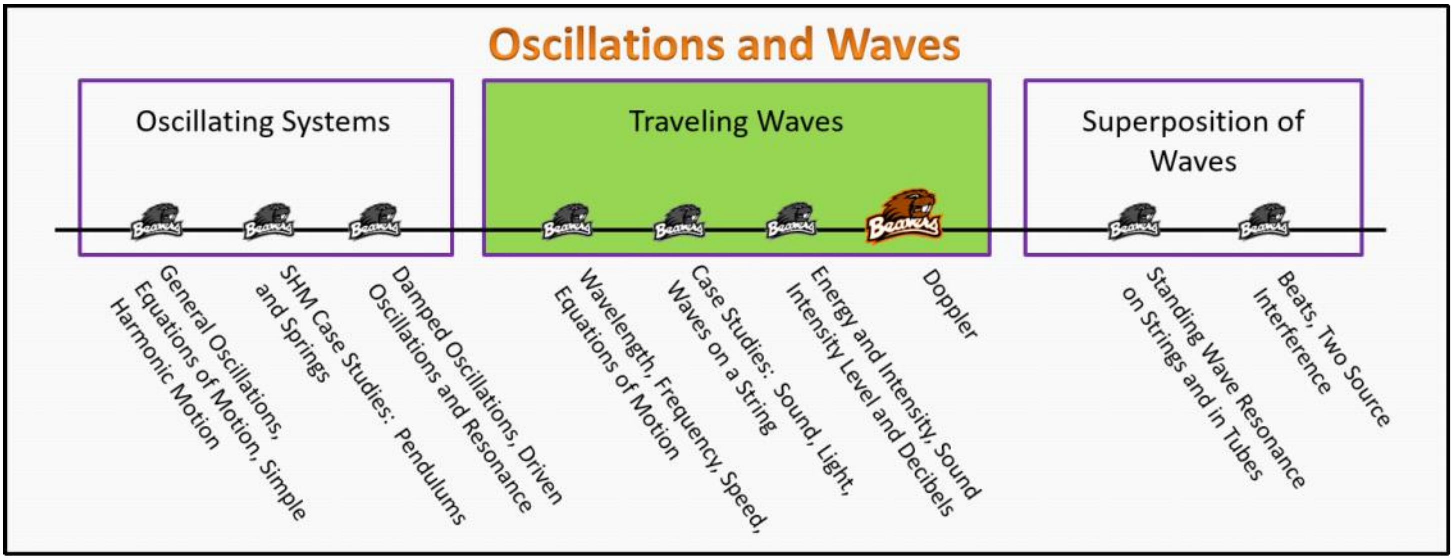
TW.2.L4 - Solutions

Tuesday, March 12, 2019 4:54 PM

Traveling Waves
Foundation Stage (TW.2.L4)

Lecture 4
Doppler



Textbook Chapters (* Calculus version)

- **BoxSand** :: KC videos (Doppler Shift)
- **Knight** (College Physics : A strategic approach 3rd) :: 15.7
- ***Knight** (Physics for Scientists and Engineers 4th) :: 16.9
- **Giancoli** (Physics Principles with Applications 7th) :: 12-7 ; 12-8 ; 12-9

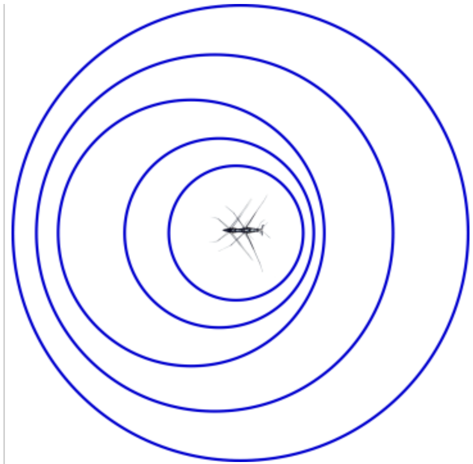
Warm up

TW.2.L4-1:

Description: Conceptual question connecting wave fronts and motion of source.

