Physics 115 Lecture 16

Decibels part I

March 1, 2018

Written quiz #4

- Based on homework #4
- Posted answer key

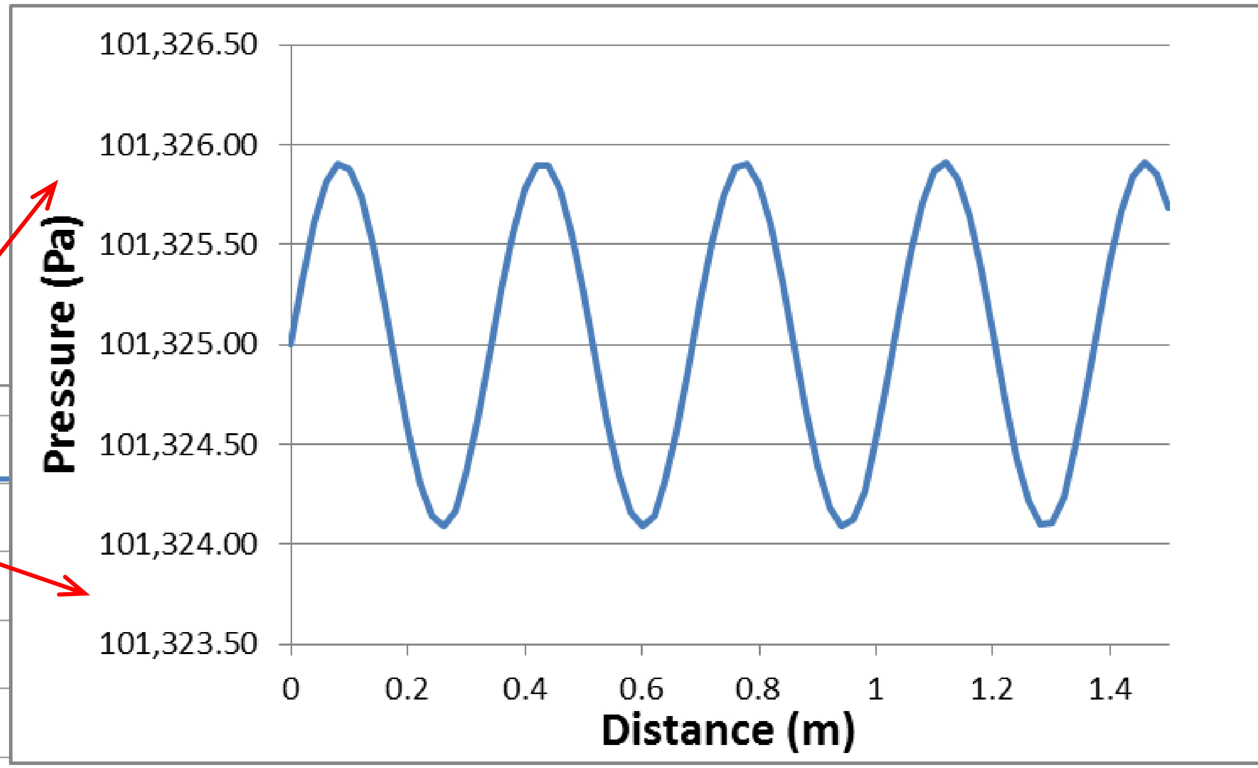
Sound is a pressure wave

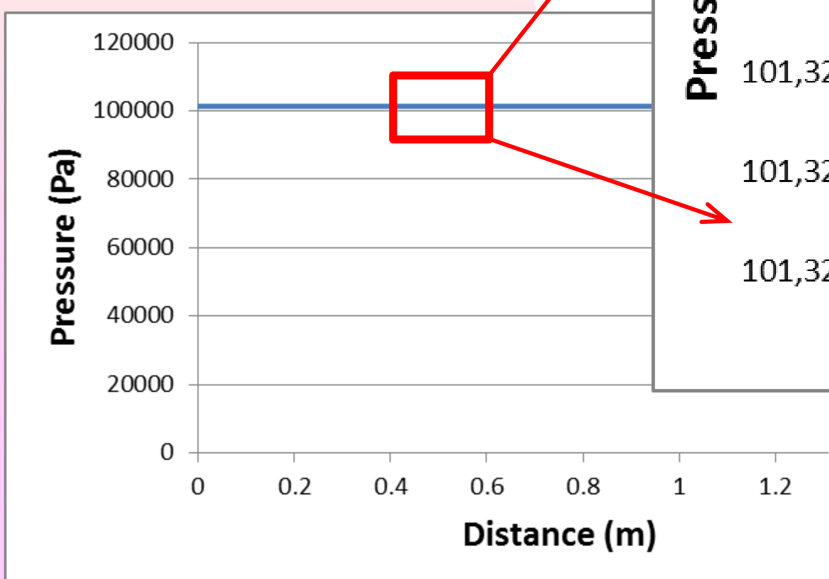
- Waves oscillate in space and time

$$k = \frac{360°}{\lambda} \begin{cases} \text{phase change} \\ \text{with distance} \end{cases}$$

$$\omega = \frac{360°}{T} \begin{cases} \text{phase change} \\ \text{with time} \end{cases}$$

$$p = p_0 \sin(kx - \omega t)$$





A loud 90-dB sound has a pressure amplitude of p_0 = 0.907 Pa

Sound Intensity

- The intensity *I* describes the rate at which energy is transported by the sound wave.

