SUPERSONIC VELOCITY IN GASES AND VAPOURS.

PART VIII. SUPERSONIC VELOCITY IN AIR, STEAM, CARBON DIOXIDE AND CARBON DISULPHIDE.

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INTRODUCTION.

Since the original work of Pierce (Proc. Amer. Acad. Arts Sci. 1925, **60**, 271), a number of papers have appeared on the velocity of sound in air at room temperature. [*cf.* Partington and Shilling, 3 Khz. (Phil. Mag. 1928, **6**, 920); Cornish and Eastman (Phys. Rev. 1929, **33**, 90, 258); Hubbard, 218-476 Khz. (Phys. Rev. 1930, **36**, 1668); Pielemeier, 1216 Khz. (Phys. Rev. 1930, **36**, 1005; 1931, **38**, 1236); Reid 42-140 Khz. (Phys. Rev. 1930, **35**, 814; 1931. **37**, 1147); Kao, 20–70 Khz. (Ann. Phys. Paris, 1932, **17**, 315); Hershberger, 20-70 Khz. (Physics 1932, **2**, 269); Vance, 30-200 Khz. (Phys. Rev. 1932, **39**, 737); Grabau, 20-70 Khz. (Jour. Acoust. Soc. 1933, **5**, 1); Kaye and Sherrat, 0.5 to 27 Khz. (Proc. Roy. Soc. 1934, **147**, 292; 1936, **156**, 504); Norton, 20-70 Khz. (Jour. Acoust. Soc, 1935, **1**, 16); Ishi, 2000-2892 Khz. (Sci. Pap. Inst. Phys. Chem. Res. Tokio, 1935, **26**, 201); Pearson, 92-800 Khz. (Proc. Phys. Soc. 1935, **47**, 136); Parker, (Proc. Phys. Soc. 1937,**49**, 95)]. Most of the results point to an average velocity of 331.7 m./sec. at 0° from 20 to 1500 Khz. The only results above room temperature are those by Kaye and Sherrat, which are confined to 0.5—27 Khz., at 18° and 100°.

Air has been recommended as a standard material for measuring the frequency of the oscillators and for the determination of the tube constants. The author resorted to this method during the course of his work on the supersonic velocity in organic vapours in narrow tubes. The results with air were unfortunately not so accurate as in the case of vapours, owing to smaller number of half wave lengths measured at lower frequencies, and to uncertain tube corrections.

In the present paper the author has given the results he obtained for supersonic velocity in air from 23.6 to 564 Khz. at room temperature and between 49.5 to 127 Khz. up to 200°. The velocity of sound in free air was found by carrying out experiments in tubes of different diameters. The value at room temperature was in agreement with the results of other worker. The supersonic velocity in steam superheated to 134° at 685mm. was also measured from 49 to 126 Khz., and the specific heat deduced, is in good agreement with the value obtained from spectroscopic data.

In carbon dioxide and carbon disulphide, owing to considerable absorption, measurements could be made only at 50 Khz. at which the velocity observed, indicated the normal molecular heat for both the gases.

EXPERIMENTAL.

The apparatus used and the experimental method of procedure was the same as that described in the previous parts. The various quartz oscillators used in this investigation were those described in Part IV of this series.

(*I*) *Velocity of Sound in Air*

A slow stream of air freed from carbon dioxide and moisture by passing over soda lime and P_2O_5, was passed into the apparatus while making measurements, the results of which are given in the following tables.

TABLE I

Air.

