TW.2.L3 - Solutions

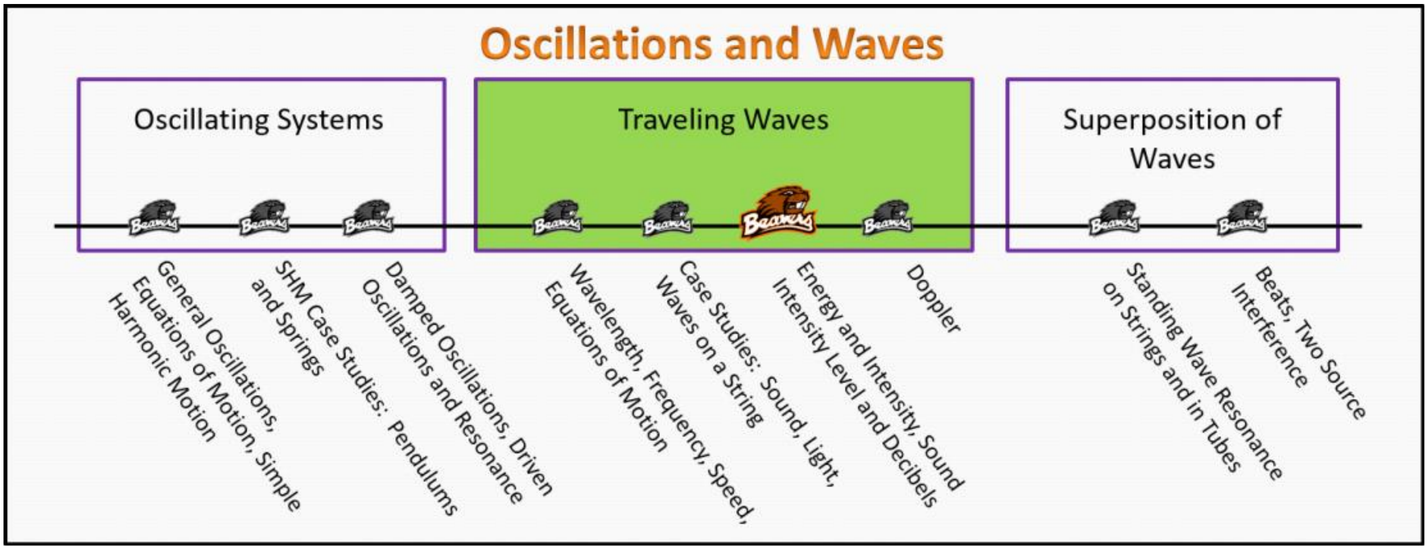
Friday, March 8, 2019 7:10 AM

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.L2-1:

Description: Using a graphing device, plot a sin function and determine its motion based on adding and subtracting a constant in the argument.

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

Problem Statement: Traveling waves arise from a collection of coupled oscillators. For each of the following waves, identify what the oscillators are. For example, the oscillators of a water wave are the water molecules.

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

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

Key Concepts

- Coming soon to a lecture template near you.

Questions

Act I: Energy, Power, and Intensity

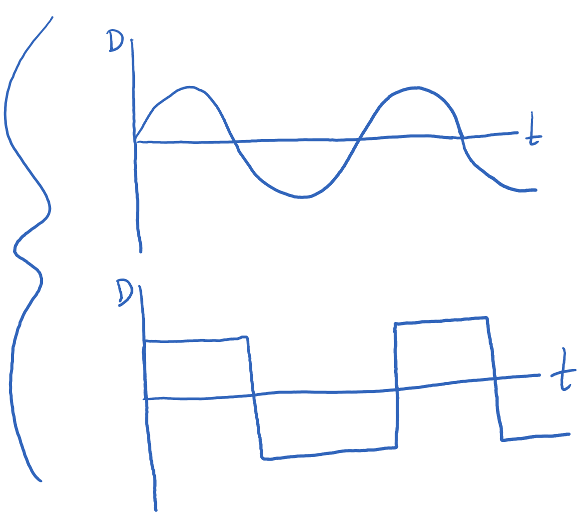
TW.2.L2-2:

Description: Conceptual question about features of oscillators. (3 minutes)

Learning Objectives: [1, 12, 13]

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

(1) Frequency. } Same
(2) Pitch.
(3) Loudness. ← Amp
(4) Shape of waveform.
(5) What planet you are on while wiggling the rope.
(6) Color.
(7) Taste.



