Noise

A Primer for the Telecommunication EH&S Professional

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Definition of Noise

- Noise is an undesired sound
  - It is a sound that is perceived as disturbing, annoying, or harmful
- The level of annoyance depends not only on the quality of the sound, but also our attitude towards it.
  - Such as children playing loudly, Rock music
- A noise does not have to be loud to be annoying
  - Creaking floor, dripping water, a record scratch
- Sound can also damage and destroy.
  - A sonic boom can shatter windows
- But the most unfortunate case is when sound damages the delicate mechanism designed to receive it - the human ear.

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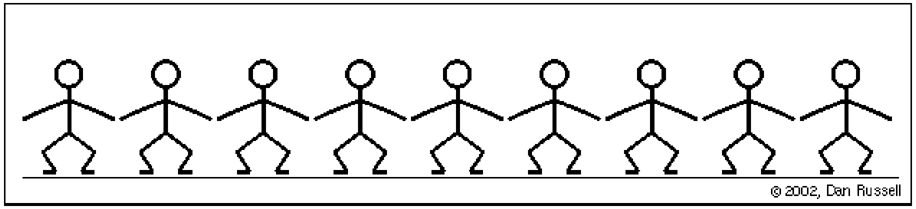
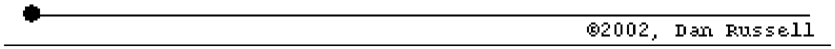
Waves

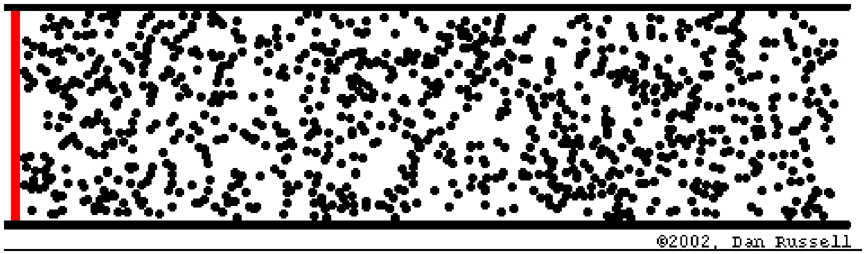
- Sound is a wave phenomena
- A wave is a disturbance or variation which travels through a medium. The medium through which the wave travels may oscillate as the wave passes, but the particles in the medium do **not** travel with the wave



A wave of people



A wave in a string



A wave through particles

- A sound wave is a disturbance that passes through a medium

Sound Waves

- Sound waves in air behave the same way. As the wave passes, the particles in the air oscillate back and forth about their equilibrium positions…but it is the disturbance which travels, not the individual particles.

- If a sound wave will displace particles of air longitudinally as the energy of the sound wave passes through it.

- A vibrating tuning fork is capable of creating such a longitudinal wave. As the tines of the fork vibrate back and forth, they push on neighboring air particles. The forward motion of a tine pushes air molecules horizontally to the right and the backward retraction of the tine creates a low-pressure area allowing the air particles to move back to the left.

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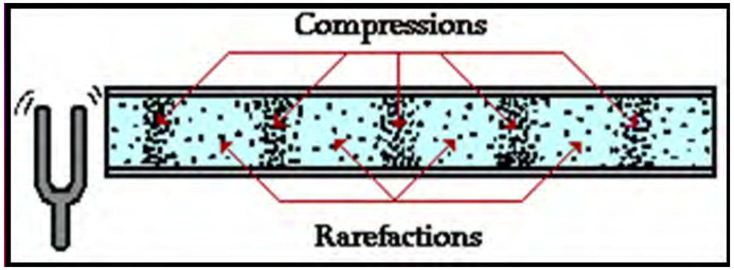
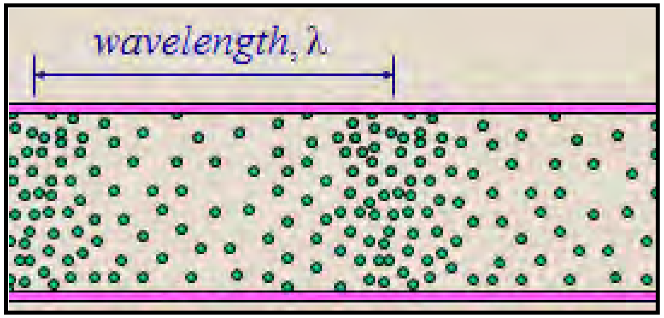
Wavelength

- Sound waves are waves of alternating pressure deviations from the equilibrium pressure, causing local regions of compression and rarefaction.



- Wavelength is the distance of the wave…the distance between areas where the particles are in compression and areas where the particles are in rarefaction



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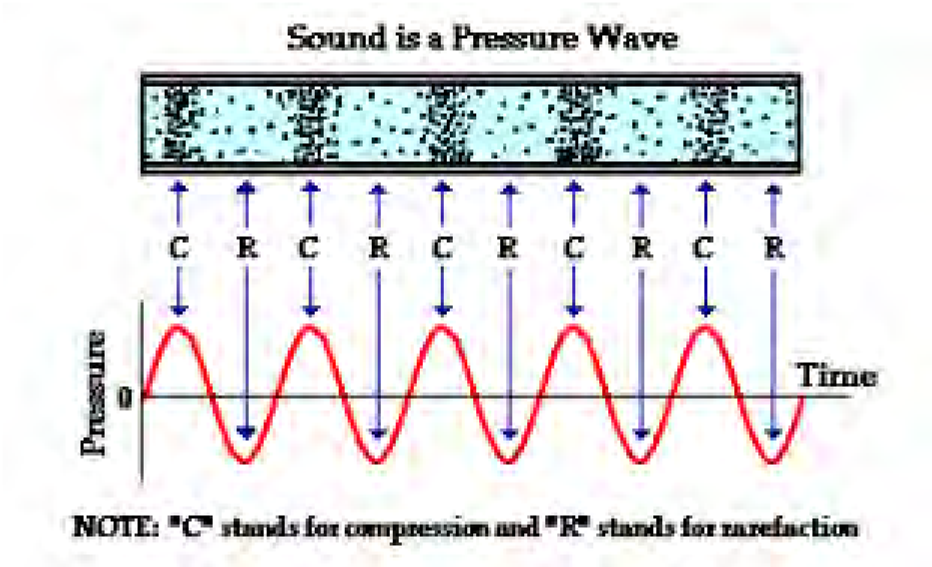
Frequency