Diameter 1·25 cm.	Diameter 1 cm.		
23·586 Khz	49·47 Khz.	49·42 Khz.	49·395 Khz.
21·2°	24·2°	97·1°	134°
n $10\lambda/2$	*n* $32\lambda/2$	*n* $30\lambda/2$	*n* $30\lambda/2$
10 − 0 73·35	33 − 1 111·45	31 − 1 117·35	31 − 1 120·30
11 − 1 73·05	34 − 2 111·65	32 − 2 117·02	32 − 2 119·50
12 − 2 73·15	35 − 3 111·65	33 − 3 116·80	33 − 3 119·65
13 − 3 72·85	36 − 4 111·63	34 − 4 117·15	34 − 4 120·32
73·10	37 − 5 111·60	35 − 5 117·10	35 − 5 119·88
$\lambda/2$=7·310	38 − 6 111·60	*117·06*	*119·93*
$10\lambda/2$	*111·60*	$\lambda/2$=3·902	$\lambda/2$=3·998
10 − 0 73·00	$\lambda/2$=3·490	$35\lambda/2$	$30\lambda/2$
11 − 1 72·53	$32\lambda/2$	35 − 0 133·65	31 − 1 120·10
12 − 2 73·00	33 − 1 111·40	36 − 1 133·65	32 − 2 119·80
13 − 3 73·00	34 − 2 111·48	*133·65*	33 − 3 120·30
14 − 4 73·23	35 − 3 111·63	$\lambda/2$=3·904	34 − 4 119·85
72·95	36 − 4 111·50	$25\lambda/2$	*120·01*
$\lambda/2$=7·295	37 − 5 111·55	25 − 0 97·30	$\lambda/2$=4·001
$10\lambda/2$	38 − 6 111·54	26 − 1 97·20	$30\lambda/2$
10 − 0 72·92	*111·52*	27 − 2 97·45	30 − 0 120·10
11 − 1 73·35	$\lambda/2$=3·485	*97·32*	32 − 2 120 30
12 − 2 73·38		$\lambda/2$=3·895	34 − 4 120·15
13 − 3 73·50		$25\lambda/2$	*120·18*
14 − 4 73·45		25 − 0 97·45	$\lambda/2$=4·006
73·11		26 − 1 97·75	
$\lambda/2$=7·311		27 − 2 97·05	
		97·42	
		$\lambda/2$=3·896	
mean $\lambda/2$=7·308 mm.	mean $\lambda/2$=3·4875mm.	mean $\lambda/2$=3·90 mm.	mean $\lambda/2$=4·002 mm.
V=344·6 m./sec.	**V=345·1 m./sec.**	**V=385·5 m./sec.**	**V=395·4 m./sec.**

TABLE 2

Air.

5 mm. diameter brass tube.

49·47 Khz, (21·2°)

n	$34\,\lambda/2$
1 − 35	117·80
2 − 36	117·73
3 − 37	117·85
	117·80

$\lambda/2$ = 3·465 mm.

n	$34\,\lambda/2$
34 − 0	117·68
35 − 1	117·72
36 − 2	117·64
	117·68

$\lambda/2$ = 3·461 mm

mean $\lambda/2$ = 3·463 mm.

V = 342·6 m./sec.

94·483 Khz (19°)

n	$70\,\lambda/2$
0 − 70	125·65
1 − 71	125·65
2 − 72	125·60
3 − 73	125·58
4 − 74	125·60
	125·62

$\lambda/2$ = 1·795 mm.

n	$70\,\lambda/2$
70 − 0	125·67
71 − 1	125·70
72 − 2	125·63
73 − 3	125·62
	125·66

$\lambda/2$ = 1·795 mm

mean $\lambda/2$ = 1·795 mm.

V = 339·2 m./sec.

94·483 Khz. (19·6°)

n	$54\,\lambda/2$
1 − 55	97·50
2 − 56	97·50
	97·50

$\lambda/2$ = 1·806 mm

n	$54\,\lambda/2$
54 − 0	97·45
55 − 1	97·40
	97·42

$\lambda/2$ = 1·804 mm

mean $\lambda/2$ = 1·805 mm.

V = 341·0 m./sec.

94·483 Khz. (23°)

n	$64\,\lambda/2$
0 − 64	116·35
1 − 65	116·21
2 − 66	116·25
3 − 67	116·23
	116·26

$\lambda/2$ = 1·817 mm.

n	$66\,\lambda/2$
66 − 0	119·73
67 − 1	119·79
68 − 2	119·75
69 − 3	119·73
70 − 4	119·79
	119·76

$\lambda/2$ = 1·815 mm.

mean $\lambda/2$ = 1·816 mm.

V = 343·2 m./sec

94·483 Khz (24·2°)

n	$64\,\lambda/2$
64 − 0	116·85
65 − 1	116·81
66 − 2	116·81
67 − 3	116·80
68 − 4	116·83
	116·82

$\lambda/2$ = 1·825 mm.

n	$56\,\lambda/2$
0 − 56	102·22
1 − 57	102·05
2 − 58	102·15
3 − 59	102·27
4 − 60	102·35
5 − 61	102·30
	102·22

$\lambda/2$ = 1·825 mm.

mean $\lambda/2$ = 1·825 mm

V = 344·9 m./sec

93·889 Khz. (134°)

n	$46\,\lambda/2$
46 − 0	97·20

$\lambda/2$ = 2·113 mm

n	$55\,\lambda/2$
0 − 55	116·23
1 − 56	116·13
2 − 57	116·28
3 − 58	116·27
	116·23

$\lambda/2$ = 2·113 mm.

mean $\lambda/2$ = 2·113 mm.

