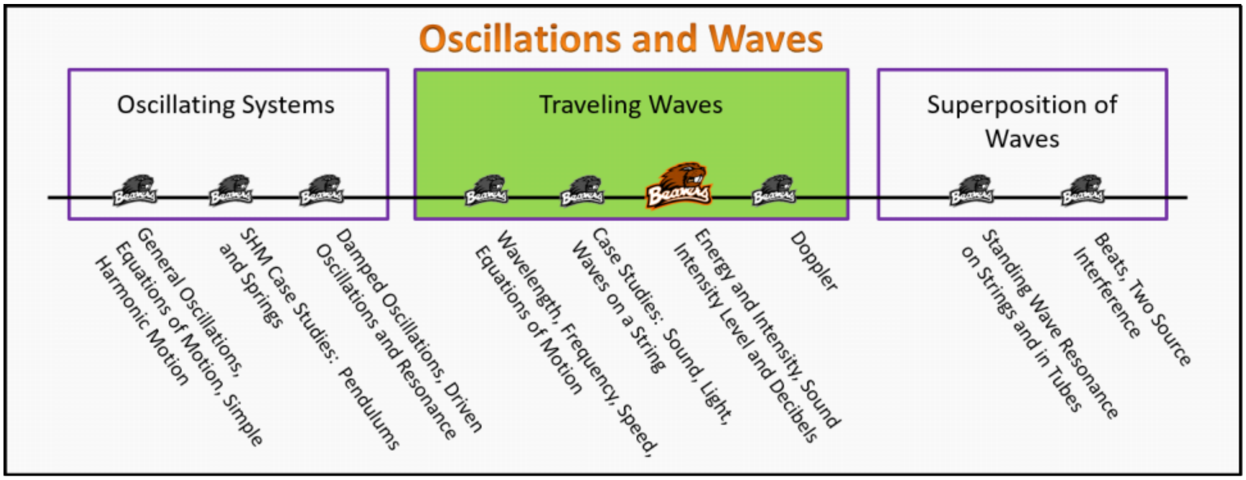
Traveling Waves
Foundation Stage (TW.2.L3)

Lecture 3
Energy and Intensity, Sound Intensity Level and Decibels



Textbook Chapters (* Calculus version)

- **BoxSand** :: KC videos (Traveling Waves)
- **Knight** (College Physics : A strategic approach 3rd) :: 15.5 ; 15.6
- ***Knight** (Physics for Scientists and Engineers 4th) :: 16.8
- **Giancoli** (Physics Principles with Applications 7th) :: 12-1 ; 12-2 ; 12-3

Warm up

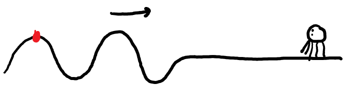
TW.2.L3-1:

Description: Identify phenomena that verifies energy is transported via traveling waves.

Learning Objectives: [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

Problem Statement: Traveling waves transport energy from one location to another without necessarily transporting mass. With your neighbors, try to identify different observations that verify energy is transported via traveling waves.

WAVE ON STRING EXAMPLE



BUG ON END OF STRING IS
INITIALLY STATIONARY w/ KE=0
BUT EVENTUALLY BEGINS TO MOVE KE ≠ 0
YET RED PIECE OF TAPE ON STRING
DID NOT TRAVEL FROM LEFT TO RIGHT.

Selected Learning Objectives

1. Coming soon to a lecture template near you.

Key Terms

- Power
- Intensity
- Threshold of human hearing intensity
- Sound intensity level
- Decibels

Key Equations

$\beta = 10\log_{10}\left(\frac{\Sigma I}{I_o}\right)$	$P = \frac{\Delta E}{\Delta t}$	$I = \frac{P}{A}$

Key Concepts

- Coming soon to a lecture template near you.