- The frequency of a wave refers to how often the particles of the medium vibrate when a wave passes through the medium.
  - It is the number of complete back-and-forth vibrations of a particle per unit of time.
  - If a particle of air undergoes 1000 longitudinal vibrations in 2 seconds, then the frequency of the wave would be 500 vibrations per second.
  - The unit for frequency is the Hertz (abbreviated Hz), where 1 Hertz = 1 vibration/second



- The sensation of a frequency is commonly referred to as the **pitch**.
  - high pitch = high frequency
  - low pitch = low frequency
- Amazingly, many people are capable of detecting a difference in frequency between two separate sounds that is as little as 2 Hz.
- The maximum range of frequencies for most people is from about 20 to 20 thousand hertz.

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Frequency, Speed, and Wavelength

- Wavelength and Frequency are related by the equation

$$v = f \cdot \lambda$$

Speed (velocity or v) = Frequency (f) x Wavelength (ʎ)

Where v = the speed of sound

- Wave speed is **not** dependent upon wavelength or frequency
- The speed of a sound wave depends on the properties of the medium through which it moves and the only way to change the speed is to change the properties of the medium.
- A change in wavelength affects the frequency in an inverse manner. A doubling of the wavelength results in a halving of the frequency; yet the wave speed is not changed.

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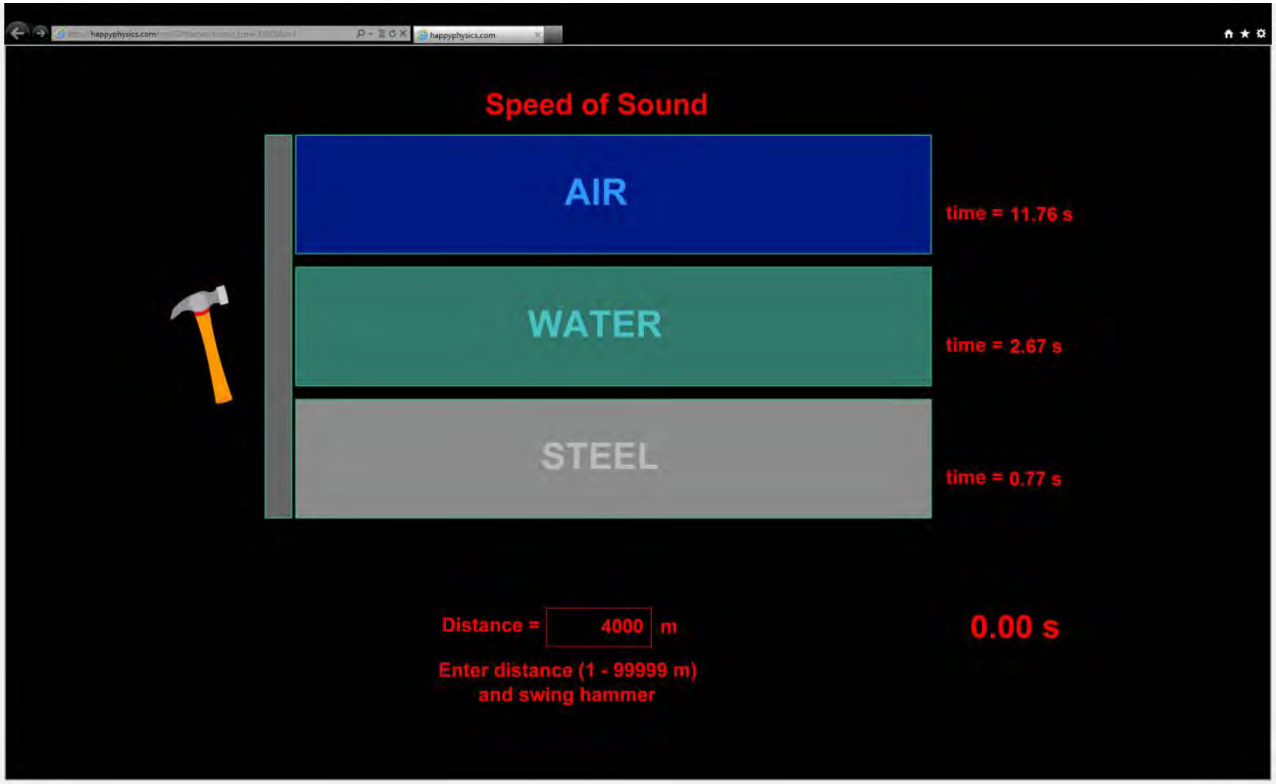
Speed of Sound in Different Mediums

The **speed of sound** in dry air at 20 °C (68 °F):

343.2 meters per second
1,236 kilometers per hour
~ 1 kilometers in three seconds

