Sound

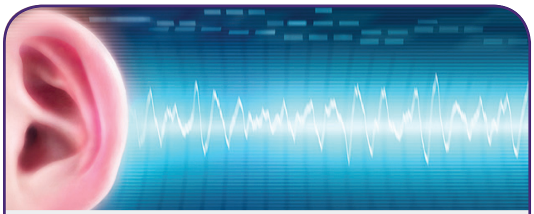
PHYSICS • WAVES • SOUND

Section 1: Sound

• What is sound?

When an object vibrates it can disturb the air around it, compressing and decompressing it, as it repeatedly pushes into and draws away from it. This causes waves to travel through the air. These waves, made up of changes in the air pressure, can be detected by the human ear if the change in pressure is large enough. We call them sound waves, and they can travel through liquids, solids and gases.

As with all waves, we can describe them in terms of wavelength and frequency. The distance between each area of high pressure is known as the wavelength, the number of waves which pass a point in one second is known as the frequency. By multiplying these together we get the distance travelled per second: the speed of the wave.



Our ears can hear sound by detecting vibrations in the air

• Suggested Films

- **What Is Sound?**
- **Echolocation: Dolphins**
- **Doppler Shift**

Extension Questions

Q1. What is an echo?

When a sound wave strikes a surface it can bounce back, meaning the reflected wave can travel back to the source and be heard. The sound wave does not need a hard surface to reflect. The wave can be reflected whenever the properties of a material abruptly change. This can be at the boundary between two liquids, or the boundary between air and water.

Echoes are used in sonar, for example, to measure the distance to objects, and the depth of water. Because the speed of sound is known, the distance can be calculated by timing how long the echo takes to return.

Q2. What is the Doppler effect?

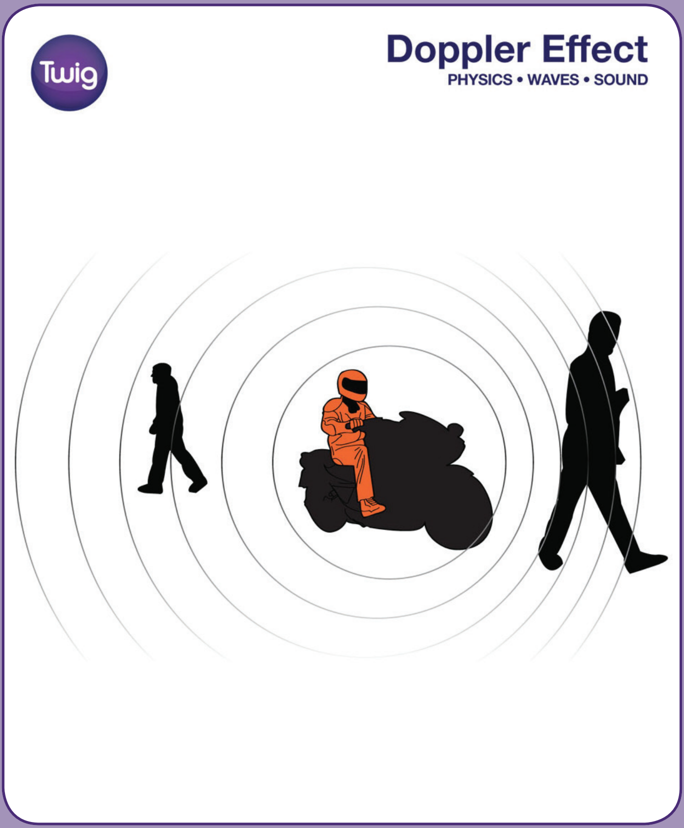
When an object is moving while emitting sound, the sound heard by an observer will appear to have changed in frequency.

For example, if a train is heading towards a stationary observer, the sound from the train will sound as if it has a higher frequency than if the train were not moving. As the train moves away from the observer, the frequency of the sound will appear to have been reduced.

This is because as the moving train emits sound, it is either catching up on, or travelling away from the waves already emitted, which either reduces or increases the distance between the waves. This means the time between the waves arriving is either reduced or increased.

The speed of an object can be calculated by measuring the change in frequency.

DIAGRAM 01:



Extension Questions

Q3. Can sound travel in space?

In science fiction, explosions and engine noise can often be heard in space, but this is only done for dramatic effect. There are very few molecules in space, and it is almost a perfect vacuum. Because of this, there is nothing for sound waves to travel through, and therefore sound cannot be heard.

Q4. How are sound waves used to investigate the structure of the Earth?

Earthquakes cause waves which travel through the Earth. These seismic waves travel at the speed of sound and tell us about the structure of the Earth. By measuring the time taken for different waves to pass through the Earth, we can predict the position and density of layers within the Earth.