Questions

Act I: Energy, Power, and Intensity

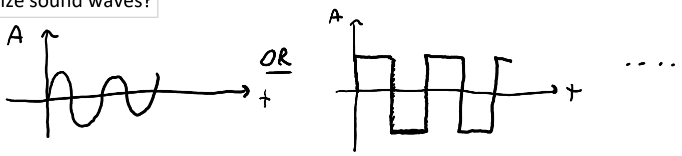
TW.2.L3-2:

Description: Conceptual question about how sound is characterized. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: What are some ways we characterize sound waves?

T [✓ (1)] Frequency.
T [✓ (2)] Pitch.
T [✓ (3)] Loudness.
T [✓ (4)] Shape of waveform.
F (5) What planet you are on while wiggling the rope.
? (6) Color.
? (7) Taste. SYNESTHESIA ?



TW.2.L3-3:

Description: Fill out an energy flow diagram involving traveling waves. (4 minutes)

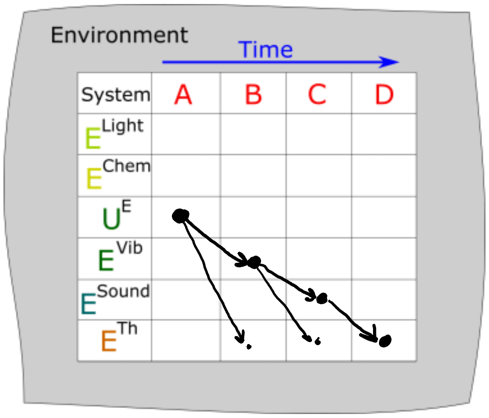
Learning Objectives: [1, 12, 13]

Problem Statement: Consider a speaker in a large empty room being driven by electricity. Fill out the energy flow diagram below given the following snapshots in time:

A: The moment the speaker is turned on.
B: The moment after the speaker is turned on the speaker cone begins to move.
C: Noise from the speaker reaches the other side of the room.
D: The speak is turned off and no noise can be heard in the room.

System: electrons in power cord, speaker (all parts including cone), atmosphere

* **U^E** is electric potential energy



TW.2.L3-4:

Description: Conceptual question about features of traveling waves and their source. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Which of the following things are constants with respect to time in a speaker system playing a constant volume tone?

F (1) Total energy output.
T [✓ (2)] Power of speaker.
F (3) Amplitude of sound wave.
T [✓ (4)] Frequency of speaker.
F (5) Displacement of sound wave.

TW.2.L3-5:

Description: Conceptual questions about power and its unit. (1 minute + 2 minutes + 2 minutes).

Learning Objectives: [1, 12, 13]

Problem Statement: Power power power power.

(a) What are the SI units for a watt?

[✓ (1)] J/s
(2) J·s
(3) J·s^2
(4) J/s^2

(b) What expression could be used to find the total energy generated by a speaker playing at a certain watt value?

[✓ (1)] Power · (delta time)
(2) Power · (delta time)^2
(3) Power / (delta time)
(4) Power / (delta time)^2

$$\text{POWER} = \frac{\text{ENERGY}}{\text{TIME}} \qquad P = \frac{\Delta E}{\Delta t}$$

(c) Which of the following are units of energy?

(1) Watt
(2) Watt/hr
[✓ (3)] Watt-hr
[✓ (4)] kW-hr

$$\sim \frac{J}{s}\cdot \text{HR} \rightarrow \frac{\text{ENERGY}}{\text{TIME}}\cdot \text{TIME} = \text{ENERGY}$$

TW.2.L3-6:

Description: Calculate time given power, energy, and frequency. (4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A speaker is emitting a constant tone of middle C (about 262 Hz) at 25 W. How long does it take to emit 400 J of energy?

(1) 0.0625 s
(2) 0.25 s
(3) 4 s
[✓ (4)] 16 s
(5) 256 s

$$P = \frac{\Delta E}{\Delta t}$$

$$\Delta t = \frac{\Delta E}{P}$$

$$\Delta t = \frac{400\ J}{23\ J/s} = \boxed{16\ s}$$

TW.2.L3-7:

Description: Calculate power given energy, time, efficiency. (4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: To warm up a cup of coffee from room temperature to a nice hot drinking temperature takes about 70000 J. It takes Black Canary 2000 seconds of yelling using her Canary Cry at a cup of coffee to warm the drink up to a nice temperature. If the efficiency of depositing the sound energy into the coffee is 1%, what is the power of her voice?

