SENIOR SIX TERM 1

TOPIC 6/6: SOUND WAVES

Competency: The learner investigates the behaviour of sound waves and their applications in different situations.

Sound waves

Sound is a form of energy produced by vibrating objects. It travels as a longitudinal wave through a material medium.

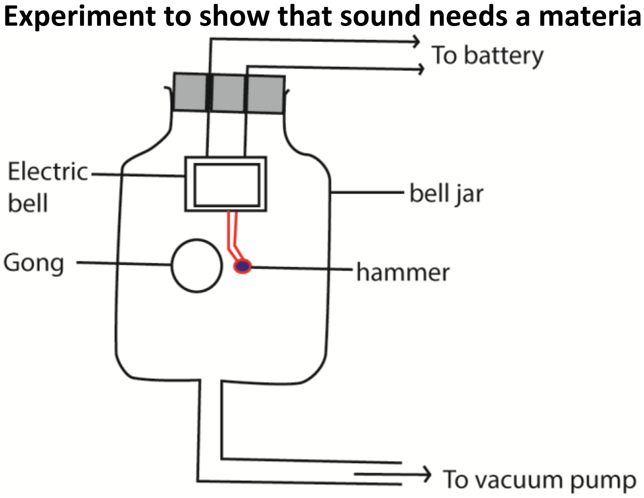
Production

Sound is produced by vibrating objects. Vibrating objects cause nearby surrounding air molecules to vibrate. When these vibrating air molecules reach our ear, sensation of sound is produced. A sound wave is a longitudinal wave

Propagation of sound

Sound waves need a material medium for transmission so that the vibrating objects cause the nearby molecules of the medium to vibrate

Experiment to show that sound needs a material medium for the transmission



Switch on the electric bell
Switching on the electric bell, a loud sound is heard

Removal of air gradually
On gradually removing the air by a vacuum pump, the loudness of sound gradually dies away.

No sound is heard when all the air has been completely removed though the hammer is seen hitting the gong.

This shows sound waves need material medium like air, liquid or solid for transmission.

The speed of sound waves depends on:-
(i) Temperature.
(ii) Density and elasticity of the medium.
(iii) Wind in the case of air.

How each factor affects the speed of sound waves?

Density: The speed of sound waves is higher in denser medium than in less denser medium. This is the reason why the speed of sound is higher in solids than in liquids and gases because solids are generally denser.

In a steel rod for example, the speed of sound is about $5000ms^{-1}$ yet in water the speed of sound is $1500ms^{-1}$ because steel is denser than water.

In daily life, an approaching train can easily be detected by human ears positioned close to the rails than in air. This is explained from the fact that sound waves travel faster through solids than through air as solids are generally denser than air.

Temperature: Increasing the temperature, increases the speed of sound in air greatly because the speed of vibrating air molecules increases with temperature.

However in solids and liquids, increasing the temperature, decreases the speed of sound waves because solids and liquids become less dense as temperature increases.

Wind in the case of air: The speed of sound waves increases if the direction of sound wave travel is the same as that of the wind. If the direction of sound waves travel is opposite that of wind, the speed decreases.

Note: Pressure change in air (gases) does not affect the speed of sound wave because density of air is negligibly affected by change in pressure.

Properties of sound waves

- Reflection
- Refraction
- Diffraction
- interference

Reflection

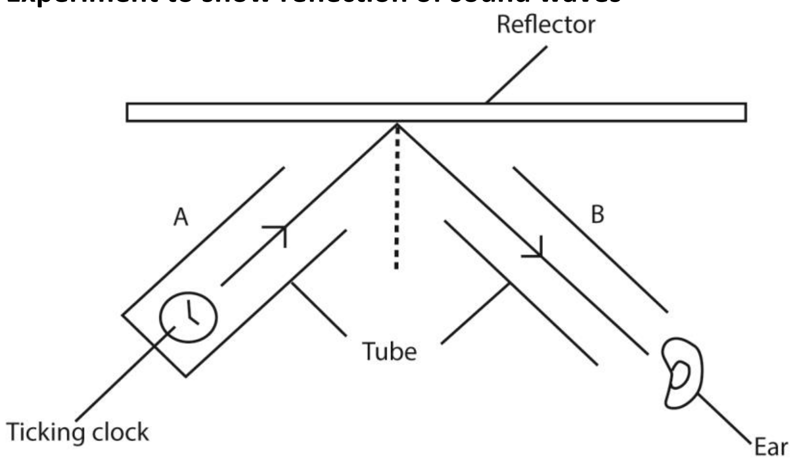
Sound is bounced back from obstacles in similar manner to light. The reflected sound is called an echo.