TW.2.L2-3:

Description: Given graphs of potential energy vs position identify non-oscillatory motion. (3 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

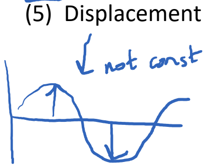
TW.2.L2-4:

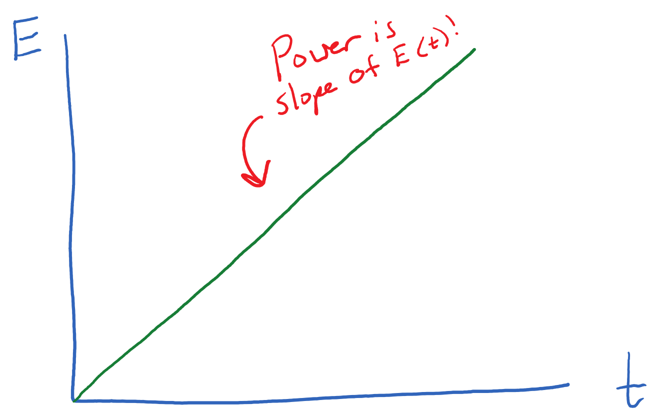
Description: Conceptual question about features of oscillators. (2 minutes + 2 minutes + 2 minutes + 2 minutes)

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?

(1) Total energy output.
(2) Power of speaker.
(3) Amplitude of sound wave.
(4) Frequency of speaker.
(5) Displacement of sound wave.





$P = \frac{\Delta E}{\Delta t} \Rightarrow$ slope!

$\Rightarrow$ const

TW.2.L2-5:

Description: Given graphs of potential energy vs position identify simple harmonic oscillators. (3 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) $J \cdot s^2$
(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

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

$$\Rightarrow \left[\frac{J}{s}\right][s] \Rightarrow [J]$$

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

(1) Watt
(2) Watt/hr
(3) Watt-s
(4) kW-hr

$$W\text{-}s \Rightarrow \left[\frac{J}{s}\right][s] = [J] \checkmark$$

$$(1000\,W)(3600\,sec) = 3.6 \times 10^6\,J = 1\,kW\text{-}hr$$

TW.2.L2-6:

Description: Given force equations as a function of displacement from equilibrium, identify which would give rise to simple harmonic motion. (3 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?

(f = 262 Hz, P = 25 W, Δt?, ΔE = 400 J)

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

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

$$\Rightarrow \Delta t = \frac{400\,J}{25\,W} = 16 \frac{[J]}{[J/s]} = 16\,s$$

TW.2.L2-7:

Description: Conceptual question about period for simple harmonic motion. (2 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 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

$P = \frac{\Delta E}{\Delta t} = \frac{70{,}000\text{ J}}{2{,}000\text{ s}} = 35\text{ W}$ absorbed by coffee

$\Rightarrow P_{BC} = 100 \times P_{absorbed}$

$P_{BC} = 3{,}500\text{ W}$

TW.2.L2-8:

Description: Conceptual question about features of oscillators. (2 minutes + 2 minutes + 2 minutes + 2 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?

(1) Total energy output of speaker.
(2) Power of speaker.
(3) Power absorbed in your ear drums.
(4) Amplitude of sound wave.
(5) Frequency of speaker.
(6) Displacement of sound wave.

power is spread over larger area as wave moves out in every direction (spherical source) ⇒ Intensity decreases ⇒ Power absorbed by ear decreases

TW.2.L2-9:

Description: Complete an energy flow diagram for a SHO. (3 minutes)

Learning Objectives: [1, 12, 13]

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

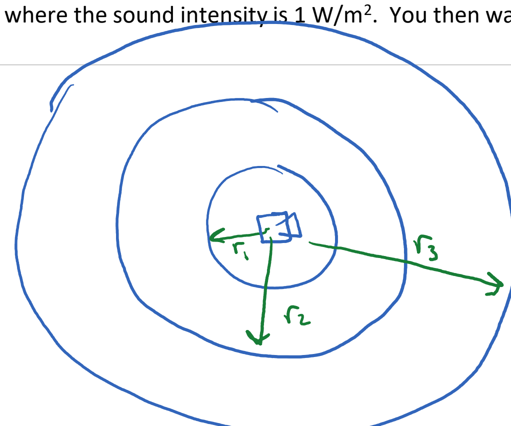
(a) What is the sound intensity at your new location?

