SECTION B (i): WAVES CONTINUED

SOUND WAVES

Sound is any mechanical vibration whose frequency lies within the audible range.
Sound waves propagate in air by series of compressions and rare factions.

Explain why sound propagates as an adiabatic process

- ✓ Sound waves propagate in air by series of compressions and rare factions
- ✓ The temperature of air rises during the compressions unless heat is withdrawn.
- ✓ The temperature decreases during in the rare factions.
- ✓ These compressions and rare factions occur so fast that heat does not enter or leave the wave hence the process is adiabatic.

Characteristic of sound

a) Pitch

This is the characteristic of sound by which the ear assigns a place on a musical scale.

It is affected by;

- ✓ The frequency of vibration of the sound waves that is it increases as the frequency of sound increases.

b) Loudness

This is the amount of sound energy entering the ear per second

It is affected by;

- ✓ Sound intensity of sound
- ✓ Amplitude of sound.

ECHOES

An echo is a reflected sound.

The time that elapses between hearing the original sound and hearing the echo depends on;

- ✓ The distance away from the reflecting surface.
- ✓ The speed of sound in the medium.

Applications of echoes

- ✓ Determination of speed of sound in air
- ✓ Determination of depth of the sea
- ✓ Used making walking sticks of the blind
- ✓ Used in ultrasound
- ✓ Detection of large shoals of fish

REVERBERATION

This is a prolonged sound as a result of multiple reflections from the walls of a room

When sound is reflected from a hard surface close to the observer, the echo follows the incident sound so closely that the observer may not be able to distinguish between the two. Instead the observer gets an impression or hears a prolonged original sound. This effect is referred to as reverberation

Advantages of reverberation

- ✓ Prevents the hall or theatre from being a caustically dead and
- ✓ Improves hearing in all parts of the building

Disadvantages

- ✓ Causes confusion if it takes too long
- ✓ Too short reverberation makes the hall appear a caustically dead

Qn. Briefly explain why reverberation is necessary while making speeches

Qn. Explain why echoes aren't heard in small rooms

REFRACTION OF SOUND

This is the change in the speed of sound waves as they move from one medium to another of different optical densities.

The speed of sound waves is affected by change in temperature

Sound waves are refracted when they pass through areas at different temperatures. This explains why it is easy to hear sound waves from distant sources at night than during day.

An experiment to demonstrate refraction of sound waves

(Leave 4lines for the illustration)

- ✓ A balloon is field with air and placed on a table
- ✓ A ticking clock is placed on the table at one side of the balloon
- ✓ The sound of the ticking clock is detected at the opposite end

Explain why sound is easily heard at night than during day time

(Leave 4 lines for the illustration)

- ✓ During day time, air layers near the ground are warm and less dense
- ✓ Sound waves are refracted towards the normal
- ✓ They gradually bend upwards and cannot be detected by someone far from the source

(Leave 4 lines for the illustration)

- ✓ During the night, air layers near the ground are cool and more sense
- ✓ Sound waves are refracted away from the normal
- ✓ They gradually bend downwards and can be detected by someone near the source

INTERFERENCE OF SOUND

This is the superposition of waves from different two coherent sources resulting into alternate regions of maximum and minimum intensity.

Types of interference

a) Constructive interference

- ✓ This is the superposition of waves from two coherent sources in phase resulting into a region of maximum **intensity**
- ✓ **It results into a loud sound**

(Leave 4lines for the illustration)

b) Destructive Interference

- ✓ This is the superposition of waves from two coherent sources out of phase resulting into a region of minimum intensity.
- ✓ It results into a soft sound

(Leave 4lines for the illustration)

An experiment to demonstrate interference of sound waves.

(Leave 8 lines for the illustration)

- ✓ Two identical loud speakers 1m apart facing the same direction are connected to the same audio frequency
- ✓ An observer a few metres from the speakers walks across the path of the sound waves
- ✓ The observer detects alternate regions of soft and loud sounds
- ✓ The regions of loud sounds demonstrate destructive interference

- ✓ This demonstrates sounds demonstrate constructive interference where as those of soft
- ✓ interference of sound waves

c) Diffraction of sound

This is he spreading of sound waves around corners or barriers

Factors that affect diffraction

- ✓ Size of the gap.

