A car stereo produces 96 dB sound (with all speakers) at a distance of 30 m. What sound level is produced at 15 m if half of the speakers are blown out?

\[ I = \frac{P}{4\pi R^2} \]  

(Point Source)

Power: Cut in half

\( P_{\text{final}} = \frac{1}{2} P_{\text{initial}} \)

Intensity:
\[ \frac{0.5}{3^2} = \frac{1}{50} \]

What dB level is a factor of 50?

\[ 10^{1.7} = 50 \quad 17 \text{ dB} \]

Final level is
\[ 96 \text{ dB} - 17 \text{ dB} = 79 \text{ dB} \]

\[ \beta = 10 \log \left( \frac{\text{Ratio}}{10} \right) \]

\[ \beta = 10 \log (10) \]

\[ \text{Ratio} = 10 \]
Optics - redirecting waves

Geometric Optics - Using the shape of a medium to control waves.

Two main effects
- Reflection - bouncing waves off a surface.
- Refraction - bending waves as they are transmitted into a new material.

Rays - Like a laser beam. Points in direction of energy flow.

Wave Fronts - Perpendicular to rays, these are the peaks and valleys of 2D & 3D waves.

Reflection & Refraction

Incident Ray \( \theta_i \) \( \rightarrow \) Reflected Ray \( \theta_r \)

\[ n_1 = \text{Air} \]
\[ n_2 = 1.33 \text{ Water} \]

Snell's Law
\[ n_1 \sin \theta_i = n_2 \sin \theta_2 \]

Transmitted Ray

\( n = \text{index of refraction} \)
Ex: \( n_1 = 1 \quad n_2 = 1.33 \)
\[ \theta_1 = 45^\circ \]

1. \( \sin(45^\circ) = 1.33 \cdot \sin \theta_2 \)
2. \( 0.832 = \sin \theta_2 \)
3. \( \theta_2 = 32^\circ \)

When the index of refraction increases, the ray bends toward the normal.

Ex: \( n_1 = 1.33 \quad n_2 = 1 \)
\[ \theta_1 = 60^\circ \]

1. \( 1.33 \cdot \sin(60^\circ) = 1 \cdot \sin \theta_2 \)
2. \( 1.15 = \sin \theta_2 \)

There is no \( \theta_2 \).

No transmitted light. Total Internal Reflection

Applications:
- Fiber optics
- Binocular prisms

\[ n_1 = 1.6 \]
\[ \text{at } \theta_1 = 45^\circ \]
\[ n_2 \sin \theta = 1.13 \]

(1) and (3): \( \Theta = 0 \)

Diagram: In \( \rightarrow \) Out
Why do waves refract?

How does a bulldozer turn?

\[ \frac{d_1}{\sin \Theta_1} = \frac{d_2}{\sin \Theta_2} \]

Let \( n_1 = \frac{c}{v_1} \)

\[ v_1 = \frac{c}{n_1} \]

\[ \frac{c}{n_1 \sin \Theta_1} = \frac{c}{n_2 \sin \Theta_2} \]

\[ \frac{c}{n_1} \frac{dx}{dt} = \frac{c}{n_2} \frac{dx}{dt} \]

\( n_1 \), describes slowing of light

\[ \frac{c}{n_1} = \frac{c}{n_2} \frac{dx}{dt} \]

\[ l_1 = v_1 dt = \frac{c dt}{n_1} \]

\[ n_1 \sin \Theta_1 = n_2 \sin \Theta_2 \]
Mirages: Refraction from a gradient.

Slower

Faster

Speed of light in air decreases with high density.

\[ \text{Air} \approx 1.0003 \]

\[ PV = NRT \]

\[ \frac{P}{T} = \frac{N}{V} R \]

High \( T \) \( \rightarrow \) Low density \( \rightarrow \) Fast light \( \rightarrow \) Higher index

Sound "Mirage"

Faster

Slower

Train (not to scale)

Speed of sound increases with temperature.