Loudness, Its Definition, Measurement and Calculation

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Part III

FROM THE ARCHIVES OF BELL TELEPHONE LABORATORIES

The values of b_k can be computed from this equation from the observed values of L and L_k by using the values of G given in Table III. Because of the difficulty in obtaining accurate values of L and L_k such computed values of b_k will be rather inaccurate. Consequently, considerable freedom is left in choosing a simple formula which will represent the results. When the values of b_k derived in this way were plotted with b_k as ordinates and Δf as abscissae and L_k as a variable parameter then the resulting graphs were a series of straight lines going through the common point (−250, 0) but having slopes depending upon L_k. Consequently the following formula

$$b_k = [(250 + \Delta f)/1000]\,Q(L_k) \qquad (17)$$

will represent the results. The quantity Δf is the common difference in frequency between the components, L_k the loudness level of each component, and Q a function depending upon L_k. The results indicated that Q could be represented by the curve in *Fig.* 11.

Also the condition must be imposed upon this equation that b is always taken as unity whenever the calculation gives values greater than unity. The solid curves shown in *Fig.* 10 are actually calculated curves using these equations, so the comparison of these curves with the observed points gives an indication of how well this equation fits the data. For this series of tones Q could be made to depend upon β_k rather than L_k and approximately the same results would be obtained since β_k and L_k are nearly equal in this range of frequencies. However, for tones having low intensities and low frequencies, β_k will be much larger than L_k and consequently Q will be smaller and hence the calculated loudness smaller. The results in *Figs.* 8 and 9 are just contrary to this. To make the calculated and observed results agree with these two sets of data, Q was made to depend upon

$$x = \beta + 30 \log f - 95$$

instead of L_k.

It was found when using this function of β and f as an abscissa and the same ordinates as in *Fig.* 10, a value of Q was obtained which gives just as good a fit for the data of *Fig.* 10 and also gives a better fit for the data of *Figs.* 8 and 9. Other much more complicated factors were tried to make the observed and calculated results shown in these two figures come into better agreement but none were more satisfactory than the simple procedure outlined above. For purpose of calculation the values of Q are tabulated in Table VI.

There are reasons based upon the mechanics of hearing for treating components which are very close together by a separate method. When they are close together the combination must act as though the energy were all in a single component, since the components act upon approximately the same set of nerve terminals. For this reason it seems logical to combine them by the energy law and treat the combination as a single frequency. That some such procedure is necessary is shown from the absurdities into which one is led when one tries to make Eq. (*17*) applicable to all cases. For example, if 100 components were crowded into a 1000-cps space about a 1000-cps tone, then it is

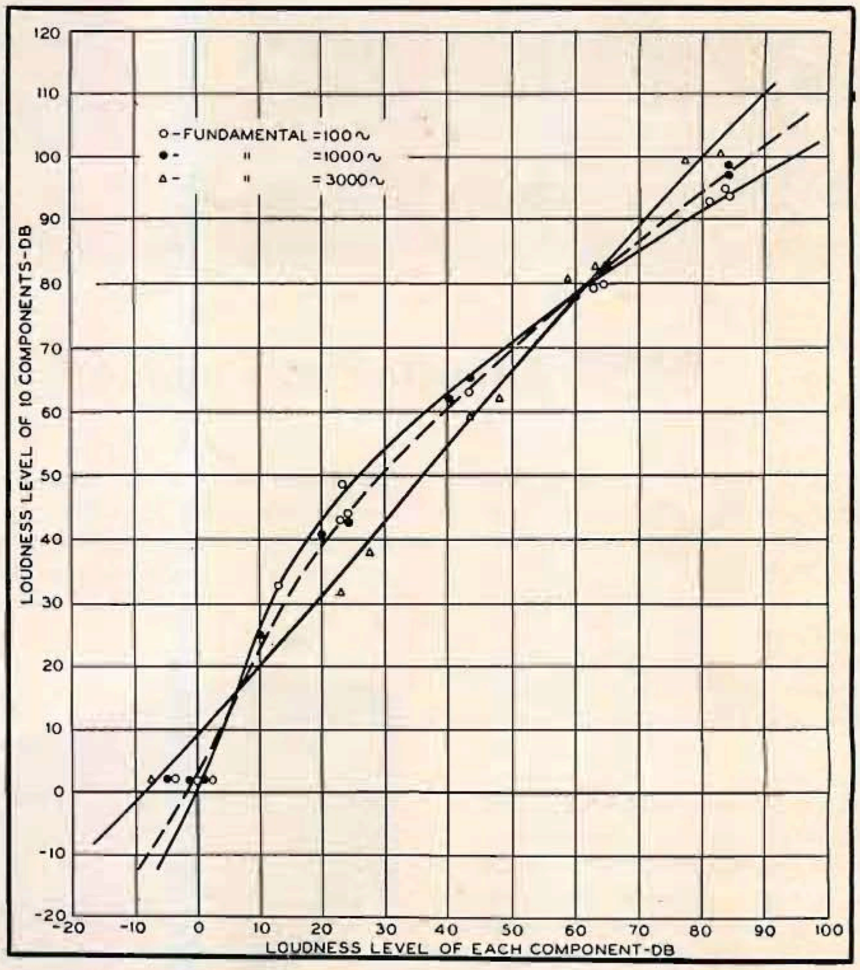

Fig. 8. Loudness levels of complex tones having ten equally loud components 50 cps apart.

