Sound and Waves 1

Chapter 1. **Properties of waves**

Waves are classified as either **mechanical waves** or **electromagnetic waves**

Mechanical waves:

- Mechanical waves need a medium (a substance to pass through)
- They are made by a disturbance in the medium (a source of energy causing a vibration)
- They pass along a medium by causing the particles of the medium to vibrate (recall S.H.M.). This vibration is passed from one particle to its neighbour. The overall motion of the particles of the medium is zero !!!!!!!!!!!!!!!!!!!!!
- Examples are sound waves, ultrasound waves, waves on water,…..

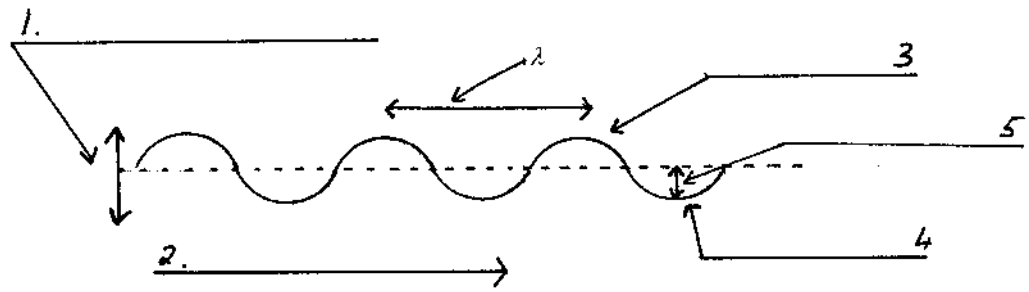
Electromagnetic waves:

- Electromagnetic waves do not need a medium.
- They can pass through a medium but they travel faster in a vacuum than in a medium.
- They consist of varying electric and magnetic fields.
- Examples are light, radio waves, X-rays,…….

Progressive waves:

- These waves consist of energy moving away from a source.
- Energy is transferred from one place to another.
- An example of this is that the students in this room can hear the sweet tones of my beautiful voice as the sound waves spread outwards from my vocal chords.!!!!!!!!!!!!
- Progressive waves are different to the **standing wave** which we meet later.

Transverse Wave



Definition of transverse wave: The direction in which the energy travels is **perpendicular** to the direction of vibration of the particles of the medium.

Wavelength: (λ) Wavelength is the distance between two successive crests. Unit is the metre

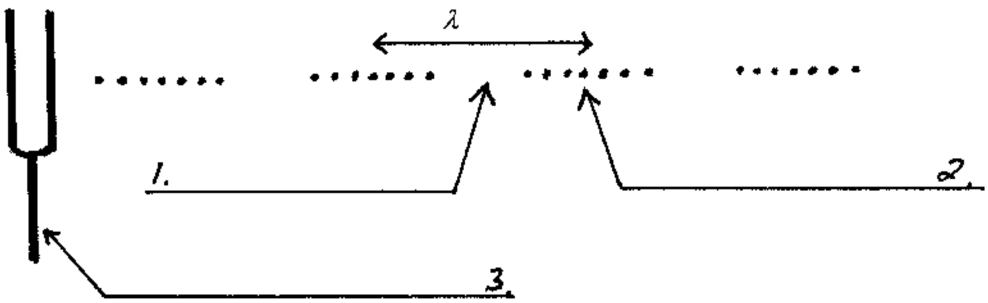
Frequency: (f) Frequency is the number of complete oscillations made by a point in one second. Unit is the Hertz (Hz)

Amplitude: The maximum displacement of a particle of the medium from its mean position.

Maths note: $c = f \times \lambda$ ……………………………. P. 59

(c = speed of wave; f = frequency; λ = wavelength)

Longitudinal Wave



Definition of longitudinal wave: The direction in which the energy travels is **parallel** to the direction of vibration of the particles of the medium.

Note: In the above diagram the energy from the vibrating tuning fork passes through the surrounding air. The regions of high particle density (high air molecule density) are called **compressions** and the regions of low particle density are called **rarefactions**.

Wavelength: (λ) Wavelength is the distance between two successive compressions.

Forced vibration: When a vibrating tuning fork touches a table top the sound from the tuning fork appears much louder. The table top is **forced to vibrate** at the same frequency as the tuning fork.

Demonstrate the difference between transverse and longitudinal waves : Transverse waves can be **polarised** but longitudinal waves cannot be polarised. !!!!!!!!!!!!

Sample question 1: Given that the speed of sound in air is $340 ms^{-1}$, calculate the wavelength of a musical note of frequency 256 Hz.

