How do we quantify Energy in waves?

Packets, bundles, localized energy:

Energy in J

Energy spread in a line, surface, volume:

Energy Density in \( \frac{J}{m} \) \( \frac{J}{m^2} \) \( \frac{J}{m^3} \)

Continuous flow of energy in a wire:

\( P \) in \( \frac{J}{s} = W \) \( P = \text{Density} \times V \)

can be \( \frac{W}{s} = \frac{J}{m \cdot s} \)

Continuous surface waves

\[ \text{Intensity} = \text{Density} \times V \]

\( W/m^2 = \frac{J/(m \cdot s)}{m^2} = \frac{J}{m^2 \cdot s} \)

Sound & Light Waves

\[ \text{Intensity} = \text{Density} \times V \]

\( W/m^2 = \frac{J/m^3}{m^2 \cdot s} = \frac{J}{m \cdot s} \)

\( I = \frac{P}{A} \)
Point Source Approx

\[ \frac{P}{4\pi r^2} = I \quad \text{Uniform emission} \]

\[ I \propto \frac{P}{r^2} \quad \text{General Far field} \]

Ex: \( I = 50 \mu W/m^2 \), go 2x further.

\[ I_2 = \frac{1}{4} I_0 = 12.5 \mu W/m^2 \]

- Our eyes/ears have a HUGE range of allowed intensities.
  - \( 10^{-12} W/m^2 \): Quietest Sound
  - \( 1 W/m^2 \): Painfully Loud

- Filters and inefficiencies tend to multiply the intensity.

- We interpret steps in intensity by the ratio, not the delta.
  - We can hear a factor of \( \frac{1}{4} \) just barely.

- We use a logarithmic scale.
Definitions: $\left( \frac{I}{I_0} \right) = 10^{\beta/10}$

- Decibel level
- Ratio of intensity vs. reference

$$\beta = 10 \log \left( \frac{I}{I_0} \right)$$

As intensity is multiplied, dB levels add.

<table>
<thead>
<tr>
<th>dB</th>
<th>ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 dB</td>
<td>10</td>
</tr>
<tr>
<td>20 dB</td>
<td>100</td>
</tr>
<tr>
<td>30 dB</td>
<td>1000</td>
</tr>
<tr>
<td>3 dB</td>
<td>$10^{0.3}$ = 2</td>
</tr>
<tr>
<td>5 dB</td>
<td>$10^{0.5}$ ≈ 3</td>
</tr>
<tr>
<td>7 dB</td>
<td>$10^{0.7}$ = 5</td>
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</tbody>
</table>

$1 \text{ dB} = 10^{0.1} \times 1.25$

$-3 \text{ dB} = 0.5$

$0 \text{ dB} = 1.0$

Reference Sound $I_0 = 10^{-12} \text{ W/m}^2$

$60 \text{ dB} = \text{conversation} \quad I = 10^{-6} \text{ W/m}^2$

$100 \text{ dB} = \text{power tools}$

$180 \text{ dB} = \text{hearing 1055}$
In a radio, we care about the energy flow on a wire. Power in W

$0 \text{ dBm} = 1 \text{ mW}$

$-70 \text{ dBm} = 10^{-10} \text{ W low level useful Wi-Fi signal}$

If sound is $80 \text{ dB @ } 1.0 \text{ m, how loud is it @ 30 m?}$

$I \propto \frac{1}{r^2} \Rightarrow \frac{I}{30^2} \propto I$

$ratio = 900 \quad \frac{30}{30} = 3 \cdot 10^2$

$log(900) = 2.9$

$\beta = 29 \text{ dB}$

$-(5 \text{ dB} + 5 \text{ dB} + 20 \text{ dB})$

New sound = $51 \text{ dB}$

New sound = $50 \text{ dB}$
Transverse waves have oscillations that are perpendicular to the velocity. Describing the direction is polarization. For a horizontally moving wave:

- Pure Vertical
- Pure Horizontal
- Circular
- Diagonal
- Random

A polarizer absorbs "undesired" waves. It also polarizes the waves.

For incoming unpolarized:

\[ I_{\text{out}} = I_{\text{in}} \left(\frac{1}{2}\right) \]

For incoming polarized:

\[ I_{\text{out}} = I_{\text{in}} \cos^2 \theta \]

The polarization is actually rotated.

\[ I_0, I_0/2, I_0/4, I_0/8 \]