tions, so the comparison of these curves

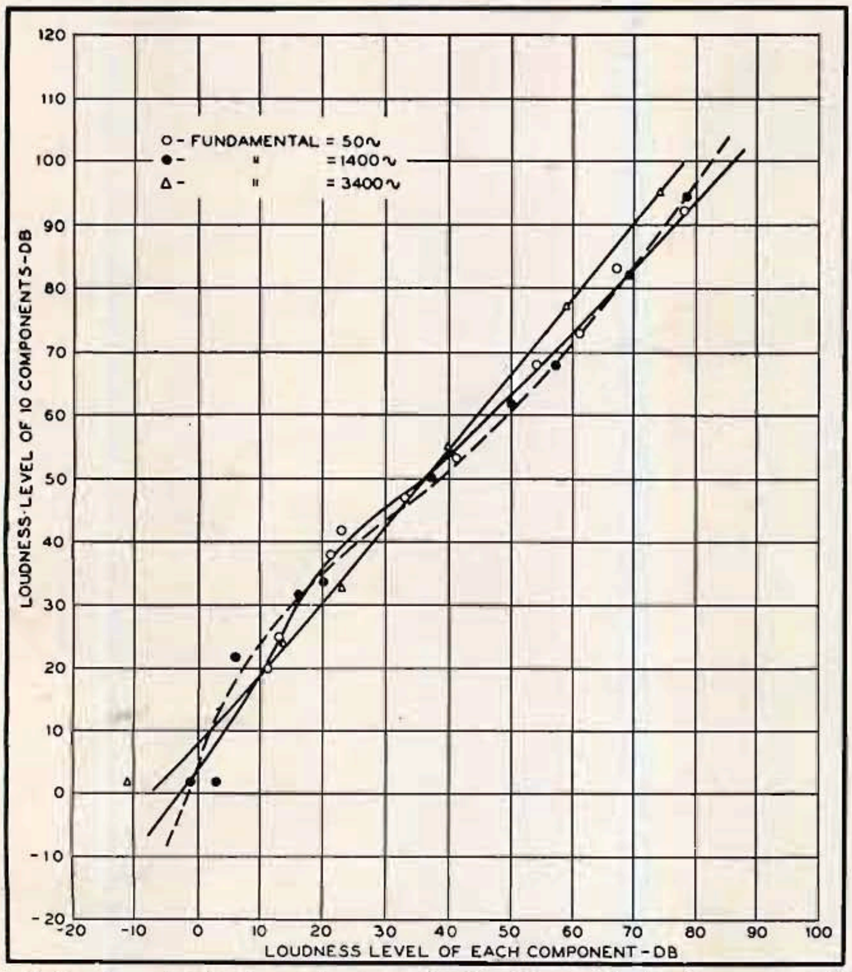

Fig. 9. Loudness levels of complex tones having ten equally loud components 100 cps apart.

