PHYSICS OF HEARING

NJ-OER TOPIC-17

Learning Outcomes

- Describe sound as a longitudinal wave.
- Describe the relationship between the speed of sound, its frequency, and its wavelength.
- Describe the effects on the speed of sound as it travels through various media.
- Describe the effects of temperature on the speed of sound.
- Define sound intensity, and sound pressure level.
- Calculate sound intensity levels in decibels (dB).
- Define Doppler effect, Doppler shift, and sonic boom.
- Calculate the frequency of a sound heard by someone observing Doppler shift.
- Define antinode, node, fundamental, overtones, and harmonics for standing waves.
- Identify sound interference.
- Calculate the length of a tube using sound wave measurements.

Concepts

v = speed of wave
vs=speed of source source
vo=speed of observer
f= frequency
λ = wavelength
F= force
I = Intensity of a sound wave
0 dB=threshold of hearing = 1.0×10^{-12} W/m^2

β= sound intensity level, decibel value
P = power
μ = mass/length
fo= frequency of observer
fs= frequency of source

fn= frequency of nth harmonic
fbeat= beat frequency

Units

SI UNITS
Frequency is in HZ
Wavelength is in meters
Velocity is in m/s
Power is in Watts
Intensity is in W/m2
β is a logarithmic scale for intensity and it is in dB

Formulas and Constants

$f = 1/T$

$v = \lambda f = \lambda / T$

$v^2 = F/(mu)$

$mu = m/L$

$v = 331\ (Tk/273)^{½}$

$fo = fs(V \pm Vo)(/V \mp Vs)$ Doppler shift

$fn = n(v/2L)$ n = 1, 2, 3, … (harmonics for pipe Open-open/Closed-closed)

$fn = n(v/4L)$ n = 1, 3, 5, … (harmonics for pipe open at one end)

$fbeat = |f1 - f2|$

$I = P/A$

$I = P/(4\pi r^2)$

$(I1)/(I2) = (R1)^2/(R2)^2$

$I_o = 1.0 \times 10^{-12}\ W/m^2$

$$\beta = (10\,db)\log\frac{I}{I_0}$$

USEFUL TABLES

Ratios of Intensities and Corresponding Differences in Sound Intensity Levels

I2/I1	β2–β1
2.0	3.0 dB
5.0	7.0 dB
10.0	10.0 dB

Speed of Sound in Various Media

Medium	vw(m/s)
Gases at 0ºC	
Air	331
Carbon dioxide	259
Oxygen	316
Liquids at 20ºC	
Ethanol	1160
Mercury	1450
Water, fresh	1480
Sea water/Human tissue	1540
Solids	
Vulcanized rubber	54
Polyethylene	920
Marble	3810
Glass, Pyrex	5640

CLASSWORK POWER AND INTENSITY

Q1) A rectangular receiver with length 0.3 m and height 0.6 m receives 24 Watts of power.
a)What is the sound intensity at the receiver's location.
b)What is the sound intensity in decibel.
c)What is the power of the source considering that it is 5 meters away from the receiver.

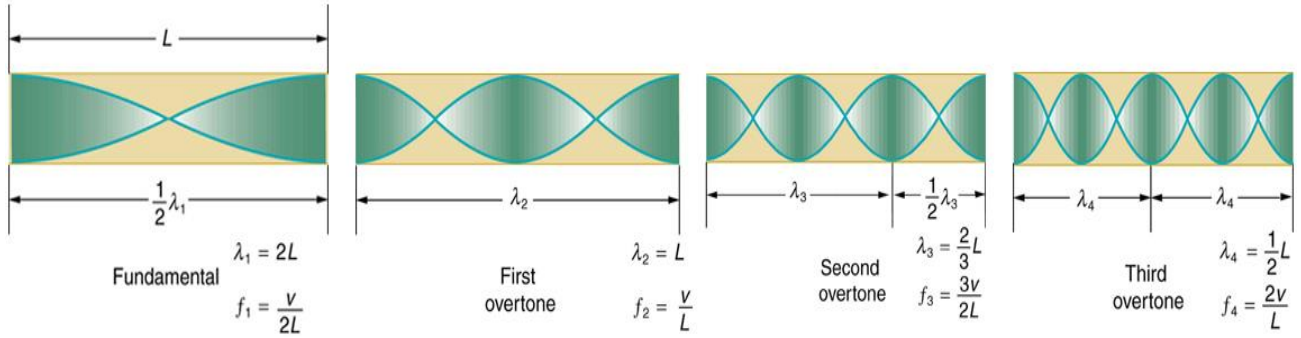
Q2) A sound speaker produces 12W power.
a) What is the intensity at 7 meters away.
b) What is the power received by a circular receiver with radius 0.4 meters.