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

Problem Statement: The picture below is a top view of ripple waves made by a water bug on the surface of the water. From the wave pattern, we can see that the bug has been moving

(1) continuously to the left. (2) continuously to the right. (3) back and forth, first to the left and then right. (4) back and forth, first to the right, and then left. (5) in a circle.	

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

$f_o = f_s\left(\frac{v \pm v_o}{v \mp v_s}\right)$		

Key Concepts

- Coming soon to a lecture template near you.

Questions

Act I: Conceptual Questions and Visualization (sound)

TW.2.L4-2:

Description: Conceptual question about how observed frequency is affected by relative motion. (5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: For which of the following situations will the observer hear a decreased frequency?

(1) A source moves towards a stationary observer.
(2) A source moves away from a stationary observer.
(3) An observer moves towards a stationary source.
(4) An observer moves away from a stationary source.
(5) Observer and source are moving in the same direction but getting closer together.
(6) Observer and source are moving in same direction but getting further apart.
(7) Observer and source are moving in opposite directions but getting closer.
(8) Observer and source are moving in opposite directions but getting further apart.

TW.2.L4-3:

Description: Conceptual question about how observed frequency is affected by relative motion. (3 minutes + 4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: You hear the siren from a police car and the frequency you hear is increasing.

(a) Which of the following can you conclude are plausible?

(1) The car is receding from you at a constant speed.
(2) The car is receding from you at an increasing speed.
(3) The car is receding from you at a decreasing speed.
(4) The car is approaching you at a constant speed.
(5) The car is approaching you at an increasing speed.
(6) The car is approaching you at a decreasing speed.

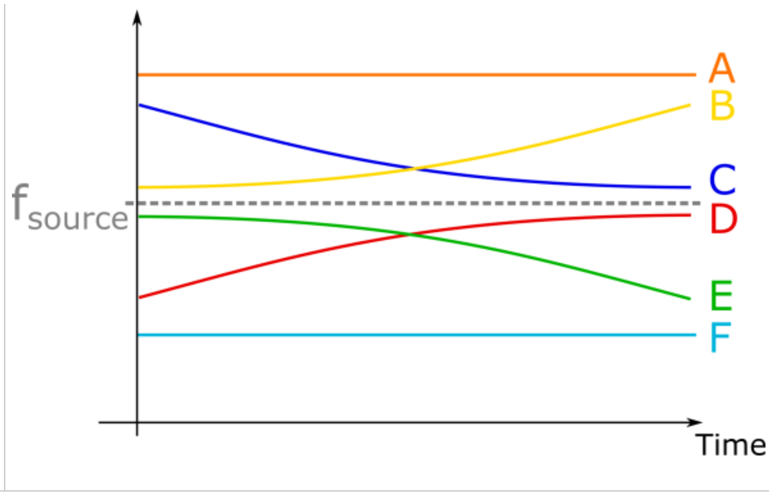
$$v \Rightarrow f$$

$$\frac{\Delta v}{\Delta t} \Rightarrow \frac{\Delta f}{\Delta t}$$

(b) Which of the following plots match with the correct answer(s) from part (a)?

(1) The car is receding from you at a constant speed.	Frequency

(2) The car is receding from you at an increasing speed.
(3) The car is receding from you at a decreasing speed.
(4) The car is approaching you at a constant speed.
(5) The car is approaching you at an increasing speed.
(6) The car is approaching you at a decreasing speed.

