

MEASUREMENT OF SOUND

e-content for B.Sc Physics (Honours)
B.Sc Part-I
Paper-I

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MEASUREMENT OF SOUND

INTRODUCTION

You have already learnt about the various elements and characteristics of sound in the previous lesson (1). In this lesson, you will be acquainted with decibels (dB) and hertz (Hz), and their usage, dynamic range and sound pressure level (SPL).

Sound is simply a wave, and its perception by our ears is of some mechanically created waves resulting from the vibration of air molecules. We experience sound, when our ears are excited by vibrations in the air that surrounds us. Sounds occur continuously every day: children crying, people talking, singing or shouting, dogs barking, the sounds of vehicles/traffic, music from radios or from television programmes. These all make up various sound waves.

Since the range of intensities that the human ear can detect is so large, the scale that is frequently used by physicists to measure intensity is a scale based on multiples of 10. This type of scale is sometimes referred to as a logarithmic scale. The scale for measuring intensity is the **decibel scale**. The threshold of hearing is assigned a sound level of 0 decibels (abbreviated as dB); this sound corresponds to an intensity of $1 \times 10^{-12} \text{ W/m}^2$. A sound that is 10 times more intense ($1 \times 10^{-11} \text{ W/m}^2$) is assigned a sound level of 10 dB. A sound that is 10×10 or 100 times more intense ($1 \times 10^{-10} \text{ W/m}^2$) is assigned a sound level of 20 dB. A sound that is $10 \times 10 \times 10$ or 1000 times more intense ($1 \times 10^{-9} \text{ W/m}^2$) is assigned a sound level of 30 dB. A sound that is $10 \times 10 \times 10 \times 10$ or 10000 times more intense ($1 \times 10^{-8} \text{ W/m}^2$) is assigned a sound level of 40 dB.

DEFINITION OF DECIBEL

Loudness or volume (also called amplitude) is an important characteristic of sound. It is a perception that is based on a scale between quietness to anything that is not. The explosion of a plastic cover in a closed room might be heard loudly, but the same noise may not even be felt, on a noisy road, which means that loudness is relative.

Loudness of sound is measured in decibels.

The decibel (dB) is a unit, used to measure sound intensity and other physical quantities. A decibel is one tenth of a bel (B), a unit named after Graham Bell, the inventor of the telephone. Its logarithmic scale is convenient to represent the entire range of human hearing. Decibels (dB) is an intricate measurement of sound levels. A sound wave's actual amplitude is measurable, however, loudness is subjective concept. So, decibel is not a unit in the sense that a 'foot' is. Feet are defined quantities and distance. A decibel is a relationship between two values of power.

What is loud to one person (announcer/anchor) may not be sound loud to another person (announcer/anchor). Sound amplitude is measured in **decibels** (abbreviated dB). It is the volume of the sound. In technical jargon/ parlance, the amplitude is the height of the sine wave (i.e. the visual representation of the characteristics of sound). The higher the amplitude, the louder the sound. Loudness is the human perception of the intensity of sound waves. Our standard conversation has an intensity of around 50 dB, whereas 20 dB is the sound level of a whisper, 75 dB is the noise level in the city. These measurements are expressed in a specific form called dB SPL i.e. decibel sound pressure level.

The decibel of sound pressure level (dB SPL) is taken as a reference for the minimum sound pressure level that the average human ear can detect. The smallest audible sound to humans, is typically 0 dB SPL (hearing threshold). In practice, "dB" often stands for "dB SPL".

Since the decibel scale is logarithmic, a three-decibel increase in the sound level represents a doubling of [sound] intensity. For example, a normal conversation may be about 65 dB and someone shouting can typically be around 80dB. The difference is only 15 dB but the shouting is 30 times more intensive.

The formula for comparing two values using decibels is as follows:

$$dB = 20 \times \text{Log } B/A$$

where dB is the answer in decibels, A is the reference value to be measured and B is the value that is being compared against the reference.

For example, let 0.0002 microbar (the threshold of hearing) be the reference level. How many decibels above the threshold of hearing is normal speech at a distance of three feet? I have already mentioned that speech at three feet is about 0.3 microbars.

