A NEW ANSI LOUDNESS STANDARD

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Loudness depends on both the acoustic properties of the sound that impinges on the listener and on the listener. In 2005 a new standard for calculating the loudness of steady sounds as perceived by listeners with normal hearing was approved by the American National Standards Institute (ANSI). The new standard replaces and supersedes the computational procedure used in the old ANSI S3.4-1980 standard. To gain some insight into the new ANSI standard, several important distinctions between the old and new loudness standards are described below.

Comparison between new and old ANSI loudness standards

The old ANSI standard was based on the procedure proposed by S. S. Stevens (1957, 1961). This procedure was relatively easy to apply without the need for high-speed computers. It was used with success to predict the loudness of noises with relatively homogeneous spectra in the mid-frequency region (e.g., Scharf and Hellman, 1980). However, more complex signals and technological advances required a standard with broader applicability. The following restrictions placed limitations on the applicability of the old ANSI standard. First, old ANSI S3.4-1980 is restricted to broadband stimuli that do not contain tonal components. Thus, it is unable to predict accurately the loudness of noises with sharp line spectral components such as transformer hum or fan noise [see ANSI S3.4-1980 (R 2003); Hellman, 1991]. The new ANSI loudness standard overcomes these limitations. Second, loudness calculated according to old ANSI S3.4-1980 is based heavily on linear loudness indices that do not reveal the detailed curvilinear shape and loudness magnitudes of the revised equal-loudness contours in ISO 226:2003 (International Organization for Standardization, Geneva); Suzuki and Takeshima (2004). In contrast, equal-loudness contours calculated according to ANSI S3.4-2005 predict equal-loudness contours that are in good overall agreement with those in ISO 226:2003. The agreement between the calculated and measured loudness levels is especially good in the frequency region below 500 Hz (Hellman, 2002, 2006). Third, old ANSI S3.4-1980 limits the description of the relation between loudness in sones and loudness level in phons to a loudness level of 20 phons, whereas the new ANSI S3.4-2005 standard extends the dynamic range for loudness calculations down to near threshold levels.

Figure 1 compares the relation between loudness in sones and loudness level in phons predicted by the old ANSI S3.4-1980 standard to the relation predicted by the new ANSI S3.4-2005 standard. According to Fig. 1, in old ANSI S3.4-1980 a simple power function in the form $L = kI^n$ describes the relation between loudness and sound intensity above 20 phons. This relation is based on an obsolete and withdrawn ISO standard (ISO/R 131:1959). In contrast, the curve based on the new ANSI S3.4-2005 standard approximates a simple power function down to 40 phons. Between 40 and 90 phons, the calculated sone values do not deviate by more than 5% from the standard sone values in ISO 532:1975. However, below 40 phons the loudness function based on ANSI S3.4-2005 becomes progressively steeper than a simple power function prediction approaching a limiting slope close to unity between loudness and sound intensity near threshold. This result means that threshold loudness cannot be zero in accord with experimental evidence (e.g., Hellman and Zwislocki, 1961, 1963; Hellman, 1976; Buus *et al.*, 1998) and theoretical considerations (Zwislocki, 1965; Moore *et al.*, 1997). Instead, consistent with the definition of threshold, threshold loudness must have a finite positive value. Given these basic improvements, ANSI S3.4-2005 was introduced and approved.

Relation between the new ANSI loudness standard and the ISO loudness standard

The new ANSI S3.4-2005 standard also updates ISO 532:1975 titled "Acoustics–Method for calculating loudness level." ISO 532 consists of two sections. Section one describes method A and section two describes method B. Method A of ISO 532:1975 is basically the same as the replaced ANSI S3.4-

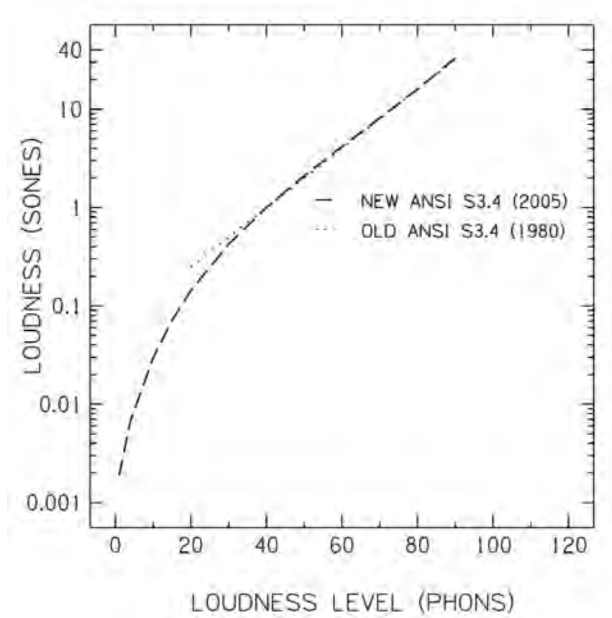

Fig. 1. Loudness in sones as a function of loudness level in phons. The dotted curve shows the loudness function based on the old ANSI S3.4-1980 standard; the dashed function shows the loudness function based on the new ANSI S3.4-2005 standard.

1980 standard with one additional restriction. Whereas ANSI S3.4-1980 is applicable to both 1/3-octave and 1/1-octave bands, ISO 532 method A is limited to an octave-band analysis. This additional restriction further limits the suitability of method A for loudness calculations. ISO 532 method B improves method A in two important respects. First, ISO 532 method B is applicable to sounds with strong line spectra (e.g., Hellman and Zwicker, 1987). Second, ISO 532 method B enables total loudness to be calculated from a one-third-octave band analysis. The new ANSI S3.4-2005 standard provides distinct improvements that extend its suitability for calculating the loudness of steady sounds.

