SUPERSONIC VELOCITY IN GASES AND VAPOURS.

PART II. SUPERSONIC SATELLITES IN VAPOURS.

By S. K. Kulkarni Jatkar.

INTRODUCTION.

In Part I (*This Journal*, 1938, **21A**, 245–71) the major satellites in a supersonic interferometer have been shown to be due to the interference between the main sound beam and the diffracted waves which are reflected by the walls of the tube. In fact, the phenomena is very similar to the wave interference which is observed in connection with radio signal fading. It is well known that fading of the wireless signals is due to interference between the direct 'ray' and that reflected from the Heaviside layer, or between two reflected rays coming from different parts of the Heaviside layer. The different reflections reach the receiver by different paths with phase shifts among themselves, the resulting signal being zero or very strong according to the difference in phase. The striking resemblance between the curves for radio signal fading and those which are obtained in the supersonic interferometer has already been pointed out by the author, which led him to suggest that the periodic signal fading, its dependance on wavelength and its pronounced peakiness with associated 'satellites' depend upon the regular movement of the Heaviside layer alone (*Proc. Ind. Sci. Congress*, 1930, p. 104) (*Electrotechnics*, 1938, No. 11. 84–6).

The use of screens suggested by Eucken and Becker (*Z. Phys. Chem.*, 1934, Abt. B., 27, 219) is only a partial remedy as shown in Part I. Lining the walls of the tube with sound-absorbing material, if such a material could be found for high frequencies, may also simplify the interference curves.

A far more serious complication, however, is due to shift of phase in front of the oscillator, in the main sound beam. The wave theory shows that the region near the radiator, is full of changes of phase and intensity, which may produce complicated reactions of the waves returned by the reflector, on the oscillator which is used to detect the phase of the reflected waves.

The apparatus used and the experimental procedure followed by Grabau, Kneser, Eucken and Becker, Zülkhe, Richards and several others, are not calculated to overcome the various complications. W. T. Richards reports having encountered startling irregularities, which he ascribes to the fact that the waves generated by piezoelectric or magnetostriction oscillators, are not plain or purely sinusoidal to any high degree of approximation, due to the various parts of the surface of the oscillator not vibrating in phase with each other. This factor may, however, produce only damping of the quartz plate which should otherwise oscillate as a whole, although the sensitivity of different portions of the radiating face to the pressure changes may vary, as found by the author.

As shown in Part I the 'satellites' observed in the supersonic interferometer in air and other gases were only apparatus effects, and disappeared when experiments were made using a resonance method in narrow tubes. Two difficulties arise in regard to the use of narrow tubes. One is the somewhat uncertain correction for the effect of viscosity and heat conduction by the walls of the tube for different gases and vapours, and the other is the decreased sensitiveness of the quartz oscillator to the reaction of the resonating tube, and the consequent difficulty in carrying out measurements in gases and vapours which showed strong absorption. It was found by the author that, in the case of carbon disulphide, in spite of the increased density, the absorption was so pronounced that, measurements could not be taken for more than a few wave-lengths near the crystal at 50 Khz., and no measurements whatever could be made at 100 Khz. and above, even near the source. In the case of vapours of methylene dichloride and ethyl acetate, measurements could not be obtained above 126 Khz. It was, therefore, necessary to examine the 'wave form' obtained in various vapours in wide tubes, to find out if reliable measurements could be obtained from the position of the major peaks, on the assumption that they correspond to integral number of half wave-lengths. It was found, however, that these peaks showed variation of phase and intensity at different positions of the reflector on the axis of the crystal oscillator, which made the observed values of wave-lengths unreliable. It has been shown in this paper, by reproductions of the numerous records, that only narrow tube method can be used for accurate determinations of velocity. The decreased sensitivity is offset to some extent by the increased reaction due to higher density of the vapours.

EXPERIMENTAL.

The apparatus used has already been described in Part I (*loc. cit.*). In Fig. 1, curves 1 and 2 represent the variation of the anode current of the valve oscillator for different positions of the reflector in ethyl ether vapour, at 95 Khz. Curve 1 was produced when the oscillations were weak and the curve 2, when oscillations were strong, the increased reaction in curve 1 being due to more favourable valve characteristic, as explained in Part I. Tube diameter was 7.5 cms. and reflector, 5 cms. in all the curves.

Curve 3 represents two records (slightly displaced from each other on purpose), showing the anode current variation in air at 50 Khz. in the same tube, with two different anode couplings.