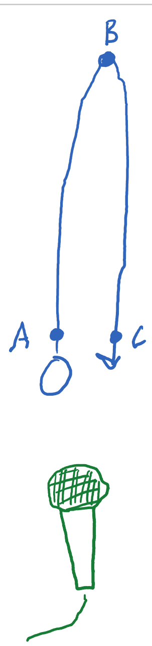


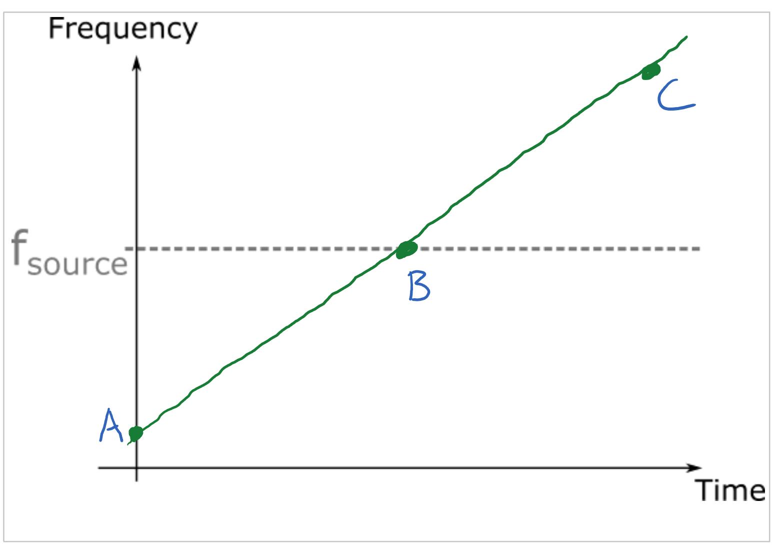
TW.2.L4-4:

Description: Conceptual question about how observed frequency is affected by relative motion. (4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A ball that generates a constant frequency (**f_{source}**) tone is thrown straight upwards above a stationary microphone. Roughly sketch on the provided plot the frequency recorded by the microphone as a function of time. Let **t** = 0 s be the time the ball leaves the hand and **t_f** be the moment right before the ball hits the ground.





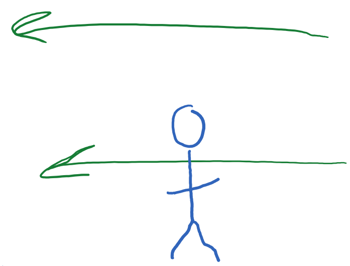
TW.2.L4-5:

Description: Conceptual question about how observed frequency is affected by wind. (3 minutes).

Learning Objectives: [1, 12, 13]

Problem Statement: On a windy day, the wind blows from a stationary source to a stationary observer. Which of the following quantities change relative to a non-windy day?

(1) Frequency of the source.
(2) Frequency of the observer.
(3) Speed of sound relative to the medium.
(4) Speed of observer relative to the medium.
(5) Speed of the source relative to the medium.
(6) Wavelength of the sound wave.



Sound travels faster

$343\,m/s + v_{wind}$

in the direction of the wind

b/c the air is moving that direction

$v = f\lambda$

$\uparrow = (\text{const}) \uparrow$

$\Rightarrow \lambda\uparrow$

Act II: Mathematical Model (sound)

TW.2.L4-6:

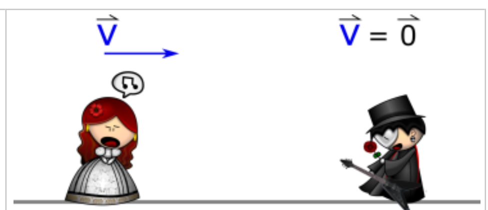
Description: Calculate observed frequency for moving source and stationary observer. (2 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: An opera lady running at 10 m/s while singing a constant frequency of 440 Hz is headed directly towards you as you are standing at rest. The speed of sound is 343 m/s.

(a) Which of the following mathematical models would correctly solve for the frequency you hear from the opera lady?

(1) $f_o = f_s\left(\frac{v}{v+v_s}\right)$	(3) $f_o = f_s\left(\frac{v-v_o}{v}\right)$
(2) $f_o = f_s\left(\frac{v}{v-v_s}\right)$	(4) $f_o = f_s\left(\frac{v+v_o}{v}\right)$



(b) Calculate the frequency you observe.

(b) Calculate the frequency you observe.

