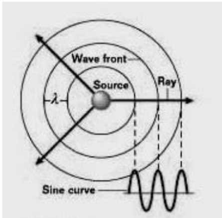
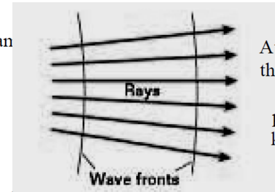
Wave Phenomena Two- and Three-Dimensional Waves
IB 12



Wavefront – line (or arc) joining neighboring points that have the san phase or displacement

Ray – line indicating direction of wave motion (direction of energy transfer).

Rays are perpendicular to wavefronts.



At great distances, the wavefronts are approximately parallel and are known as *plane waves*.

Intensity: power per unit area

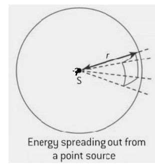
Formula: $I = \frac{P}{A}$

Units: $[W/m^2]$

1. As a three dimensional wave expands, the energy is spread out over an area of . . .

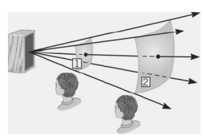
Sphere A =

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



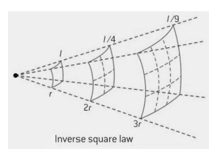
2. A person stands 3.0 meters away from a 100 watt speaker.
   a) Determine the intensity of the sound heard by this person.

$I = \frac{P}{A} = \frac{100W}{4\pi(3m)^2} = .88\,\frac{W}{m^2}$



   b) What would be the intensity of the sound if they stand 6.0 meters away?

$\frac{.88\,W/m^2}{4}$



3. As the distance from the source doubles . . .

Relationship: $I \propto x^{-2}$

Power: energy per unit time

Formula: $P = \frac{E}{t}$

Units: $[W]$

4. For a mechanical wave . . .

total energy is proportional to the square of the amplitude of the wave

NOT area

Relationship: $I \propto A^2$

Intensity:

total energy per unit time per unit area

The Doppler Effect for Mechanical Waves

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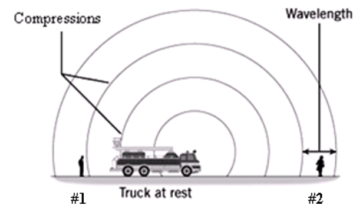
Stationary source and stationary observers

The number of compressions reaching each observer's ear per second is the same so each hears a sound of the same frequency. This frequency is identical to the frequency of the source so there is no Doppler shift.

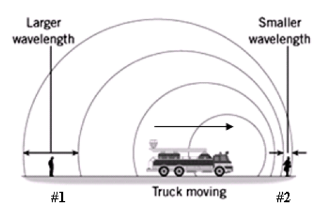


Doppler Effect: The apparent change of frequency of a wave due to the movement of the source or the observer relative to the medium of wave transmission.

Moving source and stationary observers

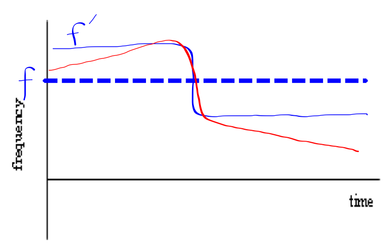
Observer #1 (source moving away):

Detects fewer waves per second = Lower frequency (pitch)
Longer wavelength
Decreasing amplitude (volume



Observer #2 (source moving toward):

Detects more waves per second = Higher frequency (pitch)
Shorter wavelength
Increasing amplitude (volume)



For truck moving at constant velocity:

one constant high pitch when moving toward and one constant low pitch heard when moving away

For truck speeding up:

pitch increases and then decreases

Doppler Formula (moving source)

$$f' = f\left(\frac{v}{v \pm u_s}\right)$$

Where:

f = original frequency

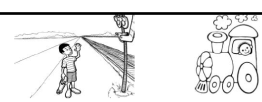
f ' = shifted frequency

v = speed of sound in medium

u_s = speed of source relative to medium

STS – source toward subtract

1. A high-speed train is traveling at a speed of 45 m/s (100 mi/hr) when the engineer sounds the 415-Hz warning horn. The speed of sound in air is 343 m/s. An observer stands at a railroad crossing that the train is approaching.



a) How fast is the sound moving relative to:

i) the air? $V = 343 m/s$

ii) the observer? $V = 343 m/s$

b) What are the frequency and wavelength of the sound as perceived by the observer?

$$f' = f\left(\frac{v}{v - u_s}\right) = 415 Hz \left(\frac{343 m/s}{343 m/s - 45 m/s}\right) = 478 Hz$$

$$\lambda' = \frac{V}{f'} = \frac{343 m/s}{478 Hz} = .718 m$$

c) What is the change in frequency and the percent change in frequency as heard by the observer?

$$\Delta f = |f - f'| = 63 Hz$$

$$\frac{63}{415} \cdot 100\% \sim 15\%$$

d) How fast would the train be moving, and in which direction, if the observer hears a whistle whose frequency is only 90% of what it is at rest?

$$.9 \cancel{f} = \cancel{f}\left(\frac{v}{v + u_s}\right)$$

2. The highest frequency you can hear is 20,000 Hz. If a plane making a sound of frequency 500 Hz went fast enough, you would not be able to hear it. How fast would the plane have to go?

Doppler shift for moving observer and stationary source

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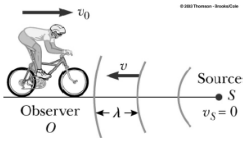
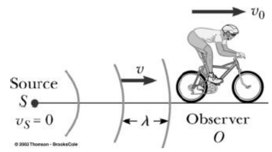


Observer moving toward source:

Detects more waves per second = higher frequency



Observer moving away from source:

Detects fewer waves per second = lower frequency

Doppler Formula (moving observer)

$$f' = f\left(\frac{v \pm u_o}{v}\right)$$

Where:

v = speed of sound in medium

u_o = speed of observer relative to medium

OTA – observer toward add

3. The security alarm on a parked car goes off and produces a frequency of 960 Hz. An observer drives toward this parked car at 20 m/s.

a) How fast is the sound moving relative to:

i) the air? 343 m/s ii) the observer? 363 m/s

b) What is the frequency and wavelength the observer perceives?

$$f' = f\left(\frac{V + U_o}{V}\right) = 960\,Hz\left(\frac{363\,m/s}{343\,m/s}\right) \sim 1016\,Hz$$

$\lambda = \frac{V}{f}$ = same .357 m

$\lambda = \frac{V'}{f'}$ = same