- It has units of watts per square meter

$$\text{sound intensity } (I) = \frac{\text{sound power } (P)}{\text{area } (A)} \quad \Rightarrow I = \frac{P}{A}$$

$$\text{also, it turns out} \quad I = \frac{p^2}{Z} = \frac{\left[p_0 \sin(kx - \omega t)\right]^2}{Z}$$

Sound Intensity

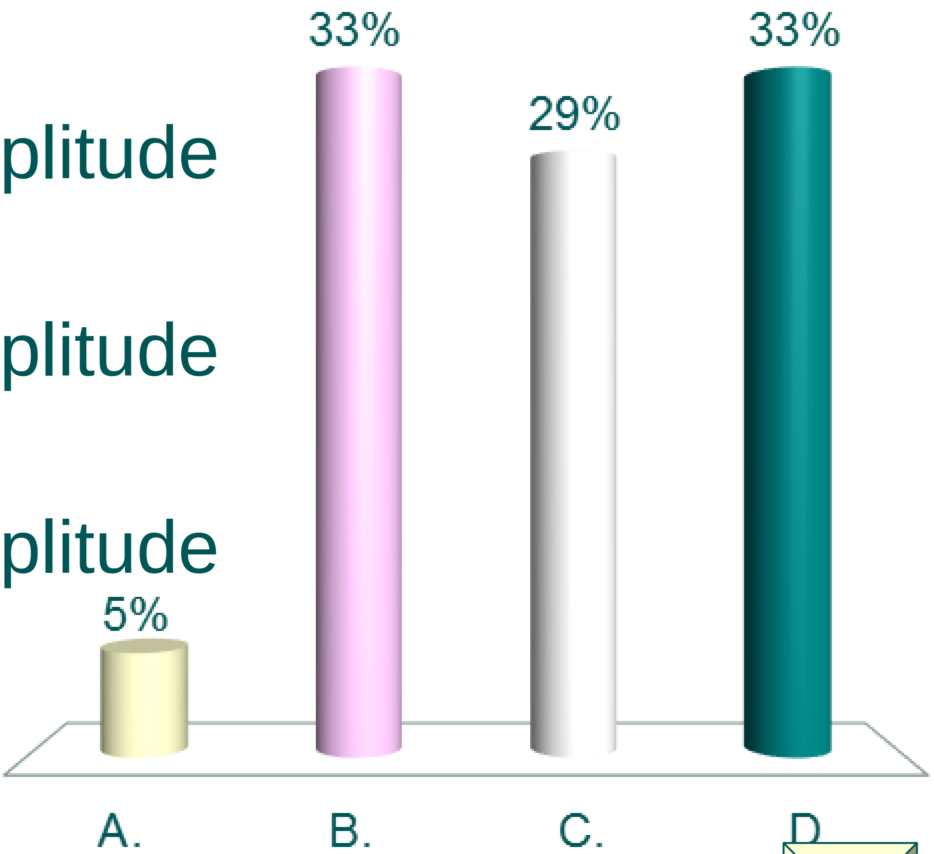
- The intensity *I* rapidly oscillates with the wave. Most often, then, the symbol *I* actually refers to the time average of the power delivered by the wave.
- The time average of $\sin^2(\omega t) = \frac{1}{2}$, so

$$I_{\text{time averaged}} = \frac{p_0^2}{2Z}$$

- Thus the intensity of a sound wave is proportional to the *square* of the pressure amplitude.