(1) 0.25 W/m^2
(2) 0.50 W/m^2
(3) 1.00 W/m^2
(4) 2.00 W/m^2
(5) 4.00 W/m^2

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

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

$\Rightarrow r\uparrow^2 \Rightarrow I\downarrow_4$



Same amount of power is spread over each sphere

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

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Same amount of power is spread over each sphere

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

$(0.25 \frac{W}{m^2})(4\pi(8m)^2)$ or

$\Rightarrow P = IA = (1 \, W/m^2)(4\pi(4m)^2)$

$= 64\pi \, W = \boxed{201 \, W}$

Act II: Non-spherical Cross-sectional Areas

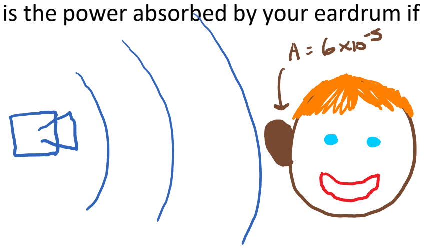
TW.2.L2-10:

Description: Conceptual question relating energy and amplitude of a simple harmonic oscillator. (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 W/m^2 ?



$I = P/A$

$\Rightarrow P = IA$

$= (1 \frac{W}{m^2})(6\times10^{-5} m^2)$

$= \boxed{6\times10^{-5} \, W}$

or!

$\frac{P_{ear}}{P_{tot}} = \frac{A_{ear}}{A_{tot}}$

$P_{ear} = (201 \, W)\left(\frac{6\times10^{-5} m^2}{64\pi \, m^2}\right)$

$= 6\times10^{-5} \, W$

(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.

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

$\Rightarrow \Delta E = P\Delta t = (6\times10^{-5} \frac{J}{s})(408 \, sec) = \boxed{0.025 \, J}$

TW.2.L2-11:

Description: Conceptual question relating energy and amplitude of a simple harmonic oscillator. (3 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?

Intensity Power eff. A?

Intensity Power eff. A?

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

$$\Rightarrow A = \frac{P}{I} = \frac{10\,W}{1360\,W/m^2} = 0.0074\,m^2$$ but 15% eff. ⇒ need bigger!

$$\frac{0.0074\,m^2}{0.15} = 0.049\,m^2 = 490\,cm^2$$

or ~ 22 cm × 22 cm

Act III: Sound Intensity Level and Decibels

TW.2.L2-12:

Description: Energy analysis for a SHO. (6 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/m²
(3) 1.20 W/m²
(4) 120 dB
(5) 120 Wm/²

$$\beta = 10\,dB \log\left(\frac{I}{I_0}\right) \qquad I_0 = 10^{-12}\,\frac{W}{m^2}$$

$$\Rightarrow 120\,dB = 10\,dB \log\left(\frac{I}{I_0}\right)$$

$$12 = \log\left(\frac{I}{I_0}\right)$$

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

$$I = (10^{12})(10^{-12}\,\frac{W}{m^2}) = 1\,\frac{W}{m^2}$$

TW.2.L2-13:

Description: Energy analysis for a SHO. (6 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
(4) 10
(5) 0.1

$$\beta_f - \beta_i = 10\,dB = 10\,dB \log\left(\frac{I_f}{I_0}\right) - 10\,dB \log\left(\frac{I_i}{I_0}\right)$$

$$\Rightarrow 1 = \log\left(\frac{I_f}{I_0}\right) - \log\left(\frac{I_i}{I_0}\right)$$

$$1 = \log\left(\frac{I_f/I_0}{I_i/I_0}\right)$$

$$1 = \log\left(\frac{I_f}{I_i}\right)$$

$$10 = \frac{I_f}{I_i}$$

+10 dB = 10x more intense!