V = 396·8 m./sec.

93·889 Khz (134°)

n	$56\,\lambda/2$
0 − 56	118·17
1 − 57	118·08
2 − 58	118·03
3 − 59	118·13
4 − 60	118·00
5 − 61	118·15
	118·09

$\lambda/2$ = 2·108 mm

n	$56\,\lambda/2$
58 − 2	117·80
59 − 3	117·90
60 − 4	117·84
61 − 5	118·00
	117·89

$\lambda/2$ = 2·106 mm.

mean $\lambda/2$ = 2·107 mm

V = 395·7 m./sec

TABLE 3

Air.

5 mm. diameter brass tube

95·93 Khz.
(28·4°)

n	$39\lambda/2$
39 – 0	69·80
40 – 1	69·78
41 – 2	70·10
	69·89

$\lambda/2 = 1{\cdot}792$ mm

V = 343·8 m/sec

95·93 Khz
(27°)

n	$40\lambda/2$
43 – 3	72·08
44 – 4	72·00
45 – 5	71·90
46 – 6	71·95
	71·98

$\lambda/2 = 1{\cdot}800$ mm

V = 345·3 m. sec

95·82 Khz.
(97·1°)

n	$55\lambda/2$
55 – 0	110·55
56 – 1	110·55
57 – 2	110·60
58 – 3	110·35
59 – 4	110·35
60 – 5	110·55
	110·49

$\lambda/2 = 2{\cdot}009$ mm

	$50\lambda/2$
50 – 0	100·48
51 – 1	100·28
52 – 2	100·65
53 – 3	100·65
54 – 4	100·73
55 – 5	100·48
	110·55

$\lambda/2 = 2{\cdot}011$ mm
mean $\lambda/2 = 2{\cdot}010$ mm.

V = 385·2 m/sec.

95·82 Khz.
(97·1°)

n	$60\lambda/2$
0 – 60	120·95
1 – 61	120·72
2 – 62	120·68
3 – 63	120·83
	120·79

$\lambda/2 = 2{\cdot}013$ mm.

	$60\lambda/2$
60 – 0	120·63
61 – 1	120·43
62 – 2	120·48
63 – 3	120·60
	120·51

$\lambda/2 = 2{\cdot}009$ mm.
mean $\lambda/2 = 2{\cdot}011$ mm.

V = 385·4 m/sec.

TABLE 4.

Air.

5 mm. diameter brass tube.

127·408 Khz. (19°)	127·408 Khz (23·8°)	126·264 Khz. (134°)
n 80 $\lambda/2$ 80 − 0 106·64 81 − 1 106 56 82 − 2 106·57 83 − 3 106·57 84 − 4 106·58 85 − 5 106·53 *106·57* $\lambda/2$ = 1·332 mm.	*n* 80 $\lambda/2$ 80 − 0 108·18 81 − 1 108·12 82 − 2 108·15 83 − 3 108·15 *108·15* $\lambda/2$ = 1·352 mm. 84 $\lambda/2$ 0 − 84 113·75 1 − 85 113·75 *113·75* $\lambda/2$ = 1·354 mm. mean $\lambda/2$ = 1·353 mm.	*n* 74 $\lambda/2$ 0 − 74 116·55 1 − 75 116·45 2 − 76 116·30 *116·43* $\lambda/2$ = 1·573 mm. 74 $\lambda/2$ 76 − 2 116·40 77 − 3 116·47 78 − 4 116·47 79 − 5 116·32 *116·41* $\lambda/2$ = 1·573 mm. mean $\lambda/2$ = 1·573 mm.
V = 339·4 m./sec.	**V = 344·5 m./sec.**	**V = 397·2 m /sec.**
127·408 Khz. (19·8°)	126·648 Khz. (97·1°)	126·264 Khz. (134°)
n 75 $\lambda/2$ 0 − 75 100·45 1 − 76 100·50 2 − 77 100·57 *100·51* $\lambda/2$ = 1·340 mm. 75 $\lambda/2$ 75 − 0 100·48 76 − 1 100·50 77 − 2 100·45 *100·48* $\lambda/2$ = 1·340 mm. mean $\lambda/2$ = 1·340 mm.	*n* 82 $\lambda/2$ 83 − 1 124·57 84 − 2 124·68 85 − 3 124·78 *124·68* $\lambda/2$ = 1·520 mm.	*n* 76 $\lambda/2$ 76 − 0 119·63 77 − 1 119·82 78 − 2 119·75 79 − 3 119·71 80 − 4 119·58 81 − 5 119·40 *119·63* $\lambda/2$ = 1·574 mm. 76 $\lambda/2$ 0 − 76 119·72 1 − 77 119·35 2 − 78 119·78 *119·62* $\lambda/2$ = 1·574 mm. mean $\lambda/2$ = 1·574 mm.
V = 341·5 m /sec.	**V = 385·0 m /sec.**	**V = 397·6 m./sec.**

TABLE 5

Air.

