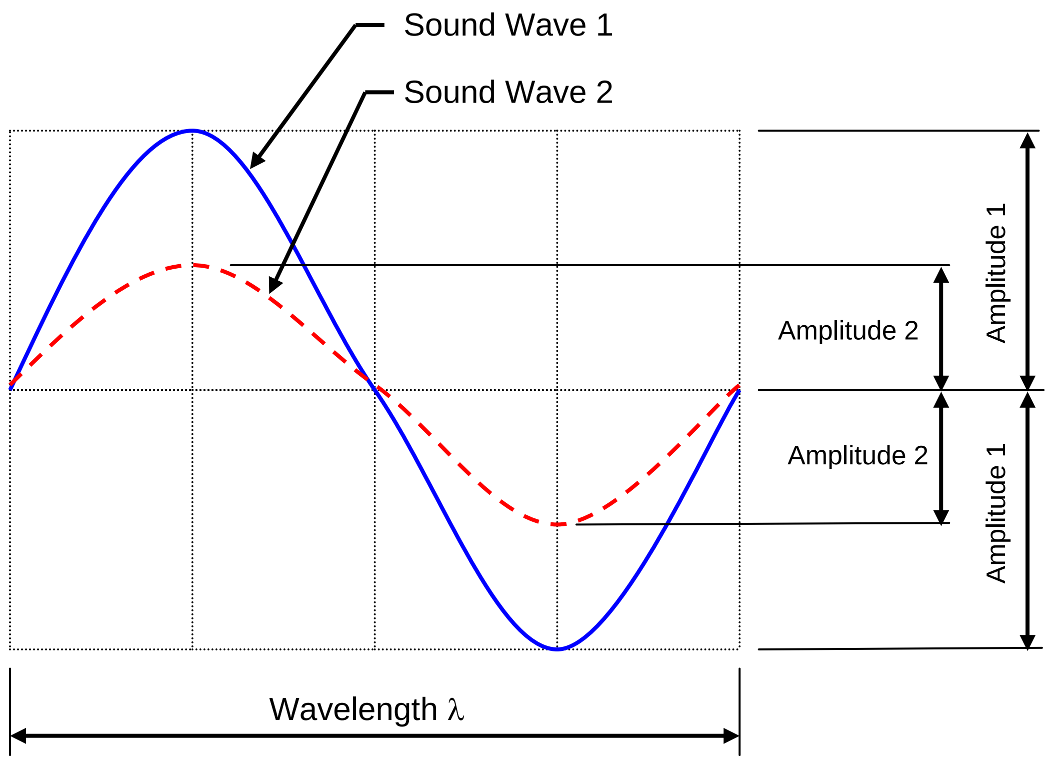
Lecture 2 – Sound Characteristics

Sound Intensity:

The height of the sound wave, or amplitude, is a measure of the intensity of the sound. Sound Wave 1 is louder than Sound Wave 2, but both have the same pitch.



Sound intensity, "I" is actually a pressure measured in watts/cm^2, and is fundamentally expressed as:

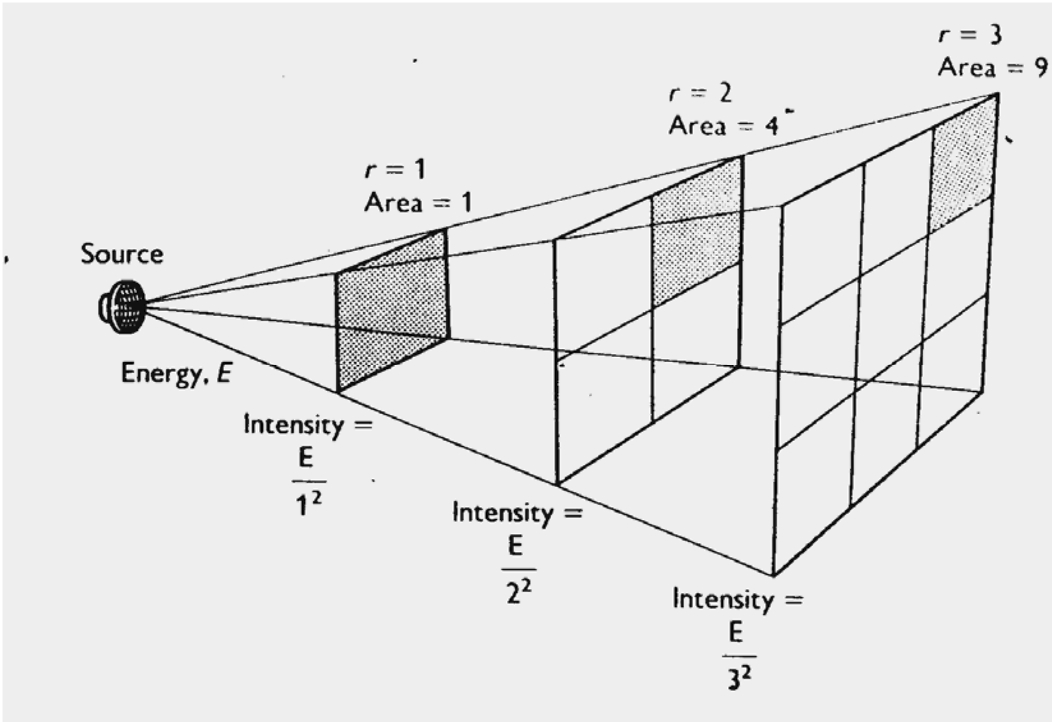
$$I = \frac{Power}{Area}$$, in units of watts/cm^2

Where: Power is in units of watts
Area is in units of cm^2

Since sound radiates in all directions, assuming outdoors, the intensity can be written as follows:

$$I = \frac{Power}{4\pi r^2}$$

Where: r = radius away from sound point source – see picture below



It can be shown that the intensity of the sound varies inversely proportional to the square of the distance away from the sound source, commonly referred to as the "inverse square law" therefore:

$$\frac{I_1}{I_2} = \frac{{r_2}^2}{{r_1}^2}$$

Intensity (W/cm^2)		Intensity Level, (dB)	
Decimal Notation	**Exponential Notation**	**Logarithmic Notation, (dB)**	**Examples**
0.001	10^{-3}	130	Painful
0.0001	10^{-4}	120	
0.00001	10^{-5}	110	75-piece orchestra
0.000001	10^{-6}	100	
0.0000001	10^{-7}	90	Shouting at 5 ft.
0.000000001	10^{-9}	70	Speech at 3 ft.
0.00000000001	10^{-11}	50	Average office
0.0000000000001	10^{-13}	30	Quiet, unoccupied office
0.00000000000001	10^{-14}	20	Rural ambient
0.000000000000001	10^{-15}	10	Rustle of leaves
0.0000000000000001	10^{-16}	0	Threshold of hearing

