Physics 1101 - Introduction to Sound Waves

(Instructor sings, and then plays various instruments)

Instructor
Oh, this unit is going to be so much fun. You guessed it. We’re going to study sounds. So let’s start by finding out what all these sounds, from the pleasing ones to the terribly irritating, have in common. This is a tuning fork, which produces a pure sound when hit by a soft mallet, like this.

Now, the instructions for this tuning fork say that I’ll hear a really cool sound if I get really close and dip the ends of the fork in the water.

Oh, that was really cute, guys. Who thought of that one?
Actually, you can’t see the tines of the tuning fork vibrating, but they must be. Watch this.

(tuning fork on screen)

VO
When we use a strobe light to take rapid snapshots of the vibrating tuning fork, the slow motion effect shows that sound is created by a vibrating source.

All sound waves are produced by a vibrating object.

Instructor
OK. So how do we get from a vibrating object, like this tuning fork, or my vocal chords, to sound waves? Let’s use a computer animation of air molecules around the tuning fork to show how the vibrations move or propagate through the air to reach your ear.

(tuning fork on screen)

VO
As the tuning fork vibrates it compresses and expands the air in front of it, causing air pressure to increase and decrease repeatedly. This creates a longitudinal wave, sometimes called a compression wave.

Notice that the air molecules don’t travel along with the wave, but just vibrate back and forth.

And under ordinary conditions, the frequency of the wave matches the vibration frequency of the sound’s source.

(bell in jar on screen)

VO
Can sound travel in a vacuum? In this demonstration an electric bell is placed in a sealed bell jar, attached to a vacuum pump.

Before the air is removed, the ringing bell can be heard.

(Sound Effect: ringing bell.)

Then the air is removed from the jar by the vacuum pump.

When the bell is turned on again, no sound can be heard, even though you can see the hammer striking the bell.

Because sound waves cannot propagate without a medium, no sound can be heard in outer space.
Sound waves are longitudinal, mechanical waves.

**Instructor**
In several demonstrations during this unit, you will see an instrument called an oscilloscope that measures density or air pressure and plots it versus time. You learned in the last unit that such a graph is a sine wave. The crests represent compressions and the troughs represent rarefactions.

Just like other waves, sound waves can be characterized by velocity, frequency, wavelength, and amplitude. And sound waves can undergo reflection, refraction, diffraction, and interference. I’d say we have lots of ground to cover.

Let’s start with frequency.

We describe our impression about the frequency of a sound as pitch. High pitch sounds like these: *(Sound Effect: flute, whistle, soprano voice, etc.)* have high vibration frequencies.

And low pitch sounds like these: *(Sound Effect: fog horn, tuba, etc.)* are produced by objects with low vibration frequencies.

Only a limited range of frequencies are audible, or can be heard by the human ear. Watch this and then you’ll take some more notes.

**VO**
Sounds with frequencies between twenty and 20,000 Hz are audible to most people. Deep base tones have low frequencies. Sounds with frequencies above 20,000 Hz can be heard by some animals but are inaudible to human beings.

The human ear can normally hear sounds between 20 and 20,000 hertz. These frequencies are classified as audible.

Sound waves with frequencies lower than 20 hertz are called infrasonic waves.

And those with frequencies higher than 20,000 hertz are called ultrasonic waves.

**Instructor**
This next demonstration uses the oscilloscope I told you about earlier. You’ll have to be very quiet in order to hear the 10,000-hertz sound at the beginning of the demo. Some of you may not be able to hear it even in a quiet room because every ear is different. Watch and listen.

The vibrational frequency spectrum for longitudinal waves is divided into three regions: infrasonic, audible, and ultrasonic. Using a speaker capable of high frequency vibrations, both audible and ultrasonic waves can be produced. As the frequency increases above 10,000 Hz, the sound becomes
fainter and then inaudible, even though the oscilloscope shows that the amplitude remains constant. Here, longitudinal waves of 50,000 Hz frequency propagate through the air and reach the microphone and reach the receiving microphone.

In the next demonstration, ultrasonic waves with a frequency of 50,000 hertz are generated, but the oscilloscope does not pick up any waves. At very high frequencies and very small wavelengths, air molecules are too far apart to transport the waves. But when the transmitter and detector are immersed in water, the waves are able to reach the detector, as indicated by the oscilloscope.