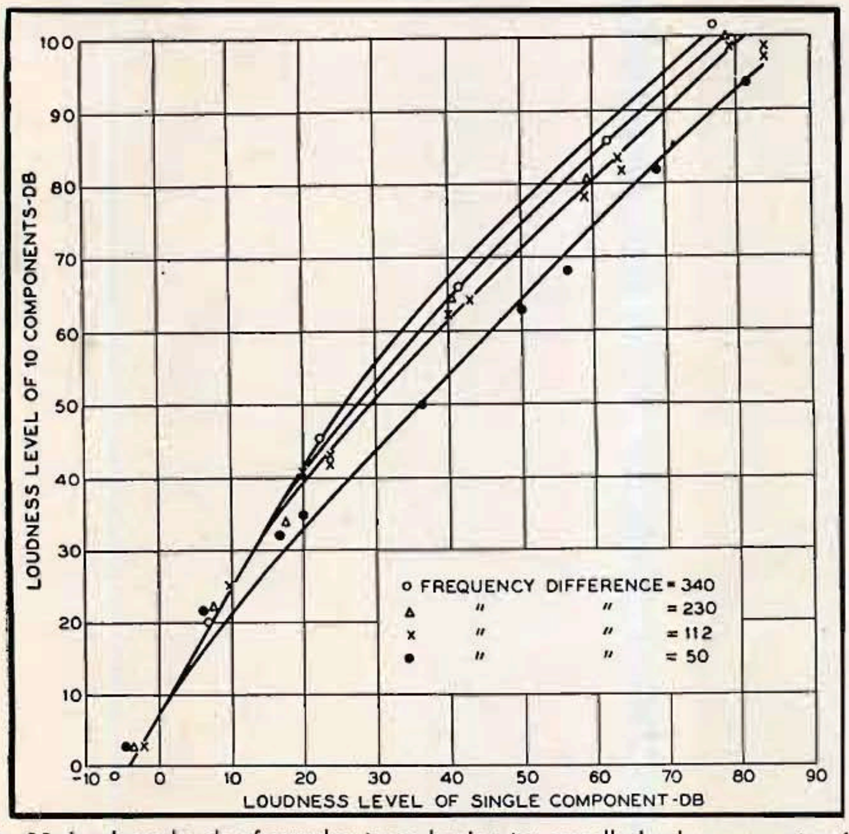

Fig. 10. Loudness levels of complex tones having ten equally loud components with a fundamental frequency of 1000 cps.

obvious that the combination should sound about 20 db louder. But according to Eq. (*10*) to make this true for values of L_k greater than 45, b_k must be chosen as 0.036. Similarly, for 10 tones thus crowded together $L - L_k$ must be about 10 db and therefore $b_k = 0.13$ and then for two such tones $L - L_k$ must be 3 db and the corresponding value of $b_k = 0.26$. These three values must belong to the same condition $\Delta f = 10$. It is evident then that the formulae for b given by Eq. (*17*) will lead to very erroneous results for such components.

In order to cover such cases it was necessary to group together all components within a certain frequency band and treat them as a single component. Since there was no definite criterion for determining accurately what these limiting bands should be, several were tried and ones selected which gave the best agreement between computed and observed results. The following band widths were finally chosen:

For frequencies below 2000 cps, the band width is 100 cps; for frequencies between 2000 and 4000 cps, the band width is 200 cps; for frequencies between 4000 and 8000 cps, the band width is 400 cps; and for frequencies between 8000 and 16,000 cps, the band width is 800 cps. If there are k components within one of these limiting bands, the intensity I taken for the equivalent single frequency component is given by

$$I = \Sigma I_k = \Sigma 10^{\beta_k/10} \qquad (18)$$

A frequency must be assigned to the combination. It seems reasonable to assign a weighted value of f given by the equation

$$f = \Sigma f_k I_k / I = \Sigma f_k 10^{\beta_k/10} / \Sigma 10^{\beta/10} \qquad (19)$$

Only a small error will be introduced if the midfrequency of such bands be taken as the frequency of an equivalent component except for the band of lowest frequency. Below 125 cps it is important that the frequency and intensity of each component be known, since in this region the loudness level L_k changes very rapidly with both changes in intensity and frequency. However, if the intensity for this band is lower than that for other bands, it will contribute little to the total loudness so that only a small error will be introduced by a wrong choice of frequency for the band.

This then gives a method of calculating b_k when the adjacent components are equal in loudness. When they are not equal let us define the difference ΔL by

$$\Delta L = L_k - L_m. \qquad (20)$$

Also let this difference be T when L_m is adjusted so that the masking component just masks the component k. Then the function for calculating b must satisfy the following conditions:

$b_k = [(250 + \Delta f)/1000]Q$ when $\Delta L = 0$,
$b_k = 0$ when $\Delta L = -T$.