(1) 427.5 Hz
(2) 427.2 Hz
(3) 400.0 Hz
(4) 452.8 Hz
(5) 453.2 Hz

Source → observer

⇒ freq ↑

⇒ denominator ↓

⇒ $- v_s$

TW.2.L4-7:

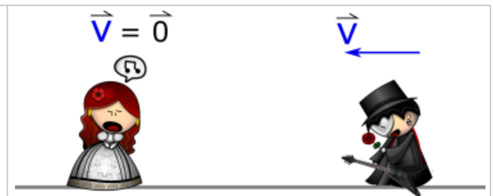
Description: Calculate observed frequency for moving observer and stationary source. (2 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: You are running at 10 m/s towards a stationary opera lady singing a constant 440 Hz tone.

(a) Which of the following mathematical models would correctly solve for the frequency you hear from the opera lady?

(1) $f_O = f_S \left(\frac{v}{v + v_S}\right)$	(3) $f_O = f_S \left(\frac{v - v_O}{v}\right)$
(2) $f_O = f_S \left(\frac{v}{v - v_S}\right)$	(4) $f_O = f_S \left(\frac{v + v_O}{v}\right)$



(b) Calculate the frequency you observe.

(1) 427.5 Hz
(2) 427.2 Hz
(3) 400.0 Hz
(4) 452.8 Hz
(5) 453.2 Hz

obs → source

⇒ f ↑

⇒ numerator ↑

⇒ $+ v_{obs}$

TW.2.L4-8:

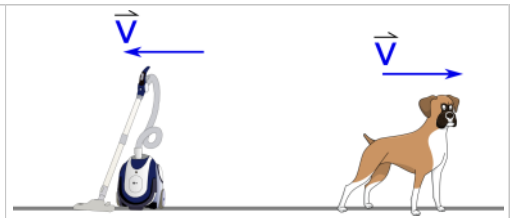
Description: Calculate observed frequency for moving source and moving observer. (3 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A dog is running away from a vacuum cleaner that is emitting a constant tone of 360 Hz. The dog and vacuum cleaner are moving in opposite directions. The dog's speed is 10 m/s and the vacuum's speed is 4 m/s.

(a) Which of the following mathematical models would correctly solve for the frequency the dog would hear from the vacuum cleaner?

(1) $f_O = f_S\left(\frac{v + v_O}{v + v_S}\right)$	(3) $f_O = f_S\left(\frac{v - v_O}{v - v_S}\right)$
(2) $f_O = f_S\left(\frac{v + v_O}{v - v_S}\right)$	(4) $f_O = f_S\left(\frac{v - v_O}{v + v_S}\right)$



(b) Calculate the frequency the dog observes.

(1) 345 Hz
(2) 354 Hz
(3) 360 Hz
(4) 366 Hz
(5) 375 Hz

← source ⇒ f↓ ⇒ denominator ↑ ⇒ + v_{source}

obs → ⇒ f↓ ⇒ numerator ↓ ⇒ − v_{obs}

TW.2.L4-9:

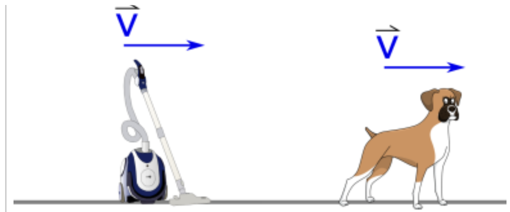
Description: Calculate observed frequency for moving source and moving observer. (3 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A dog is running away from a vacuum cleaner that is emitting a constant tone of 360 Hz. The dog and vacuum cleaner are moving in the same direction. The dog's speed is 10 m/s and the vacuum's speed is 4 m/s.

(a) Which of the following mathematical models would correctly solve for the frequency the dog would hear from the vacuum cleaner?

(1) $f_O = f_S\left(\frac{v+v_O}{v+v_S}\right)$	(3) $f_O = f_S\left(\frac{v-v_O}{v-v_S}\right)$
(2) $f_O = f_S\left(\frac{v+v_O}{v-v_S}\right)$	(4) $f_O = f_S\left(\frac{v-v_O}{v+v_S}\right)$



(b) Calculate the frequency the dog observes.

