

LOUDNESS

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1. Core Definition

Loudness is defined primarily as the subjective attribute of sound that is correlated with the intensity of the sound wave, determining how high or low the perceived amplitude of the sound is to a listener. Unlike physical properties of sound, such as Sound Pressure Level (SPL) measured in decibels (dB), which are objective and instrument-based, loudness is fundamentally a psychological and physiological phenomenon. The original source emphasizes this crucial distinction, noting that while an objective measure of intensity can be taken (e.g., a jumbo jet landing), the final judgment--whether it is "too loud"--remains subjective and varies between individuals. This subjectivity arises from the complex processing of auditory information within the human cochlea and central nervous system, which filters, compresses, and interprets the incoming sound energy based on individual sensitivity, attention, and previous experience.

The perception of loudness is directly tied to the amplitude of the sound wave, but it is not a linear relationship. Doubling the sound pressure does not necessarily double the perceived loudness. Furthermore, the intensity must be integrated over time (temporal integration) and across different frequencies (spectral integration) to form the final perceived magnitude. For instance, sounds below a certain threshold--known as the absolute threshold of hearing--are perceived as silent, regardless of their measurable pressure level. Conversely, sounds exceeding the threshold of pain, typically around 120 dB, are universally perceived as painfully loud, though the point at which discomfort begins still shifts slightly based on individual tolerance. This interaction of physical stimulus and sensory processing highlights loudness as a key concept linking physics and psychology.

Crucially, the perception of loudness is also heavily influenced by the distribution of energy across the frequency spectrum. The source material correctly points out that specific components, such as the **base element** (lower frequencies), may seem more potent or "travel further" than higher frequencies. This observation relates to the phenomenon of auditory masking and the varying sensitivity of the human ear across different frequencies. The human auditory system is most sensitive to sounds in the middle frequency range (around 2 kHz to 5 kHz) and requires significantly higher physical intensity to perceive very low or very high frequencies at the same level of loudness, a fact formalized by the equal-loudness contours.

2. Physical Basis: Sound Intensity and Pressure

To understand **loudness**, one must first grasp its physical underpinning: sound intensity, which is

typically quantified using the Sound Pressure Level (SPL), measured in decibels (dB). Sound waves are longitudinal waves that cause variations in ambient air pressure. SPL is a logarithmic measure of the effective pressure of a sound relative to a reference level (usually the threshold of human hearing, 20 micropascals). The use of the logarithmic decibel scale is itself an accommodation to human perception, as the human ear can detect sounds ranging across twelve orders of magnitude in intensity, a massive dynamic range that a linear scale would render impractical for everyday measurement.

The relationship between SPL and perceived loudness is complex because the ear acts as a non-linear receiver. A 10 dB increase in SPL often corresponds roughly to a perceived doubling of loudness, particularly in the middle frequency ranges--a principle known as Stevens' Power Law applied to audition. However, this rule of thumb breaks down at the extremes of frequency and intensity. For example, two separate sounds of equal intensity, when played together, usually result in a perceived loudness that is less than double the original sound, due to auditory summation and possible masking effects within the cochlea.

Furthermore, sound propagation dictates that lower frequencies, specifically those associated with the "base element" mentioned in the source material, tend to attenuate less rapidly over distance than high frequencies. This physical characteristic often leads to the perception that low-frequency sounds (like bass notes or heavy machinery rumble) "travel further" or penetrate barriers more effectively, contributing disproportionately to ambient environmental noise perception, even when the overall SPL measured close to the source is not dominated by those lower frequencies. This difference in propagation contributes significantly to noise complaints in urban settings, where low-frequency vibrations are often perceived as intrusive over long ranges.