component be known, since in this re-

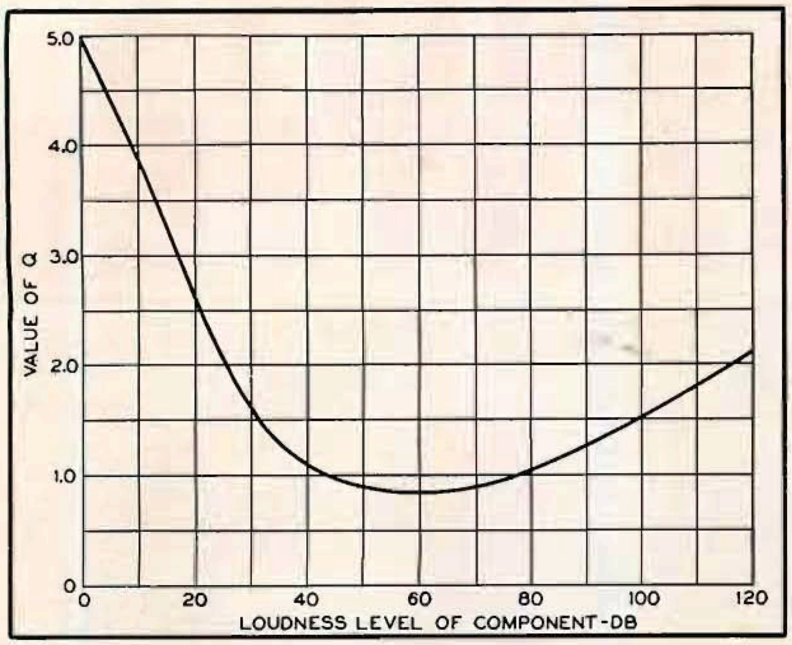

Fig. 11. Loudness factor "Q."

TABLE VI

VALUES OF $Q(X)$

X	0	1	2	3	4	5	6	7	8	9
0	5.00	4.88	4.76	4.64	4.53	4.41	4.29	4.17	4.05	3.94
10	3.82	3.70	3.58	3.46	3.35	3.33	3.11	2.99	2.87	2.76
20	2.64	2.52	2.40	2.28	2.16	2.05	1.95	1.85	1.76	1.68
30	1.60	1.53	1.47	1.40	1.35	1.30	1.25	1.20	1.16	1.13
40	1.09	1.06	1.03	1.01	0.99	0.97	0.95	0.94	0.92	0.91
50	0.90	0.90	0.89	0.89	0.88	0.88	0.88	0.88	0.88	0.88
60	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.89	0.90
70	0.90	0.91	0.92	0.93	0.94	0.96	0.97	0.99	1.00	1.02
80	1.04	1.06	1.08	1.10	1.13	1.15	1.17	1.19	1.22	1.24
90	1.27	1.29	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48
100	1.51	1.53	1.55	1.58	1.60	1.62	1.64	1.67	1.69	1.71

Note: $X = \beta_k + 30 \log f_k - 95$.

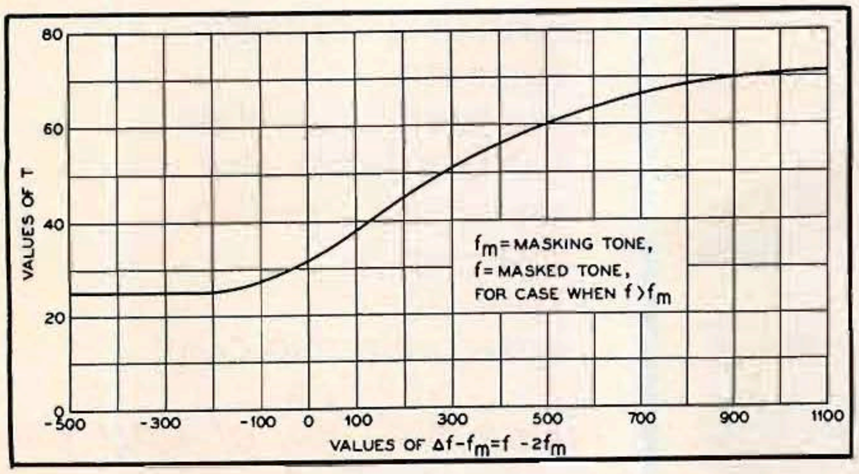

Fig. 12. Values of the masking "T."

COMPUTATIONS

k	f_k	β_k	L_k	G_k	b_k	
1	60	50	3	3	1.0	
2	180	45	25	197	1.0	$\Sigma b_k G_k$ = 1009
3	300	40	30	360	1.0	
4	540	30	27	252	1.0	L = 40
5	1200	25	25	197	1.0	

Also the following condition when L_k is larger than L_m must be satisfied, namely, $b_k = 1$ when ΔL = some value somewhat smaller than $+T$. The value of T can be obtained from masking curves. An examination of these data indicates that to a good approximation the value of T is dependent upon the single variable $f_k - 2f_m$. A curve showing the relation between T and this variable is shown in *Fig.* 12. It will be seen that for most practical cases the value of T is 25. It cannot be claimed that the curve of *Fig.* 12 is an accurate representation of the masking data, but it is sufficiently accurate for the purpose of loudness calculation since rather large changes in T will produce a very slight change in the final calculated loudness level.

Data were taken in an effort to determine how this function depended upon ΔL but it was not possible to obtain sufficient accuracy in the experimental results. The difference between the resultant loudness level when half the tones are down so as not to contribute to loudness and when these are equal is not more than 4 or 5 db, which is not much more than the observational errors in such results.

A series of tests were made with tones similar to those used to obtain the results shown in *Figs.* 8 and 9 except that every other component was down in loudness level 5 db. Also a second series was made in which every other component was down 10 db. Although these data were not used in determining the function described above, it was useful as a check on the final equations derived for calculating the loudness of tones of this sort.