We can use the formula as follows:

$$\begin{aligned} dB &= 20 \text{ Log } (0.3/0.0002) \\ &= 20 \times 3.176 \\ &= \text{approx. } 64 \text{ dB} \end{aligned}$$

The units of decibels can be used to compare many different quantities. In this case, it's comparing the relative loudness of "normal" speech to the threshold of hearing. This is in units called "dBspl", and is written "64 dBspl".

Please note that perception of loudness, is not exactly the same as sound pressure level. To account for the fact that particularly low and high-pitched sounds appear less loud to the human ear, noise is usually measured in A-weighted decibels (dB(A)). When sound waves reach the ear or measuring instrument the resulting change of pressure can be measured. Sound intensity is usually expressed in decibels of sound pressure level (dB SPL).

The table lists some common sounds with an estimate of their intensity and decibel level.

Source	Intensity	Intensity Level	# of Times Greater Than TOH
Threshold of Hearing (TOH)	$1 \times 10^{-12} \text{ W/m}^2$	0 dB	10^0
Rustling Leaves	$1 \times 10^{-11} \text{ W/m}^2$	10 dB	10^1
Whisper	$1 \times 10^{-10} \text{ W/m}^2$	20 dB	10^2
Normal Conversation	$1 \times 10^{-6} \text{ W/m}^2$	60 dB	10^6

Busy Street Traffic	$1 \cdot 10^{-5} \text{ W/m}^2$	70 dB	10^7
Vacuum Cleaner	$1 \cdot 10^{-4} \text{ W/m}^2$	80 dB	10^8
Large Orchestra	$6.3 \cdot 10^{-3} \text{ W/m}^2$	98 dB	10^9
Walkman at Maximum Level	$1 \cdot 10^{-2} \text{ W/m}^2$	100 dB	10^{10}
Front Rows of Rock Concert	$1 \cdot 10^{-1} \text{ W/m}^2$	110 dB	10^{11}
Threshold of Pain	$1 \cdot 10^1 \text{ W/m}^2$	130 dB	10^{13}
Military Jet Takeoff	$1 \cdot 10^2 \text{ W/m}^2$	140 dB	10^{14}
Instant Perforation of Eardrum	$1 \cdot 10^4 \text{ W/m}^2$	160 dB	10^{16}

Recording level and decibels

Meters measuring recording or output level on audio electronic gear (mixing consoles etc) are almost always recording the AC root mean square voltage (see links to find out about AC and rms). For a given resistor R , the power P is V^2/R , so

$$\begin{aligned} \text{difference in voltage level} &= 20 \log (V_2/V_1) \text{ dB} \\ &= 10 \log (V_{22}/V_{12}) \text{ dB} \\ &= 10 \log (P_2/P_1) \text{ dB} \end{aligned}$$

or absolute voltage level = $20 \log (V/V_{\text{ref}})$

where V_{ref} is a reference voltage.

How to convert dBV or dBm into dB of sound level?

There is no simple way. It depends on how you convert the electrical power into sound power. Even if your electrical signal is connected directly to a loudspeaker, the conversion will depend on the efficiency and impedance of your loudspeaker. And of course there may be a power amplifier, and various acoustic complications between where you measure the dBV on the mixing desk and where your ears are in the sound field.

: Sound pressure and level, together with examples

Sound pressure (micro Pascals)	Sound level (dB)	Example
200,000,000	140	threshold of pain
	130	riveting on steel plate
20,000,000	120	pneumatic drill
	110	loud car horn at 1m

2,000,000	100	alarm clock at 1m
	90	inside underground train
200,000	80	inside bus
	70	street-corner traffic
20,000	60	conversational speech
	50	business office
2000	40	living room
	30	bedroom at night
200	20	broadcasting studio
	10	normal breathing
20	0	threshold of hearing (@ 1kHz)

The human ear can hear very low frequencies from about 35 Hz to very high frequency sound up to 20,000 Hz. Our ear is very sensitive and can hear a tremendous range of sound amplitudes so the decibel scale is logarithmic. Near total silence is noted as 0 dB, a sound 10 times louder than this is 10 dB, a sound 100 times more powerful (louder) is 20 dB, and so on. Decibels represent the ratio of different audio levels and measure the relative intensity of sound.

