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Acoustics — Normal equal-loudness level contours

Acoustique — Lignes isosoniques normales

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 226 was prepared by Technical Committee ISO/TC 43, *Acoustics.*

It cancels and replaces ISO Recommendation R 226 : 1961 and ISO 454 : 1975, of which it constitutes a technical revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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Acoustics — Normal equal-loudness level contours

0 Introduction

Curves defining relations between frequencies of pure tones or narrow bands of noise and their sound pressure levels for the condition of constant loudness level (equal-loudness level contours) express a fundamental property of the human auditory system, and are of basic importance in the field of psychological acoustics.

In common with other subjective phenomena, loudness relations vary in detail from person to person but, for a group of persons within a restricted age band and free from hearing impairments, a value for the central tendency can be determined to characterize the group. This International Standard gives curves applicable to otologically normal persons in the age group from 18 to 30 years.

The data specified in this International Standard primarily relate to continuous pure tones heard under conditions of binaural listening in free progressive plane waves with the subject directly facing the source of sound (frontal incidence), and with the sound pressure level measured in the free progressive wave at the centre position of the listener's head but with the listener absent. For other conditions of listening or other configurations of sound field, different relations exist between loudness level and sound pressure level. One example of another sound field configuration is a diffuse field. The relation between frontal incidence and diffuse field together with the resulting equal-loudness level function for narrow bands of noise in a diffuse sound field are specified in annex C to this International Standard.

NOTE — The relation between frontal incidence and diffuse field was given in ISO 454; with the inclusion of this relation in this edition of ISO 226, ISO 454 has become superfluous and has been withdrawn (see the "Foreword").

The hearing threshold may be considered as a special case of equal-loudness level, and the corresponding threshold sound pressure levels [minimum audible field (MAF)] are included in this International Standard. It should be emphasized that the minimum audible field differs from the audiometric zero specified in ISO 389, since the latter refers to monaural listening through earphones with sound pressure levels referred to specified couplers and artificial ears. Direct comparison between the data in ISO 389 and in this International Standard is therefore not appropriate.

1 Scope and field of application

This International Standard specifies the relations existing, for the condition of equal-loudness level, between the sound pressure levels and frequencies of pure (sinusoidal) continuous tones in the following conditions :

a) the source of sound is directly in front of the listener (frontal incidence);

b) the sound field in the absence of the listener consists of a free progressive plane wave;

c) the sound pressure level is measured in the free progressive plane wave in the absence of the listener;

d) the listening is binaural;

e) the conditions of equal-loudness level are determined by the modal value of the judgements of an adequately large group of listeners;

f) the listeners are otologically normal persons in the age group from 18 to 30 years inclusive.

The relations are expressed by means of an equation in bilinear form, with the sound pressure level as the independent variable and the loudness level as the dependent variable, for the preferred frequencies in the one-third octave series from 20 to 12 500 Hz inclusive.

NOTES

1 In accordance with convention, the reference dependent variable is taken to be the sound pressure level of a 1 000 Hz tone, i.e. the loudness level expressed in phons. However, the form of the equation remains unchanged (but with transformed coefficients) if the variables are interchanged or if a tone of another frequency in the preferred one-third octave series is taken as the reference.

2 The data in this International Standard are approximately equal to equal-loudness level relations between narrow bands of random noise, not exceeding the auditory critical bandwidth.

3 Without extrapolation of the experimental data, the upper limit of the frequency range could not be extended to the next preferred frequency in the one-third octave series. For further information regarding the range from 12 500 to 15 000 Hz, see [1].

Graphical and short tabular presentations of the relations are given in annexes A and B.

Annex C specifies the correction to be applied to obtain the equal-loudness level relations for narrow bands of random noise in a diffuse sound field and the resulting equal-loudness level function.