The factor finally chosen for representing the dependence of b_k upon ΔL is $10^{\Delta L/T}$. This factor is unity for $\Delta L = 0$, fulfilling the first condition mentioned above. It is 0.10 instead of zero for $\Delta L = -25$, the most probable value of T. For $\Delta f = 100$ and $Q = 0.88$ we will obtain the smallest value of b_k without applying the ΔL factor, namely, *0.31*. Then when using this factor as given above, all values of b_k will be unity for values of ΔL greater than 12 db.

Several more complicated functions of ΔL were tried but none of them gave results showing a better agreement with the experimental values than the function chosen above.

The formula for calculation of b_k then becomes

$$b_k = [(250 + f_k - f_m)/1000]\; 10^{(L_k - L_m)/T} Q(\beta_k + 30 \log f_k - 95) \qquad (21)$$

where

f_k is the frequency of the component expressed in cycles per second,

f_m is the frequency of the masking component expressed in cycles per second,

L_k is the loudness level of the kth com-

ing the ΔL factor, namely, *0.31*. Then

Computations

k	f_k	β_k	L_k	G_k	f_m	L_m	$(30 \log f_k - 95)$	Q	b	$b \times G$
1	60	80	69	7440	—	—	—	—	1.00	7440
2	180	75	72	9130	60	69	−28	0.91	0.41	3740
3	300	70	69	7440	180	72	−21	0.91	0.27	2010
4	540	60	60	4350	300	69	−13	0.94	0.23	1000
5	1200	55	55	3080	540	60	− 3	0.89	0.61	1880
									loudness G =	16070
									loudness level L =	79 db

TABLE VII

Two Component Tones ($\Delta L = 0$)

Frequency Range	Δf	Loudness Levels (db)					
1000–1100	100	L_k	83	63	43	23	2
		$L_{obs.}$	87	68	47	28	2
		$L_{calc.}$	87	68	47	28	4
1000–2000	1000	L_k	83	63	43	23	−1
		$L_{obs.}$	89	71	49	28	2
		$L_{calc.}$	91	74	52	28	1
125–1000	875	L_k	84				
		$L_{obs.}$	92				
		$L_{calc.}$	92				

TABLE VIII

Ten Component Tones ($\Delta L = 0$)

Frequency Range	Δf	Loudness Levels (db)										
50–500	50	L_k	67	54	33	21	11	−1				
		$L_{obs.}$	83	68	47	38	20	2				
		$L_{calc.}$	81	72	53	39	24	8				
50–500	50	L_k	78	61	41	23	13	−1				
		$L_{obs.}$	92	73	53	42	25	2				
		$L_{calc.}$	91	77	60	42	27	8				
1400–1895	55	L_k	78	69	50	16	6	−1				
		$L_{obs.}$	94	82	62	32	22	2				
		$L_{calc.}$	93	83	65	31	17	0				
1400–1895	55	L_k	57	37	20	3						
		$L_{obs.}$	68	50	34	2						
		$L_{calc.}$	73	52	36	5						
100–1000	100	L_k	84	64	43	24	2	84	64	43	24	2
		$L_{obs.}$	95	83	59	41	2	94	80	63	44	2
		$L_{calc.}$	100	83	68	47	12	100	83	68	47	12
100–1000	100	L_k	81	64	43	23	13	−4				
		$L_{obs.}$	93	82	65	49	33	2				
		$L_{calc.}$	98	83	68	45	27	3				
100–1000	100	L_k	83	63	43	23	0					
		$L_{obs.}$	95	79	59	43	2					
		$L_{calc.}$	99	82	68	45	9					
3100–3900	100	L_k	83	63	43	23	78	59	48	27	−7	
		$L_{obs.}$	100	82	59	32	99	81	62	38	2	
		$L_{calc.}$	100	80	60	38	95	77	65	42	0	
1100–3170	230	L_k	79	60	41	17	7	−4				
		$L_{obs.}$	100	81	65	33	22	2				
		$L_{calc.}$	100	83	64	34	18	3				
260–2600	260	L_k	79	62	42	23	13	−2				
		$L_{obs.}$	97	82	65	44	28	2				
		$L_{calc.}$	100	85	68	45	27	5				
530–5300	530	L_k	75	53	43	25	82	61	43	17	−2	
		$L_{obs.}$	100	83	73	52	105	90	73	40	2	
		$L_{calc.}$	101	82	72	48	108	89	72	34	5	
530–5300	530	L_k	61	41	21	−3						
		$L_{obs.}$	89	69	45	2						
		$L_{calc.}$	89	70	42	4						

ponent when sounding alone,

L_m is the loudness level of the masking tone,

Q is a function depending upon the intensity level β_k and the frequency f_k of each component and is given in Table VI as a function of $x = \beta_k + 30 \log f_k - 95$,

T is the masking and is given by the curve of *Fig.* 12.