Curve 4 shows the same variation in steam at 110°.

Curve 5 shows the interferometer curve for ethyl alcohol vapour.

Curve 6 shows the record of the interferometer for ethyl ether.

Curve 7 shows the record of the interferometer for methyl alcohol vapour.

The following tables give the results of some of the typical measurements at 50 Khz.

Fig. 1, Curve 4.

Steam.

n	Observed value	Calculated value	Difference
1	5·80	4·90	− 0·90
3	13·40	14·70	+ 1·30
5	24·30	24·50	+ 0·20
6	29·70	29·40	− 0·30
8	40·05	39·20	− 0·85
12	58·85	58·80	− 0·05
14	68·85	68·60	− 0·25
16	78·50	78·40	− 0·10
17	83·20	83·30	+ 0·10
20	97·05	98·00	+ 0·95
23	112·25	112·70	+ 0·45
24	115·65	117·60	+ 1·95
26	126·40	127·40	+ 1·00

Fig. 1, Curve 5.

Ethyl alcohol.

n	Observed value	Calculated value	Difference
2	6·25	6·00	− 0·25
7	22·65	21·00	− 1·65
18	55·60	54·00	− 1·60
21	65·60	63·00	− 2·60
32	98·40	96·00	− 2·40
34	104·40	102·00	− 2·40
35	106·00	105·00	− 1·00
36	107·00	108·00	+ 1·00

Fig. 1, Curve 6.

Ethyl ether.

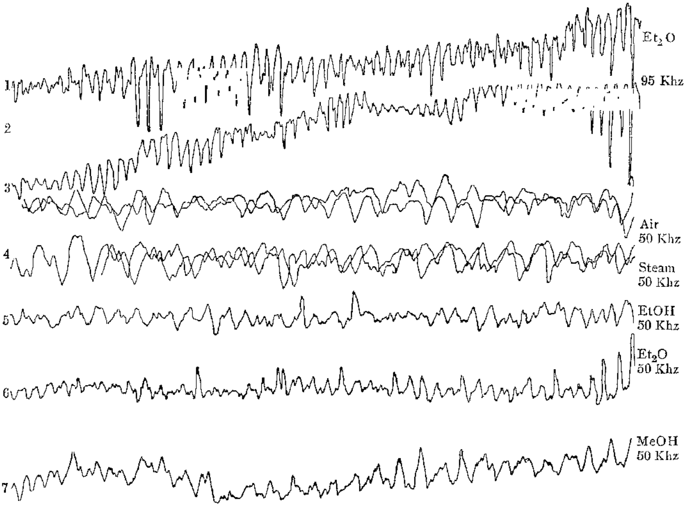
n	Observed value	Calculated value	Difference
1	2·60	2·22	− 0·38
2	4·90	4·44	− 0·46
12	26·90	26·64	− 0·26
22	48·60	48·84	+ 0·24
23	51·95	51·06	− 0·89
24	53·30	53·28	− 0·02
29	64·20	64·38	+ 0·18
30	67·45	66·60	− 0·85
32	71·80	71·04	− 0·76
33	74·05	73·26	− 0·79
38	84·70	84·36	− 0·34
40	89·40	88·80	− 0·60
42	93·23	93·24	+ 0·01
49	107·65	108·78	+ 1·13
51	114·30	113·22	− 1·08
53	117·95	117·66	− 0·29
55	122·45	122·10	− 0·35

Fig. 1, Curve 7.

Methyl alcohol.