Laws of reflection of sound waves state:-

i) Incident sound wave, reflected sound wave and the normal at the point of incidence all He in the same plane,

ii) The angle of incidence of sound waves is equal to angle of reflection of sound waves.

Experiment to show reflection of sound waves



(a) Producing sound waves

Sound waves produced by the clock at the end of tube A are reflected at the hard surface reflector.

b) Moving tube B

The ear is put at the end of the tube B and the tube B is moved until the ticks of the clock are loudest. This is the direction of reflected sound wave.

Note: Hard surfaces reflect sound waves while soft surfaces absorb sound waves.

Echoes

An echo is reflected sound waves

Echoes are produced by the reflection of sound from a hard surface. Echoes are often heard in the neighborhoods of large houses, high walls, cliffs etc.

I echoes are often heard in the big churches, halls etc. They are not heard in a small room or class-room because the reflected sound waves return very quickly and mix up with the original sound wave.

Echoes are troublesome in lecture halls, cinema etc. To reduce echoes in such places, the walls are covered with soft thick porous materials.

Furniture and people in halls also reduce echoes. So many echoes are produced in empty halls compared to one filled with people because bodies of people are soft so they absorb some of the sound.

Reverberation

It is a prolongation of sound due to reflection from nearby obstacle. If the reflecting surface is nearer, the echo joins the original sound which then seems to become prolonged.

Implications of reverberations

- To some degree, reverberation is desirable in concert halls to stop the hall sounding dead so that hearing in such places is improved.
- However, too much reverberation causes confusion.

The time taken by a particular intensity of sound to die away is the reverberation time.

For echo

Velocity $= \frac{\mathbf{2xdistance}}{\mathbf{time\ taken}}$

How to minimize reverberation

To minimize reverberation, add soft, sound-absorbing materials like carpets, heavy curtains, upholstered furniture, and acoustic panels to walls and ceilings, as these materials trap sound waves and reduce reflections, making a space sound drier and clearer, while diffusers can scatter waves for better sound balance. Strategically placing these elements, especially in large, hard-surfaced rooms, breaks up direct sound paths and controls echoes effectively.

Experiment to measure the speed of sound (echo method)

Two people one claps and the other records the time, while standing at a known distance from a high wall. The time taken for the sound wave to travel to and from the wall is recorded.

The exercise is repeated many times so that the average time is obtained.

Speed of sound = $\frac{2 \text{ x distance}}{\text{Average time}}$

Example 1

A man stands at a distance of 990m away from a tall building and makes a loud sound. He hears the echo after 6 seconds. Calculate the speed of sound.

For echo: **Speed =** $\frac{\text{2xdistance}}{\text{time taken}} = \frac{2x990}{6}$ = **330ms^{-1}**

Example 25

A man stands between two walls, but nearer one of them and makes a loud sound. If he hears the third echo after 6 seconds, calculate the distance between the two walls, (speed of sound in air is 330ms^{-1}.

V =330 **ms^{-1}** d =? T = 6 seconds

Velocity $=\frac{2d}{t}$

$330 = \frac{2xd}{6}$

d =330x3 =**990m**

Example 2

A sound of frequency 150Hz is produced 45m away from a cliff. Calculate the

(i). wavelength

From V =λ f

$\lambda = \frac{v}{f} = \frac{330}{150}$ = 2.3m

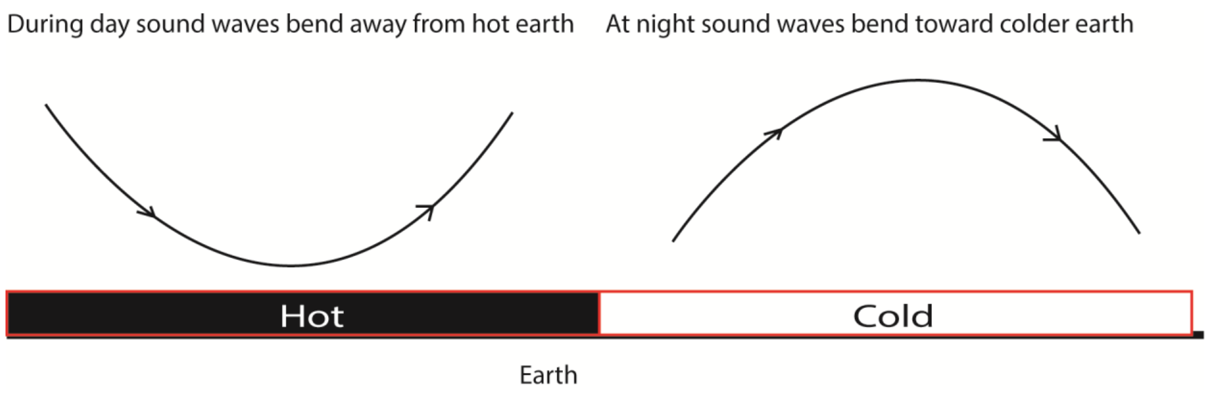
(ii). Time it takes the sound wave to travel to and from the cliff