Sound, in the ranges of 0 dB (the threshold of hearing) to 120 dB (the threshold of pain), are detected by the human ear, but those sounds which are near and exceeding the high end, can be painful and can damage your hearing. Any sound above 85 dB can cause hearing loss, but it depends on how close the listener is to the sound and how long he or she is exposed to it. The sound at many rock concerts has been measured around the 120 dB range, which explains why your ears often ring for day or two after the show. Table 1.1 gives an idea of the range of loudness measurements encountered in everyday life.

Range of loudness measurements encountered in everyday life

Power (Watts)	Power Level (db) Re:10 ⁻¹² watt	Source
20-40 million	195	Saturn rocket
100,000	170	Jet afterburner
10,000	160	Jet engine
1000	150	
100	140	Propeller airplane

10	130	Orchestra, rock band
1	120	Small plane
0.1	110	Blaring radio
0.01	100	Auto on highway
0.001	90	Voice shouting
0.0001	80	
0.000 01	70	Average conversation
0.000 001	60	
0.000 000 1	50	
0.000 000 01	40	Average house
0.000 000 001	30	Very soft whisper

MEASUREMENT OF FREQUENCY

Formerly, frequency was measured by cycles per second (cps), now, in SI units, the result is measured in **Hertz (Hz)**, named after the German physicist, Heinrich Rudolf Hertz. He was one of the pioneers of the science of sound/acoustics and demonstrated first the existence of radio waves. 1 Hz means one cycle (or wave) per second.

A sound wave that vibrates at twenty thousand cycles per second is said to have a frequency of 20,000 hertz, the term **kilohertz (kHz)** is often used. It denotes 1,000 cycles per second, so 20,000 hertz could also be called 20 kilohertz. For, example, the fundamental frequency of an average male voice is around 300 Hz. Human speech can range as higher as 9,000 Hz.

Bandwidth: Bandwidth is the range of frequencies; for example bandwidth of audible frequencies is 20-20 kHz

MEASUREMENT OF LEVEL OF SOUND

VU Meter / Meter Gauge (Potentiometer)

VU meter or volume unit indicator (Fig.-) is a metering device that enables the operator to determine what level of sounds going out of the line, relatively. One common type VU meter has moving needle on a graduated scale. Usually the upper position of the scale is calibrated in disables (dB), and the lower portion of the scale is calibrated in percentage.

In audio engineering, a reading of 0 db is 00 percent volumes, or the loudest you want the signal to go. The VU meter is important for consistent audio production

work. As discussed earlier, the level of sound or how loud something sounds is very subjective. What is loud to one announcer/ presenter/anchor may not be deemed loud by another. It also depends on how differently their monitor speaker volume has been set in. The VU meter gives an electronically precise reading of volume and it is not subjective.

The accuracy of VU meter sometimes debated /questioned. Occasionally VU meter have drawback indicating about the abrupt increases in volume of the sound signal. Most VU meters are designed to specify an average volume level and overlook the occasional sound boosts. VU meter also tend to exaggerate to the bass (low frequency) portion of the sound. When a sound signal is intense in the bass frequencies, it will perhaps show a higher VU reading than it would if the total sound signal were being correctly read. In spite of these shortcomings, the VU meter remains the best display of volume levels in sound design and audio / radio production. Usually a sound recordist or assistant/ operator should control the signal –when it ranges between 80 percent and 100 percent, approximately. When the needle goes/cross above 100 percent, the signal is designated as in the level of red, because that portion of the VU meter scale is usually indicated with a red line. This is a caution to the sound operator to lower the gain of the console /fader or pot.

Sound signal above 100 percent cause over modulated of sound transmitter or saturation of amplifiers and can cause a distorted sound. Unlike analog equipment, professionals, of digital production equipment, will instantly find that the digital equipment is very risky to record “in the red” level.

Digital equipment are not endured to record at any level above 100 percent and will create distortion in the recorded signal, that exceeds it. Professional and good production practices would be to record the sound in the range around -10 dB, when using digital equipment.

