Physics 115 Lecture 19

Attenuation and Reflection

March 8, 2018

Written quiz #5

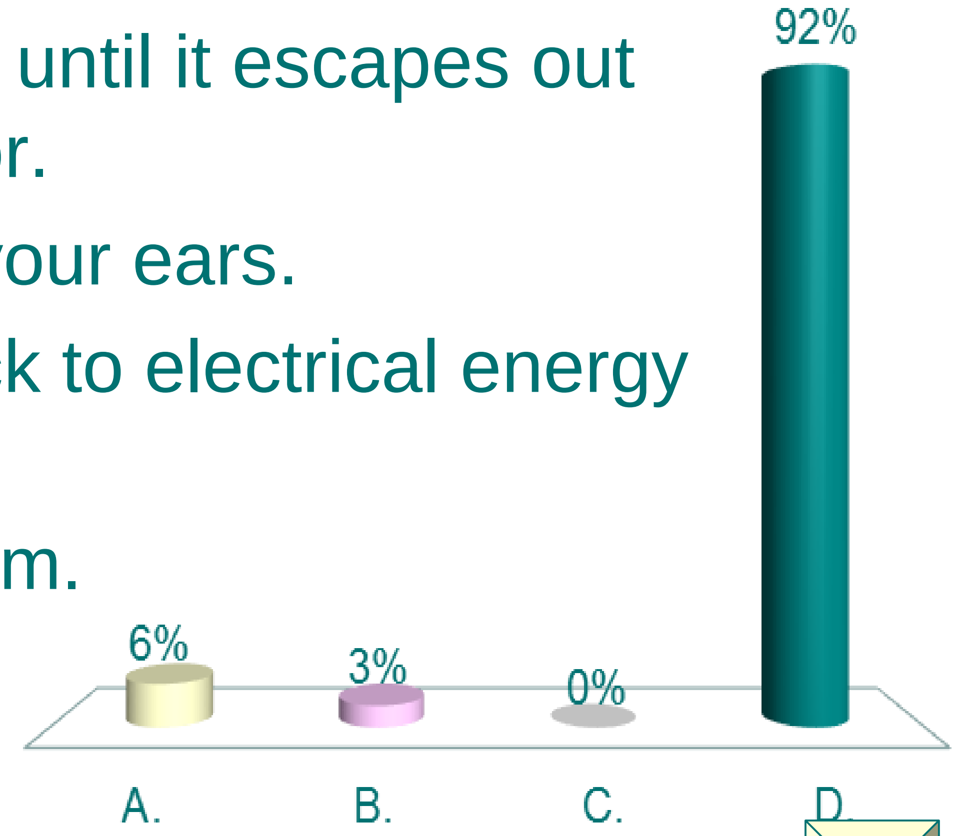
- Based on homework #5
- Posted answer key

Attenuation

- Sound waves lose intensity for several reasons:
  - Distance traveled – the wave expands as it propagates, diluting its power
  - Bulk absorption – internal friction converts the wave energy into thermal energy
  - Surface absorption – some of the incoming wave energy heats up the surface, the rest is reflected or transmitted

What happens to essentially all the sound energy in a dorm room after it is generated by a pair of stereo speakers?

A. It bounces around until it escapes out the window or door.
B. It is absorbed by your ears.
C. It is converted back to electrical energy by the speakers.
D. It heats up the room.