(Speed of sound in air=300ms^{-1}**).**

Time = $\frac{\text{distance to and fro}}{\text{speed}} = \frac{45 \times 2}{330}$ **= 0.27s**

Refraction of sound waves

Refraction of sound waves occurs when the speed of the wave changes as it moves from one medium to another of different density. The speed of sound waves in air is affected by the air temperature. When sound waves pass through layers of air at different temperature they are refracted i.e. turned into another direction. On a hot day sound waved are bent upwards away from the earth where they otherwise travel faster.



In the evening when the air near the ground becomes cool, refraction of sound is towards the earth, making it easier to hear distant sound as the range of sound is more.

Radios are clearer at night than during day because at night the sound waves are bent down towards the cool earth making the range of sound more.

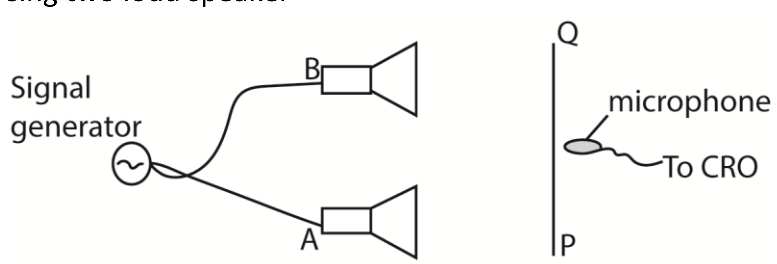
Interference of sound waves

C - Constructive interference
D - Destructive interference
Overlapping sound waves produce regions of louder sound by constructive interference and regions of quiet sound by destructive interference.

If two loud speakers are connected to the same audio frequency generator, they produce sound waves of identical frequency and similar amplitude.
A louder sound is produced when the waves from the two speakers arrive in phase and interfere constructively.
A quiet sound is produced when destructive interference occurs.
If the speakers are moved closer together, the distance between the places where loud sound is heard is increased.

Experiment to show interference of longitudinal waves.

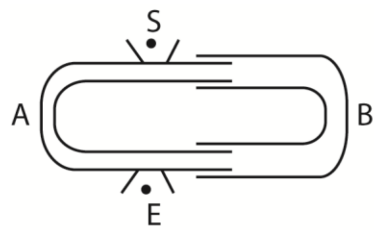
(a) Using two loud speaker



Two loud speaker A and B were connected to a signal generator. A microphone connected to the y-plates of s C.R.O with the time base switched off.

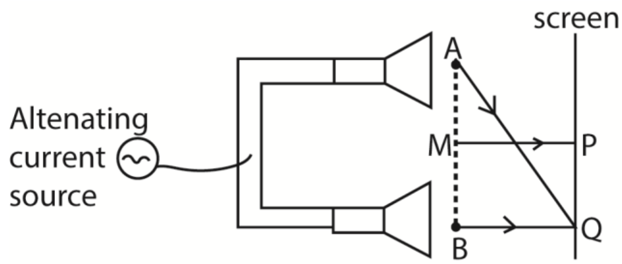
As the microphone is moved along the line PQ which is parallel to the line joining the loud speaker, the vertical trace on the screen of CRO is seen to increase to maximum and reduce to minimum at equal distances. The alternative maximum and minimum intensity are interference pattern.

(b) Using two tubes



Tube A is fixed while B is free to move. A note is sounded at S and detected at E. Tube B s then pulled out slowly. It is noted that the sound detected E increases to a maximum and reduces to minimum intensity at equal intervals of the length of the tube. The alternate maximum and minimum intensity formed are interference pattern.

