

Method for

Calculating loudness

Co-operating organizations

The Acoustics Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

- British Broadcasting Corporation*
- British Electrical and Allied Manufacturers' Association*
- British Kinematograph Sound and Television Society
- British Radio Equipment Manufacturers' Association
- Cinematograph Exhibitors' Association of Great Britain and Ireland
- Incorporated Association of Architects and Surveyors
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- Institute of Physics and The Physical Society
- Institution of Electrical Engineers*
- Institution of Municipal Engineers
- Ministry of Defence, Navy Department*
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- Royal Institute of British Architects
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- Association of Consulting Engineers
- British Internal Combustion Engine Research Institute Ltd.
- Electricity Council, the Central Electricity Generating Board and the Area Boards in England and Wales
- Greater London Council
- Ministry of Technology
- Ministry of Transport
- Motor Industry Research Association
- Telecommunication Engineering & Manufacturing Association

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Foreword

This standard makes reference to the following British Standards:

BS 3045, *The relation between the sone scale of loudness and the phon scale of loudness level*.

BS 3489, *Sound level meters (industrial grade)*.

This British Standard has been prepared under the authority of the Acoustics Standards Committee. It is based on ISO/R532:1966¹⁾ issued by the International Organization for Standardization (ISO).

It is often desirable to obtain a single figure that corresponds to the loudness or to the loudness level of a given sound. Such a value can be calculated from the spectrum analysis of the sound. The result of such a calculation is statistic, that is, it conveys less information than the spectrum measurements from which it is derived.

Frequency analysis is generally carried out in octave bands, or 1/3 octave bands. Sounds which do not have strong line spectra as a function of frequency, can be represented adequately in terms of octave bands, but sounds which contain such line spectra may require 1/3 octave band analysis if they are to be described adequately.

This British Standard specifies two methods for calculating the loudness or loudness level of a complex sound, which differ not only in the method of analysis of the sound, but also in the principles of computation. The first, method A, utilizes physical measurements obtained from spectrum analysis in terms of octave bands. The second, method B, utilizes spectrum analysis in terms of 1/3 octave bands.

The two methods differ also in other respects, and the results obtained do not in general coincide. Method B generally gives slightly higher results than those obtained from the same sounds by method A, the difference being possibly as much as 5 phons, but it would seem to take better into account those variations in sound spectra that occur within narrow ranges of frequency.

The quantities calculated by either method should be designated with specific reference to the method used by means of the system of symbols and abbreviations given in Clause 3.

NOTE For certain purposes, particularly for a comparison of similar types of sound, it may be possible to base an estimate of the loudness of a sound on the value of the sound level indicated by a sound level meter used with the A weighting network. Such a meter reads the weighted sound level, not the loudness; its characteristics are given in BS 3489, "*Sound level meters (industrial grade)*".

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

¹⁾ ISO/R532:1966, "*Method for calculating loudness level*".

1 Scope

This British Standard specifies procedures for calculating the loudness experienced by a typical (median) listener under the following conditions:

- 1) *Frontal sound*. The sound is assumed to reach the listener's ears only from the direction straight ahead of him, in the open air or in a non-reflecting environment. In all enclosures, frontal sound is approximated when a small source is operating close to and directly ahead of the listener.
- 2) *Diffuse sound*. The sound is assumed to reach the listener's ears from all directions at the same intensity. This condition is approximated in an ordinary room.
- 3) *Kind of spectrum*. Method A is designed specifically for the types of broad band spectra most commonly encountered. Errors may arise if it is applied to certain types of line spectra, or to spectra having two or more sharp maxima that are separated by more than one octave. The magnitude of the error that may result from an unusual spectrum can only be determined experimentally. Method B may be used with all types of spectra.
- 4) *Steady state*. The procedures are designed for noises that are steady rather than intermittent. Nevertheless, in a diffuse field many noises of impulsive origin behave effectively as steady noises, because reverberation serves to diminish temporal discontinuities.

NOTE 1 The error that may result with intermittent noises is not necessarily attributable to the calculation procedure. It may also be affected by the averaging characteristics of the meter used to determine the sound pressure levels.