Table 1 – Comparison of sound intensities

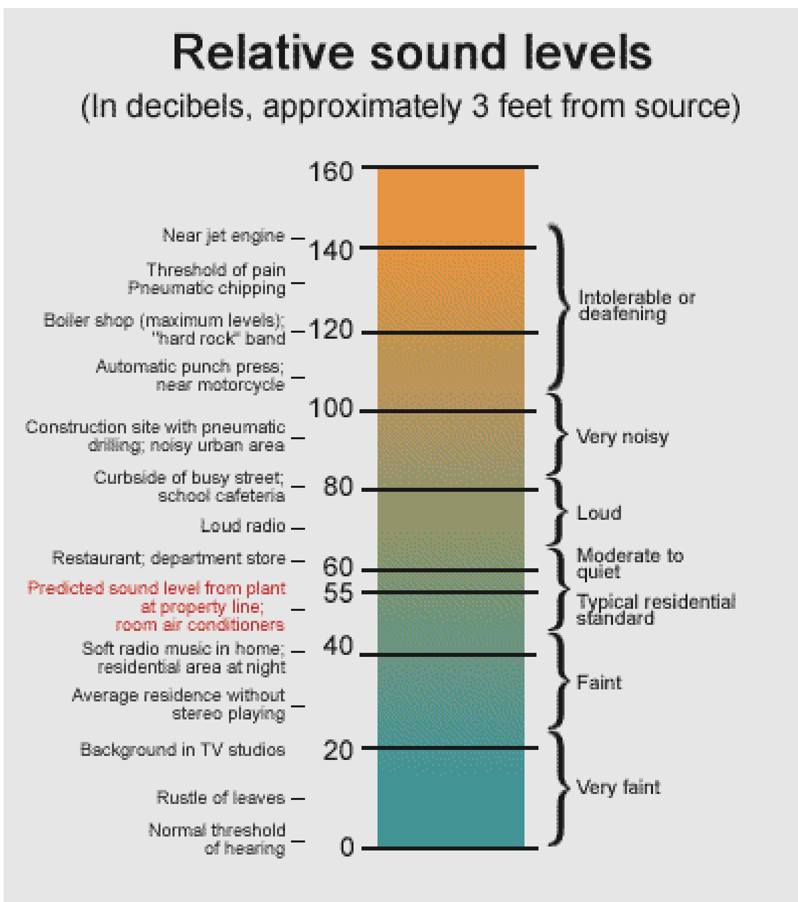
Since the sound pressure intensities involve big numbers, it is more convenient to express sound intensity levels in terms of **decibels, "dB".** The decibel scale is a logarithmic scale based on a reference intensity level, I_0, of $10^{-16}\frac{Watts}{cm^2}$ which is the threshold of hearing for normal healthy human ears.

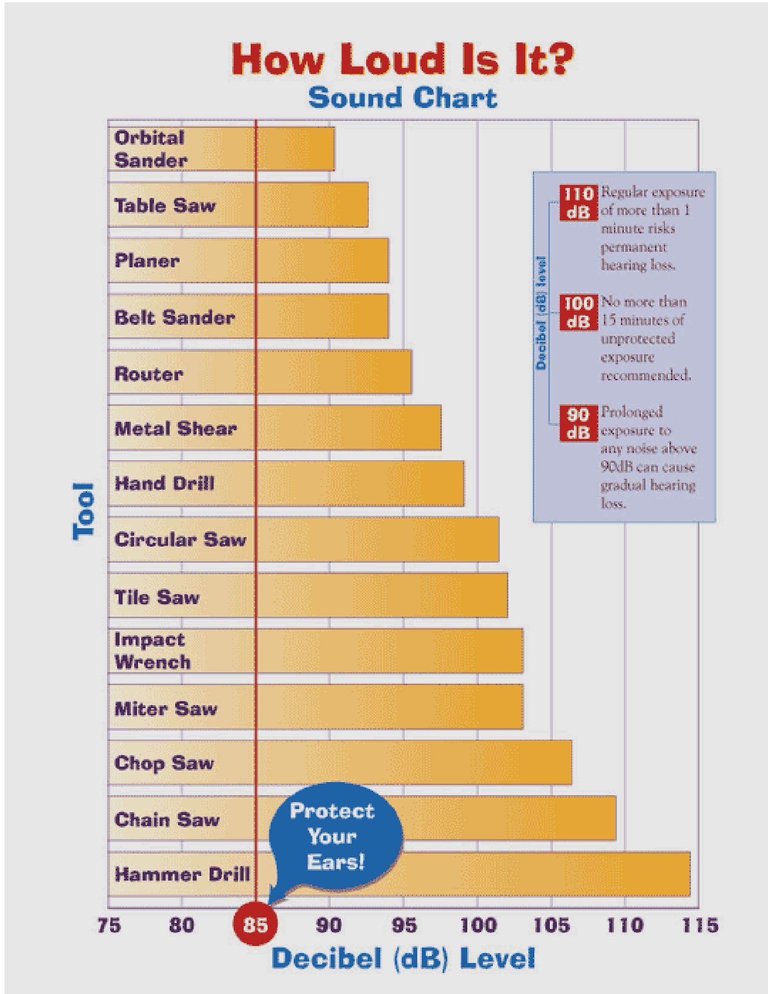
The intensity level, IL, in decibels is calculated in the formula below:

$$IL = 10\log\frac{I}{I_0}$$

where: IL = sound pressure in decibels (dB)
I = intensity, W/cm^2
I_0 = reference intensity = $10^{-16}\frac{Watts}{cm^2}$