The smaller the gap the greater the diffraction and the larger the gap, the lesser the diffraction

- ✓ The wavelength of the sound waves

The shorter the wave length of the sound waves the greater the diffraction, the longer the wavelength the lesser the diffraction

If waves have the same wavelength as that of the size of the gap, they are diffracted most

Qn. Explain why a person can be heard behind a wall without being seen

- ✓ Some sound waves have very short wavelength than that of light
- ✓ These sound waves are diffracted more than light waves, hence sound from someone can be heard without the person being seen.

Differences between sound and light waves

Sound waves	Light waves
✓ Are mechanical waves	✓ Are electromagnetic waves
✓ Travel at a low speed	✓ Travel at a high speed
✓ Does not travel through vacuum	✓ Travels through vacuum
✓ Are longitudinal waves	✓ Are transverse waves.
✓ Cannot eject electrons from a metal surface	✓ Eject electrons from a metal surface by photoelectric emission

BEATS

These are periodic rise and fall in the intensity of sound heard when two notes of nearly equal frequency but similar amplitude are sounded together.

Formation of beats

(Leave 5 lines for the illustration)

When two waves of nearly equal frequency and similar amplitude are sounded together they superpose.

When they meet in phase constructive interference takes place and a loud sound is heard. When they meet out of phase destructive interference takes place and a soft sound is heard.

A periodic rise and fall in intensity of sound is heard which is called beats

Beat frequency

This is the number of intense sounds heard per second

Derivation of Beat frequency

Let f_1 and f_2 be frequencies of two sound notes.

Suppose a note of frequency f_1 makes one cycle more than other in time T.

The number of cycles of frequency $f_1 = f_1T$

The number of cycles of frequency $f_2 = f_2T$

$$f_1T - f_2T = 1$$

$$(f_1-f_2)T = 1$$

$$\text{but } \frac{1}{T} = f$$

$$(f1-f) = f$$

$$(f_1-f_2) = \frac{1}{f}$$

This is called beat frequency

Uses of frequency

- ✓ Used in measurement of frequency of a note
- ✓ Determination of frequency of a musical note
- ✓ Tuning an instrument to a given note

Measurement of frequency of a note

- ✓ A source with unknown frequency f_1 is sounded together with a tuning fork of known frequency, f_2
- ✓ The number of beats, n in t seconds are counted and
- ✓ The beat frequency, $f_b = n/t$ is calculated
- ✓ One prong of the tuning fork is loaded with plasticine and then the experiment repeated.
- ✓ The new beat frequency f'_b is determined
- ✓ If $f'_b < f_b$ then the un known frequency f_1 of the note is calculated from $f_1 = f_2 + f_b$
- ✓ If $f'_b > f_b$ then the un known frequency f_1 of the note is calculated from $f_1 = f_2 - f_b$

Examples(Leave space for the answers)

1. Two tuning forks of frequency 256Hz and 250Hz respectively are sounded together in air. Find the number of beats per second produced
2. Two tuning forks x and y are sounded in air to produce beats of frequency 8Hz. Fork x has a known frequency of 512Hz. When y is loaded with a small piece of plasticine, beats of frequency 2Hz are heard when the two forks are sounded together. Find the frequency of y when it is unloaded.
3. Two whistles are sounded simultaneously. The wavelength sound emitted are 5.5m and 6.0m. (speed of sound in air 330m/s). Determine the;
   i. Beat frequency
   ii. Beat period
4. Two sources of sound are vibrating simultaneously with frequency of 200Hz and 240Hz. If the speed of sound in air is 340m/s
   i. How many beats are heard
   ii. What is the distance between successive locations of maximum intensity
5. Two sources, one with known frequency 224Hz and the other unknown are sounded together. The beat frequency recorded is 6Hz. When the unknown source is sounded again together with another known source of 250Hz the beat frequency is 20Hz. Find the un known frequency of the 2nd source
6. Two tuning forks A and B produce three beats per second when sounded together. If fork A has a frequency of 512Hz.
   i. What is the possible frequency of B
   ii. Explain how you determine the actual frequency of tuning fork B

   Solution for ii)
   - ✓ A piece of plasticine is attached on running fork B and
   - ✓ Tuning forks A and B are sounded together
   - ✓ The new beat frequency fb is determined
   - ✓ If the beat frequency increases, then the actual frequency of B is 509Hz and if the beat frequency decreases then the actual frequency of B is 515Hz

DOPPLER EFFECT

This is the apparent change in frequency and wave length of a wave when there is relative motion between the source of the waves and the observer