1,126 feet per second
768 miles per hour
~ one mile in five seconds



The speed of sound varies greatly in different mediums

In general the speed of sound is solids>liquids>gases

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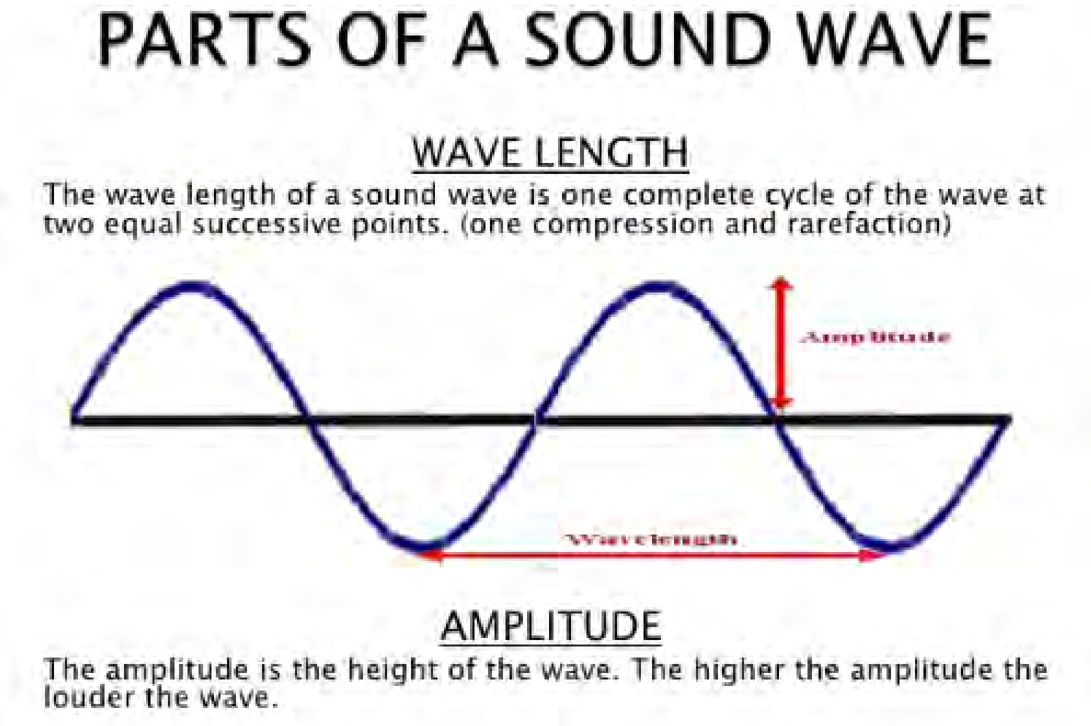
Amplitude of a Wave

Amplitude is the height of the wave.
The higher the amplitude the louder the sound.



The amplitude is related to the intensity.

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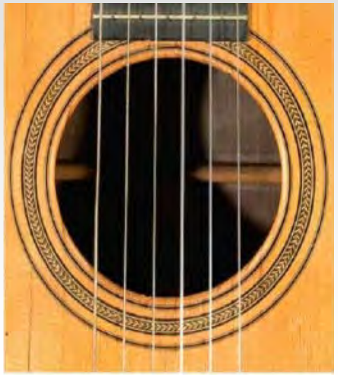
Amplitude, Intensity and Power



- A vibrating guitar string forces surrounding air molecules to be compressed and expanded, which then travels from particle to particle, transporting energy as it moves.
- The amount of energy that is transferred is dependent upon the amplitude of vibrations of the guitar string. If more energy is put into the plucking of the string (that is, more work is done), then the string vibrates with a greater amplitude.
- The greater the amplitude of vibrations of the particles of the medium, the greater the rate at which energy is transported through it, and the more intense that the sound wave is.
- The amount of energy that is transported past a given area per unit of time is known as the **intensity** of the sound wave.
- Intensity is the energy/time/area; and since the energy/time ratio is equivalent to the quantity power, intensity is simply the power/area, normally given as are Watts/meter^2.

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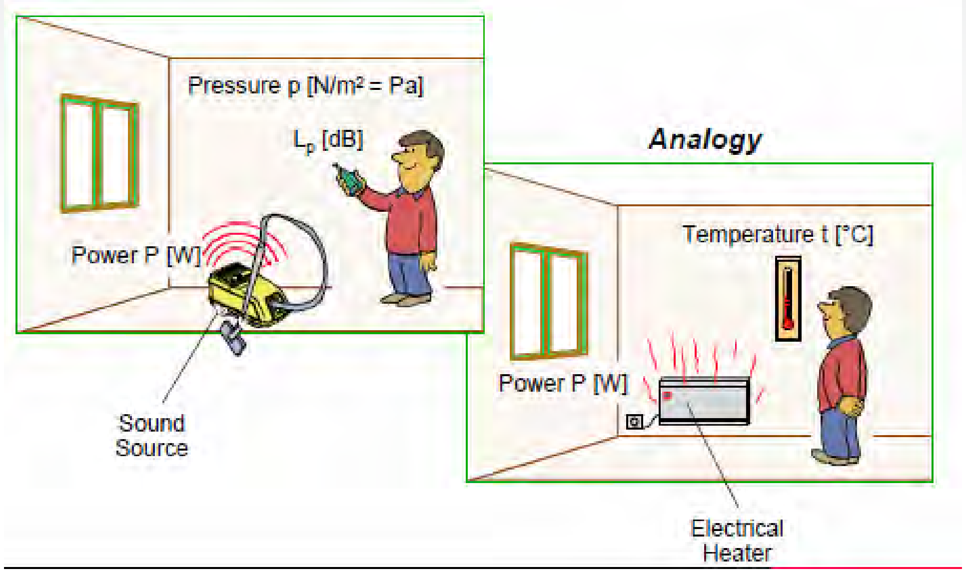
Sound Power and Pressure



- The relationship between sound power and sound pressure is analogous to the heat given off from a heater
- The heater has a certain power (watts), and delivers a certain amount of heat (joules)….a noise source similarly has a certain amount of power and delivers a certain amount of sound pressure
- The temperature felt by a person in the room is similar to the sound level experienced, in that it depends not only upon the source, but also the distance from the source and effects of the room

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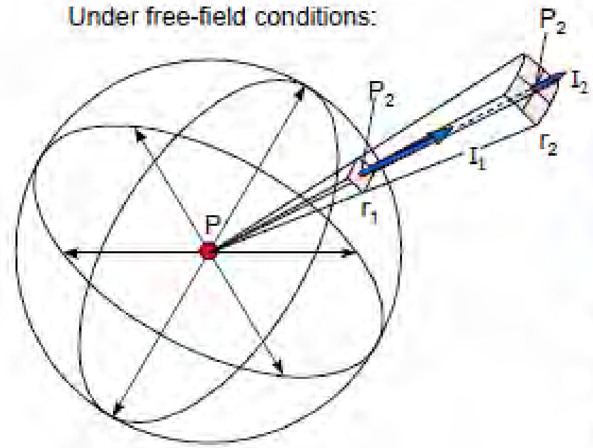