2 References

ISO 131, *Acoustics — Expression of physical and subjective magnitudes of sound or noise in air.*

ISO 266, *Acoustics — Preferred frequencies for measurements.*

ISO 389, *Acoustics — Standard reference zero for the calibration of pure tone air conduction audiometers.*

3 Definitions

For the purposes of this International Standard, the following definitions are used, the conditions of applicability stated in clause 1 being understood, where appropriate.

3.1 loudness : That attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud.

3.2 loudness level : Of a given sound, the sound pressure level of a reference sound, consisting of a sinusoidal plane progressive wave of frequency 1 000 Hz coming from directly in front of the listener, which is judged by otologically normal persons to be equally loud to the given sound. Loudness level is expressed in phons.

3.3 equal-loudness level function : For a pure tone of given frequency or for a narrow band of noise of a given frequency band, the relation between loudness level, expressed in phons, and sound pressure level, expressed in decibels.

3.4 equal-loudness level contour : A curve in the sound pressure level/frequency plane, connecting points the coordinates of which represent pure tones or narrow bands of noise judged equally loud.

3.5 normal equal-loudness level function : The equal-loudness level function corresponding to the modal judgement of otologically normal persons within the age limits from 18 to 30 years inclusive.

3.6 normal equal-loudness level contour : The equal-loudness level contour corresponding to the modal judgement of otologically normal persons within the age limits from 18 to 30 years inclusive.

3.7 hearing threshold : The level of a sound at which, under specified conditions, a person gives 50 % of correct detection responses on repeated trials.

3.8 otologically normal person : A person in a normal state of health who is free from all signs or symptoms of ear disease and from excess wax in the ear canals, and who has no history of undue exposure to noise.

3.9 minimum audible field (MAF) : At a specified frequency the sound pressure level of a pure tone or a narrow band of noise corresponding to the modal value of the binaural hearing threshold of otologically normal persons within the age limits from 18 to 30 years inclusive.

3.10 critical bandwidth : The widest frequency band within which the loudness of a band of continuously distributed random noise of constant band sound pressure level is independent of its bandwidth.

4 Specification

The loudness level, L_N, in phons, of a pure tone of frequency f, in hertz, is given by the equation

$$L_N = 4{,}2 + \frac{a_f(L_f - T_f)}{1 + b_f(L_f - T_f)} \qquad \ldots (1)$$

where

L_f is the sound pressure level of the tone, expressed in decibels (reference : 20 µPa);

T_f is the threshold sound pressure level of the tone, expressed in decibels, as given in table 1;

a_f and b_f are frequency-dependent parameters, as given in table 1.

Equation (1) applies, at each frequency, for values of L_f from the lower limit T_f to the following upper limits :

20 to 1 000 Hz : 120 dB
1 250 to 8 000 Hz : 110 dB
10 000 and 12 500 Hz : 100 dB

NOTES

1 Use of the equation outside these ranges will generally imply extrapolation of the experimental data.

2 A graphical illustration of the equal-loudness level contours is given in annex A, and annex B gives tabulated values, direct and inverse, of loudness level against sound pressure level at intervals of 10 phon and 10 dB, respectively.