(1) 0.0286 W
(2) 3.5 W
(3) 10 W
(4) 35 W
[✓ (5)] 3500 W
(6) 7500 W

$$e = \frac{GET}{PAY} = \frac{\Delta E^{TH}}{\Delta E^{Sound}}$$

$$e = \frac{\Delta E^{Th}}{\Delta E^{Sound}} \qquad P_{Sound} = \frac{\Delta E^{Sound}}{\Delta t}$$

$$e = \frac{\Delta E^{Th}}{P\Delta t}$$

$$P = \frac{\Delta E^{Th}}{e\Delta t} = \frac{7000\ J}{(0.01)(2000\ s)} \simeq 3500\ \frac{J}{s}$$

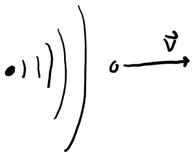
TW.2.L3-8:

Description: Conceptual question about features of traveling waves and their source. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Which of the following things are constants with respect to time in a speaker system playing a constant volume tone as you walk away from it at a constant speed?

F (1) Total energy output of speaker.
T [✓ (2)] Power of speaker.
F (3) Power absorbed in your ear drums.
F (4) Amplitude of sound wave.
T [✓ (5)] Frequency of speaker.
F (6) Displacement of sound wave.
F (7) Intensity observed.



$$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

$$I = \frac{P}{A}$$

TW.2.L3-9:

Description: Proportional reasoning with Intensity. Calculating power from spherical source given intensity and distance from source. (3 minutes + 4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: You are initially standing 4 meters from a speaker where the sound intensity is 1 x 10^8 W/m^2. You then walk to 8 meters away from the speaker.

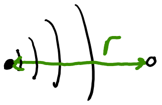
SAME SPEAKER SAME VOLUME $P = \text{CONST}$

(a) What is the sound intensity at your new location?

[✓ (1)] 0.25 x 10^8 W/m^2
(2) 0.50 x 10^8 W/m^2
(3) 1.00 x 10^8 W/m^2
(4) 2.00 x 10^8 W/m^2
(5) 4.00 x 10^8 W/m^2

$$I = \frac{P}{A}$$

$$I = \frac{P}{4\pi r^2}$$



$$I \propto \frac{1}{r^2} \qquad r \rightarrow 2r$$

$$I \rightarrow \frac{1}{4} I$$

(b) What is the power output of the ideal spherical speaker?

PICK EITHER LOCATIONS

$$I = \frac{P}{A}$$

$$P = IA$$

INITIAL

$$P = I\,4\pi r^2$$

$$= \left(1\times10^8 \frac{W}{m^2}\right)(4)(\pi)(4\,m)^2$$

$$\boxed{P \approx 2.01 \times 10^{10}\ W}$$

SAME ANSWER

FINAL

$$P = I\,4\pi r^2$$

$$= (0.25\times10^8\,W/m^2)(4)(\pi)(8\,m)^2$$

$$P \approx 2.01\times10^8\ W$$

Act II: Non-spherical Cross-sectional Areas

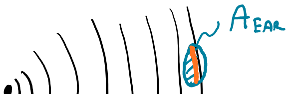
TW.2.L3-10:

Description: Calculate the power absorbed by a circular cross-section given area, intensity, and distance from source. Calculate how much energy is absorbed by circular cross-section given area, intensity, distance away from source, and time. (4 minutes + 3 minutes)

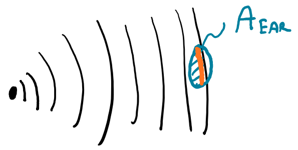
Learning Objectives: [1, 12, 13]

Problem Statement: The average human eardrum has a cross-sectional area of about 6.0 x 10^{-5} m^2.