Doppler effect takes place in both sound and light

<u>Doppler effect in sound</u>

Case 1: <u>source of sound in motion but observer fixed (stationary/at rest)</u>

a) Source moving towards a stationary observer

(Leave 3lines for an illustration)

Let $vs - velocity\ of\ the\ source$

$v - velocity\ of\ sound$

$f - frequency\ of\ the\ sound\ waves$

f'- be the apparent change in frequency

Observer source V VS f

Velocity of wave relative to source, v' =

Apparent change in wavelength, =

Velocity of wave relative to observer =

Apparent change in frequency, f' =

f' =

Since $v - vs < v$ then the apparent frequency appears to increase when the source moves towards an observer

b) Source moving away from a stationary observer

(Leave a space of about 13 lines for the derivation)

Note:

When the source is in motion, only wavelength and frequency change but the speed of the sound waves is not affected

Examples (Leave spaces for the answers)

1. A car sounds its horn as it travels at a steady speed of 15m/s along a straight road between two stationary observers A and B. Observer A hears a frequency of 538Hz while B hears a lower frequency. Calculate the frequency heard by B if the speed of sound in air is 340m/s
   Ans f_A = 514.265Hz, f_B=492.54Hz

2. A stationary observer notices that the pitch of the racing car changes in a ratio 4:3. The velocity of sound in air is 320m/s. Calculates the speed of the car.

3. A car sounds its horn as it travels at a steady speed of 20m/s along a straight road between two stationary observers X and Y. Observer X hears

a frequency of 560Hz while Y hears a lower frequency. Calculate the frequency heard by Y if the speed of sound in air is 330m/s. **Ans(495.9Hz)**

Case2: <u>Observer in motion while the source is stationary</u>

a) Observer moving away from a stationary source

(Leave a space of about 13lines for the derivation)

b) An observer moving towards a stationary source

(Leave a space of about 13lines for the derivation)

Note:

The motion of the observer has no effect on the wavelength of the sound but it affects the relative velocity of sound

Examples (Leave spaces for the answers)

1. An observer moving between two stationary sources of sound along a straight line joining them hears beats at a rate of $4s^{-1}$ at what velocity is the observer moving if the frequency of the sources is 50Hz and speed of sound in air is 340m/s
2. An observer moving between two identical stationary sources of sound along a straight line joining them hears beats at a rate of $5.0s{-}1$. At what velocity is the observer moving if the frequency of the sources is 600Hz and speed of sound in air is 330m/s. **Ans (1.38m/s)**

Case3: observer and source in motion

a) Both in same direction with the observer ahead of source

(Leave a space of about 13lines for the derivation)

b) Both in same direction with source ahead of observer

(Leave a space of about 13lines for the derivation)

c) Both moving towards each other

(Leave a space of about 13lines for the derivation)

d Both moving away from each other

(Leave a space of about 13lines for the derivation)

Examples (Leave spaces for the answers)

1. A car A travelling at 36km/h has a horn of frequency 120Hz. A second car B travelling at 54km/h approaching the first car. What is the apparent frequency of the horn to an observer in the second car given that speed of sound in air 320m/s
2. A cyclist and train approach each other with a speed of 10m/s and 20m/s respectively. A train sounded siren at 480Hz. Calculate the frequency of the note heard by the cyclist.
   (Speed of sound in air is 340m/s)
   a) Before the train passes him
   b) After the train has passed him
3. A train approaching a hill at 36km/h sounds a whistle of 580Hz. Wind is blowing at 72km/h in the direction of motion of the train. Calculate the frequency of the whistle as heard by an observer on the hill. (Speed of sound in air is 340m/s)
4. A bat can locate an obstacle by emitting a high frequency sound wave through detecting the reflected waves. A bat flying at a steady speed of 5m/s emits sound waves of frequency 7800Hz and is reflected back.

   a) Derive the equation of the frequency of sound waves reaching the bat after reflection

   b) Calculate the frequency of the sound received by the bat given that speed of sound in air is 340m/s.