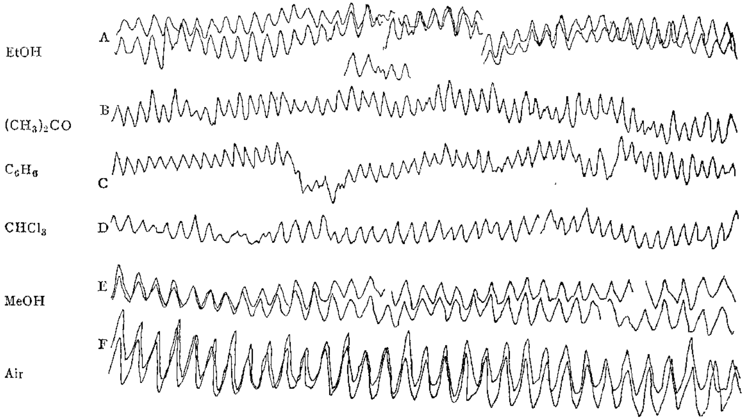
n	Observed value	Calculated value	Difference
1	3·60	3·30	− 0·30
2	5·70	6·60	+ 0·90
3	10·00	9·90	− 0·10
4	13·85	13·20	− 0·65
5	17·50	16·50	− 1·00
6	21·10	19·80	− 1·30
7	24·75	23·10	− 1·65
10	31·60	33·00	+ 1·40
11	34·70	36·30	+ 1·60
12	38·25	39·60	+ 1·35
13	40·95	42·90	+ 1·95
15	48·30	49·50	+ 1·20
17	55·05	56·10	+ 1·05
20	65·10	66·00	+ 0·90
21	67·95	69·30	+ 1·35
22	71·10	72·60	+ 1·50
23	74·50	75·90	+ 1·40
25	82·50	82·50	0
26	86·30	85·80	− 0·50
29	95·60	95·70	+ 0·10
30	99·15	99·00	− 0·15
31	101·10	102·30	+ 0·60
33	109·40	108·90	− 0·50

The above tables show the screw readings for the principal peaks obtained in Fig. 1, along with the calculated values given in the second column on the assumption of an average wave-length. The last column shows the deviations of the observed from the calculated values. *The values obtained for the deviations, if plotted against*



1
2
3
4
5
6
7
Et_2O
95 Khz
Air
50 Khz
Steam
50 Khz
EtOH
50 Khz
Et_2O
50 Khz
MeOH
50 Khz

FIG. 1.



EtOH
A
$(CH_3)_2CO$
B
C_6H_6
C
$CHCl_3$
D
MeOH
E
F
Air

FIG. 2.

distance, abundantly prove that the principal peaks shown in the Pierce interferometer are not integral numbers of half wave-lengths apart. Any simplification of the resonance curves obtained by change in the valve circuits, which has been advocated by many workers in this field, can only be due to decreased sensitivity.

At 95 Khz. the use of 4 cm. tube with a reflector of the same size gave better results than a tube of 8 cm. and a reflector of 5 cm. (see Figs. 2 and 4, Part I). The following table shows some of the typical results for the average half wave-length in air at 95 Khz.

Temp. C.°	$\lambda/2$ mm.	Temp. C.°	$\lambda/2$ mm.
19·5	1·858	99·5	2·104
22·0	1·860	,,	2·100
23·5	1·853	,,	2·095
24·5	1·871	,,	2·094

The following table gives typical values of the velocity of sound in gases and vapours as determined by the Pierce interferometer.

	Temp. C.°	50 Khz. meters	95 Khz. meters
Steam ..	110	497	..
Ethyl alcohol ..	90	266	..
Ethyl ether ..	90	222	..
Methyl alcohol ..	90	343·5	..
Air ..	25	345	345
Carbon dioxide ..	25	270	268
Methyl ether ..	25	255	256

The values are appreciably different from those found in 1 cm. tube given at the end of the paper. It is evident that no reliance can be placed on these measurements.

In Fig. 2, curve A shows the reaction-distance pattern obtained for ethyl alcohol vapour in a tube 1 cm. diameter at 50 Khz. The experiment has been repeated thrice in succession, the third curve being reproduced only for the corresponding middle portion, to show that the results are reproducible. Curve B represents 'the standing wave system' in acetone vapour under the same circumstances. Curve C shows the same phenomena in benzene vapour. Curve D is for chloroform vapour. Curve E shows two repeated patterns for methyl alcohol. Curve F shows duplicate sets of results obtained for air.

The slip produced in the records in the duplicate curves is due to the recording paper, the corresponding screw readings having shown reproducibility within 0.05 of a mm.

In the following tables are given, the results of measurements of wave-lengths of some typical vapours at 97.1° in a tube 1 cm. in diameter at 49.42 Khz. The measurements were done by recording the screw readings for the maximum anode current for individual peaks, the results being given for equal number $(n\lambda/2)$ of successive intervals of half wave-lengths.

Temp. 97·1°.