(1) 345 Hz
(2) 354 Hz
(3) 360 Hz
(4) 366 Hz
(5) 375 Hz

source → ⇒ f ↑ ⇒ denominator ↓ ⇒ $-v_{source}$

obs → ⇒ f ↓ ⇒ numerator ↓ ⇒ $-v_{obs}$

TW.2.L4-10:

Description: Calculate observed frequency for stationary source and moving observer with wind. (3 minutes + 3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: An ideal spherical speaker is in the middle of an open field playing a constant 900 Hz tone. It's a windy day with a 5 m/s breeze blowing from the north to the south. A cat is running towards the speaker from the south to the north at 10 m/s.

Calculate the frequency the cat observes.

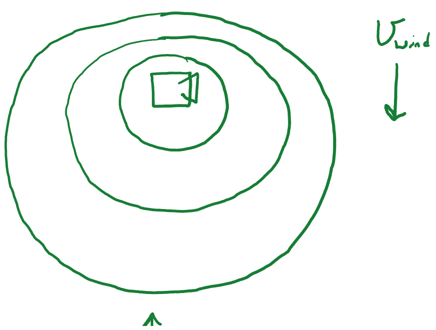
N ↕ S

Sound still travels 343 m/s relative to air

relative to medium

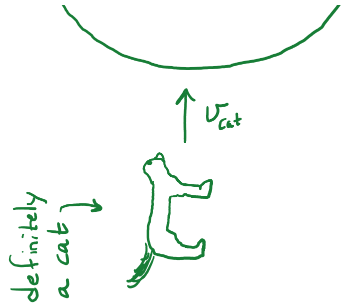
Wind will increase cat's speed relative to air

$$f_o = f_s\left[\frac{v+(v_{cat}+v_w)}{v+(0+v_w)}\right]$$



$$f_o = (900)\left(\frac{343+15}{343+5}\right)$$

$$f_o = 926\ Hz$$



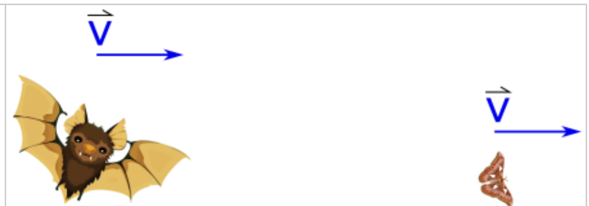
$f_o = 926$ Hz

TW.2.L4-11:

Description: Calculate observed frequency for moving source and moving observer with reflection. (1 minute + 4 minutes + 1 minute + 5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A bat makes a sonar click as it is flying at 4 m/s directly towards a bug that is flying at 1.2 m/s away from the bat. The frequency of the click emitted by the bat is 50 kHz. We wish to determine the frequency of the reflected click that the bat hears.



(a) How many stages should we break this problem into? For each stage, identify the source and observer.

(1) 1
(2) 2
(3) 3

1	2
obs ⇒ bug	obs → bat
Source → bat	Source ⇒ bug

(b) What frequency does the bug hear?

(1) 49.25 kHz
(2) 49.60 kHz
(3) 50.00 kHz
(4) 50.41 kHz
(5) 50.77 kHz

$$f_o = f_s\left(\frac{v - v_o}{v - v_s}\right)$$

$$= 50{,}000\left(\frac{343 - 1.2}{343 - 4}\right)$$

$$= 50{,}413 \text{ Hz}$$

(c) What frequency sound does the bug reflect towards the bat?

(1) 49.25 kHz
(2) 49.60 kHz
(3) 50.00 kHz
(4) 50.41 kHz
(5) 50.77 kHz

(d) What frequency does the bat hear from its reflected click off the bug?

$$f_o = f_s\left(\frac{v + v_o}{v + v_s}\right)$$

$$f_o = 50{,}413\left(\frac{343 + 4}{343 + 1.2}\right)$$

$$f_o = 50{,}823 \text{ Hz}$$

Act III: Conceptual Questions (light)

TW.2.L4-12:

Description: Conceptual question about observed wavelength given relative motion of light source and observer. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: All traveling waves exhibit Doppler shift when the source and observer are moving relative to each other. The mathematical model for the Doppler shift for light is not the same as it is for sound, but conceptually the same rules apply for how the frequency increases or decreases based on the relative motion between the source and observer.