In order to triple the sound intensity, you must

A. cut the pressure amplitude by a factor of 3
B. increase the pressure amplitude by a factor of $\sqrt{3}$.
C. increase the pressure amplitude by a factor of 3.
D. increase the pressure amplitude by a factor of 9.



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In order to triple the sound intensity, you must

A. cut the pressure amplitude by a factor of 3

B. increase the pressure amplitude by a factor of $\sqrt{3}$.

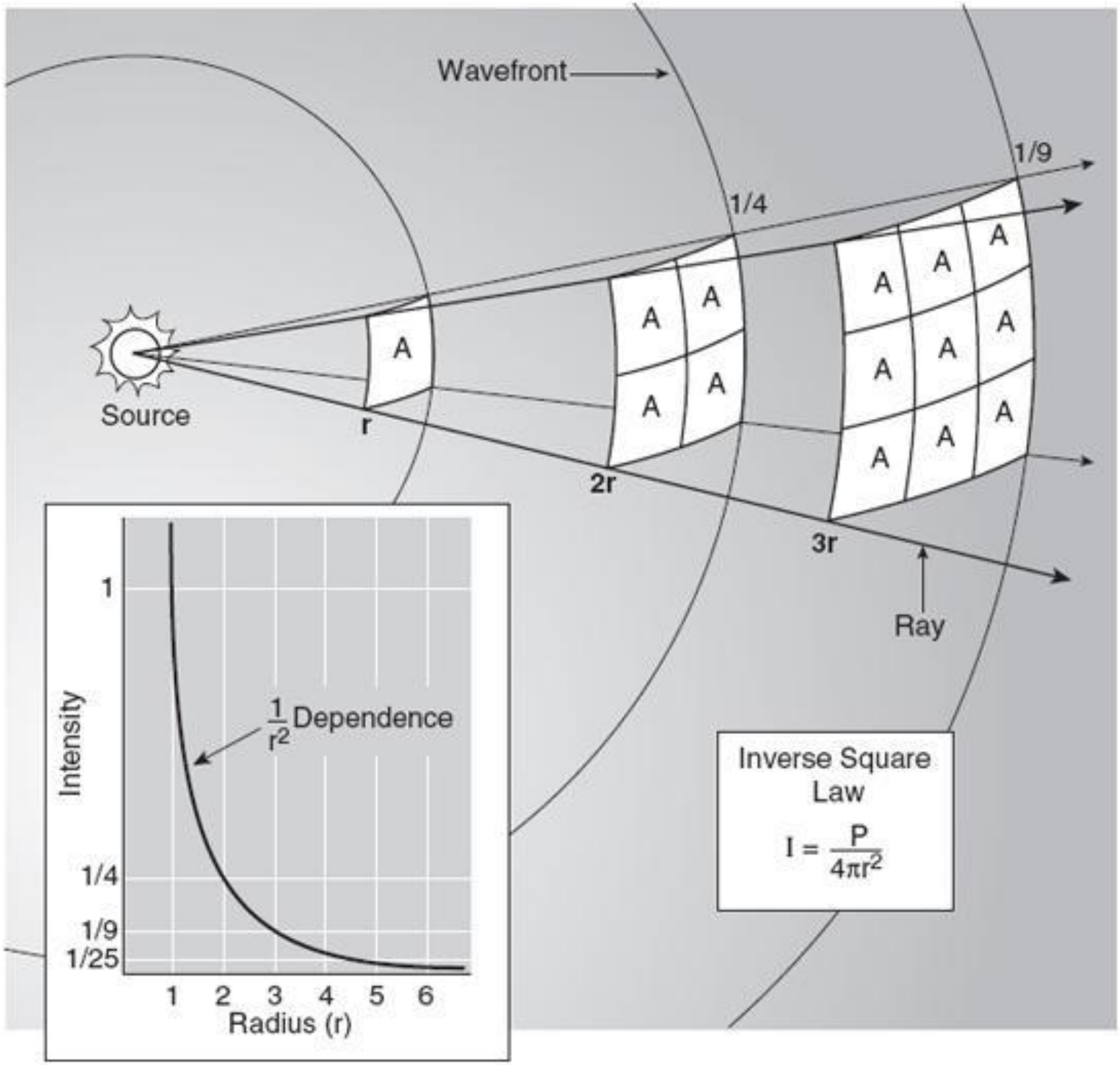
C. increase the pressur[e amplitude] by a factor of 3.