1.3 cm. Pythagoras tube.

49·47 Khz.	94·16 Khz.
23°	83°
n 50 λ/2 52 − 2 173·92 53 − 3 174·36 *174·14* λ/2 = 3·483 mm.	*n* 50 λ/2 51 − 1 100·07 52 − 2 100·00 *100·04* λ/2 = 2·001 mm.
V = 344·6 m/sec.	**V = 376·5 m/sec.**
94·483 Khz.	95·82 Khz.
22·3°	159°
n 71 λ/2 72 − 1 129·54 73 − 2 129·57 74 − 3 129·61 75 − 4 129·89 76 − 5 129·59 78 − 7 129·87 *129·68* λ/2 = 1·826mm.	*n* 60 λ/2 61 − 1 130·97 62 − 2 129·97 *130·45* λ/2 = 2·174mm.
V = 345·1 m/sec.	**V = 416·6 m/sec.**
94·483 Khz.	95·82 Khz.
23·7°	162°
n 91 λ/2 91 − 0 165·09 92 − 1 164·88 93 − 2 165·24 94 − 3 165·21 *165·11* λ/2 = 1·814 mm.	*n* 50 λ/2 51 − 1 109·74 52 − 2 109·39 *109·56* λ/2 = 2·191mm.
V = 342·8 m./sec.	**V = 419·9 m./sec.**
95·93 Khz.	95·82 Khz.
21·3°	189°
n 100 λ/2 101 − 1 179·31 102 − 2 179·14 103 − 3 179·03 104 − 4 179·07 106 − 6 179·60 107 − 7 179·34 108 − 8 179·27 *179·25* λ/2 = 1·792 mm.	*n* 10 λ/2 11 − 1 23·03 12 − 2 23·34 *23·18* λ/2 = 2·318
V = 343.8 m./sec.	**V = 444·2 m./sec.**

TABLE 6

Air.

7.5 cm. brass tube

396·5 Khz.		564·03 Khz.					
(29·8°)		(29 7°)		(29°)		(26 3°)	
No	Screw reading mm	No	Screw reading mm	No.	Screw reading mm	No	Screw reading mm.
0	0·00	0	36·05	0	429·45	0	451·58
1	0·15	1	36·32	1	429·15	1	451·28
2	0·90	2	36·65	2	428·85	2	450·98
3	1·30	3	37·06	3	428·55	3	450·68
17	7·45	4	37·25	4	428·23	4	450·38
47	20·90	5	37·60	24	418·93	114	416·53
66	29·15	25	44·80	44	415·80	134	410·38
85	37·40	45	50·00	64	409·62	154	404·20
105	46·18	65	56·20	84	403·38	174	398·00
124	54·55	85	62·42	104	397·18	185	394·65
144	63·65	105	68·62	114	394·05	186	394·32
158	69·78	106	68·95	115	393·75	187	394·00
159	70·20	107	69·25	116	393·45	188	393·72
160	70·65	108	69·55	117	393·13	189	393·40
		109	69·88	118	392·82		
		110	70·18				
	158 $\lambda/2$		105 $\lambda/2$		114 $\lambda/2$		185 $\lambda/2$
158—0	69·78	105—0	32·57	0—114	35·40	0—185	56·93
159—1	69·75	106—1	32·63	1—115	35.40	1—186	56·96
160—2	69·75	107—2	32·60	2—116	35·40	2—187	56·98
		108—3	32·55	3—117	35·42	3—188	56·96
		109—4	32·63	4—118	35·41	4—189	56·98
		110—5	32·58				
	69·76		*32·59*		*35·41*		*56·96*
$\lambda/2$ = 0·4415 mm.		$\lambda/2$ = 0.3104 mm.		$\lambda/2$ = 0·3106 mm.		$\lambda/2$ = 0.3079 mm.	
V = 350. 1 m sec. **V_{25} = 347 1. m./sec.**		**V = 350.1 m./ sec.** **V_{25} = 347.3 m./ sec.**		**V = 350 4 m./sec** **V_{25} = 347.7 m./ sec.**		**V = 347.3 m./ sec.** **V_{25} = 346.5 m./sec.**	

TABLE 7.

