 (0)	2462 (0)	
2605 (0)		
2630 (1)	2630 (0)	
2662 (2)	2662 (1)	
2698 (1)	2695 (½)	
2853 (10b)	2852 (8)	2860
2870 (1)		
2888 (2)	2889 (1)	
2898 (2)		
2922 (8)	2922 (8)	
2937 (8)	2938 (8)	2940

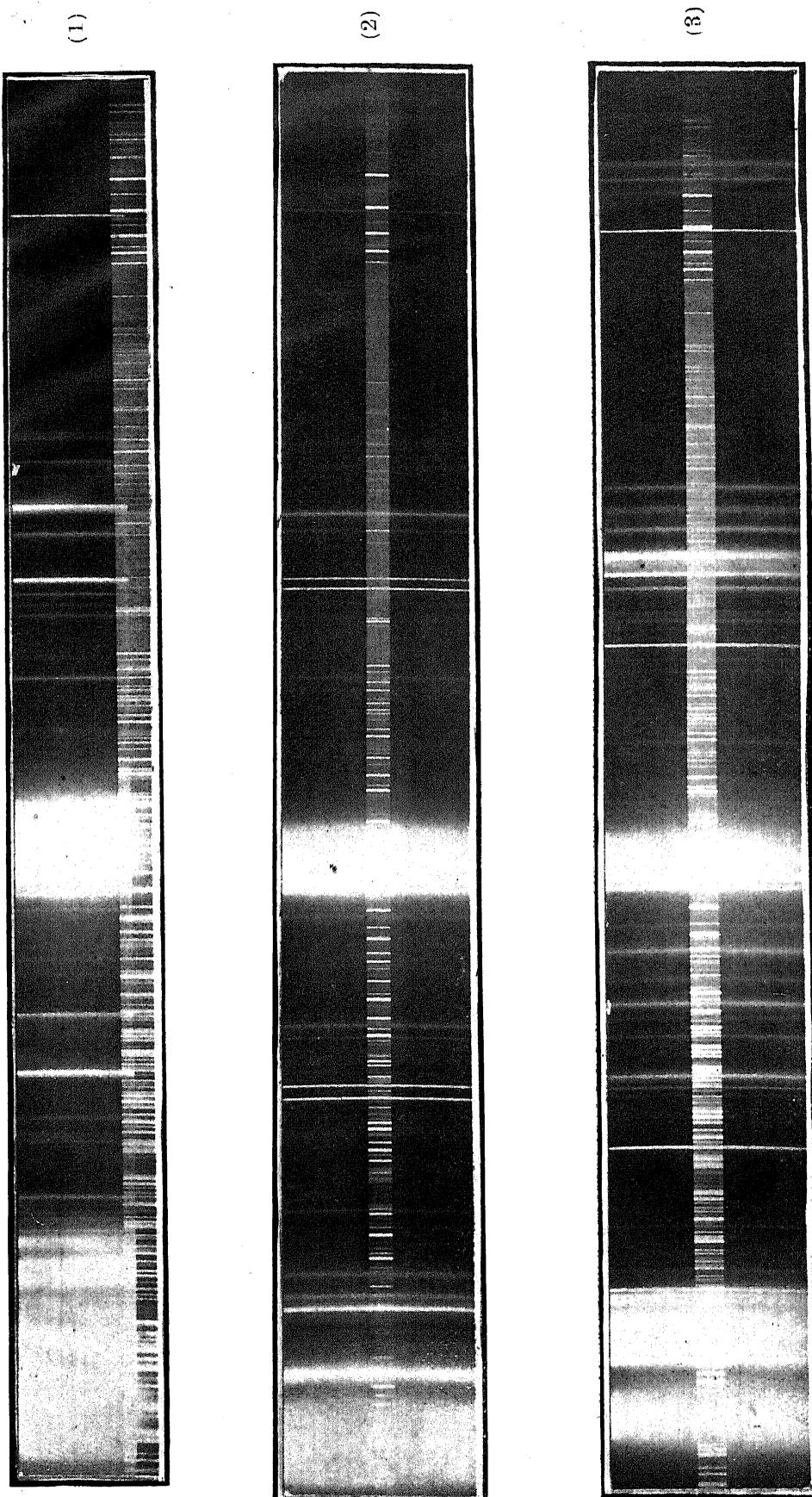


FIG. 1. Raman Spectra.
(1) Benzene; (2) Pyridine; (3) Cyclohexane.