   Ans (80328.36Hz)

<u>Applications of Doppler Effect</u>

- ✓ Used in radar speed traps
- ✓ Measurement temperature of hot gases
- ✓ Used in measurement of speed of the star

<u>The radar speed traps</u>

- ✓ Microwaves of frequency f_0 from a stationary radar set are directed towards a motor vehicle moving with speed u
- ✓ Microwaves reflected from the moving car are detected at the radar
- ✓ The reflected signal mixes with the transmitted signals to obtain beats
- ✓ The beat frequency Δf which is equal to the difference between the frequency of the received and transmitted signal is determined
- ✓ The speed of the vehicle is $u = v\Delta f / 2f_0$

Measurement of plasma temperature

- ✓ The broadening $\Delta\lambda$ of a spectral line emitted by the plasma is determined using a diffraction grating
- ✓ $\Delta\lambda\lambda o$=2uc
- ✓ Assuming u=V_{rms}
- ✓ $\mathbf{1/2mu^2=3/2RT}$ where m= $\boldsymbol{molar\ mass}$, T can thus be obtained

Speed of star

- ✓ The wavelength , λ of light emitted by the star is measured
- ✓ The absorption spectrum of an element known to be in the star is examined.
- ✓ The wavelength λ^1 of the missing line is measured
- ✓ Doppler shift =$|\lambda^1-\lambda|$is obtained
- ✓ From $|(\lambda^1-\lambda)/\lambda|=u_s/C$
- ✓ The speed of the star is obtained from; $u_s=|(\lambda^1-\lambda)/\lambda|$

<u>REVISION QUESTIONS (Don't leave any space)</u>

1. A car travelling at 72 kmh^{-1} has a siren which produces sound of frequency 500Hz. Calculate the difference between the frequency of sound heard by an observer by the roadside as the car approaches and recedes from the observer . [Speed of sound in air = 320 m s^{-1}]. **Ans (62.7Hz)**

2. An observer moving between two identical stationary sources of sound along a straight line joining them hears beats at the rate of 4.0. At what velocity is the observer moving if the frequencies of the sources are 500Hz and the velocity of sound when the observer makes the observation is 340 m s^{-1}?

3. a) Explain what is meant by Doppler effect (2mrks)

b) Deduce an expression for the frequency heard by an observer when:

i) He is stationary and a source of sound is moving towards him. (3mrks)

ii) He is moving towards a stationary source of sound. (3mrks)

c) A bat flying at a speed of 30ms-1 towards an obstacle emits sound waves of frequency 2.5x108 Hz. The bat hears an echo 0.5 s later. If the speed of the sound in air is 340ms^{-1}, how far is the obstacle from the bat when the bat hears the echo? Find the apparent frequency of the echo received by the bat

(4mrks)

4. a) A source of sound moving with velocity us approaches an observer moving with velocity U_0, in the same direction. Derive the expression for the frequency of sound heard by the observer. (5mrks)

b) Explain what happens to the pitch of the sound heard by the observer in a) above when the

i) observer moves faster than the source (2mrks)

ii) observer's velocity is equal to that of the sound (2mrks)

c) (i) What is meant by Doppler effect?

ii) A car sounds its horn as it travels at a steady speed of 15 ms^{-1} along a straight road between two stationary observers A and B. The observer A hears a frequency of 538 Hz while B hears a lower frequency. Calculate the frequency heard by B, assuming the speed of Sound in air is 340ms^{-1}

d) (i) Explain how beats are produced

ii) An observer moving between two identical stationary sources of sound along a straight line joining them hears beats at the rate of 4.0. At what velocity is the observer moving if the frequencies of the sources are 500Hz and the velocity of sound when the observer makes the observation is 340 m s^{-1}?

5 a) i) A police car sounds a siren of 1000 Hz as it approaches a stationary observer. What is the apparent frequency of the siren as heard by the observer if the speed of sound in air is 340?

ii) Give any three applications of the Doppler effect

b) An observer standing by the roadside hers sound of frequency 600 Hz coming from the horn of an approaching car. When the car passes, the frequency appears to change to 560 Hz.

Given that the speed of sound in air is 320ms^{-1}, Calculate the speed of the car. (5mrks)

c) Describe briefly one application of the Doppler effect (2 marks)

RESONANCE

This is the vibration of a body at its natural frequency due to impulses received another body vibrating at the same frequency

Other terms

i) Fundamental frequency

This is the lowest frequency produced by a vibrating body.

ii) Overtone

This is a note of higher frequency produced together with the fundamental frequency.

iii) Harmonic

This is an integral multiple of the fundamental frequency.