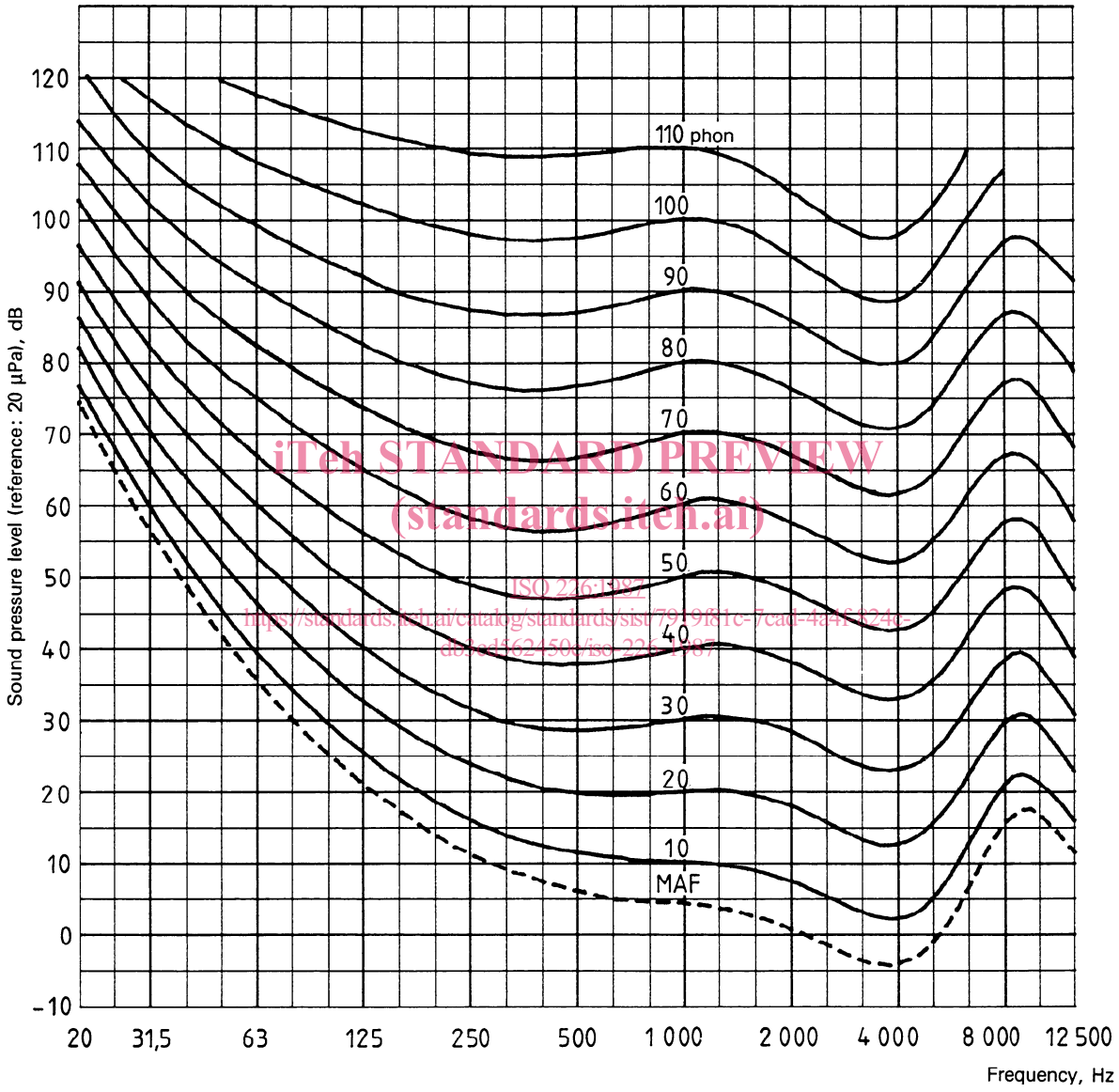
Table 1 — Parameters of the equal-loudness level functions

Frequency, f Hz	a_f dB^{-1}	b_f dB^{-1}	T_f (reference : 20 µPa) dB
20	2,347	0,005 61	74,3
25	2,190	0,005 27	65,0
31,5	2,050	0,004 81	56,3
40	1,879	0,004 04	48,4
50	1,724	0,003 38	41,7
63	1,597	0,002 86	35,5
80	1,512	0,002 59	29,8
100	1,466	0,002 57	25,1
125	1,426	0,002 56	20,7
160	1,394	0,002 55	16,8
200	1,372	0,002 54	13,8
250	1,344	0,002 48	11,2
315	1,304	0,002 29	8,9
400	1,256	0,002 01	7,2
500	1,203	0,001 62	6,0
630	1,135	0,001 11	5,0
800	1,062	0,000 52	4,4
1 000	1	0	4,2
1 250	0,967	−0,000 39	3,7
1 600	0,943	−0,000 67	2,6
2 000	0,932	−0,000 92	1,0
2 500	0,933	−0,001 05	− 1,2
3 150	0,937	−0,001 04	− 3,6
4 000	0,952	−0,000 88	− 3,9
5 000	0,974	−0,000 55	− 1,1
6 300	1,027	0,000 00	6,6
8 000	1,135	0,000 89	15,3
10 000	1,266	0,002 11	16,4
12 500	1,501	0,004 88	11,6

Annex A

Graphical illustration of equal-loudness level contours and minimum audible field (MAF) for pure tones under free-field listening conditions

(This annex forms an integral part of the standard.)