It is important to remember *that b_k can never be greater than unity so that all calculated values greater than this must be replaced with values equal to unity.* Also all components *within the limiting frequency bands must be grouped together as indicated above.* It is very helpful to remember that any component for which the loudness level is 12 db below the kth component, that is, the one for which b is being calculated, need not be considered as possibly being the masking component. If all the components preceding the kth are in this class then b_k is unity.

RECAPITULATION

With these limitations the formula for calculating the loudness level L of a steady complex tone having n components is

$$G(L) = \sum_{k=1}^{k=n} b_k G(L_k), \qquad (10)$$

where b_k is given by Eq. (*21*). If the values of f_k and β_k are measured directly then corresponding values of L_k can be found from *Fig.* 5. Having these values, the masking component can be found either by inspection or better by trial in Eq. (*21*). That component whose values of L_m, f_m and T introduced into this equation gives the smallest value of b_k is the masking component.

The values of G and Q can be found from Tables III and VI from the corresponding values of L_k, β_k, and f_k. If all these values are now introduced into Eq. (*10*), the resulting value of the summation is the *loudness* of the complex tone. The loudness level L corresponding to it is found from Table III.

If it is desired to know the loudness obtained if the typical listener used only one ear, the result will be obtained if the summation indicated in Eq. (*10*) is divided by 2. Practically the same result will be obtained in most instances if the loudness level L_k for each component when listened to with one ear instead of both ears is inserted in Eq. (*10*). [$G(L_k)$ for one ear listening is equal to one half $G(L_k)$ for listening with both ears for the same value of the intensity level of the component.] If two complex tones are listened to, one in one ear and one in the other, it would be expected that the combined loudness would be the sum of the two loudness values calculated for each ear as though no sound

100–1000 | 100 | $L_{obs.}$ | 93 | 82 | 65 | 49 | 33 | 2

Eq. (10), the resulting value of the summation is the loudness of the com-

TABLE IX

Eleven Component Tones ($\Delta L = 0$)

Frequency Range	Δf	Loudness Levels (db)						
1000–2000	100	L_k	84	64	43	24	−1	
		$L_{obs.}$	97	83	65	43	2	
		$L_{calc.}$	103	84	64	45	7	
1000–2000	100	L_k	84	64	43	24	1	
		$L_{obs.}$	99	82	65	42	2	
		$L_{calc.}$	103	84	64	45	11	
1150–2270	112	L_k	79	60	40	20	10	−5
		$L_{obs.}$	99	78	62	41	25	2
		$L_{calc.}$	98	81	61	40	23	1
1120–4520	340	L_k	77	62	42	22	7	−7
		$L_{obs.}$	102	86	66	46	20	2
		$L_{calc.}$	101	88	69	44	19	−1

TABLE X

Ten Component Tones ($\Delta L = 5$ db)

Frequency Range	Δf	Loudness Levels (db)						
1725–2220	55	L_k	82	62	43	27	17	−6
		$L_{obs.}$	101	73	54	38	30	2
		$L_{calc.}$	95	76	56	40	30	−1
1725–2220	55	L_k	80	62	42	22	12	−2
		$L_{obs.}$	94	66	50	33	22	2
		$L_{calc.}$	93	76	54	35	22	4

TABLE XI

Eleven Component Tones ($\Delta L = 5$ db).

Frequency Range	Δf	Loudness Levels (db)						
57–627	57	L_k	79	61	41	26	16	1
		$L_{obs.}$	91	73	56	41	28	2
		$L_{calc.}$	90	76	59	43	28	8
3420–4020	60	L_k	76	61	42	25	15	−9
		$L_{obs.}$	95	77	55	33	25	2
		$L_{calc.}$	89	75	54	36	26	−4

TABLE XII

Ten Component Tones ($\Delta L = 10$ db)

Frequency Range	Δf	Loudness Levels (db)						
1725–2220	55	L_k	79	59	40	19	9	−5
		$L_{obs.}$	95	71	54	33	22	2
		$L_{calc.}$	91	73	51	31	17	−1
1725–2220	55	L_k	79	61	41	27	17	−1
		$L_{obs.}$	89	67	48	37	27	2
		$L_{calc.}$	92	75	53	39	28	4

TABLE XIII

Eleven Component Tones ($\Delta L = 10$ db)

Frequency Range	Δf	Loudness Levels (db)						
57–627	57	L_k	80	62	42	27	17	2
		$L_{obs.}$	88	70	53	40	27	2
		$L_{calc.}$	90	76	59	45	30	8
3420–4020	60	L_k	81	62	42	27	17	−4
		$L_{obs.}$	100	70	50	33	26	2
		$L_{calc.}$	94	75	53	37	27	0

were in the opposite ear, although this has not been confirmed by experimental trial. In fact, the loudness reduction factor b_k has been derived from data taken with both ears only, so strictly speaking, its use is limited to this type of listening.