Uses of resonance

- ✓ Determination of the speed of sound in air
- ✓ Reception of radio signals (radio receivers)

Dangers of resonance

- ✓ Collapse of bridges
- ✓ Collapse of tall buildings
- ✓ Rattling of car windows

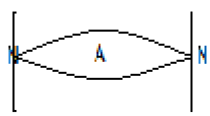
Qn. a) Define resonance

b) State any three dangers of resonance

c) State one effect of resonance

d) Describe one application of resonance

WAVES ON A STRETCHED STRING



- ✓ When a stretched string is plucked, a progressive wave is formed
- ✓ This wave travels to both ends which are fixed
- ✓ The wave is reflected back to meet the incident wave.
- ✓ The incident and reflected waves both have the same speed, frequency and amplitude and therefore when they superimpose a stationary wave is formed.

A-Antinode

N-Node

Define each of the above

Note:

- ✓ The mode of vibration above is obtained when a string is plucked in the middle
- ✓ The distance between two successive nodes or antinodes is a half of the wave length
- ✓ When a stationary wave is produced, the distance between the source and the reflector is a multiple of half the wavelength

Modes of vibration

(Leave a space of about 13 lines or more lines for the derivations)

Velocity of a transverse wave along a stretched string

The velocity of a wave on the sting depends on the following

- ✓ Tension in the string

- ✓ Mass of the string
- ✓ Length of the string

$V \propto kT^x m^y l^z$

$V = k\ T^x m^y\ l^z$………..i)

$[\ V\ ] = [\ K\ ][\ T\ ]^x\ [m\ ]^y\ [\ l]^z$

K is a dimensionless constant

$LT^{-1} = (MLT^{-2})^x\ (M)^y\ (L)^z$

For powers of T

$-2x = -1$…………………(1)

$x = 1/2$

Find the values of y and z

Write the expression relating the tension T, mass m, length l and the speed V of a wave in a string

Examples (You may leave spaces for the answers)

1. A string of length 0.5m has a mass of 5g. The string is stretched between two fixed points and plucked. If the tension is 100N. Find the frequency of the second harmonic
2. A wire under a tension of 20N is plucked at the middle to produce a note of frequency 100Hz. Calculate the;

i) diameter of the wire if its length is 1m and has a density of $600kgm^{-3}$ Ans $1.03x10^{-3}m$

ii) frequency of the first overtone **Ans (200Hz)**

3. A stretched wire of length 0.75m, radius 1.36 mm and density 1380 kg m^{-3} is clamped at both ends and plucked in the middle. The fundamental note produced by the wire has the same frequency as the first overtone in a pipe of length 0.15 m closed at one end.

i) Sketch the standing wave pattern in the wire

ii) Calculate the tension in the wire

4. The wire of a guitar of length 50cm and mass per unit length $1.5x10^{-3}kgm^{-1}$ is under a tension of 173.4N. The wire is plucked at its mid-point. Calculate the;

i) frequency **Ans(340Hz)**

ii) wavelength of the fundamental note **Ans(1.0m)**

5. A string of length 50cm vibrates in a fundamental mode. Find fundamental frequency of vibration. **Ans(330Hz)**

6. A wire of length 0.60m and mass $9x10^{-4}kg$ is under a tension of 135N. The wire is plucked such that it vibrates in its third harmonic. Calculate

i) Fundamental frequency **Ans(250Hz)**

ii) Frequency of the third harmonic **Ans (750Hz)**

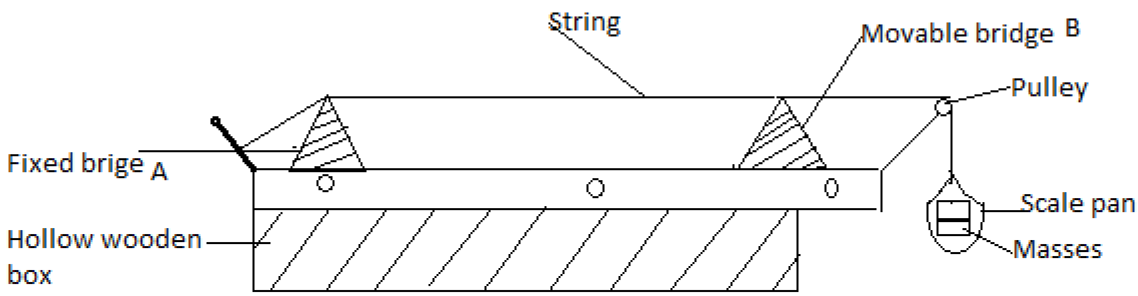
Factors on which frequency of a stretched string depends

The frequency f of a wave in a stretched string depends on;

- ✓ Length of the string
- ✓ Tension in the string
- ✓ Mass per unit length of the string (thickness of the string)