• What is the speed of sound?

The speed of sound is different in every material. In air, the speed of sound increases slightly as temperature increases, but is approximately 340m/s at room temperature. This is noticeable over large distances. At a distance of 100m there will be a delay, of just under a third of a second, between seeing an event and hearing the sound associated with it.

This speed is equivalent to around 1200km/h or 770mph, and was first officially reached by aircraft in 1947. Although there are reports that some German aircraft flew faster than the speed of sound during the Second World War, these are controversial and cannot be confirmed.

In 1997, the Thrust SSC became the first land vehicle to travel faster than the speed of sound.

Extension Question

Q5. What determines the speed of sound in a medium?

The speed of sound is determined by the material it travels through. Temperature can affect the speed of sound, and the speed of the vibrations in a material increases if the temperature of the medium increases.

The elasticity and density of the medium also affect the speed of sound. In a dense material where the particles are heavier, sound travels more slowly. The elasticity describes how much the medium changes in response to pressure. In a material which stretches easily when a force is applied, like rubber, the speed of sound is low.

• Suggested Film

- Speed of Sound

• What is a shockwave?

When the properties of a material undergo a large change, for example, because an object is moving through the material at high speed, or because of an explosion, the rate at which the disturbance spreads through the material can be greater than the speed of sound in that material. This results in a shockwave.

For example, in an explosion in air, hot gas is produced, which heads outwards from the explosion at speeds much greater than the speed of sound. This forces the surrounding air outwards, and because the air cannot get out of the way, it is squeezed. A layer of compressed, high-pressure air forms, and is pushed outwards. As this encounters objects, the quick change in pressure can cause damage, or be heard as a loud noise.

High-speed fighter planes can cause shockwaves in the air

• Suggested Film

- Shockwaves

Extension Question

Q6. What causes a sonic boom?

When an object travels faster than the speed of sound, the sound waves are not able to travel away from the object before it passes through them. As the sound waves overlap, there is a build up of pressure. This leads to a shockwave forming, and when this shockwave passes, a 'sonic boom' is heard. This shockwave is produced continuously, not only when the object first exceeds the speed of sound.

Objects like supersonic aircraft or bullets create these shockwaves, and this is the reason a loud noise is heard as they pass.

Section 2: Hearing

• How does the ear work?

The ear contains a membrane called the eardrum. When sound waves pass through air, the vibrations make the eardrum vibrate. This causes tiny bones in the ear to vibrate, which pass the vibrations to the inner ear. The inner ear contains thousands of tiny hairs and is filled with fluid. When the hairs vibrate, they stimulate nerves and send signals to the brain. This produces the sensation of 'hearing' sound.

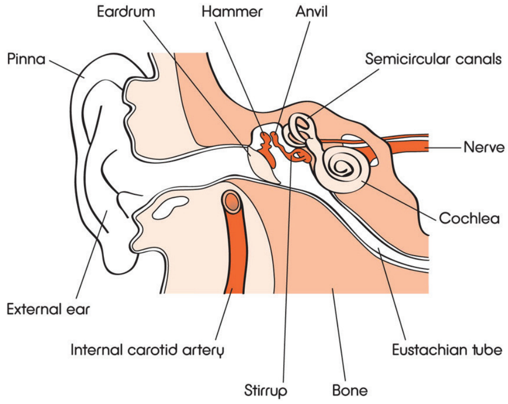
• Suggested Film

- What Is Sound?

DIAGRAM 02:

Cross-Section of the Ear

PHYSICS • WAVES • SOUND



• What is the range of human hearing?

Animals, such as dolphins, can hear different frequencies of sound

Humans can hear sounds with a frequency of 20 hertz (Hz). As we age, our ability to hear high frequency sounds diminishes. Dogs and cats can hear much higher frequencies; dogs can hear sounds of over 40,000Hz, which means that whistles can be made that are audible to dogs, but silent to humans.

• Suggested Film

- Beyond Human Hearing

Extension Questions

Q7. What is infrasound?

Sound with a frequency which is too low for humans to hear (less than 20Hz) is known as infrasound. Although infrasound cannot be heard by humans, if the intensity of the waves is large enough, it can be perceived. It is believed that infrasound can cause feelings of uneasiness and fear in humans.

Infrasound can travel over very long distances, and it is thought that animals, such as elephants, can use infrasound for communication.

Q8. What is ultrasound?

When sound has a frequency of over 20,000Hz, above the range of human hearing, it is called ultrasound.

Ultrasound is used during pregnancy to obtain images of the foetus in the womb, and can also be used to image internal organs. Images can be created as ultrasound reflects from the boundary layers between different tissues. By noting the time for the sound to return, the depth of the feature can be calculated, and an image can be produced.