Velocity of Sound in Air at 25°.

Tube diameter cm.	Frequency f Khz.	$1/d\sqrt{\pi f}$	Velocity
1.3	23.586	0.00283	346.9
P 1.3	49.47	0.00195	345.8
,,	94.483	0.00141	346.6
,,	95.93	0.00140	346.0
0.97	49.47	0.00262	345.6
,,	94.483	0.00188.	345.1
,,	127.408	0.00164	346.2
0.55	49.47	0.00461	344.9
,,	94.483	0.00333	345.4
,,	127.408	0.00289	345.2
7.5	396.5	0	347.1
,,	564.03	0	347.2
∞	∞	0	347.0

P = Pythagoras.

TABLE 8.

Velocity of Sound in Air at 97.1°

Tube Diameter cm.	Frequency f Khz.	$1/d\sqrt{\pi f}$	Velocity
0.97	49.42	0.00262	385.5
0.55	95.82	0.00331	385.2
,,	,,	,,	385.4
,,	126.648	0.00289	385.0
∞	∞	0	386.8

The values at room temperature were reduced to 25° by applying the temperature coefficient. The tube correction was applied by plotting the factor $1/d\sqrt{\pi f}$ where d is the diameter of the tube and f is the frequency, against the observed velocity, and extrapolating for zero factor. The extrapolated velocity of sound in air at 25° between 49 and 127 Khz was 347.0 m./sec. The narrow tube method could not be used for higher frequencies. The measurements were therefore carried out in a 7.5 cm. diameter tube and consequently there was no tube correction. At 396.5 Khz. the velocity was 347.1m./sec., and at 564 Khz. 347.2m./sec. At 23.5 Khz. the velocity was 347.5 m./sec. in a tube of 13 mm. diameter. There is obviously no dispersion in the velocity of sound in air at room temperature. Most of the measurements at higher temperatures were confined to frequencies between 46 to 127 Khz. and were carried out in two brass tubes of 9.7 mm. and 5.5 mm. The corrected value for the velocity of sound at 97.1° is 386.8m./sec., which is in agreement with the value obtained by Kaye and Sherrat, at lower frequencies. The values at 134° are summarised in Table 9. The line passing through tube factors at 94 and 126 Khz. gives 401.6 m./sec. as the extrapolated value, the result at 49 Khz. in a 9.7 mm. diameter tube being too low.

TABLE 9

Velocity of Sound in Air at 134°.

Tube Diameter cm.	Frequency f Khz.	$1/d\sqrt{\pi f}$	Velocity
0.97	49.395	0.00262	395.4
0.55	93.889	0.00333	396.8
,,	126.264	0.00289	397.2
,,	,,	,,	397.5
∞	∞	0	401.6

Experiments were conducted in a Pythagorous tube of 13 mm. diameter at various temperatures. The results are given in Table 5. The values at room temperature are reduced to 25° and are given in Table 7. It was found that the reduction factors for the diameters of the tube, were nearly the same as for the brass tube owing to the comparatively large diameter, the velocity at 94.5 Khz being practically the same as in free air. The velocity at 83° was 376.5 m./sec. which is in agreement with the previous values. The values of velocity at 134°, 159°–162° and 189° were on a regular curve but were different from the value at 100°, and are therefore subject to correction for the effect of tube. Experiments could not be carried at higher temperatures owing to absorption.

(2) *Steam.*

The results for steam at 134° are given in Table 10, and summarised in Table 11 along with the reduction factors for the effect of the tube. The corrected value of the velocity is 496.3 m./sec. The specific heat was calculated by using the Berthelot's equation of state. The various constants used for calculation are $M = 18.016$, $p_c = 194.6$, $t_c = 364.3$, $\pi = 0.0046$, $\tau = 1.566$, $\phi = 1.014$, $5\pi\tau^3 = 0.09$, $\frac{V^2M}{RT} = 1.3112$, $\gamma = 1.3295$, $C_p - C_v = 2.0487$, and $C_p = 8.26$. The value calculated from the expression which was deduced from spectroscopic data by Bryant (Ind. Eng. Chem. 1933, **25**, 822) and by Gordon (Jour. Chem. Phys. 1934, **2**, 65), when reduced to atmospheric pressure, comes to 8.26 calories, in excellent agreement with the result obtained from supersonic velocity.