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B. It is absorbed by your ears.
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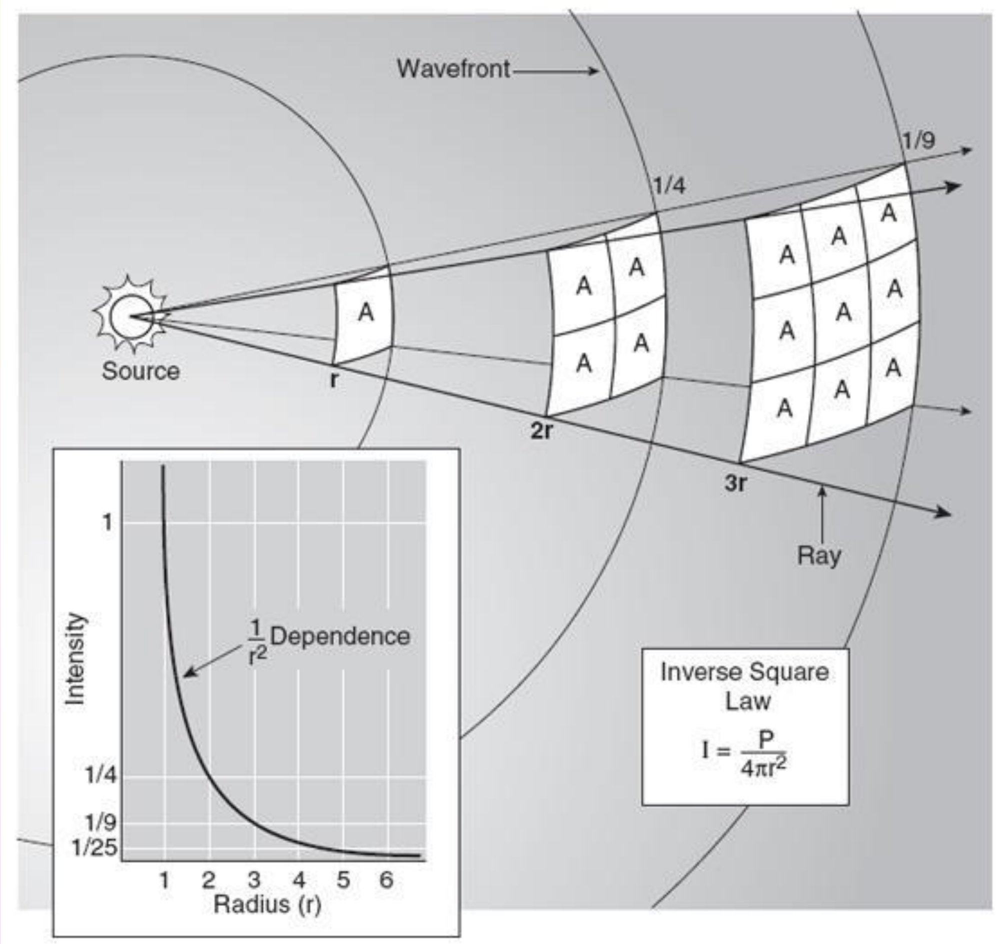
Attenuation over a distance

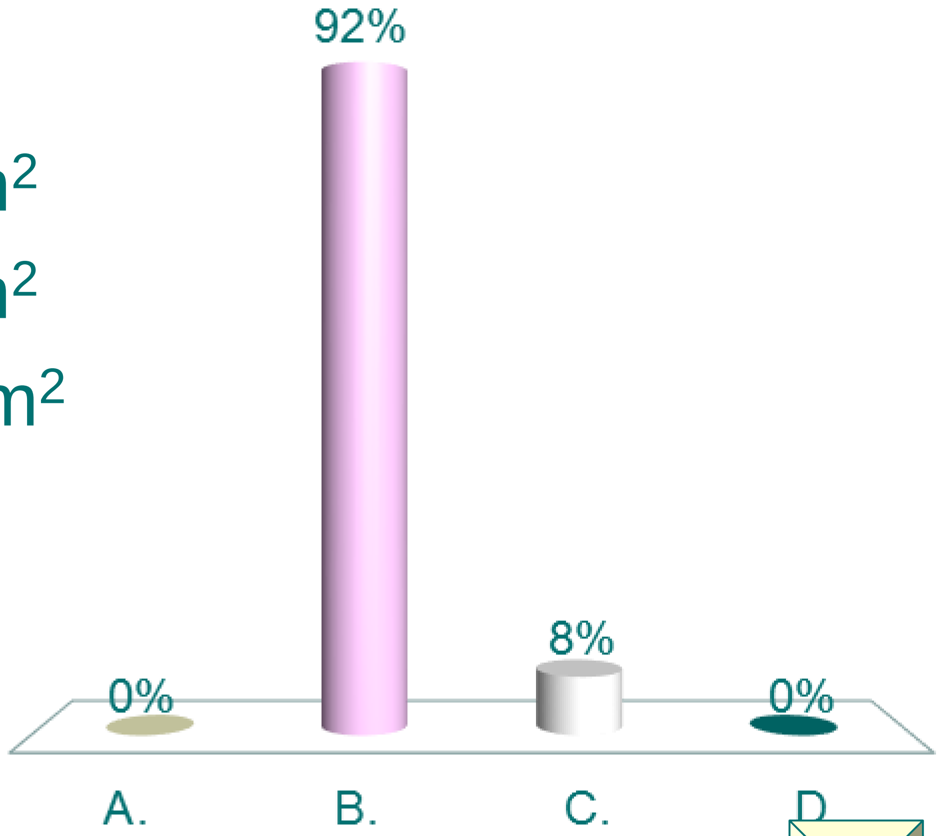
- The emitted power *P* gets spread out over the surface of an expanding sphere