(a) What is the power absorbed by your eardrum if you are standing 4 meters away from a speaker where the intensity is 1 x 10^8 W/m^2 ?



$$P_{EAR} = IA$$



$$P_{EAR} = IA$$

$$P_{EAR} = (1\times10^{8}\ W/m^2)(6.0\times10^{-5}\ m^2) \approx \boxed{6000\ W}$$

(b) How much energy is absorbed by your eardrum in the length of a Pink Floyd song? For example, Time is about 6 minutes 48 seconds long.

$$P = \frac{\Delta E}{\Delta t}$$

$$\underline{SI}$$

$$\Delta t = 6\ min \times \frac{60\ s}{1\ min} + 48\ s = 408\ s$$

$$\Delta E = P\Delta t$$

$$\Delta E = (6000\ W)(408\ s)$$

$$\Delta E = 166464\ J \approx \boxed{166000\ J}$$

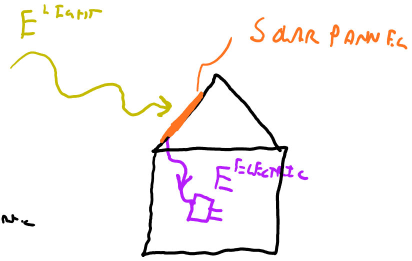
TW.2.L3-11:

Description: Calculate flat cross-sectional area given power, intensity, and efficiency. (6 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Energy, power, and intensity are quantities not only specific to sound wave, but all other types of waves (e.g. light waves). Your task is to design a solar panel that has a power output of about 10 W. The solar panel is to sit on the top of a house where the solar radiation intensity is about 1360 W/m^2. If the efficiency of the solar panels you are using is 15%, what size area of solar panels do you need?

$$e = \frac{GET}{PAY} = \frac{\Delta E^{ELECTRIC}}{\Delta E^{LIGHT}}$$



$$e = \frac{\Delta E^{ELECTRIC}}{\Delta E^{LIGHT}}$$

10 W

$\downarrow$

$$P_E = \frac{\Delta E^{ELECTRIC}}{\Delta t}$$

$$e = \frac{P_E \cancel{\Delta t}}{I_L A_L \cancel{\Delta t}}$$

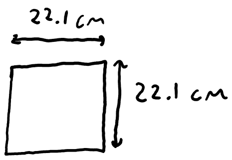
$$I_L = \frac{P_L}{A_L} = \frac{\Delta E_L}{A_L \Delta t}$$

$$\Delta E^{L} = I_L A_L \Delta t$$

$$e = \frac{P_E}{I_L A_L}$$

$$A_L = \frac{P_E}{e I_L} = \frac{10\ W}{[illegible]} \approx \boxed{0.0490\ m^2} \times \left(\frac{100\ cm}{[illegible]}\right)^2 = 490\ cm^2$$

$$\boxed{A_L = \frac{P_E}{e I_L}} = \frac{10\ W}{(0.15)(1360\ W/m^2)} \approx \boxed{0.0490\ m^2} \times \left(\frac{100\ cm}{1\ m}\right)^2 = 490\ cm^2$$



$$\sqrt{490\ cm^2} = 22.1\ cm$$

Act III: Sound Intensity Level and Decibels

TW.2.L3-12:

Description: Calculate intensity of spherical sound source given decibels, and distance from source. (5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Testing a sound system with several speakers set up so as to simulate a point source, a consumer noted that she could get as close to 1.2 m with the volume full on before sound hurt her ears (120 dB). What is the intensity of the sound at her location?

(1) 1.0 dB
[✓ (2) 1.0 W/m^2]
(3) 1.20 W/m^2
(4) 120 dB
(5) 120 Wm/^{2}

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

$$120 = 10 \log_{10}\left(\frac{\Sigma I}{I_0}\right)$$

$$10^{(12)} = 10^{\left(\log_{10}\left(\frac{\Sigma I}{I_0}\right)\right)}$$

$$10^{12} = \frac{\Sigma I}{I_0}$$

$$\Sigma I = 10^{12}\, I_0$$

$$= 10^{12}\left(1\times10^{-12}\ \frac{W}{m^2}\right)$$

$$\Sigma I = 1\ W/m^2$$

TW.2.L3-13:

Description: Calculate ratio of initial and final intensity given change in sound intensity level. (5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A sound is found to have a sound intensity level difference of 10 dB from one moment to the next. What is the ratio of the intensity of the sound at the observer final over initial (I_f/I_i)?