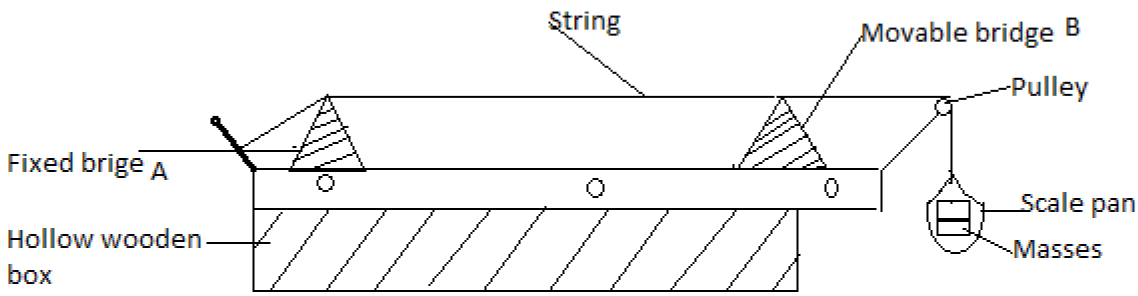
Qn. Explain how the frequency of a wave in a vibrating string depends on each of the above factors.

An experiment to investigate the variation of frequency of a stretched string with length



- ✓ With the tension and thickness of the string kept constant
- ✓ The string is plucked in the middle and a vibrating tuning fork of known frequency f is held near it
- ✓ The bridge B is moved towards A until when a loud sound is heard
- ✓ The distance l between the bridges is measured and recorded together with the frequency f of the tuning fork
- ✓ The procedures are repeated using other tuning forks of different frequencies
- ✓ The results are tabulated including values of $1/l$
- ✓ A graph of f against $1/l$ is plotted
- ✓ A straight line passing through the origin is obtained showing that $f \propto 1/l$

An experiment to show how frequency of a stretched string varies with tension



- ✓ With the thickness and length of the string kept constant
- ✓ The length l between the bridges A and B two is kept constant
- ✓ A suitable mass m is attached to the free end of a string (scale pan)
- ✓ The string is plucked in the middle and a vibrating tuning fork of known frequency f is held near it
- ✓ The mass m on the scale pan is varied until a loud sound is heard
- ✓ The mass m on the scale pan is recorded with the corresponding frequency f
- ✓ The procedures are repeated using other tuning forks of different
- ✓ The results are tabulated including values of f^2
- ✓ A graph of f^2 against m is plotted
- ✓ A straight line passing through the origin showing that $f^2 \propto m$
- ✓ Since $T = mg$, it implies $f \propto \sqrt{T}$ hence frequency increases with increase in tension

Qn.Describe an experiment to demonstrate the relationship between the frequency f and;

- **i) The length of a vibrating string**
- **ii) The tension of a vibrating string**
- **iii) The thickness of a vibrating string**

<u>Resonance of air in pipes</u>

- ✓ When air is blown in a pipe, a longitudinal wave is formed.
- ✓ This wave travels along the pipe and if the pipe is closed the wave will be reflected back.
- ✓ The incident and reflected wave both have the same speed, same frequency and same amplitude.
- ✓ This results into formation of a stationary wave.

These are two type of pipe for air vibrations.

a) Open pipe

This is one that has both ends open

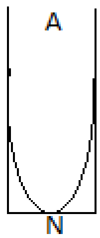
Examples of open pipes are; trumpet, a flute

b) Closed pipe

This is one in which one end is open, while the other is closed

Example of closed pipes include; a long drum.

Motion of air in a tube closed at one end and vibrating in its fundamental frequency



- ✓ Air at the open end A vibrates with maximum amplitude.
- ✓ The amplitude of vibration decreases as the closed end is approached at N.
- ✓ Air at N is stationary. End N is node while end A is antinode

Variation of pressure with displacement of air in a closed pipe

- ✓ At the mouth of the pipe, the air is free to move and therefore the displacement of air molecules is large and pressure is low.
- ✓ At the closed end the molecules are less free and the displacement is minimal and the pressure is high

Qn. Describe the motion of air in a tube closed at one end and vibrating in its fundamental frequency

Qn. Describe the variation of pressure of air with displacement in a closed pipe (3marks)

i) **Modes of vibration in closed pipes**

For closed pipes;

- ✓ a node is formed at a closed end and
- ✓ an antinode at the open end

TO BE CONTINUED

STAY SAFE, COVID-19 IS REAL