The Nature of Sound

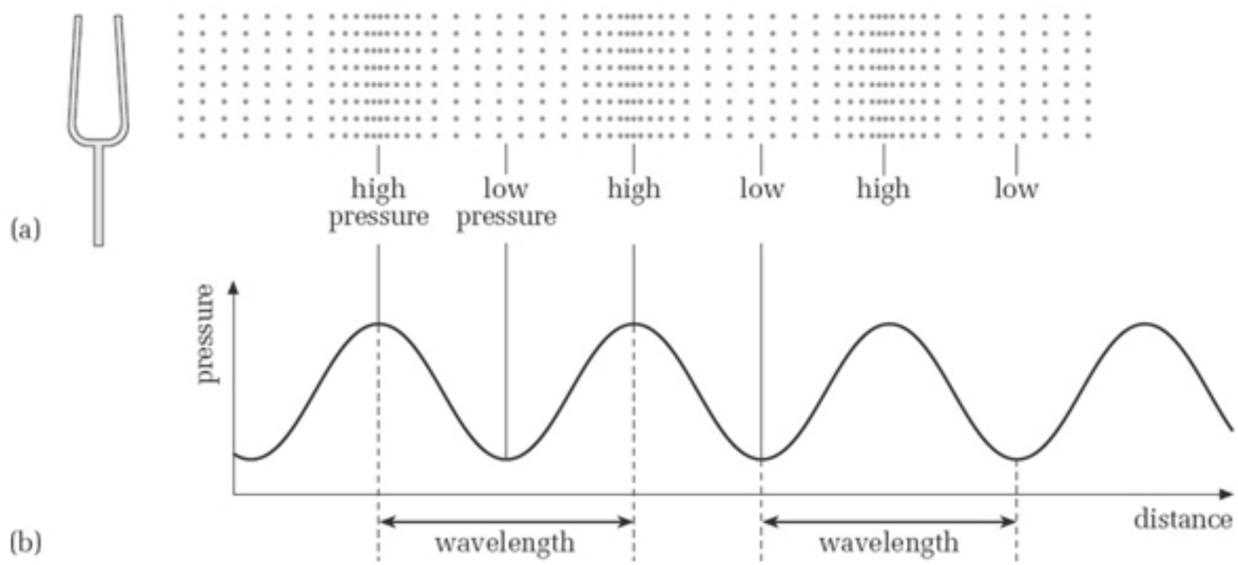
Sound is an example of a three-dimensional longitudinal wave. Though there are many types of sounds, all of them have one thing in common: they are produced by a vibrating source.

Some examples include:

- the vibration of your vocal cords produces speech
- the vibrating cone of a speaker produces the music coming out of your headphones
- musical instruments produce sound using vibrating strings or vibrating columns of air
- colliding objects vibrate on impact, producing sound
- machines with moving parts vibrate, producing sound

The vibration of these objects creates pressure variations in the air. These variations result in areas of high pressure (compressions) and low pressure (rarefactions) that radiate outward from the source.

Even though sound waves are longitudinal, they are often represented graphically by a transverse wave. This is possible because if you plot a graph of air pressure versus distance, the resulting pattern has the shape of a transverse wave.



Sound is a mechanical wave – it requires a medium. This medium is most commonly air, but it can be anything, including solids and liquids. (To see that this is true, consider the fact that sound transmits quite easily through walls.)

Sound has many characteristics that can be related to its wave form. These include speed, pitch, loudness, and timbre (quality). We will discuss each of these characteristics individually.

The Speed of Sound

As with other waves, the speed of sound depends on the medium through which it is traveling. The table below lists the speed of sound in some common media.

Medium	**Speed of Sound**
Air (at $0°C$)	331 m/s
Air (at $20°C$)	343 m/s
Water	1482 m/s
Steel	5960 m/s

In addition, the speed of sound varies with temperature. In general, as the temperature increases, the speed of sound also increases.

The speed (v) of sound in air at a temperature T (in $°C$) is given by:

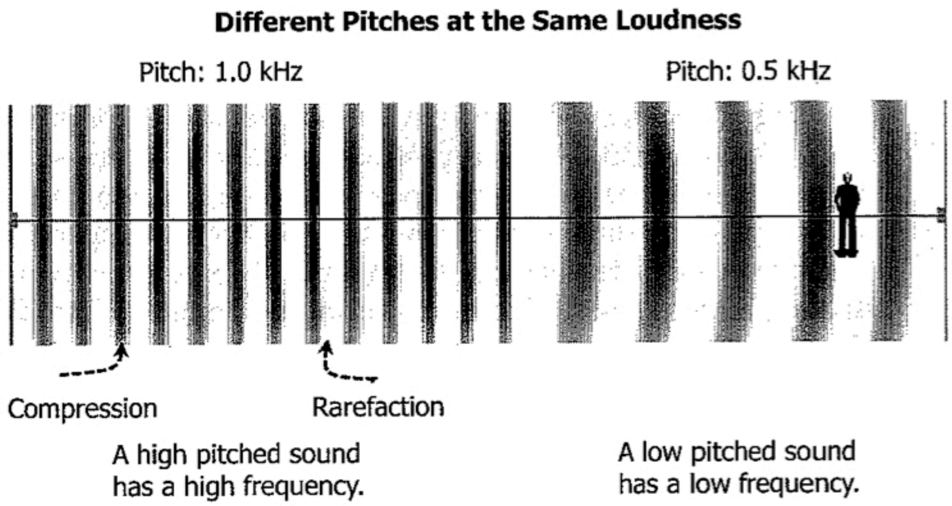
$$v = 331 + 0.6T$$

Example 1
Determine the speed of sound in air at $30°C$.

Example 2
Two people are $100\ m$ apart. One of them claps their hands, and the other hears the sound $0.3\ s$ later. What is the speed of sound?

Sound Frequency and Pitch

The **pitch** of a sound refers to how high or low the sound is. It has been observed that the pitch of a sound is directly related to its frequency. In other words, a high pitched sound has a high frequency, and a low pitched sound has a low frequency.

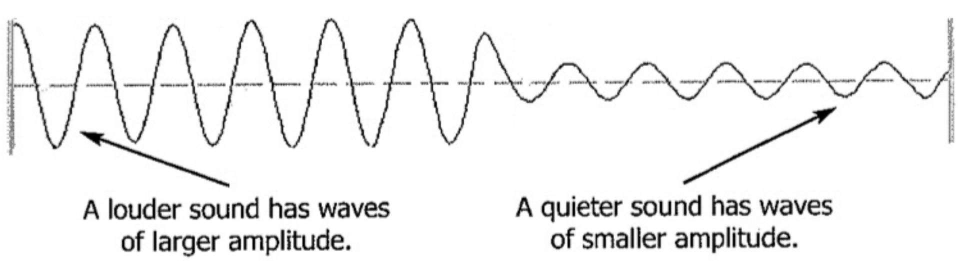


Low pitched sounds are sometimes referred to as **bass**, while high pitched sounds are sometimes referred to as **treble**. A sound with a single frequency (such as that from a tuning fork) is called a **pure tone**.

The human ear has the ability to detect sounds ranging from a frequency of around $20\ Hz$ to around $20\ kHz$. This range of frequencies is known as the **audible range**. Frequencies below $20\ Hz$ are said to be **infrasonic**, while frequencies above $20\ kHz$ are said to be **ultrasonic**.

Sound Pressure, Amplitude, and Loudness

Loudness is a measure of how strongly a sound is heard. In general, sound waves with a larger amplitude (on a graph of air pressure versus distance) are considered to be louder. It is difficult to accurately quantify the loudness of a sound, since it is a very subjective thing – different people will perceive the volume of a sound differently. There is, however, a connection between the **pressure amplitude** of a sound wave and its loudness: the larger the amplitude, the louder the sound.



Sound Intensity

The **intensity** of a sound is a measure of how much energy it carries. Intensity is closely related to amplitude. In general, larger amplitude sound waves have a greater intensity.

Sound intensity is measured in **decibels** (dB). A sound of zero decibels is the quietest sound that can be heard by a person with average hearing. This is known as the **threshold of hearing**.

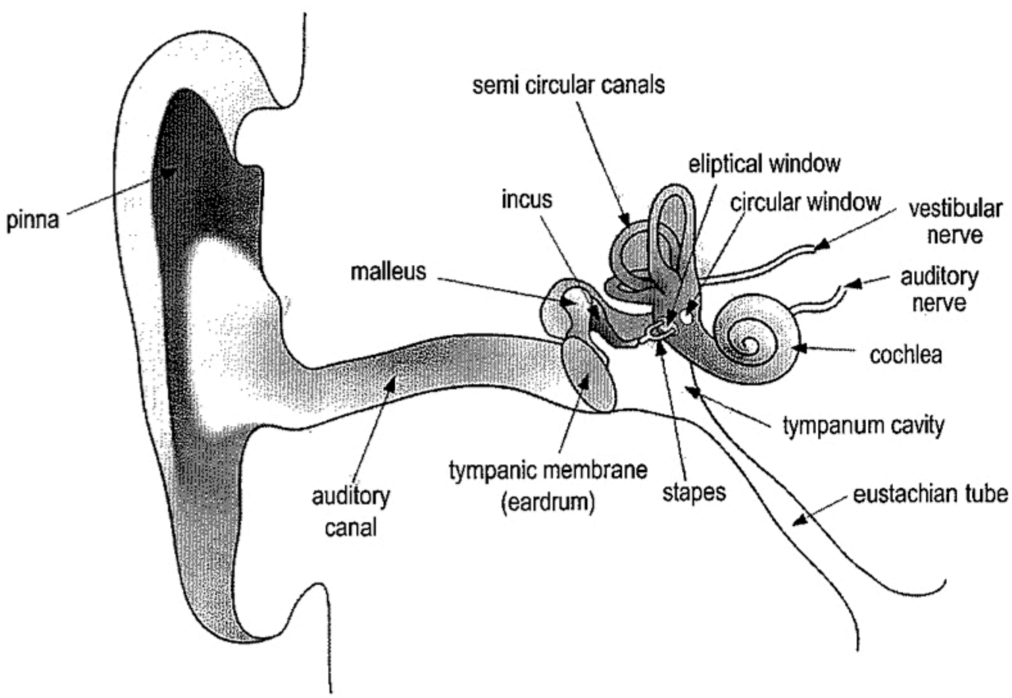
A sound that is 10 (10^1) times more intense than the threshold of hearing is assigned a sound level of $10\ dB$. Rustling leaves are an example. A sound that is 100 (10^2) times more intense than the threshold of hearing is assigned a sound level of $20\ dB$. This is the sound of a whisper. A sound that is 100 000 (10^5) times more intense has a sound level of $50\ dB$. This is the sound of an average classroom. Other examples of sound are a car without a muffler ($100\ dB$) and a rock concert ($120\ dB$). Sounds above $130\ dB$ are actually painful to hear – this is called the **threshold of pain**.