Bats, dolphins, and some whales use ultrasound to locate prey by emitting ultrasound and listening for echoes.

• How is loudness measured?

Loudness is a measure of how loud a sound is perceived to be, although this can depend on factors, such as the frequency of the sound. It is strongly related to the level of sound pressure (the increase in air pressure caused by the sound wave), which is measured in decibels (dB). For this reason, decibels are commonly used to indicate the loudness of a sound.

The decibel scale is logarithmic. Every increase of 10dB (1 bel) results in the sound becoming 10 times louder. This means that 20dB is 10 times louder than 10dB, and 30dB is 100 times louder than 10dB.

These apparently small changes in the decibel level can result in a large difference in the loudness. For example, an increase of only 3dB results in the loudness approximately doubling.

• Suggested Films

- What Is Sound?

- FactPack: Decibel Range

Section 3: Music

• How do musical instruments produce sound?

Musical instruments are usually classified according to the way they produce sound; wind, string and percussion instruments all produce sound through resonance. All objects vibrate with a specific resonant frequency.

String instruments produce sound when strings vibrate; wind instruments use a vibrating column of air; and percussion instruments use vibrating blocks, plates, or membranes to produce sound.


Musical instruments make noises by vibrating the air around them

• Suggested Films

- Musical Instruments
- Resonance

Extension Question

Q9. What are beats?

When two sounds have a similar frequency, they can combine to produce beats. The volume of the combined sound is heard to pulse, increasing and decreasing. These beats have a frequency equal to the difference between the frequencies of the two sounds.

As the frequencies become closer, the difference becomes smaller, and the beats become less frequent. This can be used to tune instruments. A tuning fork can be used to sound the required note; the instrument is then used to sound the note and adjusted until beats are heard. When the instrument is tuned the time between the beats will increase as the two notes become closer in frequency.

• What is a harmonic?

When a note is sounded, it is unlikely that the sound will only contain one frequency. Instead there is usually a mix of frequencies.

For example, when a string is held at each end, it is able to vibrate with its fundamental frequency, which has a maximum at the centre of the string, and a wavelength twice the length of the string.

As well as this frequency, the string can also support other vibrations at the same time. However, as the string is being held at each end, the only vibrations that can exist on the string are those which do not need the string to move up and down at either end. These vibrations all have frequencies which are multiples of the fundamental frequency. So, if the fundamental frequency is 20Hz, the string will also vibrate at 40Hz, 60Hz, 80Hz, 100Hz and so on. These frequencies are known as the harmonics. The fundamental frequency is the first harmonic, the next is the second harmonic, which is sometimes called the first ‘overtone’.

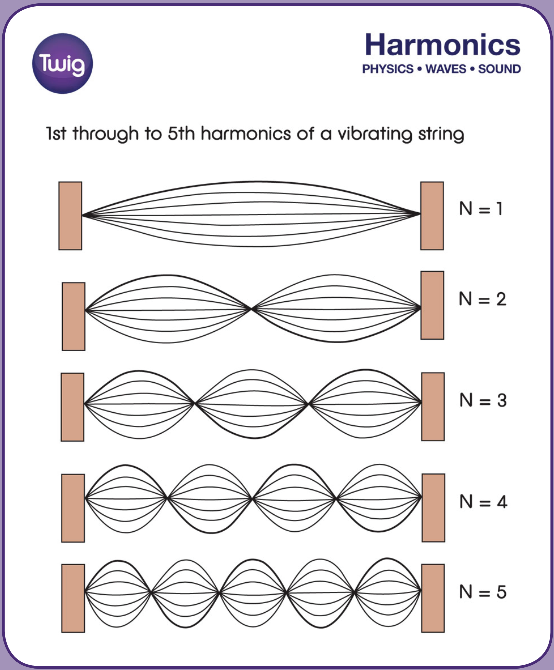
The difference in the relative strength of the harmonics means that the same note will sound different when played on two different instruments.

The fundamental frequency of a string is determined by the length of the string, its density, and the tension it is under. This is why strings are tightened or loosened when they are tuned to a specific note. Musicians playing in orchestras have to tune their instruments before playing, because small changes in temperature and humidity can affect the instruments, causing wood to expand and contract, and changing the tension on the strings.

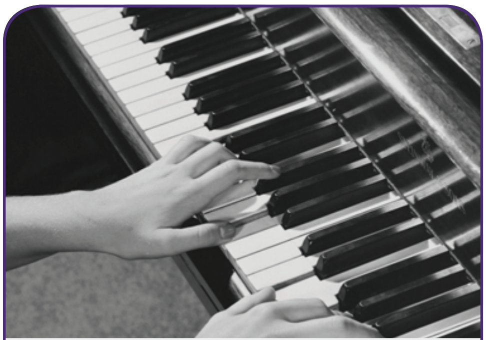
• Suggested Film

- Musical Instruments

DIAGRAM 03:



• What are octaves?