An experiment 1 to determine the velocity of sound in air by an interference method.



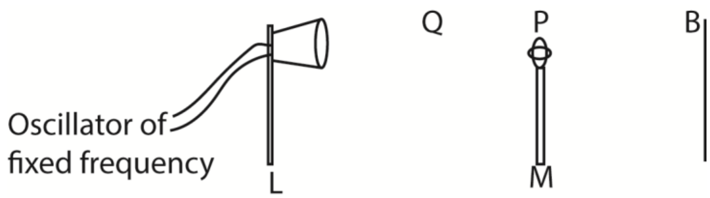
Two small loud speakers A and B about 1m apart are connected to the same oscillator so that both emit sound waves of frequency, f, in phase.

A sensitive detector is moved parallel to the line AB along PQ and it detects a maximum wave at P on perpendicular bisector MP of AB and another maximum wave when it first reaches a point Q directly opposite to B.

Constructive interference of sound wave occurs at P and Q, so the wavelength of sound wave is given by $\lambda = AQ - BQ$

The speed of sound in air is then calculated from $V = f\lambda$.

An experiment 2 to determine the velocity of sound in air by an interference method.



- The loud speaker, L is connected to an oscillator of constant frequency, f.
- A microphone, M is connected to the Y-plates of a cathode ray tube.
- The microphone is moved away from B towards L until the amplitude of the wave on C.R.O is maximum.
- The position P of the microphone is noted and distance BP is measured.
- The microphone is move farther away from B to Q where another maximum amplitude of wave front is obtained. Distance BQ is measured and recorded.
- The distance between two successive maxima d= BQ – BP = $\frac{\lambda}{2}$ where λ is the wavelength
  Velocity of sound = fλ = 2df.

Ultrasonic

Sound waves with frequencies above 20 kHz are called ultrasonic waves. They are emitted by bats. Sound of high frequency that human ear cannot detect is described as ultrasonic.

Applications of ultrasonics

1. Ultrasonic enable bats to judge the distance of an object from the time taken by the reflected wave to return.
2. Ultrasonic are used in spectacles for blind to judge distances of an object from the time taken by reflected waves to return. Such spectacles contain ultrasonic sender and receiver.
3. In sonar (echo-sounding system) of ships use ultrasonic wave to measure the depth of sea and to detect shoals of fish.
4. In industry, ultrasonic waves are used to reveal flaws in welded joints and also holes are cut in glass and steel by ultrasonic drills.

Note:

In an echo sounder (sonar, ultrasonic waves are used because they:-

i) Cannot be confused with engine sound and other sound made ship,

(ii) Can penetrate sea water to a large distance without undue loss of energy.

ii) They are not much detracted.

Frequency and audio frequency range.

The human ear has a range of sound frequencies which it can hear. The lowest limit of audibility is about 30Hz and the upper limit audibility for most people is between 20 kHz and 30 kHz.

In daily life, a dog is more able than a human being to detect the presence of a thief tiptoeing at night. A thief tiptoeing at night produces sound of low frequency that can only be detected by dog ears not human being ears because the dog has wider ears than human being ears.

The Doppler Effect

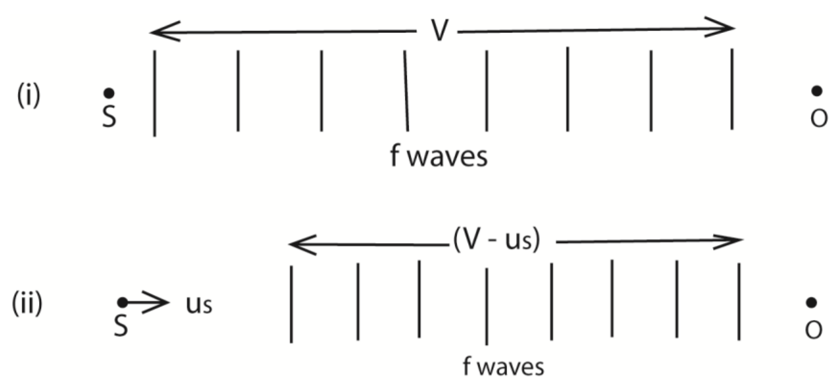
It is the apparent change in frequency of a wave motion due to relative motion between the source and observer.

Calculation of Apparent Frequency based Doppler Effect

Suppose V is the velocity of sound in air, u_s is the velocity of the source of sound S, u_0 is the velocity of an observer 0, and f is the true frequency of the source.