NOTES

1 Minimum audible field (MAF), illustrated as a broken curve, is also the contour for 4,2 phon.

2 The curves should not be extrapolated. For information beyond the range of the illustration, see [1].

Figure — Normal equal-loudness level contours for pure tones (binaural free-field listening, frontal incidence)

Annex B

Tables of the equal-loudness level functions for pure tones under free-field listening conditions

(This annex forms an integral part of the standard.)

NOTE — For practical use, it is recommended to round the tabulated values to the nearest 0,5 dB or 0,5 phon.

Table 2 — Loudness level, in phons, against free-field sound pressure level, in decibels, for pure tones of frequencies ranging from 20 to 12 500 Hz

Loudness level, phons	Sound pressure level, dB (reference : 20 µPa)													
	Frequency, Hz													
	20	25	31,5	40	50	63	80	100	125	160	200	250	315	400
10	76,8	67,7	59,2	51,5	45,1	39,2	33,7	29,1	24,8	21,0	18,1	15,6	13,4	11,9
20	81,3	72,5	64,3	57,1	51,2	45,7	40,5	36,2	32,1	28,5	25,7	23,3	21,4	20,1
30	86,0	77,6	69,7	62,9	57,5	52,4	47,7	43,5	39,7	36,2	33,5	31,4	29,6	28,6
40	91,0	82,9	75,4	69,0	64,0	59,5	55,0	51,1	47,5	44,3	41,7	39,7	38,2	37,4
50	96,2	88,5	81,3	75,4	70,9	66,7	62,7	59,1	55,7	52,6	50,3	48,4	47,1	46,5
60	101,7	94,4	87,6	82,1	78,0	74,3	70,6	67,3	64,2	61,4	59,2	57,5	56,3	56,0
70	107,6	100,7	94,3	89,2	85,5	82,2	78,8	75,8	73,0	70,4	68,4	66,9	66,0	65,8
80	113,7	107,3	101,3	96,6	93,3	90,4	87,4	84,7	82,2	79,9	78,1	76,8	76,0	75,9
90	—	114,4	108,7	104,4	101,5	99,0	96,3	93,9	91,8	89,8	88,1	87,0	86,4	86,4
100	—	—	116,6	112,6	110,1	107,9	105,6	103,6	101,8	100,1	98,7	97,8	97,2	97,3
110	—	—	—	—	119,1	117,2	115,3	113,6	112,3	110,8	109,7	109,0	108,5	108,6
120	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 2 *(concluded)*