The Sound Intensity vector, $\vec{I}$, describes the amount and direction of flow of acoustic energy at a given position

$$I = \frac{P}{4\pi r^2} = \frac{p^2}{\rho c}$$

Power:	P [W]
Intensity:	I [J/s/m^2] = W/m^2
Pressure:	p [Pa = N/m^2]

- When sound is produced by a sound source with a sound power, P, a transfer of energy from the source to the adjacent air molecules takes place.
- The rate at which this energy flows in a particular direction through a particular area is called the sound intensity, I.
- The energy passing a particular point in the area around the source will give rise to a sound pressure, p, at that point.
  - r is the density of air, c is the speed of sound.

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Sound Pressure

- Compared with the static air pressure (100,000 Pascal, or Pa), the audible sound pressure variations are very small ranging from about 20 micropascal (10^{-6} Pa) to 100 Pascal.
  - 20 mPa (10^{-12} watts) is the quietest sound that can be heard by an average person and it is therefore called the threshold of hearing.
  - A sound pressure of 100 Pa is so loud that it causes pain, and it is called the threshold of pain.
- The ratio between these two extremes is more than a million to 1, so we use logarithms of the pressures to avoid enormous or unwieldy numbers.
- To express intensity (loudness) we use a ratio of the measured pressure value to a reference pressure value – the threshold of hearing 20 mPa
- This dimensionless logarithmic ratio is called a decibel (or just dB)
- Thus we use a ratio of the measured sound level compared to the threshold of hearing (20 mPa) to express how loud something is.

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Sound Power

- A dB is a dimensionless unit used to express the logirithim of the ration of a measured quantity to a reference quantity.

- In acoustics, the dB is used to describe the level of quantities that are proportional to sound power. Sound power is measured in Watts. The sound power level (L_W) is found by the following formula:

$L_W = 10 \log W/W_o$ where W = Watts in sound power

W_o = reference power of 10^{-12}

L_W = Sound power level.

For example: If we had 1 watt of sound power, the formula for the level would read: $10 \log 1/10^{-12} = 120$ dB.

Doubling the sound power only raises the sound power level by 3 dB.

$10 \log 2/10^{-12} = 123$dB

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Sound Pressure

- Measuring Sound Pressure is much easier, and relates better to the sound experienced by the human ear, which also measures pressure:
- The sound pressure level, Lp, in dB's is defined as 20 log p/p0 , where p is the measured value in Pascals, and p_0 is a standardized reference level of 20 mPa (the threshold of hearing).

$$L_p = 20 \log \frac{p}{p_0} \text{ dB re } 20\ \mu\text{Pa}$$

$$(p_0 = 20\ \mu\text{Pa} = 20 \times 10^{-6}\ \text{Pa})$$

Example:

20 log 20/20 = 20 log 1 = 0dB

Doubling the sound pressure raises the sound pressure level by a factor of 6

20 log 40/20 = 20 log 2 = 6dB

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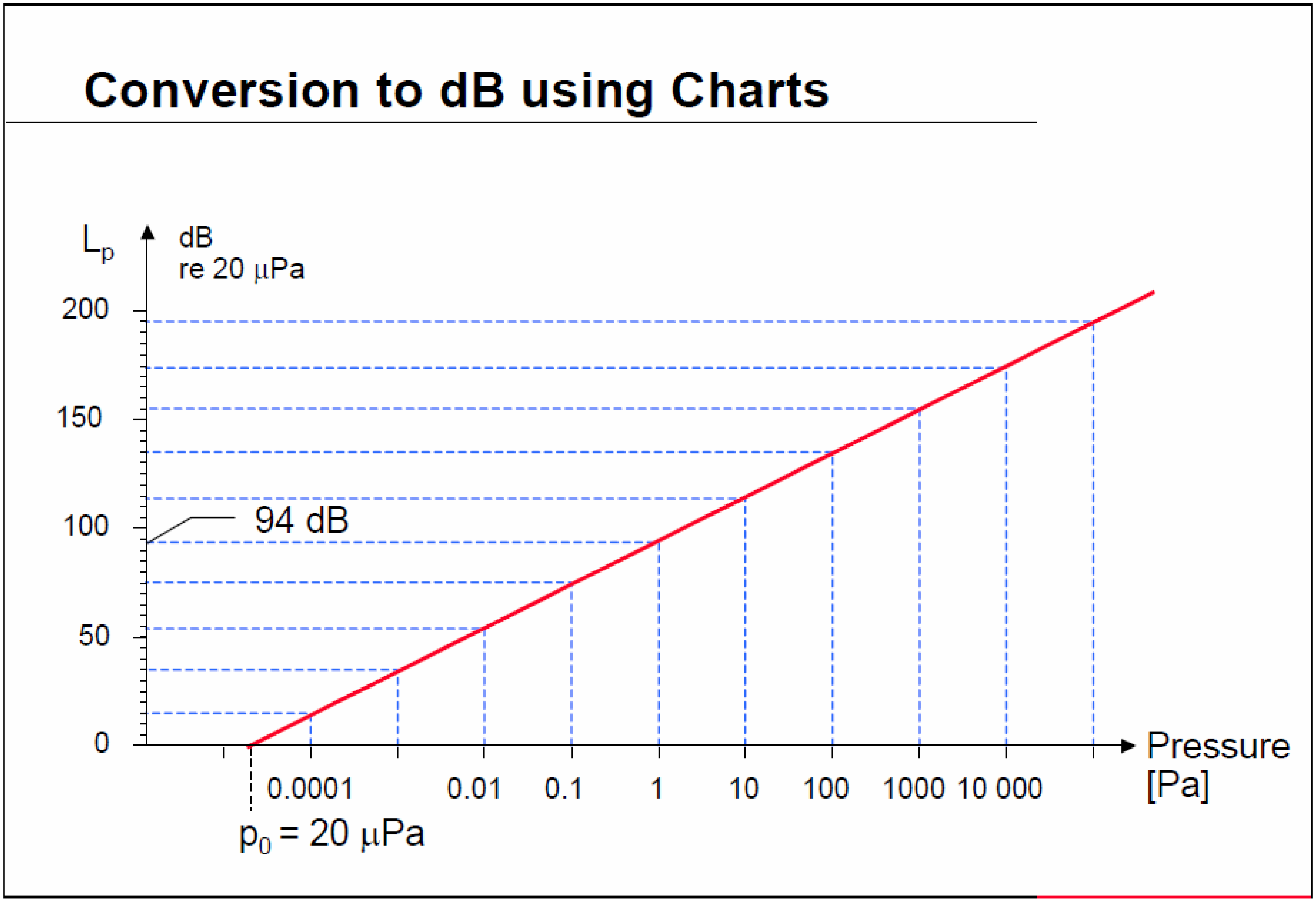
Pressure to Decibel Chart