To illustrate the method of using the formula the loudness of two complex tones will be calculated. The first may represent the hum from a dynamo. Its components are given in the table of computations.

The first step is to find from *Fig.* 5 the values of L_k from f_k and β_k. Then the loudness values G_k are found from Table III. Since the values of L are low and the frequency separation fairly large, one familiar with these functions would readily see that the values of b would be unity and a computation would verify it so that the sum of the G values gives the total loudness 1009. This corresponds to a loudness level of 40.

The second tone calculated is this same hum amplified 30 db. It better illustrates the use of the formula.

The loudness level of the combined tones is only 7 db above the loudness level of the second component. If only one ear is used in listening, the loudness of this tone is one half, corresponding to a loudness level of 70 db.

COMPARISON OF OBSERVED AND CALCULATED RESULTS ON THE LOUDNESS LEVELS OF COMPLEX TONES

In order to show the agreement between observed loudness levels and levels calculated by means of the formula developed in the preceding sections, the results of a large number of tests are given here, including those from which the formula was derived. In Tables VII to XIII, the first column shows the frequency range over which the components of the tones were distributed, the figures being the frequencies of the first and last components. Several tones having two components were tested, but as the tables indicate, the majority of the tones had ten components. Because of a misunderstanding in the design of the apparatus for generating the latter tones, a number of them contained eleven components, so for purposes of identification, these are placed in a separate group. In the second column of the tables, next to the frequency range of the tones, the frequency difference (Δf) between adjacent components is given. The remainder of the data pertains to the loudness levels of the tones. Opposite L_k are given the common loudness levels to which *all the* components of the tone were adjusted for a particular test, and in the next line the results of the test, that is, the observed loudness levels ($L_{obs.}$), are given. Directly beneath each observed

(*Continued on page 68*)

Frequency Range | Δf | Loudness Levels (db)
having two components were tested, but

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(from page 40)

value, the calculated loudness levels ($L_{calc.}$) are shown. The three associated values of L_k, $L_{obs.}$, and L_{calc} in each column represent the data for one complete test. For example, in Table VIII, the first tone is described as having ten components, and for the first test shown each component was adjusted to have a loudness level (L_k) of 67 db. The results of the test gave an observed loudness level ($L_{obs.}$) of 83 db for the ten components acting together, and the calculated loudness level ($L_{calc.}$) of the same tone was 81 db. The probable error of the observed results in the tables is approximately ±2 db.

In the next series of data, adjacent components had a difference in loudness level of 5 db, that is, the first, third, fifth, etc., components had the loudness level given opposite L_k, and the even numbered components were 5 db lower. (Tables X and XI.)

In the following set of tests (Tables XII and XIII) the difference in loudness level of adjacent components was 10 db.

The next data are the results of tests made on the complex tone generated by the Western Electric No. 3A audiometer. When analyzed, this tone was found to have the voltage level spectrum shown in Table XIV. When the r.m.s.

TABLE XIV

VOLTAGE LEVEL SPECTRUM OF NO. 3A AUDIOMETER TONE

Frequency	Voltage Level	Frequency	Voltage Level
152	− 2.1	2128	−11.4
304	− 5.4	2280	−16.9
456	− 4.7	2432	−14.1
608	− 5.9	2584	−16.2
760	− 4.6	2736	−17.4
912	− 6.8	2880	−17.5
1064	− 6.0	3040	−20.0
1216	− 8.1	3192	−19.4
1368	− 7.6	3344	−22.7
1520	− 9.1	3496	−23.7
1672	−10.0	3648	−25.6
1824	− 9.9	3800	−24.6
1976	−14.1	3952	−26.8

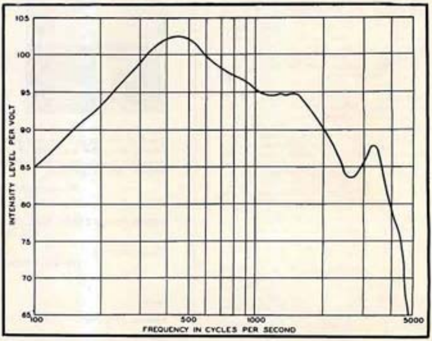

Fig. 13. Calibration of receivers for tests on the No. 3A audiometer tone.