D. increase the pressur[e amplitude] by a factor of 9.

$$I = \frac{p_0^2}{2Z} \quad \Rightarrow p_0 = \sqrt{2Z\,I}$$

$$\frac{p_{0,\text{ new}}}{p_{0,\text{ old}}} = \frac{\sqrt{2Z\,I_{\text{new}}}}{\sqrt{2Z\,I_{\text{old}}}} = \sqrt{\frac{3I_{\text{old}}}{I_{\text{old}}}} = \sqrt{3}$$

Intensity of a point source of sound waves



Intensity of a point source of sound waves

- The emitted power P gets spread out over the surface of an expanding sphere, which is the sound wave that is propagating in three dimensions
- The surface area of a sphere of radius r is $4\pi r^2$.

$$I_{\text{point source}} = \frac{P}{A} = \frac{P}{4\pi r^2}$$

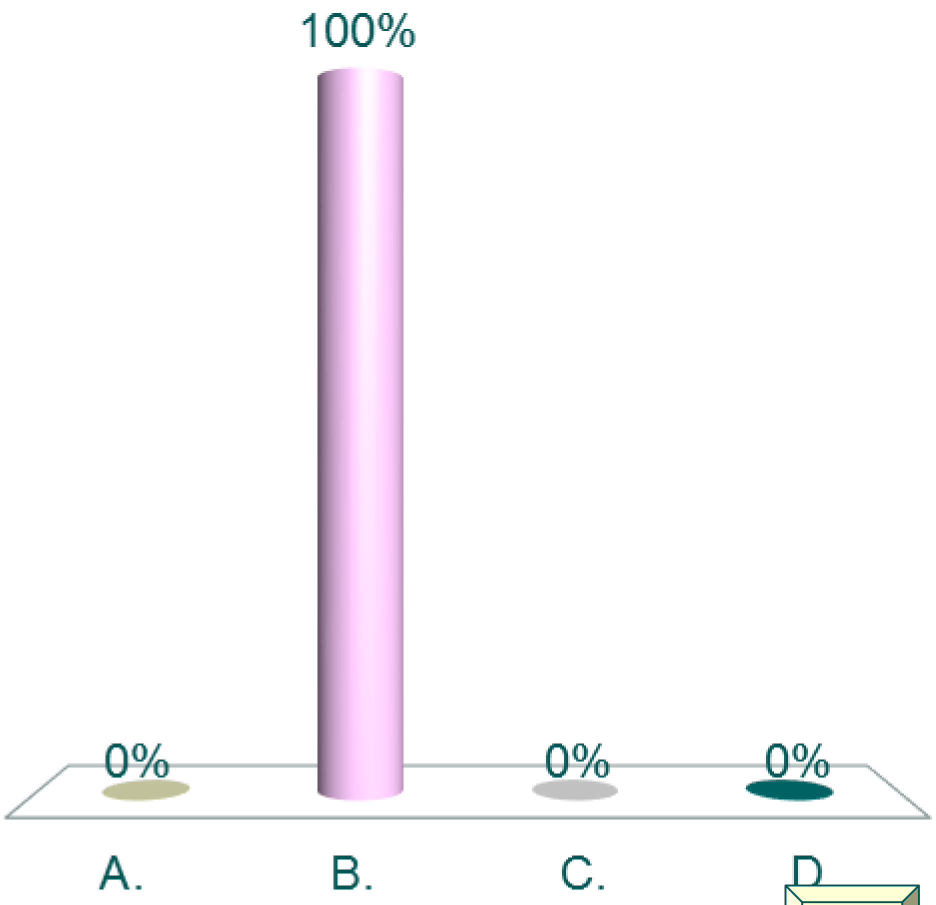
What is the intensity of a sound wave at a distance of 2.8 m from a sound source that generates 235 W of sound power?

A. 0.98 W/m^2

B. 2.39 W/m^2

C. 4.52 W/m^2

D. 8.77 W/m^2



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What is the intensity of a sound wave at a distance of 2.8 m from a sound source that generates 235 W of sound power?