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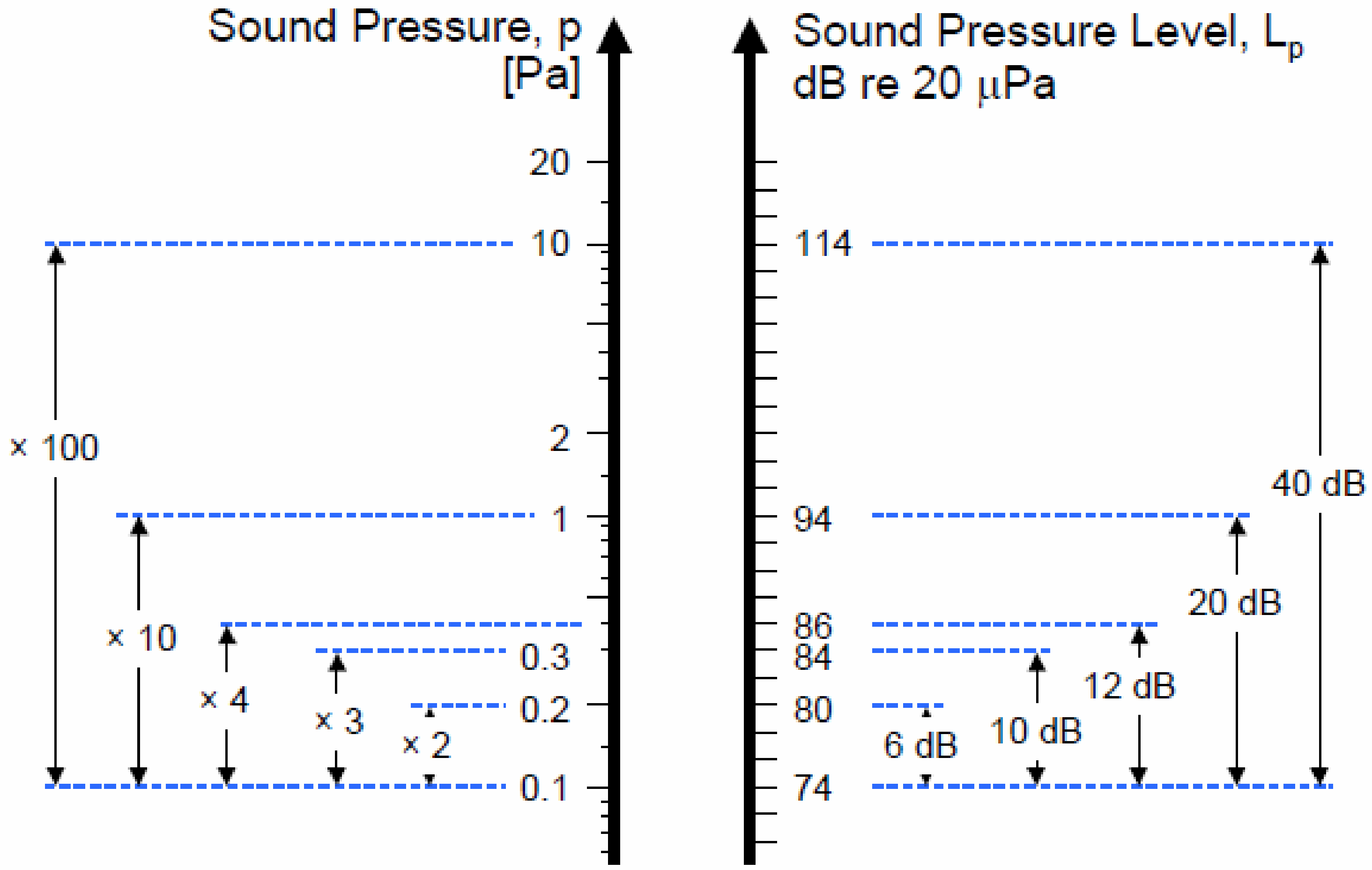
Simple Rules for Conversion



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Measuring Sound Pressure

- Measuring sound pressure is performed using sound level meters, which measure slight variations in sound pressure from the static atmospheric pressure.
- Many different types of meters, based upon their sensitivity and accuracy
  - Class 1 instruments have a wider frequency range and a tighter tolerance than a lower cost, Class 2 unit.
- Units also have advanced electronics to analyze frequency information
  - Integrating meters and Octave Band Analyzers give information on the sound levels of the various frequencies