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The origin of the new ANSI S3.4-2005 loudness standard has a long and significant history in psychoacoustics dating back to the pioneering research of Fletcher and Munson (1933). It is based on a model of loudness perception (Moore *et al.*, 1997) that was developed from a model originally proposed by Zwicker and his co-workers (1958, 1965, 1984, 1999). Zwicker's model is part of ISO 532:1975 method B. The new procedure for calculating the loudness of steady sounds is rooted in our current understanding of the human auditory system. The procedure is applicable to sounds presented in free field with frontal incidence, in a diffuse field, or via headphones. It is available as a computer program that provides a loudness estimate in sones, and the corresponding loudness level in phons. The following features distinguish the new ANSI S3.4-2005 loudness standard from Zwicker's procedure in ISO 532:1975 method B.

First, unlike ISO 532:1975 method B, ANSI S3.4-2005 is applicable to both monaural and binaural stimulus presentations. The procedure is based on the simplifying assumption that the loudness from each ear is added to give the overall loudness when listening with two ears. For binaural presentations with the same sound in both ears, the overall loudness is calculated as twice that for each ear separately (e.g., Fletcher and Munson, 1933; Hellman and Zwislocki, 1963; Marks, 1978). Second, although ISO 532 method B enables the loudness of sounds with strong line spectra to be determined (e.g., Hellman and Zwicker, 1987), its applicability is limited to mid-frequency tones combined with noise (e.g., Hellman and Zwicker, 1987; Hellman, 1991). When the added tone is located below 500 Hz, the modification by Moore *et al.* (1997) in ANSI S3.4-2005 provides a more accurate prediction of the total loudness of a tone-noise complex than loudness predictions based on ISO 532 method B (Hellman, 2002). The difference at low frequencies is probably caused by the one-third-octave band analysis. In ISO 532 method B, one-third-octave band approximations are determined from Critical Bands (Frequenzgruppen). By comparison, in the new ANSI S3.4-2005 standard, the one-third-octave-band approximations are determined from the Equivalent Rectangular Bandwidth (ERB_N) of the auditory filter (Glasberg and Moore, 1990). At 1 kHz and above, the critical-band function and the ERB_N function closely agree (Patterson and Moore, 1986). However, below 500 Hz, the critical bandwidth and the ERB_N filter deviate markedly. In this low-frequency region, the critical bandwidth has a constant value whereas the ERB_N value decreases as frequency decreases. At center frequencies below 500 Hz, the smaller ERB_N values provide a more accurate representation of the bandwidth of the auditory filter (Moore and Sek, 1995) than the critical-band function. As noted in the analysis of old ANSI S3.4-1980, this improvement probably also accounts for the good agreement between the calculated equal-loudness contours based on ANSI S3.4-2005 and the recently revised ISO 226:2003 contours at low frequencies. Third, like old ANSI S3.4-1980, the relation between loudness in sones and loudness level in phons in ISO 532 method B is based on an obsolete and withdrawn ISO standard (ISO/R131:1959). As seen in Fig. 1, this withdrawn ISO standard produces a loudness function relating loudness in sones to loudness level in phons that is described by a simple power function down to 20 phons. The accumulated empirical evidence clearly shows that below 40 phons a simple power function departs markedly as threshold levels are approached from the loudness function generated by the new ANSI S3.4-2005 loudness-calculation procedure. The departures are especially noteworthy as threshold is approached. Both experimental data and auditory theory support these results (e.g., Hellman and Zwislocki, 1961, 1963; Hellman, 1976; Zwislocki, 1965; Buus *et al.*, 1998). Instead of an incorrect value of zero loudness at threshold, within the new ANSI S3.4-2005 procedure, the absolute threshold of a sound is taken to correspond to the level at which the procedure gives a calculated loudness of 0.003 sones. This loudness value is in accord with the loudness model of Moore *et al.* (1997). It corresponds to a loudness level of 2.2 phons (Glasberg and Moore, 2006).[1] The procedure can therefore be used to calculate the absolute threshold of a given sound by determining the input level that leads to a calculated loudness of 0.003 sones. Thus calculated, the derived absolute threshold for sinusoidal stimuli are very close to those specified in ISO 389-7:2005.

Another problem with ISO 532 method B is that the calculations are based on tables of values, which result in quantization effects; the calculated loudness level in phons may "jump" by around 2 dB when the input sound level is changed by only 0.1 dB. Loudness as calculated according to ANSI S3.4-2005 varies smoothly and continuously with input sound level

Summary and conclusions

The new ANSI S3.4-2005 standard for calculating the loudness of steady sounds is described and compared to the old ANSI S3.4-1980 standard. The new ANSI loudness standard is also compared to the loudness standard in ISO 532. Taken together, the analysis indicates that loudness calculated according to ANSI S3.4-2005 provides a distinct improvement over either old ANSI S3.4-1980 or ISO 532 method A and method B. Based on its broader applicability and increased accuracy, ANSI S3.4-2005 is recommended for calculating the loudness of steady sounds as perceived by listeners with normal hearing.**AT**

[1] In ANSI standard S3.4-2005 threshold loudness of 0.003 sones is given as 2 phons.

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