3. Psychoacoustic Relationship: Loudness, Frequency, and Duration

The relationship between **loudness** and frequency is formalized by the concept of equal-loudness contours, initially mapped by Fletcher and Munson in the 1930s, and later refined by Robinson and Dadson and standardized in ISO 226. These curves illustrate that the human ear is maximally sensitive between 2 kHz and 5 kHz--the range crucial for speech intelligibility. Consequently, a sound at 100 Hz requires significantly more physical intensity (a higher dB reading) to be perceived as equally loud as a sound at 3 kHz. For instance, at low loudness levels, a 50 Hz tone might need 50 dB of SPL to sound as loud as a 3 kHz tone at 10 dB SPL.

This frequency-dependent sensitivity is why audio engineers must use weighting filters (A-weighting, C-weighting, etc.) when measuring environmental or occupational noise. A-weighting specifically mimics the human ear's response at moderate levels, heavily discounting very low and very high frequencies. Without such weighting, a simple SPL meter might indicate a high reading due to significant low-frequency rumble, yet a human listener might perceive the sound as having

only moderate loudness, demonstrating the necessary calibration required when attempting to bridge objective physics and subjective perception.

Temporal integration also plays a vital role in loudness perception. For very short sounds (typically less than 200 milliseconds), the perceived loudness increases as the duration of the sound increases, even if the sound pressure level remains constant. This is because the auditory system requires a minimum period to "sum up" the energy of the sound wave. If a sound is shorter than this integration window, the resulting perceived loudness will be less than that of a steady-state tone with the same physical intensity. This has important implications for warning signals or impulse noise, such as clicks or gunshots, where peak intensity must be carefully considered alongside duration for a complete assessment of impact.

4. Measurement Scales: Phon and Sone

Because the decibel scale measures physical intensity rather than perceived magnitude, specialized psychoacoustic units were developed to quantify **loudness** subjectively. The primary units used are the **phon** and the **sone**, which provide scales based directly on human hearing characteristics. The **phon** scale is an equal-loudness level unit. By definition, the phon level of a sound is numerically equal to the SPL (in dB) of a 1000 Hz pure tone that is judged by listeners to be equally loud. Thus, a sound that is perceived as equally loud as a 60 dB, 1000 Hz tone has a loudness level of 60 phons.

While the phon scale is useful for equating the loudness of different frequency sounds, it remains a logarithmic scale and does not represent the perceived magnitude directly. To address this, the **sone** scale was developed. The sone is a linear unit of loudness, meaning that a sound measured at 2 sones is perceived as exactly twice as loud as a sound measured at 1 sone. By definition, a loudness level of 40 phons corresponds to 1 sone. The relationship between phons and sones is generally governed by the rule that doubling the loudness (doubling the number of sones) corresponds to an increase of approximately 10 phons. This linear scale is particularly valuable in psychological experiments and regulatory contexts where proportional increases in perceived annoyance or noise pollution must be quantified accurately.

The transition from objective decibels to subjective phons and then to linear sones represents the refinement of psychoacoustic measurement over the 20th century. Modern sound level meters often incorporate sophisticated digital filters that estimate loudness in phons or sones, rather than just providing the raw SPL reading. This standardization allows industries, from telecommunications to automotive design, to ensure their products meet specific loudness targets that align with human expectations and legal limits, moving beyond mere physical power measurements toward sensory impact assessment.

5. Historical Development and Key Figures

The formal scientific inquiry into **loudness** began in the late 19th century, driven by emerging telephony technology and the need to standardize auditory communication. Early foundational work was conducted by Alexander Graham Bell and his contemporaries, leading to the development of the decibel scale (named in his honor). However, the critical link between physical intensity and psychological perception was truly forged in the 1930s with the groundbreaking work of Harvey Fletcher and Wilden A. Munson at Bell Telephone Laboratories.

Fletcher and Munson conducted extensive experiments using large groups of listeners to determine the sound pressure levels required at various frequencies to produce a consistent perceived loudness. Their resulting "equal-loudness contours" revolutionized psychoacoustics, providing the first reliable quantitative evidence that the ear's sensitivity is strongly frequency-dependent, particularly at low loudness levels. This work provided the immediate theoretical justification for the phon scale and established the foundation for modern audio engineering standards.