Some materials block ultrasonic waves and others let some of the waves pass through. Ultrasonic waves produce images by reflecting when they reach a boundary between two materials of different densities, such as amniotic fluid and a fetus, or healthy tissue and a tumor. Watch this.

(ultrasound monitor on screen)

**VO**
Ultrasound waves can be used to image parts of the human body. Directed into the womb of this expectant mother, the fetus can be clearly identified. The flow of blood through a patient’s heart can be monitored and studied by a cardiologist.”

**Instructor**
Now it may sound kind of strange to call ultrasonic and infrasonic waves sound waves. But these waves are the same kinds of waves as the ones we can hear. Other creatures such as dogs and porpoises can hear some frequencies that we can’t. In fact, as you may have observed, not everyone can hear all the sounds in the 20 to 20,000 hertz range. It depends on age, health, and experiences with loud noises. You can bet that we’ll talk more about this later.

But now let’s talk about another property of sound: velocity. Like all waves, the velocity of sound waves depends on what? Tell your teacher.

Did you say the medium? Good. Let’s get some notes on this and then work some example problems.

(green chalkboard on screen)

**VO**
The velocity of sound depends on the medium through which it travels.

Sound travels fastest in solids and slowest in gases.

The speed of sound in air depends on the temperature. At zero degrees Celsius, the speed of sound in air is 331 m/s.

For each degree above zero, the speed of sound increases by 0.6 m/s. The opposite is true for each degree below zero.

**Instructor**
If you put your ear to a railroad track, you can hear the sound of an approaching train fifteen times faster that you can hear the sound through the air. And sound travels about four times faster in water than in air.
Here’s a challenge for you. If the speed of sound is 340 m/s at sea level, how fast is that in miles per hour? Everybody write down a guess on a piece of paper. Then use the fact that one kilometer is 0.62 miles and convert. Come back when you have an answer.

(Instructor)

The answer is 760 miles per hour. This is called Mach One. Now it’s time to do a couple of example problems.

(VO)

We’re going to use 22°C as room temperature in this course. That’s about 72°F. To calculate the speed of sound, you start with 331 m/s and add 0.6 times the temperature in degrees Celsius. This gives us an un-rounded answer of 344.2 m/s. Now, how shall we round this number? Should we round to the weakest link, which would be one significant digit. But we don’t use the weak link when we’re adding. We use the weak column. So round to the one’s column. The answer is 344 m/s. You can use this as the speed of sound at room temperature without re-calculating.

In number two, we have to be careful not to surf. First, you need to know what an echo is. It’s a reflection off a boundary. The distance the sound is traveling is to the mountain and back. So when you see an echo problem, change the equation for velocity to “v equals 2 times d over t”. Now you can plug in all the data and chug out one answer.

Time equals 2 times 110 meters divided by 331 m/s plus 0.6 m/s per degree Celsius times negative 6.0 degrees. The answer is 0.67 seconds.

(Instructor)

Now your teacher will give you these problems to try. Come back when you’ve finished and we’ll go over the answers.

Local Teachers, turn off the tape and give students problem set number one from the facilitator's guide.

(VO)

The rule of thumb you may have heard is that for every 5 seconds between seeing lightning and hearing thunder, the lightning is one mile away. This problem confirms that. Because the speed of light is about a million times faster than sound, when the event is far away, you’ll see it before you hear it.

Number two involves sonar, which is an acronym for “Sound Navigation and Ranging”. This is an echo problem, so we put a two times the distance in the basic equation. Then we rearrange to solve for d, which equals “v times t divided by 2”. The distance is 2200 meters.

In the last problem, we use the wave equation and rearrange to solve for frequency. The un-rounded answer is 22,506. The rule of 5’s doesn’t apply here because this is greater than 5, so we round up to 23,000 hertz. This is in the ultrasound range, so we couldn’t hear it.
Instructor’s voice coming from tape player
Your teacher has some more practice for you. But that can wait. First, let’s have some fun with the speed of sound.

Instructor
Do I really sound like that? You’re probably saying, “Yes.” But I sound completely different to myself. That’s because much of the sound is traveling to my ear through the bones of my face. That’s a different medium, so the speed is different, but over short distances it’s not noticeable. However, the tone of the sound is affected. We’ll talk more about that later. Now here are some cool things you can try. Let’s go to the lab so that our students can show you the set up. Then try each demo for yourselves.