TABLE 10

Steam. 134°

49.395 Khz.				93.889 Khz				126.264 Khz.	
n	$20\lambda/2$	n	$25\lambda/2$	n	$42\lambda/2$	n	$42\lambda/2$	n	$62\lambda/2$
21 – 1	100·05	26 – 1	125·75	44 – 2	110·40	45 – 3	110·35	62 – 0	121·35
22 – 2	100·20	27 – 2	125·35	45 – 3	110·35	46 – 4	110·28	63 – 1	121·30
23 – 3	99·10	28 – 3	124·30						
24 – 4	99·45	29 – 4	124 85						
25 – 5	99·95	30 – 5	124·80						
26 – 6	100·25								
27 – 7	99·35								
28 – 8	99·75								
29 – 9	100·40								
	99·94		*123·01*		*110·38*		*110·32*		*121·33*
$\lambda/2 =$ 4·997 mm.		$\lambda/2 =$ 5.000mm.		$\lambda/2 =$ 2.629 mm.		$\lambda/2 =$ 2.627 mm.		$\lambda/2 =$ 1 957 mm	
mean $\lambda/2 = 4.9985$ mm.				mean $\lambda/2 = 2{,}628$ mm.				**V = 494.2/m. sec. 493,8 m./ sec. corrected for expansion.**	
V = 493.8 m./sec				**V = 493.5 m,/sec.**					

TABLE 11.

Velocity of Sound in Steam at 134°

Diameter cm.	Frequency f Khz.	$1/d\sqrt{2\pi f}$	Velocity
0.97	49.395	0.00262	493.8
0.55	126.264	0.00289	493.8
”	93.889	0.00333	493.5
∞	∞	0	496.3

(3) Carbon Dioxide.

The velocity of sound in carbon dioxide was determined at room temperature at 23.58 Khz. and 49.47 Khz. (Table 12). The average value reduced to 25° is 269.6 m./sec. as compared with 269.3 m./sec. calculated from the values obtained by Kaye and Sherrat at 9 to 27 Khz. At 97.1° the average value is 299.7 m./sec. at 49.42 Khz. This value is higher than that given by Kaye and Sherrat.

TABLE 12.

Velocity of Sound in Carbon dioxide.

23·585 Khz. (25°)		23·585 Khz. (26°)		49·47 Khz. (26·3°)		49·42 Khz. (97·1°)	
n	$20\lambda/2$	n	$20\lambda/2$	n	$10\lambda/2$	n	$35\lambda/2$
0 – 20	114·10	20 – 0	114·75	1 – 10	27·45	35 – 0	106·40
1 – 21	114·10	21 – 1	115·05	11 – 20	27·10	36 – 1	106·25
2 – 22	113·90	22 – 2	114·75	21 – 30	27·35	37 – 2	105·15
3 – 23	114·45	23 – 3	114·30				
4 – 24	114·05						
	114·08		*114·77*		*27·30*		*106·26*
	$\lambda/2=5{\cdot}704$		$\lambda/2=5{\cdot}735$		$\lambda/2=2{\cdot}730$		$\lambda/2=3{\cdot}036$
	$20\lambda/2$				$10\lambda/2$		$35\lambda/2$
20 – 0	114·40			1 – 10	27·30	35 – 0	106·10
21 – 1	114·05			11 – 20	27·20	36 – 1	105·90
22 – 2	113·70			21 – 30	27·10	37 – 2	106·00
	114·05			31 – 40	27·30		*106·00*
	$\lambda/2=5{\cdot}702$				*27·22*		$\lambda/2=3{\cdot}029$
					$\lambda/2=2{\cdot}722$		
mean $\lambda/2=5{\cdot}703$ mm.		mean $\lambda/2=5{\cdot}735$ mm.		mean $\lambda/2=2{\cdot}726$ mm.		mean $\lambda/2=3{\cdot}032$ mm.	
$V=$ **269·0** m/sec		$V=270{\cdot}5$ m/sec. $V_{25^\circ}=$ **269·4** m/sec		$V=269{\cdot}7$ m./sec. $V_{25^\circ}=$ **269·5** m. sec.		$V=$ **299·7 m./sec.**	

The specific heat C_p of carbon dioxide calculated from the supersonic velocity is 8.74 cal. at 25° and 8.94 at 97.1°. The results of calculation are given below :