(a) Source moving towards stationary observer.

(i) If the source S were stationary, the f waves sent out in one second towards the observer O would occupy a distance V, and the wavelength would be V/f



Source moving towards stationary observer.

(ii) If S moves with a velocity u_s towards 0, however, the f waves sent out occupy a distance $(V - u_s)$, because S has moved a distance u_s towards 0 in 1s, fig. (ii).

Thus the wavelength λ' of the waves reaching O is now $\frac{(V - us)}{f}$

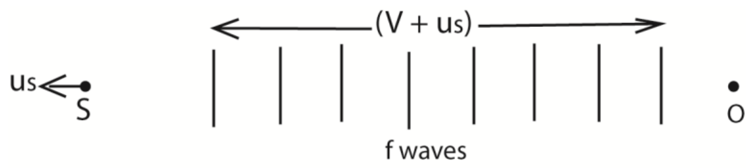
But velocity of sound = V

∴ Apparent frequency, $f' = \frac{V}{\lambda'} = \frac{V}{(V - u_s)/f} = \frac{V}{(V - u_s)} f$

Since $(V - u_s)$ is less than V, f' is greater than f; the apparent frequency thus appears to increase when a source is moving towards an observer.

(b) Source moving away from stationary observer.

In this case the f waves sent out towards 0 in 1s occupy a distance $(V + u_s)$,



Source moving away stationary observer.

Thus the wavelength λ' of the waves reaching O is now $\frac{(V + us)}{f}$

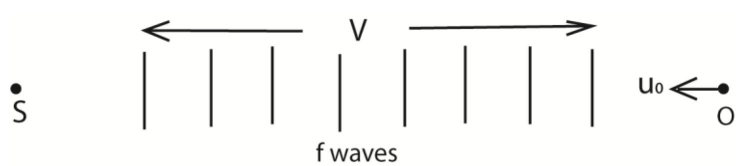
But velocity of sound = V

∴ Apparent frequency, f' = $\frac{V}{\lambda'} = \frac{V}{(V+u_s)/f}$ = $\frac{V}{(V+u_s)}f$

Since (V + u_s) is greater than V, f' is less than f; the apparent frequency thus appears to reduce when a source is moving towards an observer.

(c) Source stationary, and observer moving towards it.

Since the source is stationary, the f waves sent out by S towards the moving observer O occupies a distance V,



Source stationary while observer moving toward source.

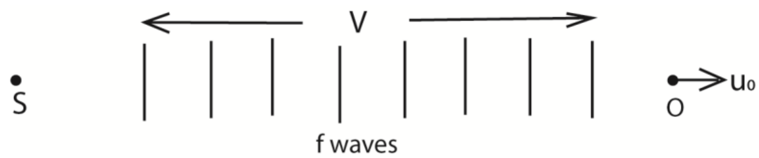
The wavelength of the waves reaching O is hence V/f, and thus unlike the cases already considered, the wavelength is unaltered.
The velocity of the sound waves relative to O is not V, however, as O is moving relative to the source.
The velocity of the sound waves relative to O is given by (V + u_o) in this case, and
Hence the apparent frequency f' is given by

∴ Apparent frequency, f' = $\frac{V+u_0}{wavelength} = \frac{V+u_0}{V/f}$ = $\left(\frac{V+u_0}{V}\right)f$

Since (V + u_0) is greater than V, f' is greater than f; the apparent frequency thus appears to increase when an observer is moving towards the source.

(d) Source stationary, and observer moving away from it.

Since the source is stationary, the f waves sent out by S towards the moving observer O occupies a distance V,



Source stationary while observer moving away from source.

The wavelength of the waves reaching O is hence V/f, and thus unlike the cases already considered, the wavelength is unaltered.
The velocity of the sound waves relative to O is not V, however, as O is moving relative to the source.
The velocity of the sound waves relative to O is given by ($V - u_o$) in this case, and
Hence the apparent frequency f' is given by

$$\therefore \text{ Apparent frequency, } f' = \frac{V - u_0}{wavelength} = \frac{V - u_0}{V/f} = \left(\frac{V - u_0}{V}\right) f$$

Since ($V - u_0$) is less than V, f' is less than f; the apparent frequency thus appears to reduce when an observer is moving away from the source.