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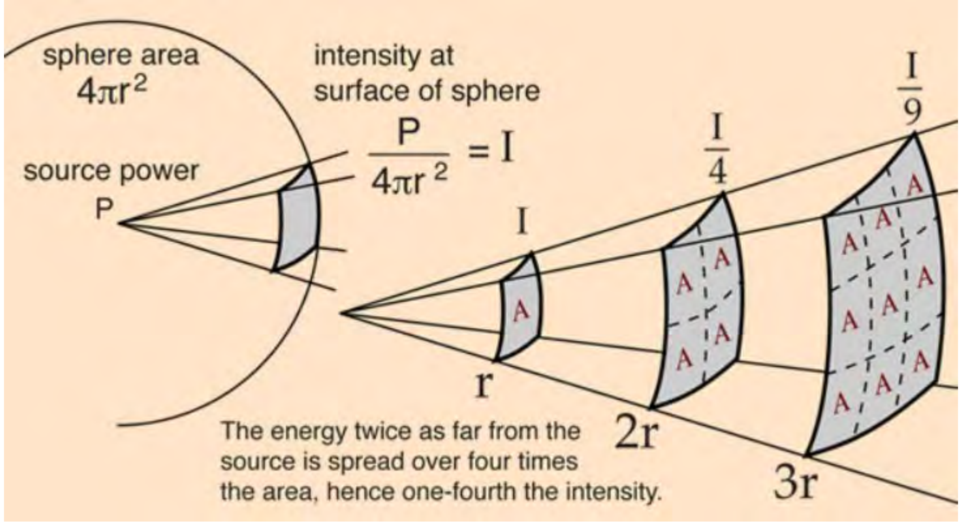
Inverse Square Law and Distance Law

- The source we looked at earlier is called a point source, and in a free field situation (explained further) **Sound intensity** (power) falls inversely proportional to the square of the distance $\mathbf{1/r^2}$ from the sound source.



•If we double the distance, the value for the sound intensity falls to a quarter (25%) of its initial value. Since a halving of the sound intensity lowers the sound intensity level by 3 dB, this means a – 6dB decrease with a doubling in distance.

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Inverse Square Law and Distance Law

- Note! Since the sound intensity level is difficult to measure, it is common to use sound pressure level measured in decibels instead.
- **Sound pressure** falls inversely proportional to the distance **1/*r*** from the sound source.**This is the 1/r law or distance law**.
- If we double the distance, the value for the sound pressure falls to a half (50%) of its initial value.
- Since having the sound pressure lowers the sound pressure level (SPL) by 6 dB, this correspond to a drop in sound pressure of 6 dB.
- Inversely, the sound pressure is increased by 6 dB when the distance to the source is halved.

  .

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How Humans Perceive Loudness

- There is no linear relationship between the loudness level in dB and the perception by man.

Change in Sound Level (dB)	Change in Perceived Loudness
3	Just perceptible
5	Noticeable difference
10	Twice (or 1/2) as loud
15	Large change
20	Four times (or 1/4) as loud

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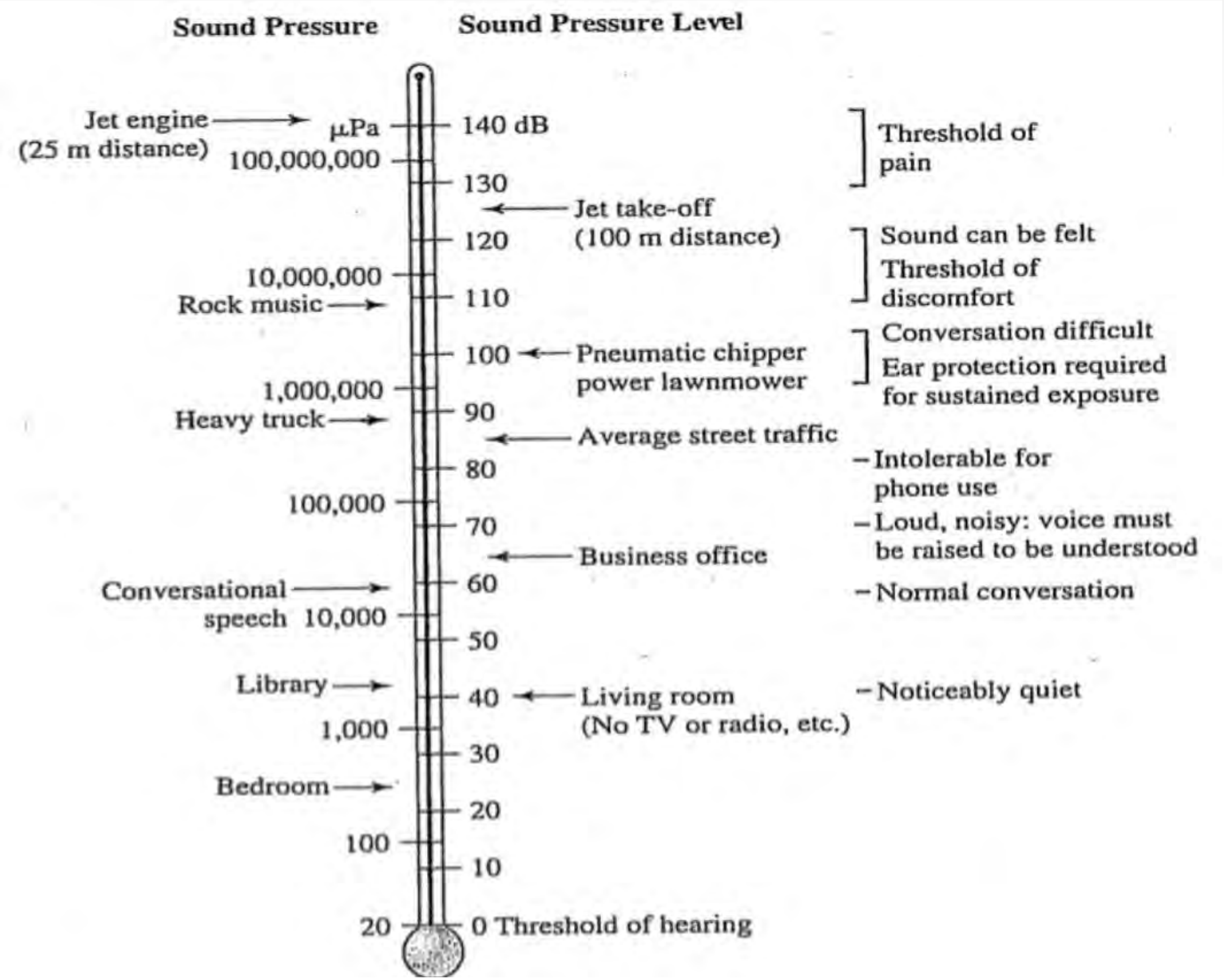
Examples of Sound Pressure Levels