NOTE 2 Since loudness depends upon the nature of the environment in which the sound is heard, it is important that comparative evaluations of different noise sources should be based on measurements made in essentially similar environments.

NOTE 3 In the case of diffuse field, the band levels should be measured by means of an omnidirectional microphone located in the unobstructed sound field, at the position of, and replacing the listener's head.

2 Definitions

For the purposes of this British Standard the following definitions apply:

2.1

sound pressure level (*L*)

a value, in decibels, which is $20 \log_{10} (p/p_o)$ dB where p is the measured sound pressure and p_o is a reference sound pressure having the value 2×10^{-5} N/m² r.m.b (2×10^{-4} dyn/cm²)

2.2

band pressure level

the sound pressure level L_{OD} , L_{GD} or L_{GF} corresponding to the part of the spectrum under measurement. The suffixes indicate the band width and the type of sound field, viz. *O* for octaves, *G* for critical bands, see 2.3, *F* for frontal sound and *D* for diffuse sound

2.3

critical bands

a band of frequencies, centred round a nominal frequency, such that the loudness is equal to that of a narrower band of the same sound pressure level, but less than that of a wider band of the same sound pressure level. Critical bands are approximated by bands 1/3 octave wide above 280 Hz and by groups of 1/3 octave bands for lower frequencies

2.4

loudness level (*P*) in phons

a value, numerically equal to that sound pressure level, expressed in dB, of a 1 000 Hz tone, presented frontally, in a free progressive wave, which a median listener judges to be as loud as the sound to be evaluated; the two sounds being presented alternately

2.5

calculated loudness level

a value expressed in phons (*GF*), phons (*GD*) or phons (*OD*), and obtained by the procedures specified. The abbreviations *GF* and *GD* signify that the calculation is based on critical bands and refer to frontal sound and a diffuse field respectively. The abbreviation *OD* signifies analysis by octave bands in a diffuse field and the use of the simpler method of computation, method A

NOTE 1 The term "phon", without a qualifying abbreviation, should be reserved for the expression of loudness levels determined by direct subjective measurement.

NOTE 2 When loudness levels are computed from calculated loudness values the results may differ from those obtained by direct subjective judgement. It is important, therefore, to state whether the values have been calculated or have been measured by other means.

2.6

loudness (*S*) in sones

a numerical designation of the strength of a sound which is proportional to the subjective magnitude as estimated by normal observers. One sone is the loudness of a sound whose loudness level is 40 phons

2.7

loudness; loudness level relation

the loudness level *P* in phons of a sound is related to the loudness *S* in sones by the relation:

$$S = 2^{(P - 40)/10}$$

2.8

loudness index

a number determined by the geometric mean frequency and the band pressure level of the octave band, according to the curves of Figure A

3 Designation of calculated loudness and loudness level

Method	Quantity measured		Band width of analysis	Sound field
	Loudness	Loudness level		
A	Sones (<i>OD</i>)	Phons (<i>OD</i>)	octave	diffuse
B	Sones (<i>GD</i>) Sones (<i>GF</i>)	Phons (<i>GD</i>) Phons (<i>GF</i>)	1/3-octave	diffuse frontal

4 Method A

4.1 General. Method A has the advantage of simplicity and is specified for sounds for which octave-band analyses are appropriate. Many noises of practical interest fall into this class.

Since the purpose of the present British Standard is to provide a simple and convenient method by which complex sounds of diverse levels and spectra may be ordered on a scale of subjective magnitude, certain simplifying assumptions and linear approximations have been made. The procedure is derived from three relations:

- 1) A loudness function relating loudness in sones to loudness level in phons, which is identical to that in BS 3045²⁾.
- 2) An empirical set of equal loudness contours for bands of noise in a diffuse sound field.
- 3) A rule relating the total loudness of a sound to the loudness indices of the frequency bands composing it.

On the basis of these empirical relations, the total loudness of a sound may be calculated with the aid of a table or a chart, together with a linear equation. Subject to certain restrictions, the recommended procedure may be expected to assess loudness, or loudness level, with an accuracy that is sufficient for engineering purposes.