Solution: rearrange $c = f \times \lambda$ to give $\lambda = \frac{c}{f}$

$$\lambda = \frac{340}{256}$$

$$\lambda = 1.328 m$$

Sample question 2: A radio station broadcasts at 92 M Hz. Calculate the corresponding value of wavelength. ($c = 3 \times 10^8 ms^{-1}$)

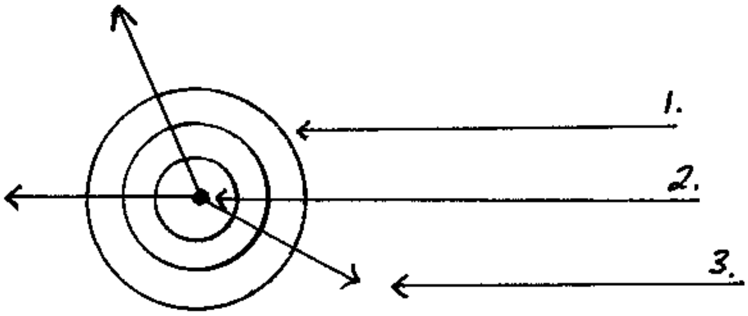
Solution: rearrange $c = f \times \lambda$ to give $\lambda = \frac{c}{f}$

$$\lambda = \frac{3 \times 10^8}{92 \times 10^6}$$

$$\lambda = 3.26 m$$

Note: The speed of a radio wave is taken to be the same as the speed of light i.e. $3 \times 10^8 ms^{-1}$

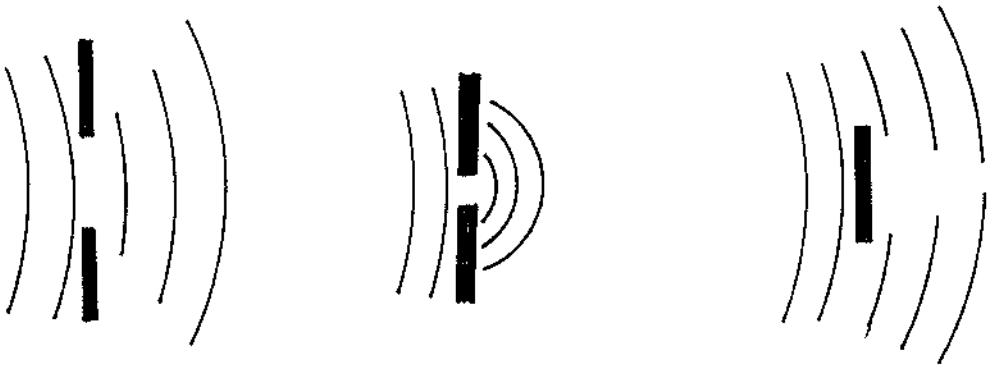
Note on waves: Waves spreading out from a source are often represented by the diagram below.



- The **source** refers to the origin of the wave.
- A line which shows the direction of travel of the wave is called a **ray**.
- The concentric circles above are called **wavefronts**. The distance between consecutive wavefronts is equal to the wavelength.

Diffraction

diffraction *more noticeable diffraction smaller gap* *diffraction for an obstacle*



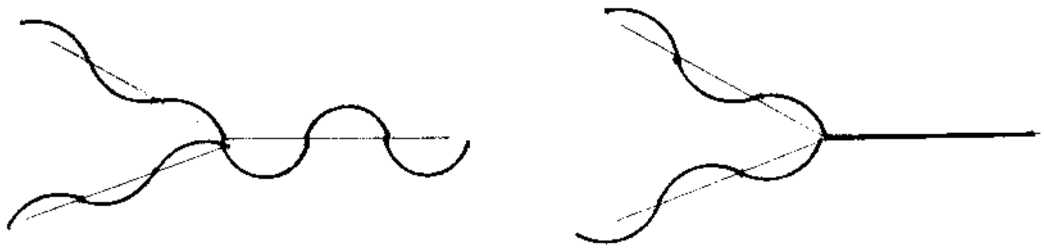
Definition of diffraction: Diffraction is the spreading out of a wave into the geometrical shadow when it passes through a gap or around an obstacle.

Note:

- Diffraction is much more noticeable when the size of the gap or obstacle is approximately equal to or less than the wavelength of the wave.
- Sound waves easily diffract as they pass through an open door. The wavelength of the sound wave is approximately equal to the width of the open door.
- Since light waves have a very small wavelength they require very small gaps to diffract. To demonstrate diffraction of light waves we use a **diffraction grating**.

Question: A very thin fibre is being viewed with an optical microscope. Is there any limit as to how thin the fibre may be and still be visible??????????????????????

