Today, we will:

- Finish our discussion of **Hearing and Noise**
- Do some example problems

Consider a *source of sound* i.e., an *ear* or *microphone* that detects the sound.

\[
W = \text{sound power of the source (in Watts)}
\]

\[
L_w = \text{"""" level \"\" (in dB) \text{(decibel)}}
\]

**Are independent of who or what or where anyone detects the sound**

\[
P = \text{sound pressure}
\]

\[
L_P = \text{sound pressure level in dB}
\]
Define a **sound pressure level**:

\[ L_p = 20 \log_{10} \left( \frac{P}{P_0} \right) \quad (3-17) \]

where the term \( P_0 \) is a reference value,

\[ P_0 = 2 \times 10^{-5} \text{ N/m}^2 \approx \text{lower threshold of human hearing} \quad (3-18) \]

Define a **sound intensity level** \( (L_I) \),

\[ L_I = 10 \log_{10} \left( \frac{I}{I_0} \right) \quad (3-19) \]

where reference value \( I_0 \) corresponds roughly to the reference pressure level \( (P_0) \). At SATP,

\[ I_0 = \frac{P_0^2}{\rho a} \approx 1 \times 10^{-12} \text{ watt/m}^2 \quad (3-20) \]

We also define a **sound power level** or **acoustic power level** \( (L_W) \),

\[ L_W = 10 \log_{10} \left( \frac{W}{W_0} \right) \quad (3-21) \]

where

\[ W_0 = 1 \times 10^{-12} \text{ watt} \quad (3-22) \]

The unit used to express the sound pressure level, sound intensity level, and sound-power level is called the **decibel** (dB).

Multiplying each side by 10 and using the above equations, one obtains

\[ L_I (r) = L_p (r) \quad (3-23) \]

It is useful at this point to define a **reference distance** \( (r_0) \) equal to 1 meter,

\[ r_0 = 1 \text{ m} \quad (3-24) \]

Then,

\[ L_I (r) = L_W + 10 \log_{10} Q - 11.0 - 20 \log_{10} \left( \frac{r}{r_0} \right) \quad (3-26) \]

or,

\[ L_p (r) = L_W + 10 \log_{10} Q - 11.0 - 20 \log_{10} \left( \frac{r}{r_0} \right) \quad (3-27) \]

Where \( Q \) is the **directivity factor**. \( Q \) depends on how many walls (including the floor) are nearby and the reflectivity (hardness) of those walls.
\[ Q = \text{Directivity factor} \ (\text{depends on walls & reflection}) \geq 1 \]

\[ Q = 1 \rightarrow \text{Sound source in "Free space" (no walls)} \]

Can simulate this in an anechoic chamber.

\[ Q = 2 \]

\[ 10 \log_{10} Q \]

\[ 10 \log_{10} Q = 3 \text{ dB} \]

For a soft surface, \( 1 < Q < 2 \)

\[ Q = 4 \]

2 walls \( \uparrow \)

\( 4 \log \ L \text{ dB} \)

For hard wall, \( 4 \text{ dB} \)

\[ Q = 8 \]

3 walls \( \rightarrow \) hard wall

\( 4 \log \ L + 6 \text{ dB} \)

Sound source in a corner

\( L_p + 9 \text{ dB} \)
Figure 3.29 (corrected) Relationship between sound pressure, sound pressure level, and sound power, and some common sources of noise (adapted from US NIOSH, 1973).

Sound pressure level (dB)

<table>
<thead>
<tr>
<th>Sound pressure (N/m²)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 2000</td>
<td>turbojet engine</td>
</tr>
<tr>
<td>150 633</td>
<td>air compressor</td>
</tr>
<tr>
<td>140 200</td>
<td>pneumatic chipper at 5 ft</td>
</tr>
<tr>
<td>130 63.3</td>
<td>rock-n-roll band</td>
</tr>
<tr>
<td>120 20</td>
<td>textile loom</td>
</tr>
<tr>
<td>110 6.33</td>
<td>lawn mower at operator’s ear</td>
</tr>
<tr>
<td>100 2</td>
<td>diesel truck at 40 mph at 50 ft</td>
</tr>
<tr>
<td>90 0.633</td>
<td>milling machine at 4 ft</td>
</tr>
<tr>
<td>80 0.2</td>
<td>vacuum cleaner</td>
</tr>
<tr>
<td>70 0.0633</td>
<td>car at 50 mph at 50 ft</td>
</tr>
<tr>
<td>60 2 x 10⁻²</td>
<td>conversation at 3 ft</td>
</tr>
<tr>
<td>50 6.33 x 10⁻³</td>
<td>quiet room</td>
</tr>
<tr>
<td>40 2 x 10⁻³</td>
<td></td>
</tr>
<tr>
<td>30 6.33 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>20 2 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>10 6.33 x 10⁻⁵</td>
<td></td>
</tr>
<tr>
<td>0 2 x 10⁻⁵</td>
<td></td>
</tr>
</tbody>
</table>
Example

Given: The noise level of a factory machine is 85 dB at 10 m in free space.

To do: Estimate the sound pressure level at a distance of 4.0 ft away when the machine sits in the corner of the building, and all walls are concrete.

