The famous band “Spinal Tap” bragged of an amplifier that went to “11”. Let’s say when the amp was set to “1,” a certain listener received a sound intensity of 10 dB. If “11” means that the listener now hears a sound 11 times louder (i.e., 110 dB), what is the ratio of the intensity of the loud sound to that of the original sound?

1) 11 : 1                    2) 110 : 1
3) 10^{10} : 1               4) 10^{11} : 1
5) 10^{12} : 1               6) 10^{13} : 1

Consider the following:

• It doesn’t matter where in the room you sit: when I speak, you hear me.

• Some of you will hear me before others of you (those in the front will hear my voice a short time before those who sit in the back).

Everyone seated at the same distance from me will hear me at the same time, however.

What must be the shape of the sound wave fronts, therefore, as they propagate across the room?

They must be spherical!

So the energy that is emitted by the source is spread out over the area of a sphere!
These spherical waves are in contrast to the plane waves we’ve mentioned that travel across the ocean or a slinky. Water waves are an example of plane waves.

For plane waves, the direction of propagation and the direction of modulation (for transverse waves) form a 2-dimensional plane.

What happens to the sound if the emitter is moving relative to the listener, or vice versa? Let’s think about it from the point of view of the number of waves per second which pass our location as the listener. And let’s consider a stationary source and a moving listener. Will the number of waves per unit time reaching her ear increase or decrease as she moves toward the sound emitter?

If she moves with speed $v_o$ toward the source of the sound, what frequency does she hear? How many fronts does she intercept in time $t$?

If the wave fronts were stationary, she would move through a distance $v_o t$ and therefore intercept $n = \frac{v_o t}{\lambda}$ wave fronts.

But the wave fronts are also moving, and in the same time $t$ move through a distance $v_{\text{sound}} t$, so she intercepts extra $\frac{v_{\text{sound}} t}{\lambda}$ wave fronts by the fact that the wave is moving towards her.

If she moves with speed $v_o$ toward the source of the sound, what frequency does she hear? How many fronts does she intercept in time $t$?

So the total number of wave fronts she intercepts in time $t$ is

$$n = \frac{v_o t}{\lambda} + \frac{v_{\text{sound}} t}{\lambda}$$

Since frequency is the number per unit time, we get that the frequency she hears, $f'$, is

$$f' = \frac{n}{t} = \frac{v_o}{\lambda} + \frac{v_{\text{sound}}}{\lambda} = \frac{v_o}{\lambda} + \frac{v_{\text{sound}}}{\lambda}$$

$$f' = \frac{1}{\lambda} (v_o + v_{\text{sound}}) = \frac{f}{v_{\text{sound}}} (v_o + v_{\text{sound}})$$
The frequency ($f'$) a MOVING OBSERVER hears is

$$f' = f \left(1 \pm \frac{v_o}{v_{\text{sound}}}\right)$$

- observer moves toward source
- observer moves away from source

$f$ the frequency emitted by the source
$v_o$ the speed of the observer

As the observer approaches the source, the frequency heard is higher. As she recedes, the frequency heard is lower.

What if the source is moving and the observer stationary?

- Well, the wave fronts in front of the source are closer together, and the wave fronts behind the source are more spread apart than if the source was not moving.
- The number of waves per time reaching the listener will be greater as the source approaches.

So we need to compute the effective wavelength between the wave fronts in front of the source.

If $T$ is the time between the emitted fronts, and at time $t = 0$, wave front $W_1$ is emitted, then wave front $W_2$ will be emitted at $t = T$.

The spacing between wave front $W_1$ and wave front $W_2$ is the effective wavelength, $\lambda'$, for which we seek a value.

In time $T$, $W_2$ has moved through a distance given by $v_{\text{sound}} T$. 

Let’s look at the case for the approaching source.

Each wave front moves toward our observer with speed equal to the speed of sound $v_{\text{sound}}$. 

The spacing of those fronts determines how many pass the observer in a given time interval.
In time $T$, the source has moved through a distance given by $v_s T$. It is at this position that wave front $W_2$ is emitted. The spacing between wave front $W_1$ and wave front $W_2$ is the effective wavelength, $\lambda'$, for which we seek a value. In time $T$, the source has moved through a distance given by $v_s T$. It is at this position that wave front $W_2$ is emitted.

The spacing between wave front $W_1$ and wave front $W_2$ is therefore $\lambda' = \frac{v_{\text{sound}} T - v_s T}{v_s T}$. So the frequency our observer hears is given by $f' = \frac{v_{\text{sound}}}{v_{\text{sound}} T - v_s T}$.