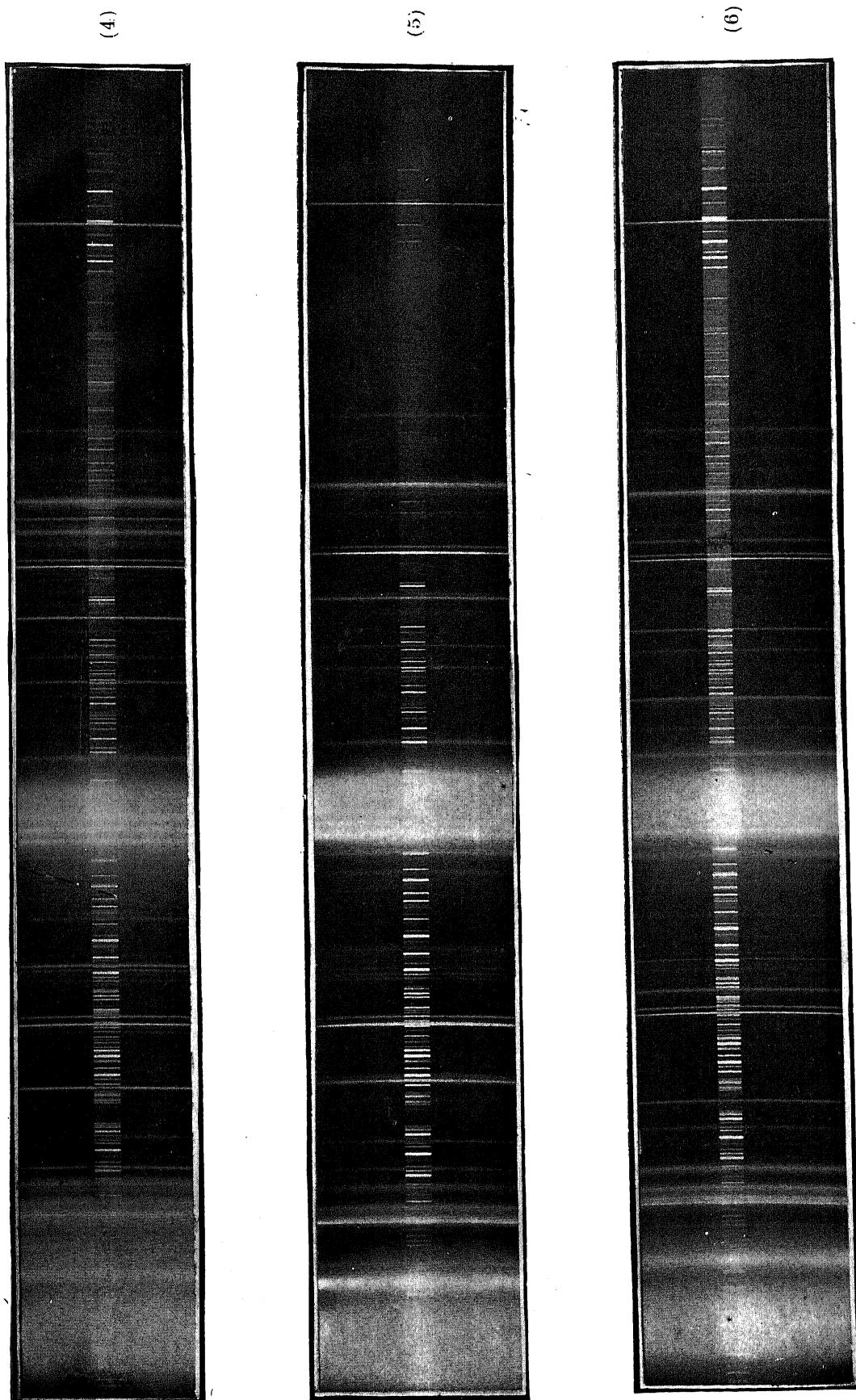


FIG. 2. Raman Spectra.