Below are charts of typical sound magnitudes:





<u>Exposure to Loud Noise</u>:

Permanent hearing loss can result if loud noised are experienced for too long. The Occupational Safety and Health Administration (OSHA) paragraph 1910.95 has established criteria dictating exposure limits for various environments, as shown below:

Maximum Exposure Duration:	Sound Level, dB:
8 hours	90
6 hours	92
4 hours	95
3 hours	97
2 hours	100
1½ hours	102
1 hour	105
½ hour	110
15 minutes	115

Combining Decibels:

Since the decibel scale is logarithmic, multiple decibels cannot be simply added together. For example, if two 60 dB sounds were combined together, the new level would be 63 dB (i.e., NOT 120 dB!!). The change in intensity level, "ΔIL" can be calculated as follows:

$$\Delta IL = 10 \log \frac{I_2}{I_1} \quad \text{in units of dB}$$

Where: I_1 = louder intensity (W/cm^2)
I_2 = softer intensity (W/cm^2)

The total intensity, "I_{tot}" would be the sum of $I_1 + I_2$

Example 1

GIVEN: Two simultaneous sound sources, I_1 = 100 dB and I_2 = 90 dB are to be combined.
REQUIRED: Determine the total sound intensity, "IL_{tot}".

Step 1 – Determine total intensities, "I_{tot}":

From Table 1 above the intensities can be found.
where: $I_1 = 10^{-6}$ w/cm^2 and $I_2 = 10^{-7}$ w/cm^2

$$\begin{aligned} I_{tot} &= I_1 + I_2 \\ &= 10^{-6} + 10^{-7} \\ &= (10 \times 10^{-7}) + 10^{-7} \\ &= 11 \times 10^{-7} \end{aligned}$$

Step 2 – Determine total intensity level, "IL_{tot}":

$$IL = 10 \log \frac{I}{I_0}$$

$$IL_{tot} = 10 \log \frac{I_{tot}}{I_0}$$

$$= 10 \log \frac{11x10^{-7}}{10^{-16}}$$

$$\begin{aligned} &= 10(\log 11 + \log 10^9) \\ &= 10(1.041 + 9) \\ &= 10(10.041) \end{aligned}$$

IL_{tot} = 100.41 dB

The table below can be used to determine ***approximate*** new decibel level from adding 2 separate sources:

Difference between two decibel values	Amount added to higher value
0 or 1	3
2 or 3	2
4 to 9	1
10 or more	0

Example 2

GIVEN: Sound 1 = 58 dB and Sound 2 = 52 dB.
REQUIRED: What is the combined sound level?

Since the difference between the two sound sources is 6 dB, add 1 dB to the higher sound source as shown in the table above.

New sound level = 58 dB + 1 dB
= **59 dB**

Differences Between Two Sound Sources:	Observed Change in Level:
20 dB	Much louder 4X (or ¼)
10 dB	2X (or ½) as loud
5 dB	Clearly noticeable in most spaces
3 dB	Barely perceptible in typ. rooms
1 dB	Perceptible only in Lab environment

Distance Attenuation:

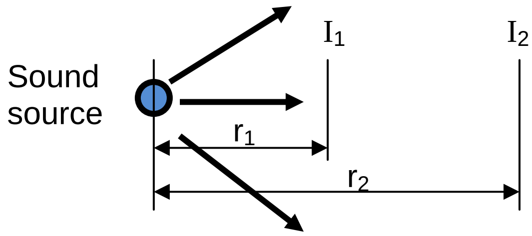
Sound intensity is reduced by the "Inverse square law" as distance from the sound source increases, as noted above:

$$\frac{I_1}{I_2} = \frac{r_2^{\,2}}{r_1^{\,2}}$$

Example 3

GIVEN: A sound intensity is to be measured at a distance r_1 and r_2 away from its source. Assume $r_2 = 2r_1$.