Solution:

\[ L_p = L_{p_c} + 20 \log_{10} \left( \frac{r}{r_0} \right) - 10 \log_{10} Q_c + 11.0 \] (1)

\[ L_w = L_{p_c} + 20 \log_{10} \left( \frac{r}{r_0} \right) - 10 \log_{10} Q_c + 11.0 \]

\[ L_w \] is independent of \( r, Q_c \), etc.

Actual case of this machine in a corner \( r = 4.0 \) ft

Use Eq. 3-27 again

\[ L_p = L_w - 20 \log_{10} \left( \frac{r}{r_0} \right) + 10 \log_{10} Q_c - 11.0 \] (2)

Plug (1) into here

\[ L_p = L_{p_c} + 20 \log_{10} \left( \frac{r}{r_0} \right) - 10 \log_{10} Q_c + 11.0 \]

\[ - 20 \log_{10} \left( \frac{r}{r_0} \right) + 10 \log_{10} Q_c - 11.0 \]
**logarithm review**

\[ \log(ab) = \log a + \log b \]

\[ \log \left( \frac{a}{b} \right) = \log a - \log b \]

We get

\[ L_p = L_{p_c} + 20 \log_{10} \left( \frac{C_c}{r} \right) - 10 \log_{10} \left( \frac{Q_c}{Q} \right) \]

\[ \text{Ans in variable} \]

\[ L_p = 85 \text{ dB} + 20 \log_{10} \left( \frac{10 \text{ m}}{1.219 \text{ m}} \right) - 10 \log_{10} \left( \frac{1}{8} \right) \]

4 ft

\[ L_p = 112.31 \text{ dB} \rightarrow \text{always round ans to nearest dB} \]

\[ L_p = 112 \text{ dB} \]

**SOUND FROM MULTIPLE SOURCES**

\[ L_p = 10 \log_{10} \left[ \sum_{j=1}^{5} \left( \frac{L_{p,j}}{10} \right) \right] \]
Example

**Given:** A man stands between two noisy machines on a concrete floor with no walls nearby.
- Machine 1 has an acoustic power of ~0.40 W, and is 1.0 m away to the man’s right.
- Machine 2 has an acoustic power of ~0.50 W, and is 2.0 m away to the man’s left.

**To do:** Estimate the sound pressure level at the man’s ears.

**Solution:**

Need $L_w$ for each sound source

$$L_{w_1} = 10 \log_{10} \left( \frac{W_1}{W_0} \right) = 10 \log_{10} \left( \frac{0.40 \text{ W}}{10^{-12} \text{ W}} \right) = 116.02 \text{ dB}$$

$$L_{w_2} = 10 \log_{10} \left( \frac{W_2}{W_0} \right) = 10 \log_{10} \left( \frac{0.50 \text{ W}}{10^{-12} \text{ W}} \right) = 117.00 \text{ dB}$$

These are independent of distance.

Use Eq. 3.27 with \[ Q = 2, Q_1 = Q_2 = 2 \]

$$L_{p_1} = L_{w_1} + 10 \log_{10} Q_1 - 11.0 - 20 \log_{10} \frac{r_1}{r_0} - 1.0 \text{ m}$$

$$L_{p_1} = 116.02 \text{ dB}$$

Similarly, $L_{p_2} = 102.98 \text{ dB}$
Now, we have: \[ L_{p_{th1}} = 10 \log_{10} \left( \frac{108.03}{10} + \frac{102.98}{10} \right) \]

\[ = 109.2 \text{ dB} \]

\[ L_{p_{th1}} = 109 \text{ dB} \]

Noise level does not add up linearly.

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Suppose floor is carpeted with \( Q = 1.5 \)

Recalculate: \[ L_p = 106.8 \]

\[ L_{L2} = 101.7 \]

\[ L_{p_{th1}} = 108 \text{ dB} \]

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**Noise Standards**

- OSHA - regulatory agency
  - can give fines
- ACGIH - give recommendations
  - no fines, no authority
Table 3.5  ACGIH and OSHA noise limit standards for the workplace (from Internet websites and US Office of the Federal Register, 1988).

<table>
<thead>
<tr>
<th>sound intensity (dBA)</th>
<th>ACGIH exposure time (hr)</th>
<th>OSHA exposure time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>82</td>
<td>16</td>
<td>24.3</td>
</tr>
<tr>
<td>85</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>88</td>
<td>4</td>
<td>10.6</td>
</tr>
<tr>
<td>90</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>91</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>92</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>94</td>
<td>1</td>
<td>4.6</td>
</tr>
<tr>
<td>95</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>97</td>
<td>0.5</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>0.25</td>
<td>2</td>
</tr>
<tr>
<td>102</td>
<td>-</td>
<td>1.5</td>
</tr>
<tr>
<td>105</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>115</td>
<td>-</td>
<td>0.25 or less</td>
</tr>
</tbody>
</table>

OSHA also define a sound exposure parameter when workers are exposed to different sound levels.

Define

$$E_n = \sum_{j} \frac{t_j}{t_{j, \text{permitted}}}$$

Using above table