Methyl Alcohol		Ethyl Alcohol		Ethyl Ether	
	30 $\lambda/2$		40 $\lambda/2$		60 $\lambda/2$
35—5	101·05	41—1	108·95	62—2	124·55
36—6	101·05	42—2	108·85	63—3	124·40
37—7	100·80	43—3	108·70	64—4	124·60
38—8	100·80	44—4	108·10	65—5	124·40
39—9	101·00	45—5	108·25	66—6	124·50
40—10	101·05	46—6	108·35	67—7	124·20
	100·96		*108·53*		*124·44*
$\lambda/2 = 3{\cdot}363$ mm.		$\lambda/2 = 2{\cdot}713$ mm.		$\lambda/2 = 2{\cdot}074$mm.	
$v = 332{\cdot}4$ m./sec.		$v = 268{\cdot}2$ m./sec.		$v = 204{\cdot}9$ m./sec.	

Methyl ether.

Temp. 25°		Temp. 97·5°	
	50 $\lambda/2$		40 $\lambda/2$
51—1	123·25	44—4	110·20
52—2	123·05	45—5	110·65
53—3	123·05	46—6	109·95
54—4	123·03	47—7	110·25
55—5	123·30	48—8	109·25
56—6	123·20		
57—7	123·10		
58—8	123·01		
	123·12		*110·06*
$\lambda/2$ = 2·462		$\lambda/2$ = 2·751	
	51 $\lambda/2$		45 $\lambda/2$
51—0	126·15	1—46	123·65
52—1	126·55	2—47	123·70
55—4	126·45	3—48	123·60
		4—49	123·80
		5—50	123·40
	126·38		*123·63*
$\lambda/2$ = 2·478		$\lambda/2$ = 2·747	
	Mean 8 $\lambda/2$		50 $\lambda/2$
1—8	20·08	50—0	136·95
9–16	19·75	51—1	137·05
17–24	19·80	52—2	136·80
25–32	19·40		
33–40	19·90		
	19·77		*136·93*
$\lambda/2$ = 2·477		$\lambda/2$ = 2·738	
Mean $\lambda/2$ = 2·472 mm.		Mean $\lambda/2$ = 2·745 mm.	
Velocity = $n\lambda$ = 245·1 m./sec.		Velocity = $n\lambda$ = 271·3 m./sec.	

Acetone.

49·42 Khz. Temp. 97·1°		94·57 Khz. Temp. 97·1°	
	10 $\lambda/2$		100 $\lambda/2$
11—1	24·55	101—1	127·25
12—2	24·80	102—2	127·12
13—3	24·60	103—3	126·98
14—4	24·50	104—4	127·06
15—5	24·25	105—5	126·98
16—6	24·30		
17—7	24·35		
18—8	24·25		
19—9	24·35		
20–10	24·50		
	24·45		*127·08*
$\lambda/2$ = 2·445		$\lambda/2$ = 1·271	
	Mean 20 $\lambda/2$		Mean 20 $\lambda/2$
1—20	48·442	1—20	25·496
21—40	48·628	21—40	25·602
41—60	48·450	41—60	25·458
61—80	48·273	61—80	25·128
		81–100	25·390
	48·448		*25·419*
$\lambda/2$ = 2·422		$\lambda/2$ = 1·271	
Mean $\lambda/2$ = 2·433 mm.		Mean $\lambda/2$ = 1·271 mm.	
Velocity = $n\lambda$ = 240·5 m./sec.		Velocity = $n\lambda$ = 240·4 m./sec.	

Benzene 97·1°		Chloroform 97·1°		Acetone Temp. 134°		Benzene Temp. 134°	
	60 $\lambda/2$		30 $\lambda/2$		50 $\lambda/2$		60 $\lambda/2$
65—5	121·75	34—4	51·70	51—1	127·53	61—1	128·62
66—6	121·55	35—5	51·75	52—2	127·33	62—2	128·72
67—7	121·40	36—6	51·70	53—3	127·10	63—3	129·05
68—8	121·40	37—7	51·70	54—4	127·25	64—4	128·97
69—9	121·30	38—8	51·70	55—5	127·47	65—5	128·80
70–10	121·35	39—9	51·65	56—6	127·62	66—6	129·50
	121·46		*51·70*	57—7	127·40	67—7	129·00
$\lambda/2 = 2·024$ mm.		$\lambda/2 = 1·723$ mm.		58—8	127·68	68—8	129·12
$v = 200·1$ m./sec.		$v = 170·3$ m./sec.			*127·42*		*128·92*
				$\lambda/2 = 2·548$ mm.		$\lambda/2 = 2·149$ mm.	
				Velocity $= n\lambda$ $= 250·5$ m./sec.		Velocity $= n\lambda$ $= 213·9$ m./sec.	