Q3) Ten drummers produces 34dB sound intensity from a 2 meters distance.
a) What would be the sound intensity of 100 drummers heard from a 2meters distance (in decibel)
b) What would be the sound intensity of 100 drummers heard from a 20 meters distance (in decibel)

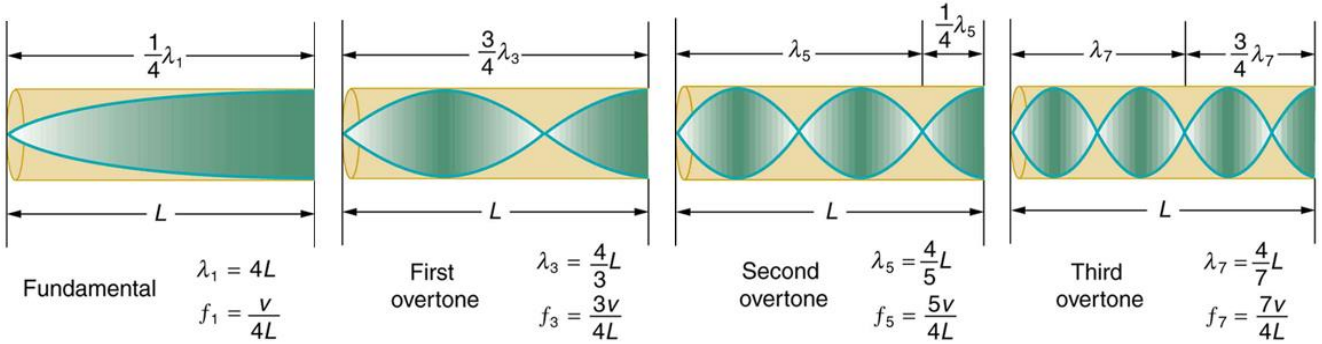
Q4) A sound wave produces 10,000 Pascal pressure difference at 0 degrees temperature. Find its intensity

$I = P/A$ $I=P/(4\pi r2)$ $(I1)/(I2) = (R1)2/(R2)2$ $I = (\Delta p2)/(\rho v)$ $v= 331\ (Tk/273)^{½}$ $\rho(air)=1.225\ kg/m^3$
$Io= 1.0 \times 10\text{-}12\ W/m2$ $\beta = 10 \log (I/Io)$ rules for β: If intensity increases 10 times, add ten to β

STANDING WAVES



Typical standing waves for a woodwind instrument with both sides open or closed
n=1,2,3,…..



Typical standing waves for a woodwind instrument with only one side open
n=1,3,5,…..

Q) Find the wavelengths and the frequencies for each graph. Consider L=0.420 m and v = 340 m/s

ADVANCED CLASSWORK FOR STANDING WAVES

A tube with length "L", produces sound with frequency "fn" by forming standing waves with n number of antinodes. Air is at the temperature "T" in Kelvin.
Complete the table below using the known quantities and the formula.

f Frequency Hz	Wavelength (m)	n	Length (m)	Type of tube	Temperature	Velocity
f4=?		4	0.50	both end closed		331 m/s
f5=?		5	0.80	one end closed	300K	
			0.75	both end open		343
	0.44		0.66			340

$v = \lambda f$

$f_n = n(v/2L)$ n = 1, 2, 3, … (harmonics for pipe Open-open/Closed-closed)