A. 0.98 W/m^2

B. 2.39 W/m^2

C. 4.52 W/m^2

D. 8.77 W/m^2

$$I = \frac{P}{4\pi r^2} = \frac{235\ \text{W}}{4\pi(2.8\ \text{m})^2}$$

$$= \boxed{2.39\ \text{W/m}^2}$$

(This would be an extremely loud 124 dB sound, above the threshold of pain!)

Intensity range of hearing

- The human ear can sense an enormous range of sound intensities

	Minimum intensity (reference level)	**Threshold of pain**
Pressure (μPa = 10^{-6} Pa)	20	2.0×10^{7}
Intensity (W/m^2)	1.0×10^{-12}	1.0

- This large range of intensities can be more easily handled by a logarithmic scale. Actually, *two* logarithmic scales…

The Decibel

- Developed in the Bell Telephone Labs initially as a way to describe power loss over telephone transmission lines.
- The Bel

$$L = \log_{10}\left(\frac{\text{sound power}}{\text{reference power}}\right) = \log_{10}\left(\frac{P}{P_r}\right)$$

- Initially believed to correlate with human perception of loudness.

The Intensity Level Decibel (dB IL)

- The standard means of measuring the amplitude of an acoustic signal.
- Intensity Level (bels) = Log I / I_r
  - Too small, would be working with decimals quite a bit
- Intensity Level (decibels)

$$L = 10\log_{10}\left(\frac{I}{I_r}\right)\ [\mathrm{dB\ IL}]$$

  - Less need to work with decimals.

Finding the intensity level

- The threshold of pain occurs at around *I* = 1.0 W/m^2. The corresponding intensity level is:

$$L = 10\log\left(\frac{I}{I_r}\right)$$

$$= 10\log\left(\frac{1.0\ \mathrm{W/m^2}}{1.0\times 10^{-12}\ \mathrm{W/m^2}}\right)$$

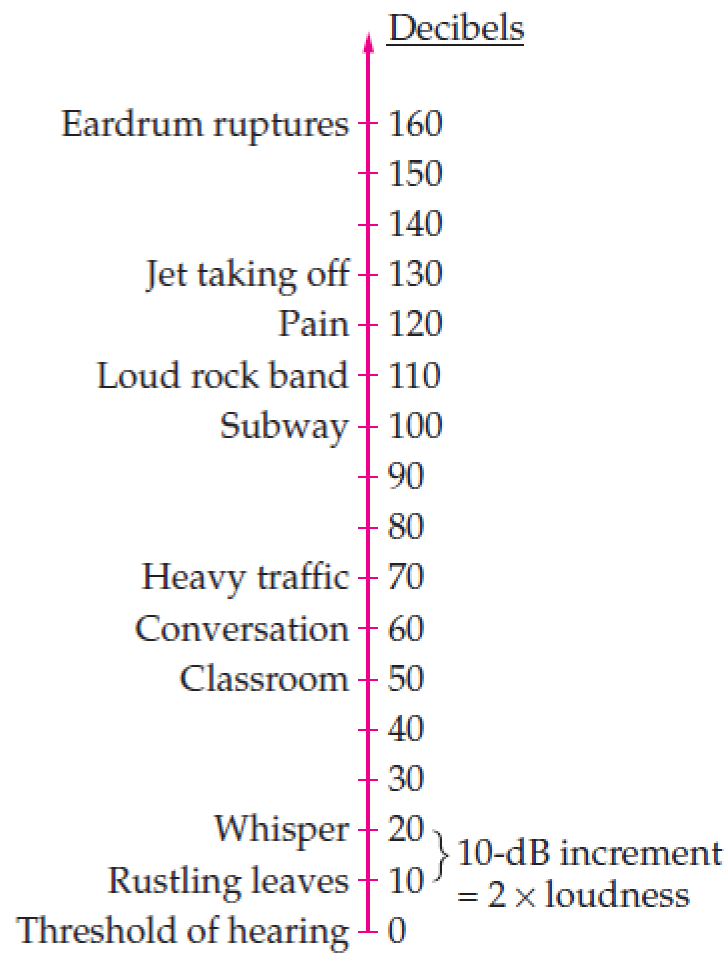
$$= 10\log\left(1.0\times 10^{12}\right) = 10[12]$$