(1) 2
(2) 100
(3) 0.01

$$\Delta\beta = \beta_f - \beta_i$$

$$= 10 \log\left(\frac{I_f}{\ }\right) - 10 \log\left(\frac{I_i}{\ }\right)$$

(1) 2
(2) 100
(3) 0.01
[✓ (4)] 10
(5) 0.1

$$\Delta\beta = \beta_f - \beta_i$$

$$= 10\log_{10}\left(\frac{I_f}{I_0}\right) - 10\log_{10}\left(\frac{I_i}{I_0}\right)$$

$$\Delta\beta = 10\left(\log_{10}\left(\frac{I_f}{I_0}\right) - \log_{10}\left(\frac{I_i}{I_0}\right)\right)$$

$$= 10\log_{10}\left(\frac{I_f}{I_0}\cdot\frac{I_0}{I_i}\right)$$

$$\Delta\beta = 10\log_{10}\left(\frac{I_f}{I_i}\right)$$

$$10^{10/10} = \boxed{10^{\Delta\beta/10} = \frac{I_f}{I_i}}$$

TW.2.L3-14:

Description: Calculate final power and distance from source given initial power, and decibels (5 minutes + 4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Listening to a speaker you record the sound intensity level to be 97 dB from a 6.3 W source. The source is then amplified, and the new sound intensity level is 107 dB.

(a) What is the new power coming from the source?

(1) 6.95 W
(2) 12.6 W
(3) 25.2 W
[✓ (4)] 63.0 W

$$\Delta\beta = 10\log_{10}\left(\frac{I_f}{I_i}\right)$$

10 dB

$$\Delta\beta = 10\log_{10}\left(\frac{(P_f/A_f)}{(P_i/A_i)}\right) \qquad A_i = A_f$$

$$\Delta\beta = 10\log_{10}\left(\frac{P_f}{P_i}\right)$$

$$10^{\Delta\beta/10} = \frac{P_f}{P_i}$$

$$\boxed{P_f = P_i\,10^{\Delta\beta/10}} = 6.3\,W\left(10^{10/10}\right)$$

$$= 63\,W$$

(b) How far away are you from the source?

USE EITHER INITIAL OR FINAL

(1) 1 m
(2) 2 m
[✓ (3)] 10 m
(4) 25 m

$$I_i = \frac{P_i}{A}$$

$$\beta_i = 10\log_{10}\left(\frac{I_i}{I}\right)$$

(1) 1 m
(2) 2 m
[✓ (3) 10 m]
(4) 25 m
(5) 100 m

$$I_i = \frac{P_i}{A_i}$$

$$I_i = \frac{P_i}{4\pi r_i^2}$$

$$\boxed{r_i = \sqrt{\frac{P_i}{4\pi I_1}}}$$

$$r_i \approx 10 \text{ m}$$

$$\beta_i = 10 \log_{10}\left(\frac{I_i}{I_0}\right)$$

$$97 = 10 \log_{10}\left(\frac{I_i}{I_0}\right)$$

$$10^{9.7} = \frac{I_i}{I_0}$$

$$I_i = I_0 10^{9.7} \text{ W/m}^2$$

TW.2.L3-15:

Description: Conceptual question about which quantities add linearly when multiple sources are present. (2 minutes + 1 minute)

Learning Objectives: [1, 12, 13]

Problem Statement: Sound intensity level with multiple sources of sound.

(a) If you have multiple sources, what quantities can you add together to find the sound intensity level at a location of interest?

(1) Power
[✓ (2) Intensity]
(3) Intensity level (dB)

$$\beta = 10 \log_{10}\left(\frac{\overset{\checkmark\; I_1 + I_2 + I_3 + \dots}{\Sigma I}}{I_0}\right) \quad \frac{P_1}{A_1} + \frac{P_2}{A_2} + \frac{P_7}{A_3} + \dots$$

(b) If you have multiple sources that HAPPEN to be at the same location, what quantities can you add to find the sound intensity level at a location of interest?