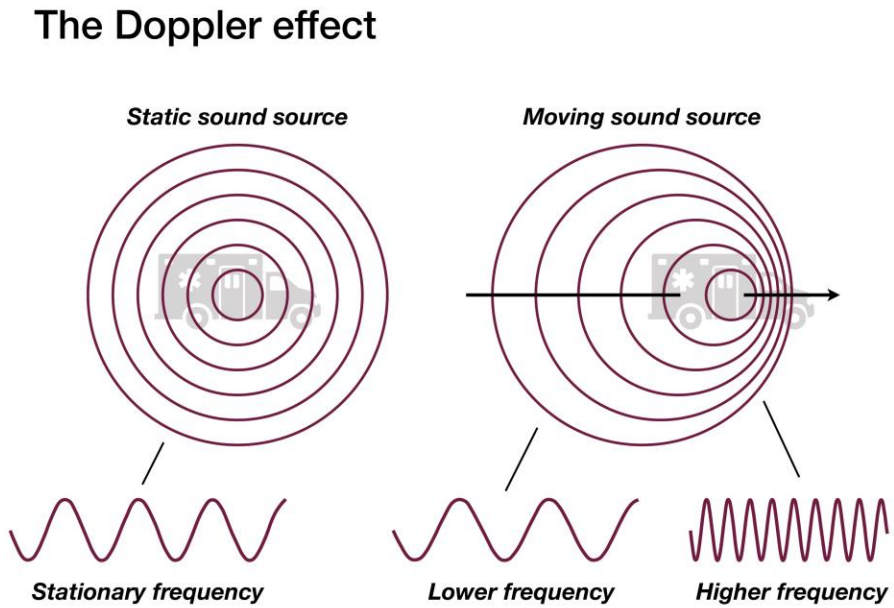
$f_n = n(v/4L)$ n = 1, 3, 5, … (harmonics for pipe open at one end)

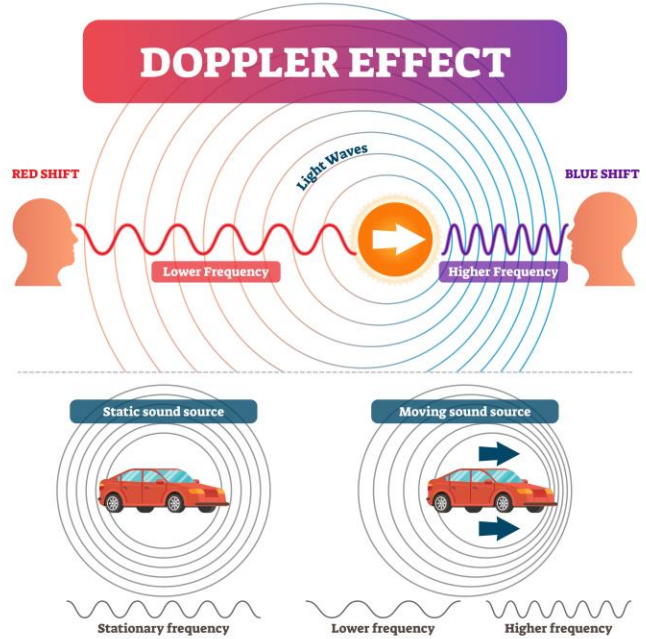
DOPPLER EFFECT

Doppler effect is a frequency shift, it doesn't affect the velocity but it effects the wavelength as well. Doppler formula relates frequency heard by the observer to the original source frequency.

Formula	Motion
fobs=fs (v+vobs)/(v-vs)	Observer and source move towards one another
fobs=fs (v-vobs)/(v+vs)	Observer and source move away from one another
fobs=fs (v+vobs)/(v+vs)	Observer moves towards, source moves away
fobs=fs (v-vobs)/(v-vs)	Observer moves away, source moves towards

fobs= frequency observed
fs= frequency of the source
vs= speed of the source, (this is a + quantity, sign comes from the table)
vobs= speed of the observer, (this is a + quantity, sign comes from the table)
v= speed of sound





CLASSWORK DOPPLER EFFECT

Using the sign convention table, answer the following questions.
Stationary means v=0
Take speed of sound as 340m/s

Formula	Motion
fobs=fs (v+vobs)/(v-vs)	Observer and source move towards one another
fobs=fs (v-vobs)/(v+vs)	Observer and source move away from one another
fobs=fs (v+vobs)/(v+vs)	Observer moves towards, source moves away
fobs=fs (v-vobs)/(v-vs)	Observer moves away, source moves towards