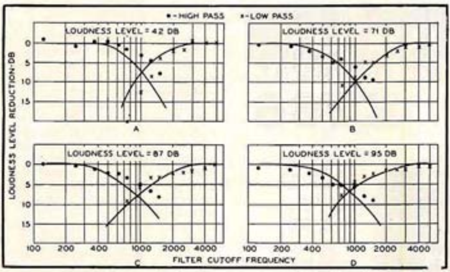

Fig. 14. (A to D)—Loudness level reduction tests on the No. 3A audiometer tone.

voltage across the receivers used was unity, that is, zero voltage level, then the separate components had the voltage levels given in this table. Adding to the voltage levels the calibration constant for the receivers used in making the loudness tests gives the values of β for zero voltage level across the receivers. The values of β for any other voltage level are obtained by addition of the level desired.

Tests were made on the audiometer tone with the same receivers[11] that were used with the other complex tones, but in addition, data were available on tests made about six years ago using a different type of receiver. This latter type of receiver was recalibrated (*Fig.* 13) and computations made for both the old and new tests. In the older set of data, levels above threshold were given instead of voltage levels, so in utilizing it here, it was necessary to assume that the threshold levels of the new and old tests were the same.

Computations were made at the levels tested experimentally and a comparison of observed and calculated results is shown in Table XV.

The agreement of observed and calculated results is poor for some of the tests, but the close agreement in the recent data at low levels and in the previous data at high levels indicates that the observed results are not as accurate as could be desired. Because of the labor involved these tests have not been repeated.

At the time the tests were made several years ago on the No. 3A Audiometer tone, the reduction in loudness level which takes place when certain components are eliminated was also determined. As this can be readily calculated with the formula developed here, a comparison of observed and calculated results will be shown. In *Fig.* 14A, the ordinate is the reduction in loudness level resulting when a No. 3A Audiometer tone having a loudness level of 42 db was changed by the insertion of a filter which eliminates all of the components above or below the frequency indicated on the abscissa. The observed data are the plotted points and the smooth curves are calculated results. A similar comparison is shown in *Figs.* 14B, C and D for other levels.

This completes the data which are available on steady complex tones. It is to be hoped that others will find the field of sufficient importance to warrant obtaining additional data for improving and testing the method of measuring and calculating loudness levels.

[11] See Calibration shown in *Fig.* 1.

TABLE XV

A. Recent Tests on No. 3A Audiometer Tone

R.m.s. Volt. Level	−38	−55	−59	−70	−75	−78	−80	−87	−89	−100	−102
$L_{obs.}$	95	85	79	61	56	41	42	28	22	2	2
$L_{calc.}$	89	74	71	57	49	44	40	28	25	7	4

B. Previous Tests on No. 3A Audiometer Tone

R.m.s. Volt. Level	+10	−9	−40	−49	−60	−69	−91
$L_{obs.}$	118	103	77	69	61	50	2
$L_{calc.}$	119	103	82	73	56	41	6

In view of the complex nature of the problem this computation method cannot be considered fully developed in all its details and as more accurate data accumulates it may be necessary to change the formula for b. Also at the higher levels some attention must be given to phase differences between the components. However, we feel that the form of the equation is fundamentally correct and the loudness function, G, corresponds to something real in the mechanism of hearing. The present values given for G may be modified slightly, but we think that they will not be radically changed.

A study of the loudness of complex sounds which are not steady, such as speech and sounds of varying duration, is in progress at the present time and the results will be reported in a second paper on this subject.

APPENDIX A. EXPERIMENTAL METHOD OF MEASURING THE LOUDNESS LEVEL OF A STEADY SOUND

A measurement of the loudness level of a sound consists of listening alternately to the sound and to the 1000-cps reference tone and adjusting the latter until the two are equally loud. If the intensity level of the reference tone is L decibels when this condition is reached, the sound is said to have a loudness level of L decibels. When the character of the sound being measured differs only slightly from that of the reference tone, the comparison is easily and quickly made, but for other sounds the numerous factors which enter into a judgment of equality of loudness become important, and an experimental method should be used which will yield results typical of the average normal ear and normal physiological and psychological conditions.

A variety of methods have been proposed to accomplish this, differing not only in general classification, that is, the method of average error, constant stimuli, etc., but also in important experimental details such as the control of noise conditions and fatigue effects. In some instances unique devices have been used to facilitate a ready comparison of sounds. One of these, the alternation phonometer,[12] introduces into the comparison important factors such as the duration time of the sounds and the effect of transient conditions. The merits of a particular method will depend upon the circumstances under which it is to be used. The one to be described here was developed for an extensive series of laboratory tests.

[12] D. Mackenzie, "Relative sensitivity of the ear at different levels of loudness," *Phys. Rev.* 20, 331 (1922).

TO BE CONCLUDED

only in general classification, that is, the method of average error, constant