(4) Toluene, (5) Phenol, (6) Chlorobenzene.

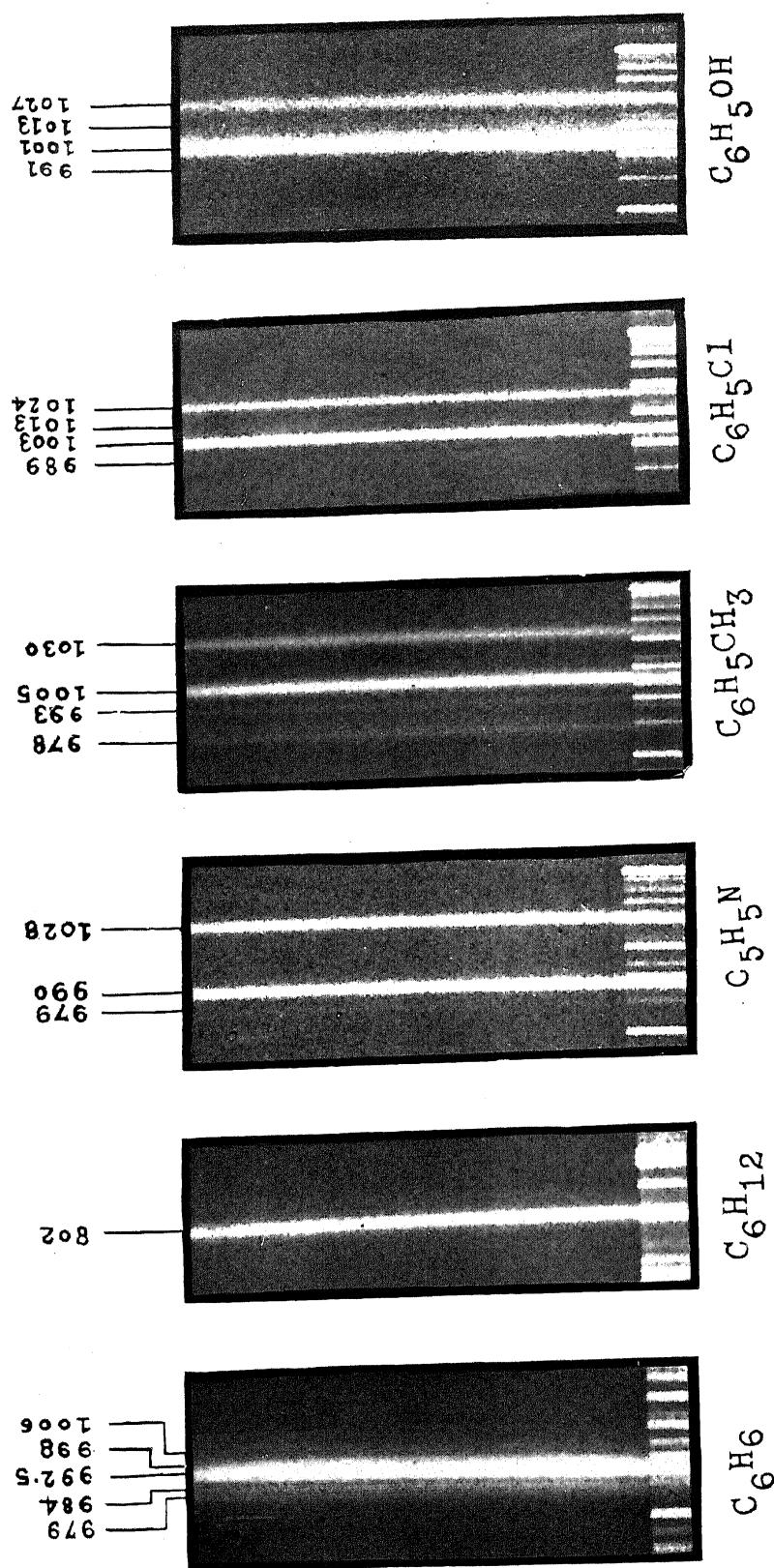


FIG. 3. Fine Structure of Raman Lines.