Loudness level, phons	Sound pressure level, dB (reference : 20 µPa)														
	Frequency, Hz														
	500	630	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000	5 000	6 300	8 000	10 000	12 500
10	10,9	10,1	9,9	10,0	9,7	8,7	7,2	5,0	2,6	2,2	4,8	12,2	20,4	21,0	15,5
20	19,4	19,1	19,4	20,0	19,9	19,2	17,7	15,4	13,0	12,5	15,0	22,0	29,4	29,2	22,7
30	28,2	28,3	29,0	30,0	30,1	29,5	28,0	25,7	23,2	22,6	25,0	31,7	38,5	37,7	30,4
40	37,3	37,7	38,7	40,0	40,2	39,6	38,1	35,7	33,1	32,5	34,9	41,5	47,8	46,5	38,6
50	46,6	47,2	48,5	50,0	50,2	49,6	48,0	45,5	42,9	42,3	44,7	51,2	57,2	55,6	47,5
60	56,2	57,0	58,4	60,0	60,1	59,5	57,7	55,1	52,5	51,8	54,4	60,9	66,7	65,0	57,0
70	66,0	67,0	68,4	70,0	70,0	69,3	67,3	64,5	61,8	61,3	64,0	70,7	76,4	74,8	67,4
80	76,2	77,1	78,5	80,0	79,8	78,9	76,7	73,7	71,0	70,5	73,5	80,4	86,3	84,9	78,6
90	86,6	87,5	88,7	90,0	89,5	88,4	85,9	82,7	80,0	79,6	82,9	90,1	96,3	95,5	90,9
100	97,4	98,1	99,0	100,0	99,1	97,7	94,9	91,5	88,8	88,5	92,2	99,9	106,6	—	—
110	108,6	109,0	109,5	110,0	108,6	107,0	103,8	100,1	97,4	97,3	101,4	109,6	—	—	—
120	120,0	120,0	120,0	120,0	—	—	—	108,6	105,9	106,0	—	—	—	—	—

Table 3 — Sound pressure level, in decibels, against loudness level, in phons, for frequencies ranging from 20 to 12 500 Hz

Sound pressure level, dB (reference : 20 µPa)	Loudness level, phons													
	Frequency, Hz													
	20	25	31,5	40	50	63	80	100	125	160	200	250	315	400
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—	—	—	—	—	—	5,6	7,7
20	—	—	—	—	—	—	—	—	—	8,6	12,6	15,8	18,3	19,9
30	—	—	—	—	—	—	4,5	11,3	17,2	22,0	25,5	28,3	30,4	31,6
40	—	—	—	—	—	11,3	19,2	25,2	30,4	34,7	37,9	40,3	42,1	42,8
50	—	—	—	7,2	18,1	26,4	33,2	38,5	43,1	46,9	49,7	51,8	53,2	53,7
60	—	—	11,7	25,0	33,9	40,8	46,5	51,2	55,1	58,5	60,9	62,7	63,9	64,2
70	—	14,9	30,5	41,5	48,7	54,3	59,3	63,2	66,6	69,5	71,7	73,2	74,1	74,2
80	17,2	34,6	47,8	56,9	62,7	67,2	71,4	74,8	77,6	80,1	82,0	83,2	83,9	84,0
90	38,1	52,6	63,6	71,1	75,8	79,5	82,9	85,8	88,1	90,2	91,8	92,8	93,4	93,4
100	56,9	68,9	78,2	84,4	88,2	91,2	94,0	96,3	98,2	99,9	101,2	102,0	102,5	102,4
110	74,0	83,9	91,7	96,9	99,9	102,3	104,6	106,4	107,8	109,3	110,3	110,9	111,3	111,2
120	89,6	97,6	104,2	108,6	110,9	112,9	114,8	116,1	117,1	118,2	119,0	119,4	119,7	119,7