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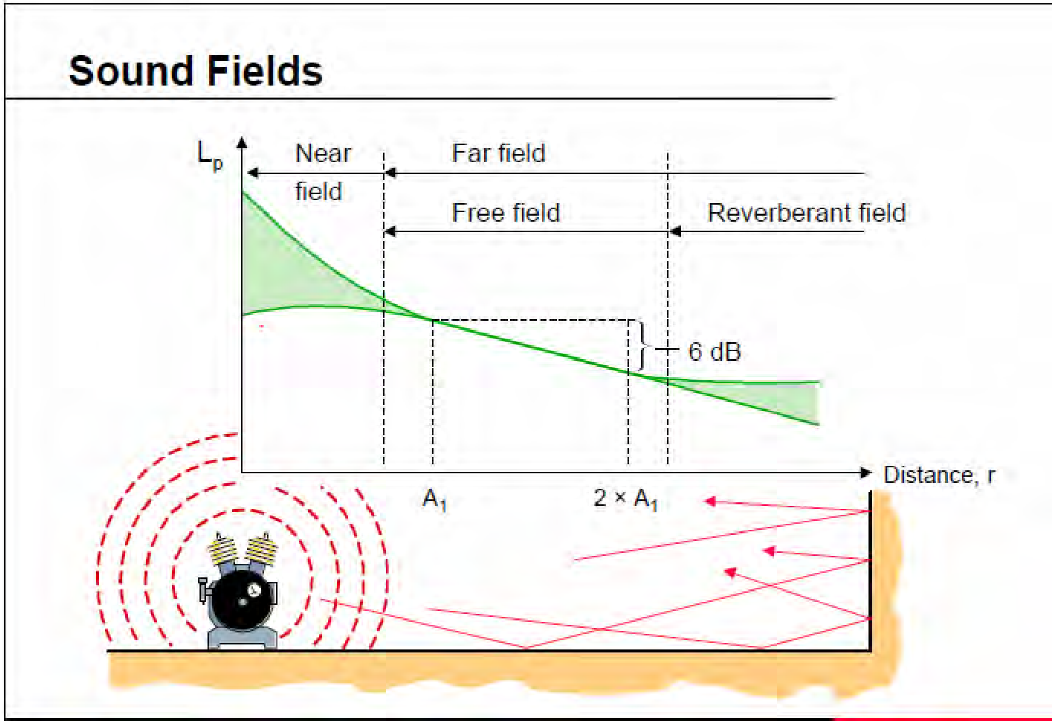
Measuring Sound Pressure

- In practice, the majority of sound measurements are made in rooms that are neither anechoic nor reverberant - but somewhere in between. This makes it difficult to find the correct measuring positions where the noise emission from a given source must be measured.
- It is normal practice to divide the area around a noise source e.g. a machine into three different fields:



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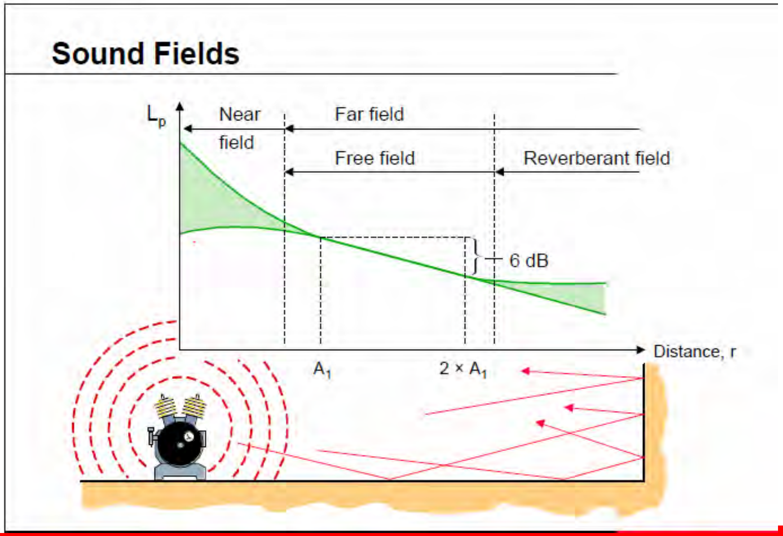
The Near and Free Fields

- The **near field** is the area very close to the machine where the sound pressure level may vary significantly with a small change in position.
  - The area extends to a distance less than the wavelength of the lowest frequency emitted from the machine, or at less than twice the greatest dimension of the machine, whichever distance is the greater. Sound pressure measurements in this region should be avoided.
- In the **free field** the sound behaves as if in open air without reflecting surfaces to interfere with its propagation. This means, that in this region the sound level drops 6 dB for a doubling in distance from the source.