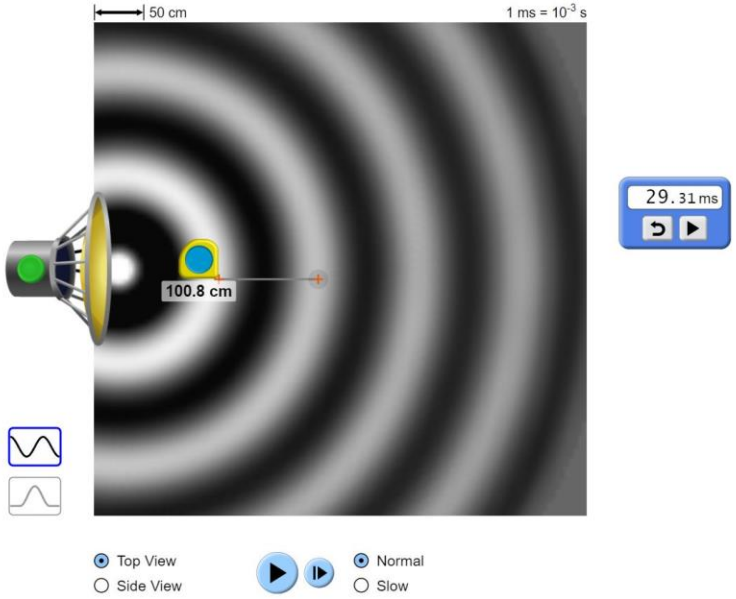
Q1) A police car has siren with frequency 1000Hz. The car is moving with a speed of 34m/s
a)What is the frequency heard by a stationary observer when the car is approaching
b)What is the frequency heard by a stationary observer when the car is moving away

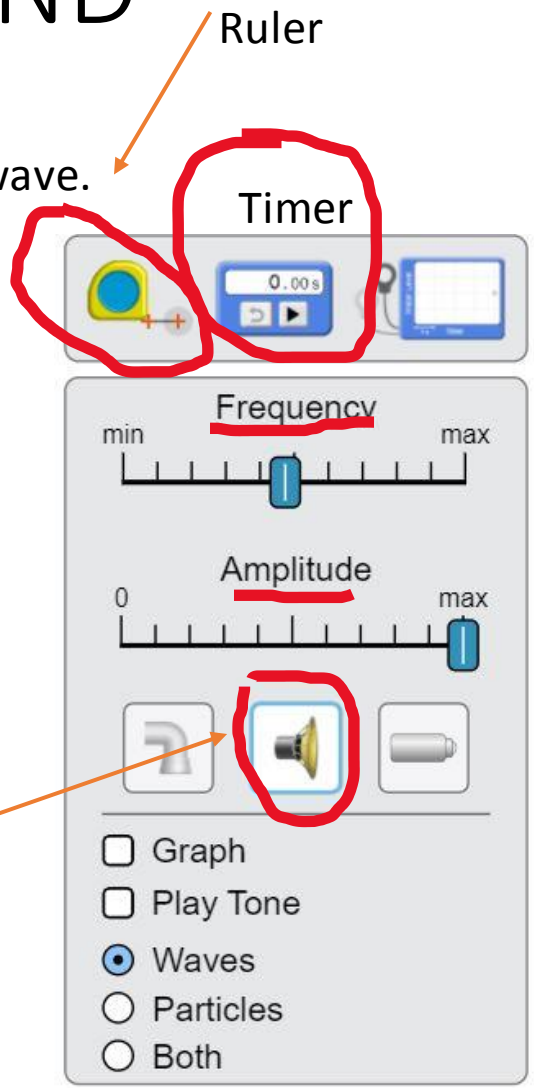
Q2) Sound source with 450 HZ frequency is moving with a speed of 17m/s towards East. What is the frequency heard by an observer located East of the sound source and moving with a speed 42m/s towards East.

Q3) A moving sound source is observed as 95HZ when moving towards the observer and it's observed as 90HZ when moving away from the observer. What is the speed of the source. What is the original source frequency (This is a problem with two equations and two unknowns)

ACTIVITY ON WAVE PROPERTIES OF SOUND

Open the link https://phet.colorado.edu/en/simulations/wave-interference and click on the app
Choose the middle option under the amplitude tab on the right. This will make the wave a sound wave.
Choose your frequency and amplitude using the slider tool. Drag the timer and the ruler tool.
Start your times and start your source. Count 10 waves and stop the timer and the source.
Timer gives you the time for 10 oscillations. To find the period, divide this number by 10
Use f=1/T formula to calculate the frequency. Measure the wavelength using the ruler tool
Using v= frequency * wavelength calculate the speed of sound. Using v=331 (T/273)^{½} estimate the temperature of the environment. Change the frequency and amplitude and repeat