$$L = \boxed{120\ \mathrm{dB\ IL}}$$

Range of intensities and levels

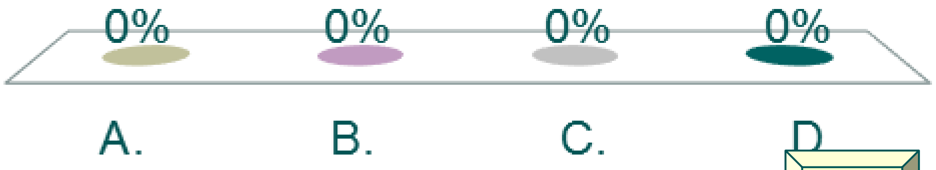
TABLE 14–2 Sound Intensities (W/m^2)

Loudest sound produced in laboratory	10^9
Saturn V rocket at 50 m	10^8
Rupture of the eardrum	10^4
Jet engine at 50 m	10
Threshold of pain	1
Rock concert	10^{-1}
Jackhammer at 1 m	10^{-3}
Heavy street traffic	10^{-5}
Conversation at 1 m	10^{-6}
Classroom	10^{-7}
Whisper at 1 m	10^{-10}
Normal breathing	10^{-11}
Threshold of hearing	10^{-12}



A sound has an intensity of 5.0×10^{-4} W/m^2. What is the sound level?

A. 87 dB IL
B. 50 dB IL
C. 40 dB IL
D. −33 dB IL



Response Counter

150

A sound has an intensity of 5.0×10⁻⁴ W/m². What is the sound level?

A. **87 dB IL**
B. 50 dB IL
C. 40 dB IL
D. −33 dB IL

$$L = 10\log_{10}\left(\frac{I}{I_r}\right)$$

$$= 10\log_{10}\left(\frac{5\times10^{-4}\ \mathrm{W/m^2}}{1\times10^{-12}\ \mathrm{W/m^2}}\right)$$

$$L = \boxed{87\ \mathrm{dB\ IL}}$$

Similarly, an $I = 1\times10^{-4}\ \mathrm{W/m^2}$ sound has a level of 80 dB. In other words, an 87-dB sound has five times the *intensity* of an 80-dB sound (but it is *not* perceived as "five times louder" to the ear)

Finding the intensity

- The intensity of a 55 dB IL sound is:

$$\frac{L}{10} = \frac{10}{10}\log\left(\frac{I}{I_r}\right)$$

$$L/10 = \log\left(I/I_r\right) \quad \text{make both sides an exponent}$$

$$10^{L/10} = 10^{\log\left(I/I_r\right)} = I/I_r \quad \text{multiply both sides by } I_r$$

$$\boxed{I_r 10^{L/10} = I} = I_r 10^{(55\text{ dB})/10}$$

$$I = \left(1.0\times10^{-12}\text{ W/m}^2\right)10^{5.5}$$

$$I = \boxed{3.17\times10^{-7}\text{ W/m}^2}$$

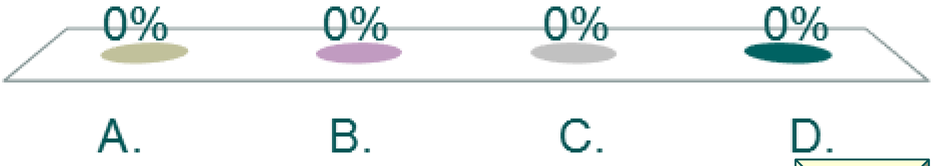
What is the intensity of a 102-dB sound?

A. 1.02×10^{-12} W/m^2

B. 1.58×10^{-2} W/m^2

C. 3.72×10^{-4} W/m^2

D. 4.51×10^{-8} W/m^2



Response Counter

120

What is the intensity of a 102-dB sound?

A. 1.02×10^{-12} W/m²

B. 1.58×10^{-2} W/m²

C. 3.72×10^{-4} W/m²

D. 4.51×10^{-8} W/m²

$$I = I_r 10^{L/10}$$

$$= \left(1.0\times10^{-12}\ \text{W/m}^2\right)10^{102/10}$$

$$I = 1.58\times10^{-2}\ \text{W/m}^2$$

$$= \boxed{0.0158\ \text{W/m}^2}$$