4.2 Calculated loudness. The procedure for calculating loudness is embodied in a table and a formula. For convenience, the table is also presented graphically as a chart (Figure A). The table or chart provides a means for converting each band level to a loudness index, and the formula provides a rule for combining the loudness indices to obtain the calculated total loudness.

The procedure is as follows:

- 1) Enter the geometric mean frequency of each band in the abscissa of Figure A. Then from the band level (ordinate in Figure A), determine the loudness index of each band.

²⁾ BS 3045, "The relation between the sone scale of loudness and the phon scale of loudness level".

2) Compute the total loudness S_t in sones (OD) by means of the formula:

$$S_t = S_m + 0.3 (S - S_m)$$

where S_m is the greatest of the loudness indices and S is the sum of the loudness indices of all the bands.

4.3 Calculated loudness level. The total loudness may be converted into calculated loudness level in phons (OD) by means of the formula:

$$S_t = 2^{(P - 40)/10}$$

of $P = 40 + 10 \log_2 S_t$.

A nomogram giving this relation is included in Figure A.

4.4 Table of loudness index. In Table 1 values of the loudness index are tabulated for the frequency of 1 000 Hz. Values at other frequencies can be obtained by means of the following rules:

Contours of constant loudness index are drawn as follows. At low frequencies the slope is -6 dB/octave. A change of slope to -3 dB/octave occurs at the intersection with the line passing through the point (1 000 Hz, 10 dB) and having the slope -21 dB/octave. A further change of slope to $+12$ dB/octave occurs at 9 000 Hz.

NOTE The chart in Figure A shows one means of presenting the relation between loudness index, band pressure level and frequency. Here the loudness index is the parameter of the family. For certain purposes, it may be convenient to prepare charts for the band pressure level as a parameter, and the loudness index as an ordinate.

5 Method B

5.1 General. This clause specifies a procedure, method B, for calculating the loudness of steady complex sounds for which 1/3-octave band analyses have been obtained. By means of graphs, the 1/3-octave band levels are transformed into parts of an area which correspond to parts of loudness. The loudness level in phons (GF or GD) is calculated from the total area and is read from a scale. The loudness level may then be converted into loudness in sones (GF or GD) by means of the relations specified in BS 3045³⁾.

Since the purpose of this method is to provide a convenient method by which complex sounds of various levels and spectra may be ordered on a scale of subjective magnitude, certain simplifying assumptions have been made, especially the approximation of critical bands by 1/3-octave bands, or multiples thereof. The procedure is based on five empirical relations and concepts.

- 1) The use of critical bands.
- 2) A rule relating the total loudness of a sound to the contributions from the critical bands composing it.
- 3) A relation between the part of the loudness appropriate to each band and the mid-band (geometrical mean) frequency.
- 4) The difference between the equal-loudness contours for frontal sound and for a diffuse sound field.
- 5) A loudness function relating loudness in sones to loudness level in phons, which is identical to that in BS 3045³⁾.

On the basis of these concepts the total loudness or the loudness level of a sound may be calculated, with the aid of a set of graphs, either for a frontally incident sound or for a diffuse sound field.

5.2 Procedure. The procedure for the calculation of loudness level consists of three steps based on a set of graphs. These graphs (Figure 1–Figure 10, according to the level range and type of sound field), provide a means of combining and converting the 1/3-octave band levels to give the total loudness level. Figure 1–Figure 5 are used for frontal sound and Figure 6–Figure 10 for a diffuse field.

5.2.1 Step 1. Each graph contains stepped curves designated by numbers related to the 1/3-octave band levels L_T . Select a graph which corresponds to the appropriate type of sound field, and which just includes the highest 1/3-octave band level measured. Draw the measured level in the bands centred on 315 Hz and upwards as horizontal lines so that the cut-off frequencies of the 1/3-octave band corresponds to the abscissa of the graph and the measured levels correspond to the numbering of the stepped curves.

³⁾ BS 3045, "The relation between the sone scale of loudness, and the phon scale of loudness level".