TW.2.L2-14:

Description: Energy analysis for a SHO. (6 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

$$107\,dB - 97\,dB = 10\,dB \log\frac{I_f}{I_0} - 10\,dB \log\frac{I_i}{I_0}$$

$$10\,dB = 10\,dB \log\left(I_f/I_i\right)$$

$$1 = \log\left(I_f/I_i\right)$$

$$I_f = 10 \times 6.3\,W = 63\,W$$

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

(1) 1 m
(2) 2 m
(3) 10 m
(4) 25 m
(5) 100 m

$$I = \frac{P}{A}$$ ← depends on distance from source!

$$4\pi r^2 = \frac{P}{I}$$ P ← know (6.3W); I ← we know intensity level

$$97\,dB = 10\,dB \log\left(\frac{I}{I_0}\right)$$

$$9.7 = \log\left(\frac{I}{I_0}\right)$$

$$10^{9.7} = \frac{I}{10^{-12}\,\frac{W}{m^2}}$$

$$I = 10^{-2.3}\,\frac{W}{m^2}$$

$$\Rightarrow r = \sqrt{\frac{1}{4\pi}\frac{P}{I}} = \sqrt{\frac{1}{4\pi}\frac{6.3}{10^{-2.3}}} = 10\,m$$

TW.2.L2-15:

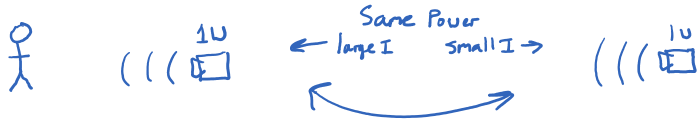
Description: Energy analysis for a SHO. (6 minutes)

Learning Objectives: [1, 12, 13]

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

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

(1) Power
(2) Intensity
(3) Intensity level (dB)



Can't add Power, need to add Intensities

if have 1 speaker, then add another speaker
⇒ intensity doubles
⇒ intensity level (β) does not double!!

$$\Delta\beta = 10\,dB \log\left(\frac{I_f}{I_i}\right)$$
$$\Delta\beta = 10\,dB \log(2)$$
$$\Rightarrow \Delta\beta = +3\,dB$$

(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?

Power, Intensity

TW.2.L2-16:

Description: Energy analysis for a SHO. (6 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?

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

$$\frac{I_f}{I_i} = \frac{1}{4}$$

$$\beta_f - \beta_i = 10\,dB \log\left(\frac{I_f}{I_0}\right) - 10\,dB \log\left(\frac{I_i}{I_0}\right)$$

$$\Delta\beta = 10\,dB \log\left(\frac{I_f}{I_i}\right)$$

$$\Delta\beta = 10\,dB \log\left(\frac{1}{4}\right)$$

$$\Delta\beta = 10\text{ dB}\,\log\left(\tfrac{1}{4}\right)$$

$$\Delta\beta = -6\text{ dB}$$

TW.2.L2-17:

Description: Energy analysis for a SHO. (6 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 65 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.

$$185\text{ dB} = 10\text{ dB}\,\log\left(\frac{I}{I_0}\right)$$

$$10^{18.5} = \frac{I}{10^{-12}}$$

$$I = 10^{6.5}\ \frac{W}{m^2}$$

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

$$P = IA = \left(10^{6.5}\ \frac{W}{m^2}\right)(1.1 \times 0.75)\,m^2$$

$$= 2.61 \times 10^{6}\ W$$

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

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

$$\Rightarrow \Delta E = (2.61 \times 10^{6}\ W)(3600\text{ sec})$$

$$\Rightarrow \boxed{\Delta E = 9.39 \times 10^{9}\ J}$$

Conceptual questions for discussion

1. Coming soon to a lecture template near you.

Hints

TW.2.L2-1: No hints.

TW.2.L2-2: No hints.

TW.2.L2-3: No hints.

TW.2.L2-4: No hints.

TW.2.L2-5: No hints.

TW.2.L2-6: No hints.

TW.2.L2-7: No hints.

TW.2.L2-8: No hints.

TW.2.L2-9: No hints.

TW.2.L2-10: No hints.

TW.2.L2-11: No hints.

TW.2.L2-12: No hints.

TW.2.L2-13: No hints.