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

A cap gun emits a sound wave with a power of 0.0248 W. What is its intensity after it has traveled 101 m?

A. 3.16 W/m^2
B. 1.93×10^{-7} W/m^2
C. 2.95×10^{-5} W/m^2
D. 4.17×10^{-12} W/m^2



A cap gun emits a sound wave with a power of 0.0248 W. What is its intensity after it has traveled 101 m?

A. 3.16 W/m^2

B. 1.93×10^{-7} W/m^2

C. 2.95×10^{-5} W/m^2

D. 4.17×10^{-12} W/m^2

$$I = \frac{P}{4\pi r^2} = \frac{0.0248\ \text{W}}{4\pi\left(101\ \text{m}\right)^2}$$

$$= \boxed{1.93\times10^{-7}\ \text{W/m}^2}$$

$$L = 10\log\left(I/I_r\right) = \boxed{52.9\ \text{dB}}$$

If held 2.5 cm from the ear, the cap gun produces

$$I = \frac{P}{4\pi r^2} = \frac{0.0248\ \text{W}}{4\pi\left(0.025\ \text{m}\right)^2} = 3.16\ \text{W/m}^2 \quad \Rightarrow 125\ \text{dB}$$

This is a very brief sound, but above threshold of pain!

Attenuation by absorption

- The wave intensity decreases due to *internal* friction among the molecules of the medium
- Attenuation is described by a bulk absorption coefficient called *m*:

$$I = I_0 e^{-2mx}$$

I = final intensity in W/m^2

I_0 = initial intensity in W/m^2

e = base of the natural logarithm

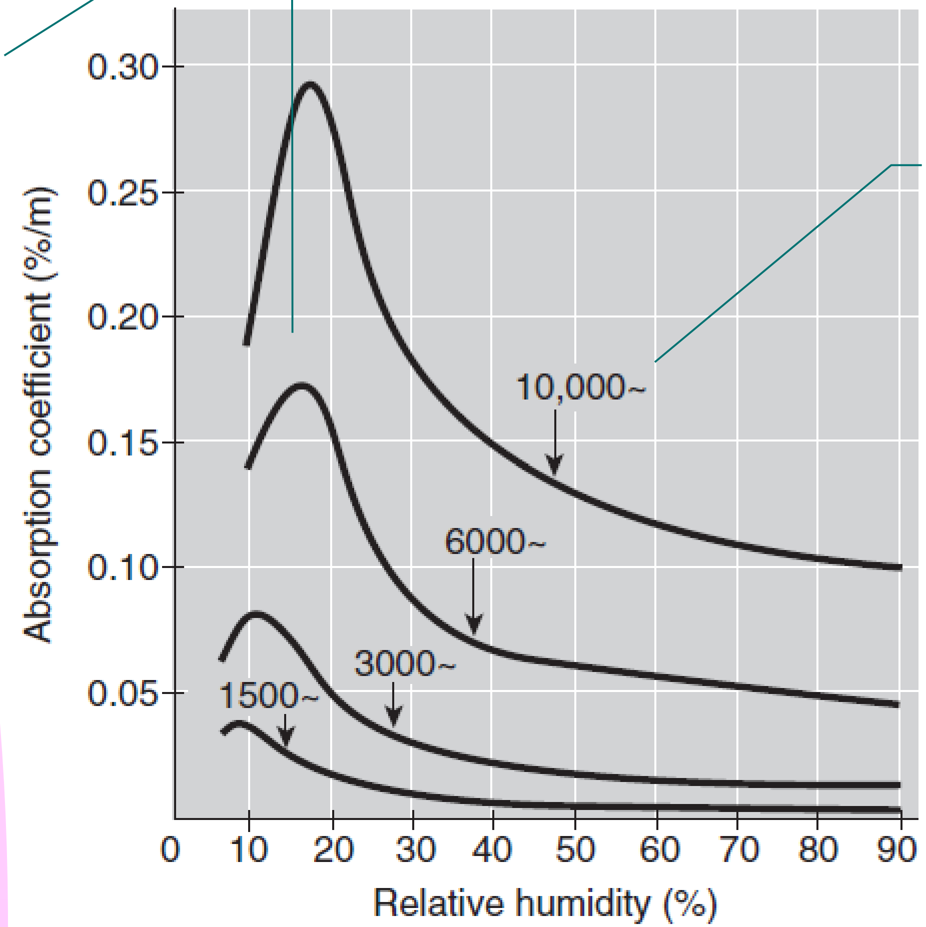
m = bulk absorption coefficient

x = distance the wave has traveled

Atmospheric absorption

- The amount by which air absorbs sound depends on frequency, relative humidity, and other factors.

Maximum absorption around 15% RH



High frequencies are attenuated more

Another (easier?) way to calculate

- The coefficients *m* for absorption in air are small. For instance, at 4000 Hz (peak sensitivity for human ear) at 20°C and 50% RH, $m = 0.00255\ \text{m}^{-1}$.
- The coefficient can also be expressed as decibels per kilometer

$$L = L_0 - a\,x$$

L_0 = initial sound level in decibels

L = final sound level in decibels

a = absorption coefficient in dB/km

x = distance in kilometers

The two are related (FYI only)

$$I = I_0 e^{-2mx} \quad m \text{ has units of 1/m}$$

$$\log\left(I/I_r\right) = \log\left(I_0/I_r\right) + \log\left(e^{-2mx}\right)$$

$$\log\left(I/I_r\right) = \log\left(I_0/I_r\right) - 2mx\log(e)$$

$$10\log\left(I/I_r\right) = 10\log\left(I_0/I_r\right) - 20mx\log(e)$$

$$L = L_0 - ax \quad \text{where}$$

$$a = 20m\log_{10}(e) \times \frac{1000\text{ m}}{\text{km}}$$

$$\boxed{a = 8686m \text{ dB/km}}$$

Example from Figure 6.1

- Interactive applet for finding absorption coefficient *a*.
- Figure 6.1 shows for 20°C, 20% relative humidity, f = 6000 Hz, that m = 0.0016 m^{-1}.

$$a = 8686\,m = 8686\left(0.0016\ \mathrm{m}^{-1}\right)$$

$$= 13.90\ \mathrm{dB/km}$$

- Wolfram value: 144.4 dB/km (m = 0.0166 m^{-1})
- Handbook of Chemistry and Physics 1995: 134.98 dB/km at 6300 Hz (m = 0.0155 m^{-1})
- I conclude that figure 6.1 *y*-axis labels should all be multiplied by ten. [publisher confirmed 3/12/2013]

Attenuation by reflection

- The wave intensity decreases due to partial absorption and transmission of the sound wave at a boundary (*external* absorption)
- Attenuation is described by a boundary “absorption” coefficient called *α*:

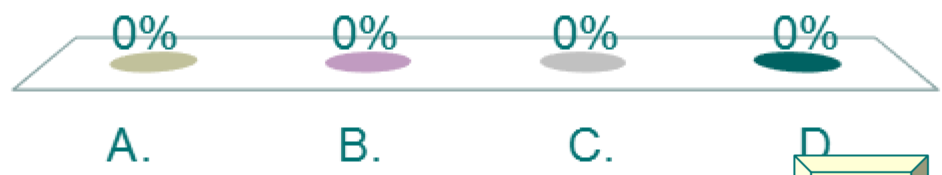
$$\alpha = \frac{\text{absorbed or transmitted intensity}}{\text{incident intensity}} = \frac{I_{\text{absorbed}}}{I_0}$$

$$\beta = \frac{\text{reflected intensity}}{\text{incident intensity}} = \frac{I_{\text{reflected}}}{I_0}$$

$$\alpha + \beta = 1 \text{ (total energy is conserved)}$$

A cap gun emits a sound wave of intensity $I_0 = 1.93\times10^{-7}$ W/m^2 after it has traveled 101 m. What will I be if absorption by a painted concrete wall is taken into account? Let $\alpha = 0.080$.

A. 4.17×10^{-5} W/m^2
B. 1.78×10^{-7} W/m^2
C. 9.69×10^{-8} W/m^2
D. 4.17×10^{-12} W/m^2



Response Counter

180

A cap gun emits a sound wave of intensity $I_0 = 1.93\times10^{-7}$ W/m² after it has traveled 101 m. What will I be if absorption by a painted concrete wall is taken into account? Let $\alpha = 0.080$.

A. 4.17×10^{-5} W/m²

B. 1.78×10^{-7} W/m²

C. 9.69×10^{-8} W/m²

D. 4.17×10^{-12} W/m²

$$\beta = 1 - \alpha = 1 - 0.080 = 0.92$$

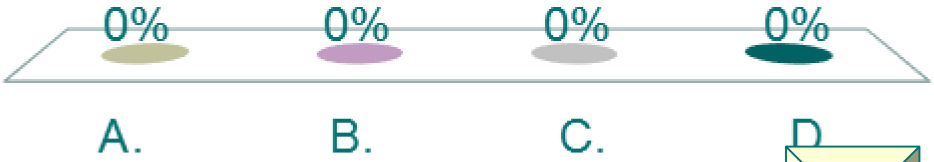
$$I_{\text{reflected}} = \beta I_0 = (0.92)\left(1.93\times10^{-7}\ \text{W/m}^2\right)$$

$$= \boxed{1.78\times10^{-7}\ \text{W/m}^2}$$

The reflection reduced the level from 52.9 dB to 52.5 dB

A cap gun emits a sound level L_0 = 52.5 dB after it has traveled 101 m and reflected from a concrete wall. What will L be if atmospheric absorption is taken into account? Let a = 29.63 dB/km.

A. 2.99 dB
B. 18.7 dB
C. 49.5 dB
D. 52.9 dB



Response Counter

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A cap gun emits a sound level L_0 = 52.5 dB after it has traveled 101 m and reflected from a concrete wall. What will *L* be if atmospheric absorption is taken into account? Let *a* = 29.63 dB/km.

A. 2.99 dB

B. 18.7 dB

C. 49.5 dB

D. 52.9 dB

$$L = L_0 - a\,x$$

$$= 52.5\text{ dB} - (29.63\text{ dB/km})(0.101\text{ km})$$

$$L = 52.5\text{ dB} - 2.99\text{ dB} = \boxed{49.5\text{ dB}}$$

We would get 52.9 dB if reflection and absorption not taken into account.

The values given in these examples are intended to be realistic for the cap gun experiment in the basement hallway last week. The temperature was assumed to be 20°C, RH 50%, f = 4000 Hz, a value from Wolfram web site, α from Table 6.1 p. 109 for painted concrete.