REQUIRED: Determine the intensity change (in dB) between distance r_1 and r_2.



Recall that $\Delta IL = 10\log\frac{I_2}{I_1}$

And using $\frac{I_1}{I_2} = \frac{r_2^{\,2}}{r_1^{\,2}}$ inverting into $\frac{I_2}{I_1} = \frac{r_1^{\,2}}{r_2^{\,2}}$

Substituting $r_2 = 2r_1$:

$$\frac{I_2}{I_1} = \frac{r_1^{\,2}}{(2r_1)^2}$$

$$\frac{I_2}{I_1} = \frac{1}{4}$$

Substituting back into $\Delta IL = 10\log\frac{I_2}{I_1}$

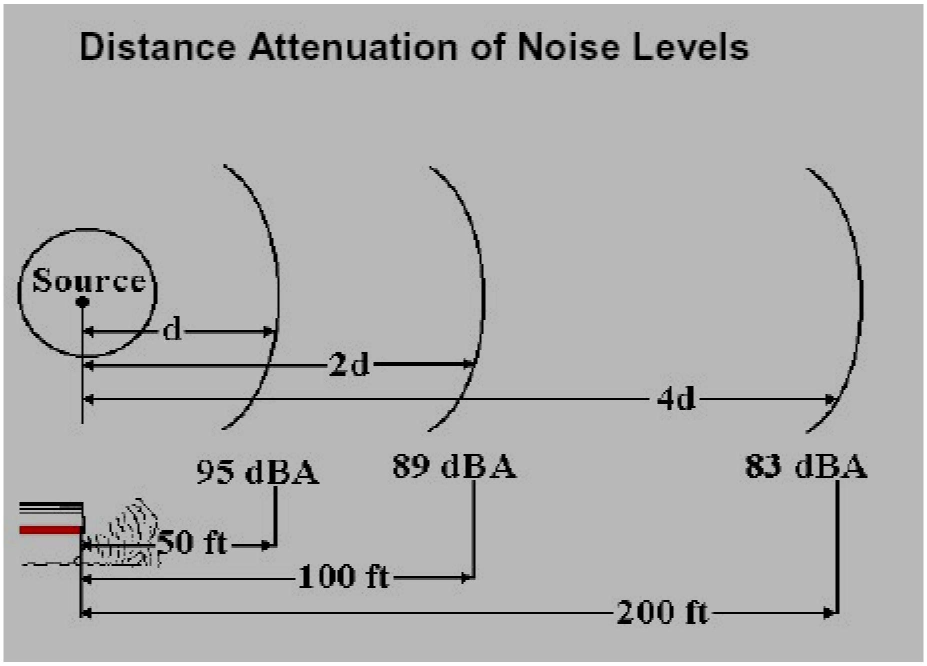
$$\Delta IL = 10\log\left(\frac{1}{4}\right)$$

$$\Delta IL = 10(-0.60205)$$

ΔIL = -6 dB

When the distance is <u>doubled</u> from a ***Point*** source the sound level decreases 6 decibels.

Example 4: If a sound level is: 95 decibels at 50 feet it will be
89 decibels at 100 feet, and
83 decibels at 200 feet.



Sound Pressure Level (SPL):

Another useful measurement of sound intensity is the Sound Pressure Level (SPL), also measured in decibels. It is based upon pressures, using a reference pressure, "p_0" = 2×10^{-5} Pa (or 20 μPa) as the threshold of hearing. SPL is typically used to define unwanted sounds, i.e., "noise."

$$SPL = 20 \log \frac{p}{p_0}$$

where: SPL = sound pressure level, dB

p = pressure, Pa or μbar

p_0 = reference base pressure, 20 μPa or 2×10^{-4} μbar