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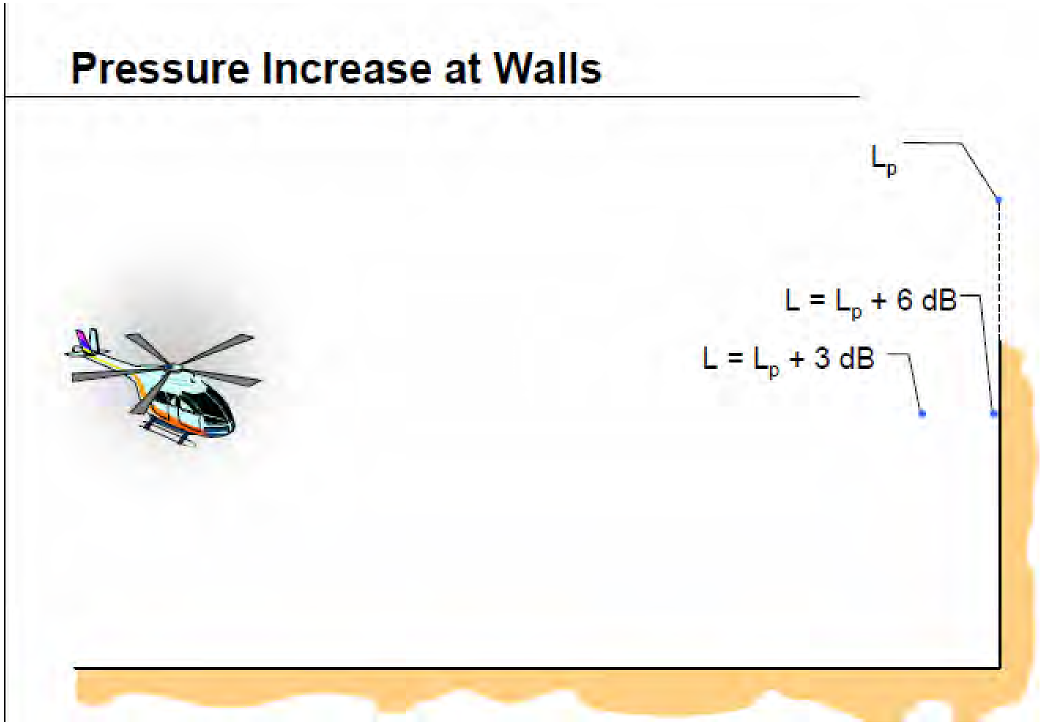
Sound Reflections at Walls

- In the **reverberant field**, reflections from walls and other objects may be just as strong as the direct sound from the machine
  - The sound pressure Lp close to a reflecting surface will be ‘mirrored’ and should be considered as two pressure levels with same magnitude and phase. Thus the sound pressure close to the surface L will be doubled: L = Lp + 6dB



Noise Monitoring

- Sound Level Meter (area noise level)
  - Used to identify work locations where hazardous noise levels exits.

- Noise Dosimeter (personal noise exposure level)
  - Monitors the variable noise at intervals and integrates values into actual exposure levels

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Weighting Scales of Monitors

There are three weighting scales used when measuring sound pressure levels.

- The A-scale is designed to approximate the sensitivity of the human ear to various frequencies.
  - Very low frequencies are discriminated (attenuated) quite severely.
- The A-scale is the scale of choice for compliance using a slow response level on the sound meter.
- The B-scale measures medium sound pressure levels and low frequencies are moderately attenuated. (hardly ever used)
- The C-scale measures high sound pressure levels. These are hardly attenuated at all.
  - In other words, if the noise measured is higher on the C-scale than on the A, then much of the noise is probably low frequency.

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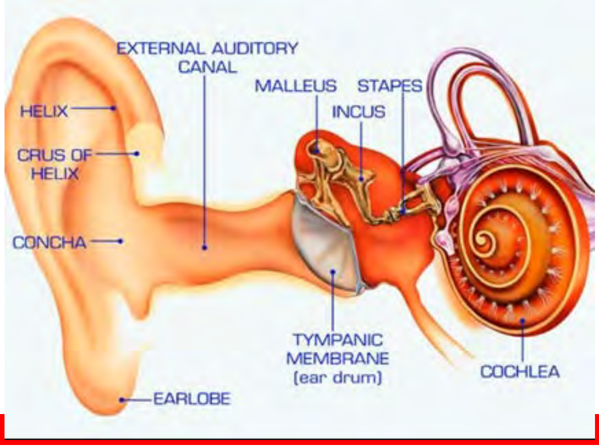
Hearing Damage

Scientific studies have shown that hearing loss can occur when 8-hour average noise exposure exceeds 85 decibels.

Our ears can recover from short exposure to loud noise, but over time nerve damage will occur.

Damage from noise exposure depends on the loudness and length of exposure….The longer and louder the noise, the greater chance permanent damage will occur.

Exposure to noise levels above 115 decibels for even five minutes is very risky. Noise above 140 decibels causes pain and immediate hearing loss (e.g. gunshots).



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- OSHA PEL is 90 dBA for an 8-hour TWA (Time Weighted Average)
  - Employees subjected to noise exceeding permissible noise limits shall be provided hearing protection devices, if feasible administrative or engineering controls failed to reduce noise levels.

- Hearing Conservation Program – 85 dBA 8 hour TWA
  - Employee exposed to noise at or above the 8-hour time-weighted average (TWA) of 85 dB, or equivalently, a dose of 50% shall be notified and enrolled in HCP.

When you feel the need to shout in order to be heard 3 feet away, the noise levels are probably 85 dB or more and hearing protectors are recommended

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OSHA PEL Comparison

Sound Level (dBA)	Permitted Duration per Workday (hours)	Sound Level (dBA)	Permitted Duration per Workday (hours)
90	8.00	103	1.32
91	6.96	104	1.15
92	6.06	105	1.00
93	5.28	106	0.86
94	4.60	107	0.76
95	4.00	108	0.66
96	3.48	109	0.56
97	3.03	110	0.50
98	2.63	111	0.43
99	2.30	112	0.38
100	2.00	113	0.33
101	1.73	114	0.28
102	1.52	115	0.25

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Hearing Conservation Program

- Noise Monitoring
- Hearing Protectors
- Audiometric Testing
- Evaluation of Audiogram
- Audiometric Test Requirements
- Audiometer Calibration
- Training
- Record Keeping

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Hierarchy of Controls

- Administrative Control
  - Operate noisy equipment on second or third shifts.
  - Rotate employees through high-noise areas.
  - Modify existing machinery.
  - Place noise limit specs. on new equip.
  - Maintain equip. in good condition.

- Engineering Control
  - Reduce noise at the source.
  - Interrupt the noise path.
  - Reduce reverberation and structural vibration.

- Personal Protective Equipment (hearing protective devices)
  - employees exposed to 8 hr TWA of 90dB or greater
  - by employees exposed to 8 hr TWA of 85dB or greater and:
    - Whose baseline audiogram has not been established
    - Who have experienced a threshold shift

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