Interference of waves



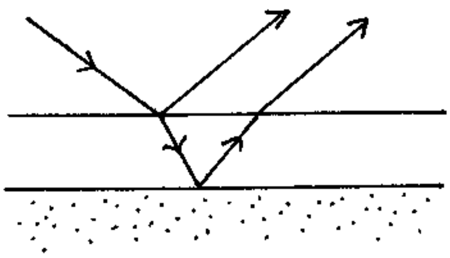
Constructive interference
When these two waves meet
the amplitude increases

Destructive interference
When these two waves meet
the amplitude decreases

Definition of interference: Interference will occur when waves from coherent sources meet and combine.
Constructive interference gives a wave of greater amplitude.
Destructive interference gives a wave of smaller amplitude.

Note:

- **Coherent sources** emit waves of the same frequency and the waves are in phase or have a constant phase difference.
- The **condition for constructive interference** is that when the waves meet they are in phase and the waves have the same frequency. The crest of one wave meets the crest of the other wave.
- The **condition for destructive interference** is that when the waves meet they are out of phase with a path difference of $\frac{\lambda}{2}$ or a multiple of this. The crest of one wave meets the trough of the other wave.
- Waves are **in phase** when they are doing the same thing at the same time.

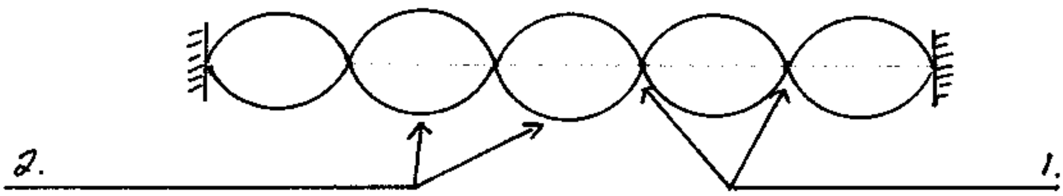


- The colours of oil films on water results from interference between the light waves reflected from the air oil interface and the oil water interface.
- The colour in soap bubbles results from interference between the light waves reflected from the outer and the inner surface of the bubble.

Noise reduction using destructive interference:

- You are in a room with a lot of noise coming in from the street.
- A microphone captures some of this noise, feeds it to an electronic device to analyse the wave pattern.
- The wave pattern is inverted and emitted as a sound from the device.
- Your ears now receive two sounds which are the exact “opposite” of each other.
- Due to destructive interference you hear no sound.

Stationary (Standing) Wave



To produce: Stationary waves are produced when two progressive waves of the same amplitude, same frequency, same speed and moving in opposite directions meet.

What are: stationary waves are waves where there is no net transfer of energy

Note:

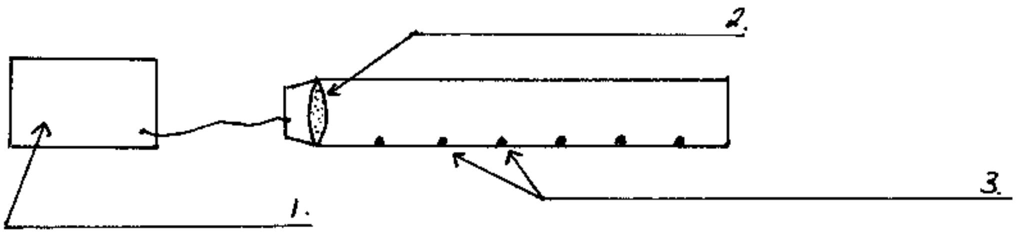
- Stationary waves are produced on the strings of musical instruments and in the air columns of wind instruments.
- The example above of a stationary wave on a string would be a **transverse stationary wave.**

Nodes: Nodes are points along the medium where the displacement is zero

Antinodes: Antinodes are points along the medium where the displacement is a maximum.

Maths Note: the wavelength of the stationary wave is twice the distance between successive nodes or successive antinodes.

Note:



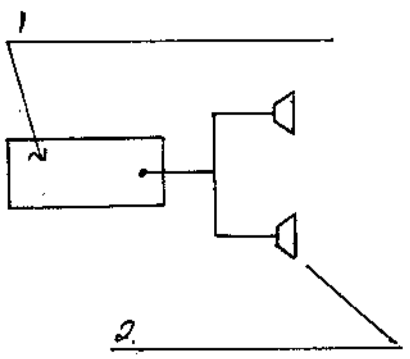
- A speaker connected to a signal generator is inserted into the open end of a long graduated cylinder. A layer of lycopodium powder is sprinkled inside the cylinder.
- Adjust the frequency on the signal generator until a stationary wave is set up.
- The powder gathers in small bundles at the nodes. This would be an example of a **longitudinal stationary wave**.