(student on screen)
VO
Your school should have some tuning forks. Strike it with something soft, like your knee or a mallet or rubber stopper. Listen to the sound through the air. Then wrap a tissue around the stem and place it between your teeth. The sound will be entirely different.

Next, tie a string to a fork, wrap the string around your finger, and place it in your ear, like this. Now strike the fork with another utensil and listen. It sounds like a chime.

This one may bring back memories of childhood. Make a toy telephone out of a long string and two cans. Take turns talking and listening, keeping the string tight. Have a friend strike a tuning fork and touch the tight string. It will sound like a buzz saw.

Instructor
Why does my voice sound funny when I breathe in helium? Well, the helium does not freeze your vocal cords as some people may have told you. But the speed of sound in helium is almost three times the speed in air. So when you fill your vocal tract and mouth with helium, sound waves travel faster, and the higher frequencies in your voice are enhanced.

Now, here’s a warning. When you inhale helium, you deprive your brain of a little oxygen. So don’t do this often and never breathe in helium from a pressurized tank.

Now it’s time to practice on the problems we’ve shown you. When you’ve finished, come back and we’ll talked about the Doppler Effect and..
(Sound Effect: a sonic boom) sonic booms.
(Pause Tape Now graphic)

Instructor
(Sound Effect: race cars passing – pitch rises and then falls)
Listen. Do you hear the sound’s pitch change? It rises when the car is approaching and drops when the car is moving away. The same thing can be observed from a car horn or siren on a passing vehicle.
(Sound Effect: ex of Doppler effect)
Now, I told you earlier that pitch depends on the frequency of a sound. Frequency depends only on the vibration of the sound’s source. But the frequency of the horn or siren isn’t changing. Did I lie to you? Nope. Earlier I said, “under ordinary conditions.” If you don’t believe me, just rewind the tape. When the sound source or the observer start moving toward or away from each other, the situation changes, and so does the pitch.
It’s called the Doppler effect, named for the Austrian physicist Christian Doppler who first discovered it. Let’s go back to the beach to explain.

**VO**
Over a short period of time, the frequency of water waves at the beach is constant. But watch this dog running into the water, toward the waves. The frequency with which the waves hit him increases. And when he is going in the opposite direction, toward the beach, the waves hit him with decreasing frequency.

Sound waves are spherical, moving out in all directions from the source. And it doesn’t matter whether the sound source, like this car’s horn, or the observer moves. As the car moves to the left, person A hears the horn at a higher pitch than the driver, and person B hears a lower pitch.

*(green chalkboard on screen)*
The Doppler effect is a change in observed pitch caused by the relative motion of the sound source and the observer.

As the source and observer approach each other, the observed frequency increases, so the pitch rises. The opposite happens when the source and observer move away from each other.

**Instructor**
The Doppler effect applies to all kinds of waves. You may have heard of Doppler radar used in weather forecasts. The radar waves locate the storm front, and Doppler shifts tell meteorologists how fast the storm is approaching.

And police use computers to compare the frequency of emitted radar waves and the ones reflected from a moving car to determine the speed of the car. It works whether the car is approaching or leaving and whether the police car is moving or staying still. Remember that it’s the relative motion that produces the change in frequency. And here’s one more example of the Doppler effect used by astronomers.

*(stars on screen)*
**VO**
This phenomenon also occurs with stars. Stars moving away from the earth have a shift towards the red, while those moving toward the earth have a shift toward the blue end of the visible light spectrum.

**Instructor**
Now let’s take this moving sound source one step further… one giant step. What happens when the source of a sound moves as fast as the sound waves it produces? You may have heard of the sound barrier. This is an actual physical wall of pressure that is responsible for the break up of early high-speed planes and the loss of lives. So we need to see what causes it. Let’s start with a simple analogy, a Chihuahua swimming in a pool. Put your pencils down. We’ll tell you when to take notes.

*(diagram of dog in water.)*
**VO**
Let’s start with our little dog treading water, staying in one spot in the pool while he wiggles his legs at regular intervals, producing water waves. These circles represent crests of the waves the Chihuahua creates. This is the first wave he made, and this is the last one.
Now, suppose the dog starts moving from left to right as he is making the same waves as before. You’ll recognize this as the Doppler effect. The wave crests in front of him are crowded together and those behind him are spread apart.

What will happen if the tiny dog moves at the same speed as the water waves he produces? By the time each wave reaches this point, so does he. Instead of the crests staying ahead of the dog, they pile up on one another, right in front of the dog. What happens when wave crest meets crest?