Temp.	M	p_c	t_c	V	$\frac{V^2M}{RT}$	ϕ	γ	$C_p - C_v$	C_p
25°	44.01	73	31.1	269.6	1.2908	1.0093	1.3028	2.0309	8.74
97.1°	,,	,,	,,	299.7	1.2844	1.0043	1.2899	2.0099	8.94

The value of molecular heat of carbon dioxide at 25° is in agreement with the previous results obtained by the sound velocity method both at audible frequencies by Partington and others, and by Kaye and Sherrat, Kueser, Richards and others in the lower supersonic range. This value is appreciably less than the results obtained by continuous flow calorimeter by Scheele and Heuse, but appears to be in agreement with the spectroscopic specific heat. The older values given in literature at 100° vary from 9.07 to 9.54 cals. It may therefore appear that there is a dropping out of a vibrational specific heat from the acoustic cycle, even at audible frequencies.

The theoretical value of the specific heat C_p for a linear triatomic molecule, consists of, R (for $C_p - C_v$,) $\frac{3}{2}$R (translation), $\frac{2}{2}$R (rotation), $\sum_i q_i E v_i$ valence vibrations of 2 C—O bonds (=2 x 0.032 at 17°, 2 x 1.119 at 97.1°) and the contribution of the deformation vibrations $\frac{(3n-6-\Sigma q_i)}{\sum_i q_i} \sum_i q_i E\delta_i$ [½ (2 x 1.47) at 17° and ½ (2 x 1.647) at 97.1°]. The calculated value comes to 8.68 at 25° and 8.93 at 97.1°, which are in very good agreement with the values (8.74 and 8.94) obtained in the present investigation. The results obtained by the previous workers by the velocity of sound at lower frequencies at room temperature are normal values, while those at higher temperatures which are determined by the thermal methods are appreciably higher. The discrepancy is not therefore due to the failure of any portion of the specific heat from the sound waves even at audible frequencies as suggested by Richards and by P.S.H. Henry.

A knowledge of the various components of the specific heat of carbon dioxide makes it possible to check the dispersion data obtained by previous workers. The square of velocity of sound at 400 Khz. and above, is 77660, at room temperature. The value of C_p calculated therefrom, comes to 7.21 calories. The value calculated by the method given above by dropping out the share of the deformation oscillation is, (2.03 for $C_p - C_v$, $\frac{3}{2}R$ for translation, $\frac{2}{2}R$ for rotation and 0.064 for vibrational energy, total along with 0.06 calorie for reduction to atmospheric pressure) = 7.15 calories, which is in satisfactory agreement with the value determined from the supersonic velocity.

Kneser (Ann. d. Physik, 1931, **11**, 761) explains the dispersion on the assumption that there is an exchange of energy between the translational and vibrational degrees of freedom in the carbon dioxide molecule involving a time lag of about 10^{-5} seconds. " Roughly one may picture a gas composed of complex molecules as being stiffer for vibrations above a certain frequency range than for those below. If the vibrations are slow enough, all the degrees of freedom will have their full share of energy. As the frequency increases, the vibrational degrees of freedom, for which there is a relatively slow rate of energy exchange, will fail to take up the share of heat and the apparent ratio of specific heats and therefore the velocity will be increased."

(*4*) *Carbon Disulphide*

The results of the measurements in carbon disulphide are given in Table 13. Owing to considerable, absorption the measurements could be carried out with some difficulty only at 49.4 Khz. at 97.1°. At other temperatures and at higher frequencies, the absorption was significant. The velocity is 220.1 m./sec. at 97.1°. This value is considerably higher than that given by the formula given in I.C.T., which apparently holds good between 0°-70° for saturated vapours. It is interesting to point out that W.T. Richards, who measured the velocity of sound in carbon disulphide vapour at 9 Khz. and at 309.14 mm., pressure, also observed that the values were higher than those given in literature.

TABLE 13

Carbon disulphide 97.1°.