Following World War II, further refinements were made by researchers like Donald W. Robinson and R.S. Dadson in the UK, leading to updated international standards (ISO 226). Concurrently, S.S. Stevens introduced the concept of the **sone** in the 1950s, formalizing the relationship between physical intensity and perceived magnitude using his Power Law, providing a crucial linear measure of loudness. This continuous development demonstrates the transition of loudness studies from empirical observation to robust mathematical and physiological modeling, essential for both acoustics and psychology.

6. Subjectivity and Individual Variation

Despite the development of standardized measurement scales, the fundamental subjectivity of **loudness**, as highlighted in the provided source material ("some may disagree, this is the subjective nature of loudness"), remains a critical area of study. Individual differences in auditory perception are influenced by physiological factors, including the condition of the middle and inner ear, age (presbycusis often leads to loss of sensitivity to high frequencies), and genetics. Two individuals exposed to the exact same acoustic stimulus may report significantly different loudness levels due to these inherent differences in sensory apparatus.

Beyond physiological differences, psychological factors heavily modulate perceived loudness. Attention plays a crucial role; a sound deemed highly annoying or loud when unexpected or unwanted (e.g., the jumbo jet scenario) may be perceived as less intrusive if the listener is focused on a task or if the sound is part of an expected or pleasurable context (e.g., listening to loud music at a concert). Furthermore, emotional state and cultural expectations influence tolerance thresholds. Individuals experiencing hyperacusis, a condition characterized by an abnormal

intolerance to ordinary environmental sounds, perceive moderate sounds as intensely and painfully loud, dramatically illustrating the neurological component of this subjectivity.

This variation necessitates the use of large statistical samples in psychoacoustic research to establish average listener responses, which form the basis of the ISO standards. However, in legal and regulatory contexts, especially concerning occupational health and safety, the subjective nature of noise exposure is often balanced against objective measures. Regulations must typically rely on objective dB levels (often A-weighted) to set limits, even while acknowledging that for a subset of the population, those levels may still result in higher-than-average perceived loudness and potential distress or damage. The challenge remains to bridge the reliable objectivity of physics with the inherent variability of human sensory experience.

7. Applications in Audio Engineering and Health

The principles governing **loudness** perception are central to numerous practical applications, particularly in audio engineering and public health. In broadcasting and music production, understanding equal-loudness contours is vital for mastering audio. For instance, producers utilize 'loudness normalization' techniques to ensure that different tracks or advertisements maintain a consistent perceived loudness, regardless of their peak volume or frequency content, preventing listeners from having to constantly adjust their volume controls. Standards like ITU-R BS.1770 provide algorithms that measure and normalize broadcast loudness in terms of perceived magnitude rather than simple peak amplitude.

In the realm of health and safety, precise measurement of loudness is crucial for determining noise exposure limits. Occupational safety agencies rely on established phon and dB levels to protect workers from Noise-Induced Hearing Loss (NIHL). Because the risk of hearing damage is related to the total energy absorbed over time, standards differentiate between steady-state noise and impulsive noise, applying dose metrics that account for temporal integration and frequency sensitivity. Furthermore, understanding how low frequencies penetrate barriers is essential for urban planning and architectural acoustics, influencing the design of soundproofing materials and buffer zones to mitigate noise pollution.

Finally, clinical audiology utilizes loudness perception tests extensively. Procedures like the measurement of uncomfortable loudness levels (UCLs) help diagnose specific auditory pathologies, such as recruitment (an abnormally rapid growth of loudness perception often associated with sensorineural hearing loss). By quantifying how quickly perceived loudness increases as physical intensity rises, clinicians can tailor hearing aid settings to compress the acoustic input appropriately, ensuring that quiet sounds are audible without making loud sounds uncomfortably intense, thereby optimizing the dynamic range for the user.

8. Further Reading

[Loudness \(Wikipedia\)](#)

[Equal-Loudness Contour \(Fletcher-Munson Curves\)](#)

[Phon \(Unit of Loudness\)](#)

[Sone \(Unit of Loudness\)](#)

[Stevens' Power Law](#)

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