Table 3 *(concluded)*

Sound pressure level, dB (reference : 20 µPa)	Loudness level, phons													
	Frequency, Hz													
	500	630	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000	5 000	6 300	8 000	10 000	12 500
0	—	—	—	—	—	—	—	5,3	7,6	7,9	5,3	—	—	—	—
10	9,0	9,8	10,1	10,0	10,3	11,2	12,7	14,8	17,1	17,6	15,1	7,7	—	—	—
20	20,7	20,9	20,6	20,0	20,1	20,8	22,2	24,4	26,9	27,4	25,0	18,0	9,5	8,7	16,3
30	32,0	31,8	31,0	30,0	29,9	30,5	32,0	34,3	36,8	37,5	35,0	28,2	20,7	20,9	29,5
40	43,0	42,4	41,3	40,0	39,8	40,4	41,9	44,4	47,0	47,7	45,2	38,5	31,6	32,7	41,6
50	53,6	52,8	51,5	50,0	49,8	50,4	52,0	54,7	57,4	58,1	55,4	48,8	42,4	43,9	52,7
60	63,9	63,0	61,6	60,0	59,9	60,5	62,3	65,2	68,0	68,7	65,8	59,0	53,0	54,7	63,0
70	74,0	73,0	71,6	70,0	70,0	70,8	72,9	76,0	78,9	79,4	76,3	69,3	63,4	65,2	72,4
80	83,7	82,8	81,5	80,0	80,2	81,2	83,6	87,0	90,0	90,4	86,9	79,6	73,6	75,2	81,2
90	93,1	92,4	91,2	90,0	90,6	91,7	94,5	98,3	101,4	101,6	97,6	89,9	83,7	84,9	89,3
100	102,3	101,7	100,9	100,0	101,0	102,5	105,7	109,8	113,0	113,1	108,5	100,1	93,6	94,2	96,9
110	111,3	110,9	110,5	110,0	111,4	113,3	117,1	121,7	124,9	124,7	119,5	110,4	103,3	—	—
120	120,0	120,0	120,0	120,0	—	—	—	—	—	—	—	—	—	—	—

Annex C

Equal-loudness level functions for narrow bands of random noise in a diffuse field

(This annex forms an integral part of the standard.)

The relation between sound pressure levels of narrow bands of random noise in a diffuse field and in a frontally-incident field for the condition of equal loudness, i.e. the amount by which the sound pressure level in a frontally-incident free progressive plane sound wave exceeds that in a diffuse sound field for equal-loudness level, is given in table 4 as a function of frequency (see [4] to [7]). This relation may be used as a correction factor to derive equal-loudness level functions and contours for narrow bands of random noise in a diffuse field starting from the pure-tone frontal-incidence specification in clause 4. Narrow-band noise in this context means noise of less than critical bandwidth (see, for example, [2] and [3]).

The loudness level, L_N, in phons, of a narrow-band noise centred on frequency f, in hertz, is given by the equation

$$L_N = 4{,}2 + \frac{a_f(L_f - T'_f)}{1 + b_f(L_f - T'_f)} \qquad \ldots (2)$$

where

L_f is the band sound pressure level of the noise;

a_f and b_f are parameters which have the same values as given for pure tones in table 1;

T'_f is the threshold sound pressure level of the noise band under diffuse-field listening conditions — values for T'_f are given in table 4; they are derived from the values of T_f given in table 1 by subtracting the value for ΔL given in table 4.

NOTES

1 In practice, the use of equation (2) for one-third octave bands of noise instead of critical (or narrower) bandwidths does not introduce errors of more than 1 phon.

2 The values for ΔL given in table 4 refer to otologically normal persons in the age group from 18 to 25 years. In this International Standard, the wider age band from 18 to 30 years inclusive is to be understood. In practice, the difference is negligible in terms of loudness level.

Table 4 — Parameters of the loudness level functions for diffuse field

Frequency, f Hz	Values for ΔL ($\Delta L = L_{free} - L_{diff}$)[1] dB	T'_f (reference: 20 μPa) dB
20	0	74,3
25	0	65,0
31,5	0	56,3
40	0	48,4
50	0	41,7
63	0	35,5
80	0	29,8
100	0	25,1
125	0	20,7
160	0	16,8
200	0,3	13,5
250	0,6	10,6
315	0,9	8,0
400	1,2	6,0
500	1,6	4,4
630	2,3	2,7
800	2,8	1,6
1 000	3,0	1,2
1 250	2,0	1,7
1 600	0,0	2,6
2 000	−1,4	2,4
2 500	−2,0	0,8
3 150	−1,9	− 1,7
4 000	−1,0	− 2,9
5 000	0,5	− 1,6
6 300	3,0	3,6
8 000	4,0	11,3
10 000	4,3	12,1
12 500	—	—

1) The value for ΔL is the amount by which, for equal loudness level, the sound pressure level in a frontally-incident free progressive plane sound wave, L_{free}, exceeds the sound pressure level in a diffuse sound field, L_{diff}.