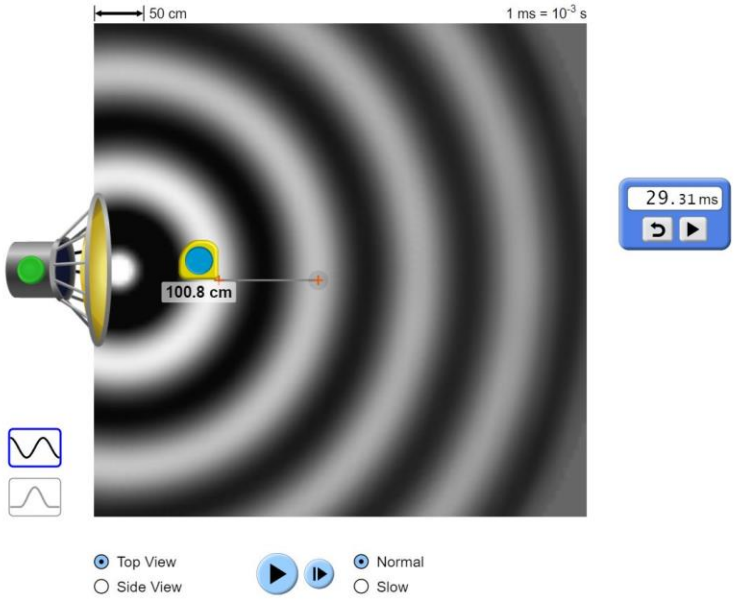


Sound option

ACTIVITY ON WAVE PROPERTIES OF SOUND

Open the link https://phet.colorado.edu/en/simulations/wave-interference and click on the app

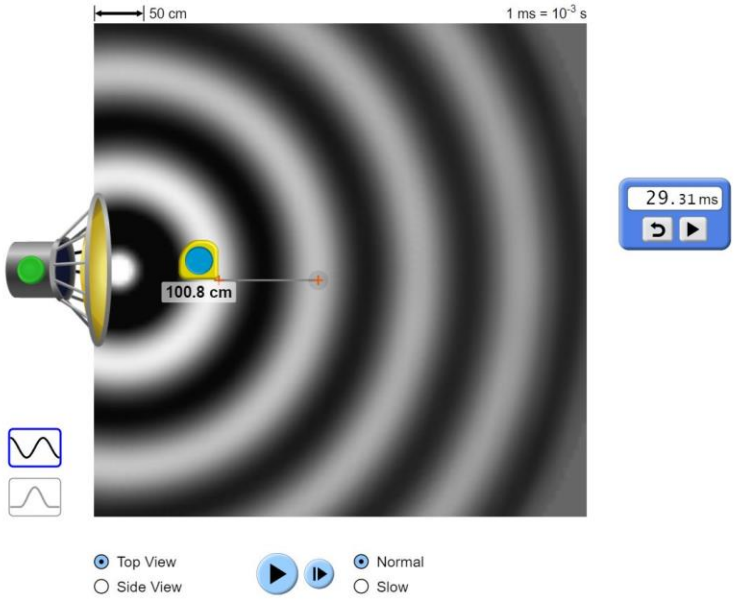
Type	Time for 10 waves	Period	Frequency	Wavelength	Speed	Temperature
Frequency minimum						
Frequency middle						
Frequency middle						
Frequency maximum						
Frequency maximum						



ACTIVITY ON INTERFERENCES

Open the link https://phet.colorado.edu/en/simulations/wave-interference and click on the app

Type	Time for 10 waves	Period	Frequency	Wavelength	Speed	Temperature
Frequency minimum						
Frequency middle						
Frequency middle						
Frequency maximum						
Frequency maximum						



REFERENCES

- Slide 1: Adobe id= 216379246 Hearing test showing ear of young woman with sound waves simulation technology By Pixsooz
- Slide 8: Open Stax College Physics online textbook
- Slide 10 Top image: Adobe id=388859337 The Doppler effect explained by comparing a static and a moving sound source By Dimitrios
- Slide 10 Lower image: Adobe id= 305961504 Doppler effect vector illustration. Labeled educational sound, light graph.
- By VectorMine
- Slides 12-13-14: Screenshot from PhET Interactive Simulations University of Colorado Boulder