Air.

50 Khz.

Temp. 24·2 °C.		Temp. 23·8° C.		Temp. 97·1° C.	
	32 $\lambda/2$		32 $\lambda/2$		32 $\lambda/2$
33—1	111·45	33—1	111·40	32—0	126·35
34—2	111·65	34—2	111·48	33—1	125·90
35—3	111·65	35—3	111·63	34—2	126·00
36—4	111·63	36—4	111·50	35—3	125·98
37—5	111·60	37—5	111·55	36—4	126·15
38—6	111·60	38—6	111·54	37—5	126·15
	111·60		*111·52*		*126·088*
$\lambda/2 = 3·490$ mm.		$\lambda/2 = 3·485$ mm.		$\lambda/2 = 3·940$ mm.	
$v = 345·3$ m./sec.		$v = 344·8$ m./sec.		$v = 389·4$ m./sec.	

Carbon tetrachloride Temp. 97·1°		Propyl ether Temp. 97·1°		Steam 134°	
	80 $\lambda/2$		70 $\lambda/2$		20 $\lambda/2$
91—11	116·60	70—0	131·05	20—0	100·05
92—12	116·55	71—1	130·85	21—1	100·20
93—13	116·55	72—2	131·45	22—2	99·10
94—14	116·60	73—3	131·20	23—3	99·45
95—15	116·50			24—4	99·95
96—16	116·50			25—5	100·25
97—17	116·45			26—6	99·35
98—18	116·42			27—7	99·75
				28—8	100·40
	116·52		*131·14*		*99·944*
$\lambda/2 = 1·4565$ mm.		$\lambda/2 = 1·8734$ mm.		$\lambda/2 = 4·9972$ mm.	
$v = 144·0$ m./sec.		$v = 185·2$ m./sec.		$v = 492·0$ m./sec.	

It will be seen from curve A that the portion, where there is slight irregularity, shows an inverted peak. But there is apparently no phase shift. The wave-length is 5.42 mm. in ethyl alcohol.

In curve B for acetone, the wave-length is 4.89 mm., and there are three inverted peaks.

In curve C for benzene, where the wave-length is 4.05 mm. there are at least two regions of complicated wave form. The measurements, however, show that there is no phase shift, as could be found by noting the differences between the calculated and observed readings.

In the curve D for chloroform vapour, in which the wave-length is 3.4 mm., the tendency to show complexity is apparent with diminished wave-length.

In curve E for methyl alcohol, the improvement of the wave-form is due to the increased wave-length which is 6.72 mm.

In curve F for air, the wave-length is 7.0 mm. at 25° C. The further improvement in the wave-form with the increased wave-length is quite clearly shown.

It will be shown in a subsequent communication that at higher temperatures, when the wave-length becomes 8 mm. the correction for the diameter of the tube is appreciable, as the wave-length is comparable with the diameter of the tube.

As the wave-lengths in vapours are lower and as further experiments were done at higher frequencies, a tube of 5 mm. diameter was used for subsequent experiments. Although the reaction was enormously decreased, there was no difficulty in getting reliable measurements by adjusting the power in the oscillator and the position of the valve characteristic, so as to get maximum anode reaction.

SUMMARY.

Further evidence regarding the complexity of the wave-form in the Pierce interferometer in vapours, has been brought forth by reproduction of the typical records, which show variations of intensity and phase, due to diffraction effects. The anomalous results obtained are thus due to experimental method, rather than to any characteristic of the physical situation, such as complexity of the molecule and its structure, and the attendant absorption and dispersion.

As a result of many experiments, only the narrow tube method has been found to be satisfactory for accurate determination of velocity. The following table shows the values of the velocity of sound in meters/sec. at 49.42 Khz. in a few typical gases and vapours in 1 cm. brass tube, at 685 mm.

	25°	97·1°	134°
Steam	..	..	492·0
Air	345·0	389·4	..
Methyl alcohol	..	332·4	..
Methyl ether	245·1	271·3	..
Ethyl alcohol	..	268·2	..
Acetone	..	240·5	250·5
Ethyl ether	..	204·9	..
Benzene	..	200·1	214·0
Propyl ether	..	185·0	..
Chloroform	..	170·3	..
Carbon tetrachloride	..	144·0	..

Department of General Chemistry,
Indian Institute of Science,
Bangalore (India).

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