[✓ (1) Power]
[✓ (2) Intensity]
(3) Intensity level (dB)

$$\Sigma I = \frac{P_1}{A} + \frac{P_2}{A} + \frac{P_3}{A} + \dots$$

$$\frac{1}{A}\left(P_1 + P_2 + P_3 + \dots\right)$$

$$\frac{\Sigma P}{A}$$

TW.2.L3-16:

Description: Calculate change in decibels given multiple identical sources at same location when one or more of them suddenly stop. (5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Four identical trumpet players are playing the same note at the same positions. If three of them suddenly stop, the sound intensity level decreases by how much?

Problem Statement: Four identical trumpet players are playing the same note at the same positions. If three of them suddenly stop, the sound intensity level decreases by how much?

(1) 3 dB
(2) 4 dB
[✓ (3) 6 dB]
(4) 12 dB
(5) 40 dB
(6) Depends on the frequency

$P_1 = P_2 = P_3 = P_4 = P$

$\Delta\beta = 10\log_{10}\left(\frac{\Sigma I_f}{\Sigma I_i}\right)$

B/c @ SAME LOCATION

$\Sigma I_i = \frac{1}{A}\Sigma P_i = \frac{4P}{A}$

$\Sigma I_f = \frac{1}{A}\Sigma P_f = \frac{P}{A}$

$$\Delta\beta = 10\log_{10}\left(\frac{(4P/A)}{(P/A)}\right)$$

$$\Delta\beta = 10\log_{10}(4) \approx 6.02 \text{ dB}$$

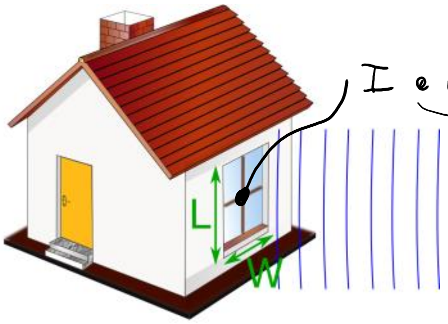
TW.2.L3-17:

Description: Calculate energy absorbed by square cross-sectional window given side lengths, decibels, and time. (8 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Sound is coming through an open window whose dimensions are 1.1 m x 0.75 m. The sound intensity level is 95 dB above the pain threshold of human hearing. How much sound energy comes through the window in one hour? The threshold level of pain for humans is about 120 dB.

$\beta = 95 + 120 = 215$ dB



I @ window

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

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

$$10^{\beta/10} = \frac{I}{I_0}$$

$$I = I_0 10^{\beta/10}$$

I @ window

$$I = \frac{P}{A} = \frac{\Delta E/\Delta t}{A}$$

$$I = \frac{\Delta E}{A\Delta t}$$

$$\frac{\Delta E}{A\Delta t} = I_0 10^{\beta/10}$$

$$\Delta E = A\Delta t I_0 10^{\beta/10}$$

$$(1.1m)(0.75m)(3600 s)(1\times10^{-12} W/m^2)10^{215/10}$$

$$\approx \boxed{9.39\times10^{12} J}$$

Conceptual questions for discussion

1. Coming soon to a lecture template near you.

Hints

TW.2.L3-1: No hints.

TW.2.L3-2: No hints.

TW.2.L3-3: No hints.

TW.2.L3-4: No hints.

TW.2.L3-5: No hints.

TW.2.L3-6: No hints.

TW.2.L3-7: No hints.

TW.2.L3-8: No hints.

TW.2.L3-9: No hints.

TW.2.L3-10: No hints.

TW.2.L3-11: No hints.

TW.2.L3-12: No hints.

TW.2.L3-13: No hints.

TW.2.L3-14: No hints.

TW.2.L3-15: No hints.

TW.2.L3-16: No hints.

TW.2.L3-17: No hints.