Consider a distant star that emits yellow light, which of the following colors could someone on Earth observe if the star is moving away from us?

Hint: The speed of light is constant and the wavelengths are the following ($\boldsymbol{\lambda}_{\mathbf{yellow}}$ = 575 nm, $\boldsymbol{\lambda}_{\mathbf{blue}}$ = 475 nm, $\boldsymbol{\lambda}_{\mathbf{red}}$ = 650 nm)

(1) Blue
(2) Yellow
(3) Red

earth star →

⇒ f ↓

$v = f\lambda$ ⇒ λ ↑ ⇒ red-shifted
const ↓ ↑

TW.2.L4-13:

Description: Conceptual question about what quantities can be found via Doppler shift with light from galaxies. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Which of the following quantities can we determine from observations of light from a distant galaxy using Doppler shift principles?

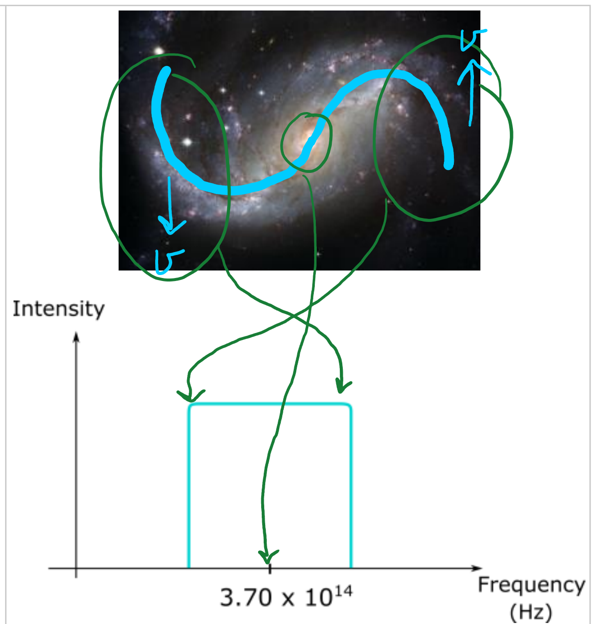
(1) Relative speed. ← red shift ⇒ find speed
(2) Distance to galaxy.
(3) Mass of galaxy.
(2)–(3): more complicated, but astronomers are awesome!
(4) Name of galaxy.

TW.2.L4-14:

Description: Conceptual question about observed frequency from light emitted by distant galaxy. (5 minutes + 5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Hydrogen gas (the most prevalent gas in the universe) emits a characteristic frequency of 4.57 x 10^{14} Hz. While observing this frequency in a distant galaxy we find the following plot.



(a) Compare the characteristic frequency of hydrogen with the frequency of the center of the "box" seen in the plot. With your neighbors, figure out a possible explanation for why we observe the hydrogen emissions at this new frequency.

the light is redshifted

$\Rightarrow f\downarrow + \lambda\uparrow$

(b) With your neighbors, come up with a plausible explanation for why we observe the spread out "box" shape instead of sharp peak or spike at a single frequency.

Hint 1: Where in the galaxy could the mix and max frequencies be coming from?

Hint 2: Look at the picture of the galaxy. What does it look like it is doing?

the whole galaxy has v away,

but galaxy is spinning → left side

less redshift ⇐ is receding less fast, right side is receding

more quickly ⇒ more redshift

Conceptual questions for discussion

1. Coming soon to a lecture template near you.

Hints

TW.2.L4-1: No hints.

TW.2.L4-2: No hints.

TW.2.L4-3: No hints.

TW.2.L4-4: No hints.

TW.2.L4-5: No hints.

TW.2.L4-6: No hints.

TW.2.L4-7: No hints.

TW.2.L4-8: No hints.

TW.2.L4-9: No hints.

TW.2.L4-10: No hints.

TW.2.L4-11: No hints.

TW.2.L4-12: No hints.

TW.2.L4-13: No hints.

TW.2.L4-14: No hints.

TW.2.L4-15: No hints.

TW.2.L4-16: No hints.

TW.2.L4-17: No hints.