Every twelfth note on the piano is separated by an octave

When the frequency of a sound doubles, we say that the note is the same, but in different octave. Humans hear notes as similar when their frequency is doubled or halved, and when heard together these notes sound pleasing.

The range of human hearing covers approximately ten octaves. For example, if 20Hz is the lowest frequency a human can hear, the frequencies of its octaves of this note would be 40Hz, 80Hz, 160Hz, 320Hz, 640Hz, 1280Hz, 2560Hz, 5120Hz, 10240Hz and 20480Hz. As 20480Hz would be outside the range of human hearing, we are left with 10 audible octaves.

Most musical instruments would not cover this entire range. For example, a piano would usually cover just over seven octaves.

• Suggested Film

- Musical Instruments

Extension Question

Q10. What is a note?

Each octave is split into 12 intervals, called semitones. This would give us 12 notes in each octave. However, we only use seven letters to describe these notes, giving us the seven notes C, D, E, F, G, A, B, as well as five others which we call sharps or flats, depending on whether they are higher or lower the neighbouring note we are considering. We say that an octave contains eight notes, as we also include the first note of the next octave.

The frequencies of the notes could be altered without affecting the relationship between notes in different octaves. For example, we could say that C was 256Hz in one octave, 512Hz in the next and 1024Hz in the next, or we could instead say C was 250Hz in one octave, giving 500Hz and 1000Hz in the next two octaves. The octave structure would still work, but this would lead to confusion if different musicians used different frequencies for the same note. For this reason it is commonly agreed that A in the middle octave should be set at 440Hz. This then defines all other notes, and sets middle C at 261.6Hz.

• Quizzes

Speed of Sound

Basic

• What happens to the speed of sound as temperature increases?

A – the speed of sound decreases

B – there is no effect

C – the speed of sound increases

D – the speed of sound increases, but only in liquids

• How does elasticity affect the speed of sound?

A – the speed of sound is slower in more elastic materials

B – the elasticity doesn't affect the speed of sound in solids

C – the elasticity doesn't affect the speed of sound in liquids

D – the speed of sound is faster in more elastic materials

• Why does sound travel faster in helium than air?

A – the helium molecules are closer together

B – the helium molecules are travelling faster than the molecules in air

C – the helium molecules are further apart

D – the helium molecules are heavier than the molecules in air

Advanced

• In general, which types of materials transmit sound most quickly?

A – solids, then gases, then liquids

B – gases, then liquids, then solids

C – solids, then liquids, then gases

D – gases, then solids, then liquids

• What is the usual value given for the speed of sound in air?

A – 1500 m/s

B – 200,000,000 m/s

C – 340 m/s

D – 300,000,000 m/s

• How much faster is sound in water than in air?

A – 4 times as fast

B – 2 times as fast

C – 10 times as fast

D – 100 times as fast

• What is the speed of sound in water?

A – 1500 m/s

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Speed of Sound

Basic

• How does the density of a material affect the speed of sound?

A – the speed of sound increases for denser materials

B – the density only affects the speed of sound in solids

C – the speed of sound is not affected by density

D – the speed of sound decreases for denser materials

What Is Sound?

Basic

• What is the amplitude of a wave?

A – the speed of the wave

B – the height of the wave

C – the distance between two waves

D – the number of waves passing a point in one second

• What types of waves are sound waves?

A – radio waves

B – mechanical waves

C – transverse waves

D – electromagnetic waves

• Does sound have to travel through a medium?

A – no, sound can travel through a vacuum

B – yes, but sound cannot travel through solids

C – yes, but sound can travel through solids, liquids or gases

D – yes, but sound cannot travel through liquids

Advanced

• What is the frequency?

A – the number of waves passing a point in one second

B – the distance between two waves

C – the height of the wave

D – the speed of the wave

• What is a longitudinal wave?

A – a wave that travels slower than sound

B – a wave that oscillates at right angles to the direction of travel

C – a wave which travels at the speed of light

D – a wave that oscillates in the direction of travel

• How is pitch related to frequency?

A – the pitch is not related to the frequency

B – the higher the frequency the higher the pitch

C – the pitch depends on the frequency, but also on the amplitude

D – the lower the frequency the higher the pitch

What Is Sound?

Basic

- How is the amplitude of a wave related to volume?

A – the smaller the amplitude, the louder the sound

B – the volume only depends on the frequency

C – the larger the amplitude, the louder the sound

D – the volume only depends on the wavelength

Advanced

- What is frequency measured in?

A – decibels

B – metres

C – hertz

D – metres per second

• Answers

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