Frequency 49 42 Khz

n	Screw reading mm.	n	Screw reading mm	n	Screw reading mm.	n	Screw reading mm.
0	12 80	0	127.75	0	32.75		40 $\lambda/2$
1	14.75	1	125 45	1	34 80	40—1	88.40
3	19.30	2	123 10	2	37.20	41—1	88.30
5	25.00	10	105 60	11	56 10	42—2	88.30
14	44.75	15	94 40	20	77.10	44—4	88.40
23	64.58	20	83 35	30	100 45	45—5	88.40
33	86.90	25	72·30	35	111.20		*88 36*
45	113.35	30	61 25	40	122.25		$\lambda/2=$
46	115 55	35	50·15	41	124 30		2.209 mm.
47	117.92	40	39 25	42	126.70		
							25 $\lambda/2$
48	120 05	45	28.00	43	128.95		
						25—0	55 50
	45 $\lambda/2$	mean	$\lambda/2$		40 $\lambda/2$		
						26—1	55.45
45—0	100.55	40 $\lambda/2$	2.212	40—0	89.50		
							55.175
46—1	100.80	,, 34 ,,	2.216	41—1	89 50		
							$\lambda/2=$
48—3	100.72	,, 38 ,,	2.223	42—2	89 50		
							2.219 mm.
	100 69		*2.217*		*89.50*		
$\lambda/2 =$ 2 2375 mm.		$\lambda/2 =$ 2.217 mm.		$\lambda/2 =$ 2.2375mm.		mean $\lambda/2=$ 2.214 mm	

mean $\lambda/2 = 2.2265$ mm.

Velocity $= n\lambda$

$= 220.07$ m./sec.

The specific heat C_p of carbon disulphide calculated from the supersonic velocity is 11.2 cal. at 97.1° at 49.4 Khz. The details of calculations are given below :

Temp.	M	p_c	t_c	V	$\frac{V^2M}{RT}$	ϕ	γ	C_p-C_v	C_p
97.1	76.13	72.9	273.0	220.1	1.198	1.0309	1.235	2.123	11.2

The calculated value of the molecular heat of carbon disulphide compares favourably with the result 11.6, obtained by Bhagavantam (Proc. Ind. Acad. Sci. 1938. **7A**, 245-50) from spectroscopic data, and also with the value (12.2) given in literature at 138°. The result shows that at 49 Khz. the value of the observed velocity of sound is normal. This observation is in agreement with the conclusion reached by W. T. Richards (J. Chem. Phys. 1937, **2**, 193) as a result of measurements of supersonic velocity in carbon disulphide vapour at low pressures and at lower temperatures. Richards however remarks: "It is surprising to find that although carbon dioxide and carbon disulphide so closely resemble each other, that a part of the heat capacity fails to participate in the velocity of sound at audible frequencies in the former, while in the latter all the heat capacity remains fully active well in the ultrasonic range". The results obtained by the author, however, show that both carbon disulphide and carbon dioxide behave in the same way at 50 Khz.

SUMMARY

The velocities of sound in air, steam, carbon dioxide and carbon disulphide have been measured at different frequencies in narrow tubes, at different temperatures and 685 mm. pressure.

The average value of velocity in air between 23.58 and 564 Khz. when corrected for the effect of the tube, is 347.1 m./sec. at 25°, there being no dispersion. At 97.1° the velocity is 386.8 m./sec. and at 134°, 401.6 m./sec. between 49.5 and 126 Khz. The results at higher temperatures, namely, 160° and 190° in a Pythagoras tube were not on the same curve as the values obtained between 25° and 100° owing to uncertain tube corrections.

The supersonic velocity in steam at 134° is 496.3 m./sec., between 49.4 to 126.3 Khz. after correcting for the effect of the tube. The value for specific heat calculated from the velocity is 8.26 cal., which is in exact agreement with the value derived from spectroscopic data.

The supersonic velocity in carbon dioxide was determined at room temperature and 97.1°, at 49.5 Khz. It was not possible to obtain measurements at higher frequencies owing to absorption. The value of velocity at 25° is 269.6 m./sec., which is in agreement with the

previous results. At 97.1°. the velocity increases to 299.7 m./sec. The specific heats calculated from the supersonic velocities are, 8.74 cal. at 25°, and 8.94 cal. at 97.1°. These results are in agreement with the previous values obtained by the velocity of sound at lower frequencies, and with those calculated from spectroscopic data, but are lower than the results obtained by the calorimetric method.

In carbon disulphide the supersonic velocity is 220.1 m./ sec. at 97.1°, at 49.4 Khz. The specific heat calculated from the supersonic velocity comes to 11.2 cal., which is in agreement with the spectroscopic value.

The results of the present investigation are summarised in the following table :

	V m./sec.	γ	C_p	
			obs.	cal
Steam (134°)	496.3	1.3295	8.26	8.26
Carbon dioxide (25°)	269.6	1.3028	8.74	8.68
(97.1°)	299.7	1.2899	8.94	8.93
Carbon disulphide (97.1°)	220.1	1.2350	11.2	11.6

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