In general, every $10\ dB$ increase represents an increase of 10 times the intensity of the sound. Loudness and sound intensity are related: **for every 10 *dB* increase in sound intensity, the loudness of a sound will double**. Thus, a $70\ dB$ sound is twice as loud as a $60\ dB$ sound, while a $80\ dB$ sound is four times as loud as a $60\ dB$ sound.

Detection of Sound

In humans, sound is detected primarily by our ears. A simplified version of how you hear would go something like this:

- sound enters your ear
- your eardrum vibrates
- the vibration of the eardrum is picked up by nerves
- nerves carry the vibration to your brain
- your brain interprets the vibration and translates it to sound



Source: Dan Pickard. Human Ear.jpg

Your whole body can also "feel" certain sounds. Anyone who has attended an action movie, or a rock concert has probably experienced this.

Waves Worksheet #9

1. Distinguish between

    a) loudness and pitch.
    b) ultrasonic and infrasonic.

2. A dog can hear a sound produced by a dog whistle, while its owner cannot. Explain how this is possible.

3. What physical characteristic of a wave would you change to

    a) increase the loudness of a sound?
    b) change the pitch of a sound?

4. In the nineteenth century, people put their ears to a railroad track to get an early warning of an approaching train. Why did this work?

5. When timing the $100\ m$ run, officials at the finish line are instructed to start their stopwatches at the sight of smoke from the starter's pistol and not at the sound of its firing. Explain. What would happen to the times for the runners if the timing started when the sound was heard?

6. The speed of sound increases by about $0.6\ m/s$ for each degree Celsius when the air temperature rises. For a given sound, as the temperature increases, what happens to the

    a) frequency?
    b) wavelength?

7. Determine the speed of sound at the following temperatures:

    a) $-30°C$
    b) $8°C$
    c) $37.5°C$

8. Find the frequency of a sound wave moving in air at room temperature ($20°C$) with a wavelength of $0.667\ m$.

9. The human ear can detect sounds with frequencies between $20\ Hz$ and $20\ kHz$. Find the largest and smallest wavelengths the ear can detect, assuming the sound travels through air with a speed of $343\ m/s$ at $20°C$.

10. A sound wave has a frequency of $9800\ Hz$ and travels along a steel rod. If the distance between compressions, or regions of high pressure, is $0.580\ m$, what is the speed of the wave?

11. If you clap your hands and hear the echo from a distant wall $0.20\ s$ later, how far away is the wall? Assume the speed of sound is $343\ m/s$.

12. You hear the sound of the firing of a distant cannon $6.0\ s$ after seeing the flash. How far are you from the cannon? Assume the speed of sound is $343\ m/s$.

13. What is the frequency of sound in air at $20°C$ having a wavelength equal to the diameter of a $38\ cm$ woofer loudspeaker? Of a $7.6\ cm$ tweeter?

14. A rifle is fired in a valley with parallel vertical walls. The echo from one wall is heard $2.0\ s$ after the rifle was fired. The echo from the other wall is heard $2.0\ s$ after the first echo. How wide is the valley? (The air temperature is $20°C$.)

Answers

7. (a) $313\ m/s$ (b) $335.8\ m/s$ (c) $353.5\ m/s$
8. $514\ Hz$
9. Shortest: $0.017\ m$ Longest: $17\ m$
10. $5684\ m/s$
11. $34.3\ m$
12. $2058\ m$
13. Woofer: $903\ Hz$ Tweeter: $4513\ Hz$
14. $1029\ m$