DYNAMIC RANGE

Dynamic range is a measure of the ratio of the largest signal in a circuit that is capable of handling to the highest amplitude frequency component present in the system. It describes the range of the input signal levels that can be reliably measured simultaneously, in particular the ability to accurately measure small signals in the presence of the large signals. According to this definition the dynamic range may be a useful parameter of any system and is the very important parameter of the measurement system. The dynamic range is mostly given in dB. For example, an 8-bit converter can achieve 60 dB or more dynamic range.

Here is a table of dynamic ranges for some frequently used audio equipment:

Audio cassette (standard tape)	35 dB
Standard VHS VCR audio tracks	45 dB
Professional Beta video deck (BVW-35)	50 dB
Sony TCD-D5 cassette, Chrome tape	58 dB
w/ Dolby C on	68 dB
BVW-35 w/metal tape, regular tracks	72 dB
Nagra tape recorders	73 dB
BVW-35 AFM tracks	85 dB
Sony TCD-D10 portable DAT recorder	85 dB
Best quality CD players	92 dB
Hafler P-500 power amp (225 watts)	95 dB
Human ear	120 dB

Sound professionals often use dynamic range to describe the ratio of the amplitude of the loudest possible undistorted sine wave to the root mean square (rms) noise amplitude, say of a microphone or loudspeaker.

The dynamic range of human hearing is roughly 140 dB. The dynamic range of music as normally perceived in a concert hall, doesn't exceed 80 dB, and human speech is normally perceived over a range of about 40 dB.

The dynamic range differs from the ratio of the maximum to minimum amplitude, a given device can record, as a properly dithered recording device can record signals well below the rms noise amplitude (noise floor).

For example, if the ceiling of a device is 5V (rms) and the noise floor is 10 μ V (rms) then the dynamic range is 500000:1, or 114 dB:

$$20 \times \log_{10} \left(\frac{5\text{V}}{10\mu\text{V}} \right) = 20 \times \log_{10}(500000) = 20 \times 5.7 = 114 \text{ dB}$$

SOUND PRESSURE LEVEL

In the field of acoustic /sound measurements, the sound pressure level SPL is measured in decibels. SPL is the logarithmic ratio of sound pressure (p) referred to a sound pressure $p_0 = 20 \mu\text{Pa}$ (micro Pascal's). Sound pressure p_0 is the lower limit of the pressure, which the human ear can perceive in its most sensitive frequency range (around 3 kHz). This pressure level is known as the threshold of hearing.

When stimulus strength is expressed in terms of sound pressure, the following relationship is used, where P_1 and P_2 are two sound pressures. For studies of hearing, P_2 is taken as the sound pressure at the threshold hearing of a normal listener.

$$\text{dB} = 20 \log_{10} (P_1/P_2)$$

If, for example, the sound pressure from one source (P_1) is ten times greater than that from a second source (P_2), the difference is 20 dB.

$$\text{dB} = 20 \log_{10} (10/1) = 20 \times 1 = 20$$

The sound pressure of a very loud sound, such as a jet plane, may be one million times (10^6) the pressure of the weakest sound that can be detected by someone with normal hearing; these two sounds differ by 120 dB:

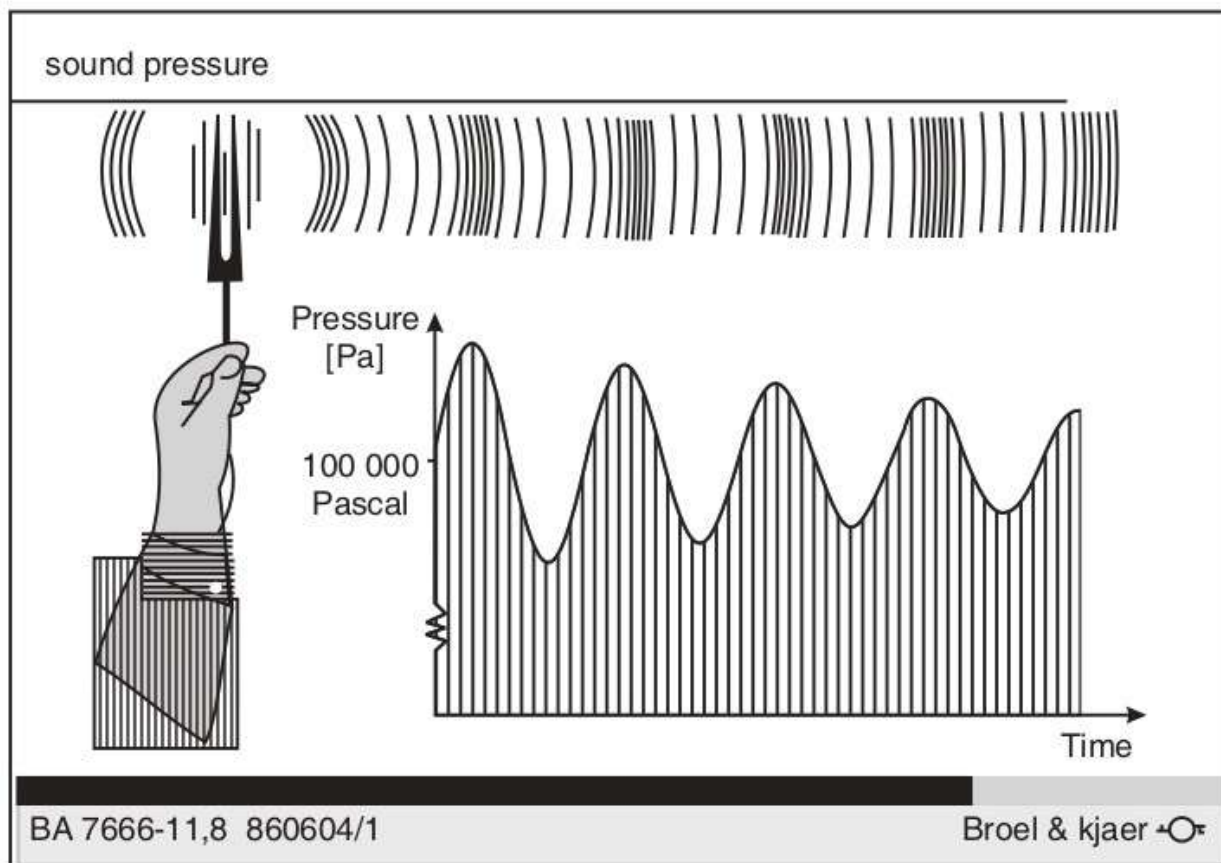
$$20 \log_{10} (P_1/P_2) = 20 \log_{10} 10^6 = 20 \times 6 = 120 \text{ dB}$$

Human ear's audible sound pressure levels range from $20 \mu\text{Pa}$ (hearing threshold) till 20 Pa (pain threshold), resulting in the scale 1:10,000,000.

Since, using such a large scale is not practical, a logarithmic scale in decibels (dB) was introduced which is also in agreement with physiological and psychological hearing sensations.

Decibel (dB) of sound pressure level (dB SPL) is defined as: $20 \log_{10} p_1/p_0$ where p_1 is actually measured sound pressure level of a given sound, and p_0 is a reference value of $20 \mu\text{Pa}$, which corresponds to the lowest hearing threshold of the young, healthy ear. In the logarithmic scale the range of human ear's audible sounds is from 0 dB SPL (hearing threshold) to 120-140 dB SPL (pain threshold) (table).

Source/observing situation	Typical sound pressure level (db SPL)
Hearing threshold	0 dB
Leaves fluttering	20 dB
Whisper in an ear	30 dB
Normal speech conversation for a participant	60 dB
Cars/vehicles for a close observer	60-100 dB
Airplane taking-off for a close observer	120 dB
Pain threshold	120-140 dB



When a sound source such as a tuning fork, vibrates it sets up pressure variations in the surrounding air. The emission of the pressure variations can be compared to the ripples in a pond caused by a stone thrown in the water. The ripples spread out from the point where the stone entered. However the water itself does not move away from the center. The water stays where it is, moving up and down to produce the circular ripples on the surface. In the case of Sound, the stone is the source, the pond is the air, and the ripples are the resulting sound wave.