Source and Observer Both Moving

If the source and the observer are both moving, the apparent frequency f' can be found from the formula $f' = \frac{V'}{\lambda'}$

where V' is the velocity of the sound waves relative to the observer, and λ' is the wavelength of the waves reaching the observer. This formula can also be used to find the apparent frequency in any of the cases considered before.

(i) Suppose that the observer has a velocity, u_o, the source a velocity u_s, and that both are moving in the same direction. Then

$V' = V - u_o$

And

$\lambda' = (V - u_s)/f$

$$f' = \frac{V'}{\lambda'} = \frac{V - uo}{(V - u_s)/f} = \left(\frac{V - u_O}{V - u_s}\right) f$$

Suppose that the observer has a velocity, u_o, the source a velocity u_s, and If the observer is moving towards the source, then

$V' = V + u_o$

And

λ' = (V - u_s)/f

$$f' = \frac{V'}{\lambda'} = \frac{V + u_o}{(V - u_s)/f} = \left(\frac{V + u_O}{V - u_s}\right) f$$

(ii) A source of sound moving with velocity, u_s. approaches an observer moving with velocity u_0 in the same direction. Derive the expression for frequency of sound heard by observer. (05marks)

Let c be the velocity of sound from a source of frequency, f.
Apparent wave length, $\lambda' = \frac{c-u}{f}$
Apparent velocity $c' = c - u_0$
∴ Apparent frequency = $\frac{c'}{\lambda'} = \frac{(c - u_0)}{\frac{(c-u)}{f}} = \left(\frac{(c-u_0)}{(c-u)}\right) f$

Example 3

One species of bats locates obstacles by emitting high frequency sound waves and detecting the reflected waves. A bat flying at a steady speed of 5ms^{-1} emits sound of frequency 78.0 kHz and is reflected back to it.

(i) Derive the equation for the frequency of the sound waves reaching the bat after reflection (05marks)
Suppose the velocity of sound wave is c and that of the bat is v_0 and the frequency is f.
The velocity v' of reflected sound relative to the bat is given by $v' = v_0 + c$.
The apparent wave length $\lambda' = \frac{c - v_0}{f}$
But the apparent frequency, $f' = \frac{v'}{\lambda'} = \frac{c + v_0}{\frac{c - v_0}{f}}$

Hence $f' = \frac{c + v_0}{c - v_0} f$

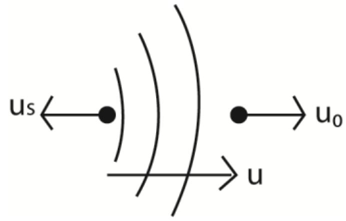
(ii) Calculate the frequency of sound received by the bat given the speed of sound in air is 340ms^{-1}. (02 marks)

From, $f' = \frac{c + v_0}{c - v_0} f$

$f' = \frac{340+5}{340-5} x\ 78\ x\ 10^3$ = 90.3kHz

Example 4

A motor cyclist and police car are approaching each other. The motor cyclist is moving at 10ms-1 and the police car at 20ms-1. If the police siren is sounded at 480Hz. Calculate the frequency of the note heard by the cyclist after the police car passes by.



Apparent wavelength reaching the observer, λ' = $\frac{v+u_s}{f}$

Apparent velocity of sound received, v' = v – u_0

Apparent frequency of sound received, f' = $\frac{v'}{\lambda'} = \frac{v-u_0}{v+u_s} f = \frac{340-10}{340+20} x\ 480 = 440Hz$

Example 5

(a) A source of sound moving with velocity, u. approaches an observer moving with velocity u_0 in the same direction. Derive the expression for frequency of sound heard by observer. (05marks)

Let c be the velocity of sound from a source of frequency, f.

Apparent wave length, λ' = $\frac{c-u}{f}$

Apparent velocity c'= c-u_0

∴ Apparent frequency = $\frac{c'}{\lambda'} = \frac{(c-u_0)}{\frac{(c-u)}{f}} = \left(\frac{(c-u_0)}{(c-u)}\right) f$

(b) Two whistles are sounded simultaneously. The wavelengths of the sounds emitted are 5.5m and 6.0m respectively. Find the beat frequency if the speed of sound is 330ms^{-1}.

For 1st sound $f_1 = \frac{V}{\lambda_1} = \frac{330}{5.5} = 60Hz$

For 2nd t sound $f_2 = \frac{V}{\lambda_2} = \frac{330}{6} = 55Hz$

Beat frequency $f_b = f_1 - f_2 = 60 - 55 = 5Hz$

Thank you
Dr. Bbosa Science