Constructive interference occurs, making one giant crest that acts as a wave barrier. This could be real trouble for our tiny dog. He could drown trying to get through the wall.

**Instructor**

The same basic thing happens when a plane moves through the air. It disturbs the air as it moves through it, creating sound in the form of air pressure waves. These waves move outward from the plane in three dimensions at the speed of sound. When a plane is flying at low speeds, the compressed air has time to move out of the way to let the plane through.

Now, as the aircraft moves faster and faster, these wave fronts begin to crowd together in front of it, but the waves are still moving faster than the plane.

At Mach One, the speed of sound, compression overlaps with compression after compression, creating a wall of high pressure that can make the pilot lose control of the plane or shake the plane apart if it is not specifically designed for such supersonic flight.

*(photo of Chuck Yeager on screen)*

**VO**

In 1947, test pilot and United States Air Force officer Chuck Yeager was the first to break through the sound barrier in an experimental X-1 aircraft. The X-1 was carried into flight under the bomb bay of a larger plane. After it was air-launched, Captain Yeager fired the rocket engines of the X-1 and broke through the sound barrier at a little under 700 miles per hour, which is the speed of sound at the high altitude of 43,000 feet.

**Instructor**

Today, aircrafts are properly designed to break through the sound barrier and fly at supersonic, or hypersonic speeds. Now, here is a once in a lifetime photo taken in 1999 by Ensign John Gay from an aircraft carrier in the Pacific. The F-18 was flying at an altitude of about 1,000 feet and accelerating when the ensign snapped his camera shutter just as an egg-shaped cloud developed. All the conditions of humidity, air density, and temperature were just right to depict the moment the plane passed through the sound barrier. But what caused the cloud?

*(diagram of plane and waves on screen)*

We’ve described the sound barrier as compressions, like wave crests, overlapping to form a region of very high pressure in front of the plane.

Well, just behind these compressions are overlapping rarefactions, like troughs, shown by the red dotted lines. Constructive interference produces a region of very low pressure here, making the temperature drop suddenly. And at just the right humidity, water vapor in the air condenses into a cloud.

**Instructor**

That’s what you’re seeing in this incredible photograph. Such a picture couldn’t be taken over land,
because supersonic flight is prohibited except above 30,000 feet and over specified areas. Why? Because of sonic booms. Let’s go back to our dog in the pool to see how sonic booms are created.

(diagram of dog and waves on screen)

VO
Let’s say that, with a burst of speed, our little dog plowed right through the wave barrier and is now moving faster than the water waves it is producing. The wave crests trail along behind the high-speed dog, overlapping at the edges to produce a more moderate constructive interference pattern in a V shape. This is called a bow wave because it’s often seen behind a speedboat. If you’ve ever water skied you may have observed a bow wave first hand. In fact, one may have knocked you down. Out in front of the bow wave, the dog or boat or skier is moving through smooth water.

The same conditions produce a three-dimensional shock wave trailing behind a supersonic plane. This cone of high-pressure air spreads out until it reaches the ground, producing a sonic boom. If you’ve never experienced a sonic boom it sounds like thunder or an explosion.

Now a common misconception is that a sonic boom is heard the instant the plane breaks the sound barrier. Wrong. The shock wave travels behind the plane the entire time it is flying faster than the waves it creates. A person at point B on the ground is hearing and feeling the boom now. The person at position A has already heard it, and the one at position C hasn’t experienced anything, even though the plane has passed overhead already.

The intensity of the sonic boom depends on the speed, shape and size of the plane and on the plane’s altitude. The closer it is to the ground the more concentrated the waves will be and the more damage the shock wave can do.

(Read Fact or Fiction statement on screen)

Instructor
It’s a fact. The moving object doesn’t have to emit a sound to make a sonic boom. Just like a plane or a speeding bullet, the tip of the whip travels faster than 760 miles per hour and makes the cracking sound by disturbing the air. So the sound you hear is not the whip hitting the lion. The sonic boom just gets his attention…and mine, too.

Well, we’ve shown you lots of interesting things about sound today. Your teacher has the Show What You Know quiz for you. We’ve just started our study of sound. In our next program we’ll talk about loudness….

(Sound Effect: LOUD rock music plays over instructor’s voice.) …and the fact that it cannot be measured. Turn that noise off! Off! Oh well, see you next time.