Moving Source

What if the source is moving and the observer stationary?

Recalling that $T$ is the period of the wave, and that $T = \frac{1}{f}$, we can make a substitution and get $f' = f \frac{1}{1 \mp \frac{v_s}{v_{\text{sound}}}}$.

$- \quad$ source moves toward observer

$+ \quad$ source moves away from observer

$f$ the frequency emitted by the source

$\frac{v_s}{v_{\text{sound}}}$ the speed of the source

Final case: the source moves AND the observer moves

$f' = f \left( \frac{1 \pm \left( \frac{v_s}{v_{\text{sound}}} \right)}{1 \mp \left( \frac{v_s}{v_{\text{sound}}} \right)} \right)$. + approach – recede

– approach + recede

$v_o = \text{speed listener}$

$v_s = \text{speed source}$

$f = \text{frequency of source}$
Rules of Thumb:

• If the objects are getting closer together, the frequency should be higher.
• If the objects are separating, the frequency should be lower.

\[ f' = f \left( 1 \pm \frac{v_o}{v_{\text{sound}}} \right) \left( 1 \pm \frac{v_s}{v_{\text{sound}}} \right) \]

Final case: the source moves AND the observer moves

Ch. 20: Traveling Waves

An ambulance is stationary by the side of the road. Cars A & B approach the ambulance, with the speed of Car A twice that of Car B. Cars C & D drive away from the ambulance, with the speed of Car C twice that of Car D. Rank the pitch each of the drivers of the cars hear from highest to lowest.


Ch. 21: Superposition

Superposition

In the last couple of chapters, we examined simple harmonic motion and traveling waves. We now look more carefully at waves that interfere (superimpose themselves) with one another and the resulting standing waves in pipes and on strings.

Superposition of Waves

How do I add waves together?

Superposition Principle

• Overlapping waves add algebraically to produce a resultant wave.
• One such wave in no way alters the other traveling wave.

Let's look at a couple of examples...

constructive interference

• When waves interfere constructively, the anti-nodes become greater in magnitude than either of the waves from which the resulting wave is composed.
• Sounds emanating from stereo speakers are louder in places of constructive interference.
These two waves are 180° out-of-phase. That is, if you shifted one by 180° relative to the other, the two waves would appear exactly the same.

destructive interference

- When waves interfere destructively, the anti-nodes are reduced in magnitude. If the phase is just right, these waves can entirely cancel one another (as we saw on the previous slide), resulting in a constant node.
- Sounds emanating from stereo speakers are softer in places of destructive interference. If the tone is pure, the sound disappears completely.

Have you ever been outside, in a large open space, and wandered around as someone spoke over loudspeakers?

Depending on where you are on the field, the voice can sound louder or softer.

What’s going on here?

- Technically, we call it constructive (louder) and destructive (softer) interference.
- Recall, sound travels in waves (longitudinal pressure waves to be specific).
- The waves move out in all directions from the two speakers on either side of the stage, arriving at the location on the field at which we happen to be standing.

The sound wave from the left speaker arrives in time \( t = \frac{d(\text{left})}{v_{\text{sound}}} \)

The sound wave from the right speaker arrives in time \( t = \frac{d(\text{right})}{v_{\text{sound}}} \)

If \( d(\text{right}) > d(\text{left}) \), the sound waves from the left speaker arrive before those from the right speaker.

From the left... From the right...

\( v_{\text{sound}} = 343 \text{ m/s} \)

For a typical audible frequency (343 Hz), \( \lambda = 1 \text{ m} \)
For this case, the right speaker is exactly 1 m further away than the left speaker...

From the left... From the right...

\[ v_{\text{sound}} = 343 \text{ m/s} \]

Notice that the yellow wave is exactly one wavelength away when the red wave arrives.

So, when the yellow wave first arrives, the second crest of the red wave will just be arriving as well. This is a case of constructive interference. The sound will be louder at this spot on the field.

The crests and troughs arrive from the two speakers simultaneously and in phase!

What will happen if I now move to a point on the field that is 50 cm closer to the left speaker than the right speaker?

From the right... a crest arrives

From the left... a trough arrives

For this case, the crests arrive from the left speaker at the same time as the troughs arrive from the right speaker. And the troughs arrive from the left speaker at the same time as the crests from the right speaker. In this case, the waves interfere destructively and the sound we hear is softer.

Worksheet Problem #3