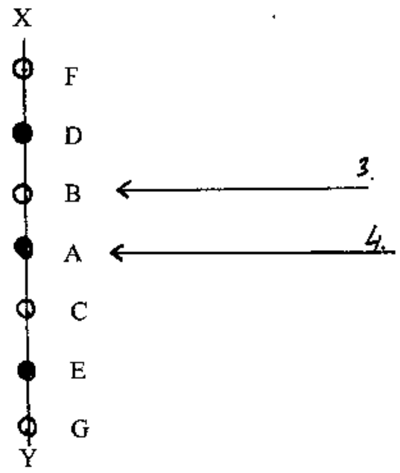
Sample question 3: A wave of frequency 2400 Hz is reflected off a surface back along its own path so that a stationary wave is set up. The distance between successive nodes is 7 cm. What is the speed of the wave?

Solution: λ = 2 $\times$ distance between successive nodes = 2×7 = 14 cm.

$$c = f \times \lambda$$
$$c = 2400 \times 0.14$$
$$c = 336 ms^{-1}$$

Demonstration experiment to show the wave nature of sound:





- The two speakers are connected in parallel to a signal generator and emit sounds of the same frequency and amplitude and are in phase. The speakers are coherent sources.
- A person walking along the line X Y will notice the sound intensity vary from loud to faint in a regular manner. **Constructive and destructive interference is taking place**.
- Interference is a phenomenon associated with waves, so if sound exhibits interference then we conclude that sound is a wave.

Explanation:

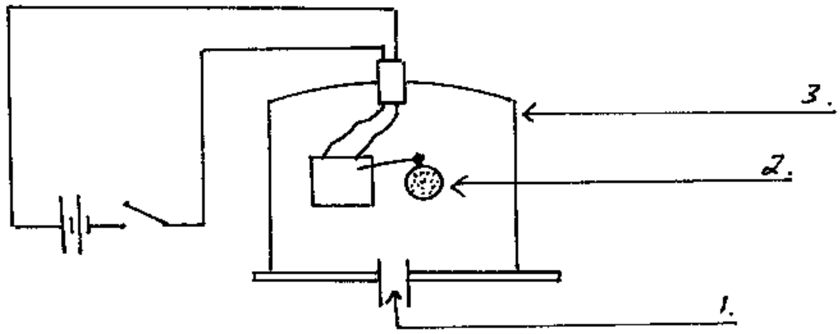
- The distances from the speakers to the central position of loudness (A) are equal. If the waves leave the speakers in phase then they arrive at A in phase and constructive interference occurs i.e. the sound is loud.
- The distances from the speakers to the first positions of faint sound (B) and (C) are not equal. There is a difference of $\frac{\lambda}{2}$ in the distances. Thus waves that left the speakers in phase will arrive at B and C out of phase. Destructive interference will occur and the sound is faint.
- The distances from the speakers to the first positions of loudness (D) and (E) are not the same. There is a difference of λ in the distances. Waves that left the speakers in phase will again be in phase when the arrive at D and E. Constructive interference will happen and a loud sound is heard.
- The distances from the speakers to the second positions of faint sound (F) and (G) are not the same. There is a difference of $\frac{3\lambda}{2}$ in the distances. Waves that left the speakers in phase will arrive at F and G out of phase. Destructive interference will occur and the sound is faint.

Note :

- For constructive there should be no difference in distances or a difference of integer multiples of wavelength.

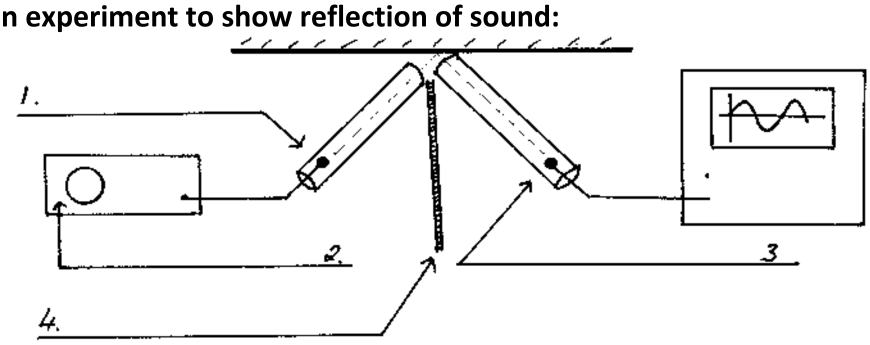
- For destructive interference the difference in distances should be $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2},$ etc.

Demonstration experiment to show that sound requires a medium in which to travel:



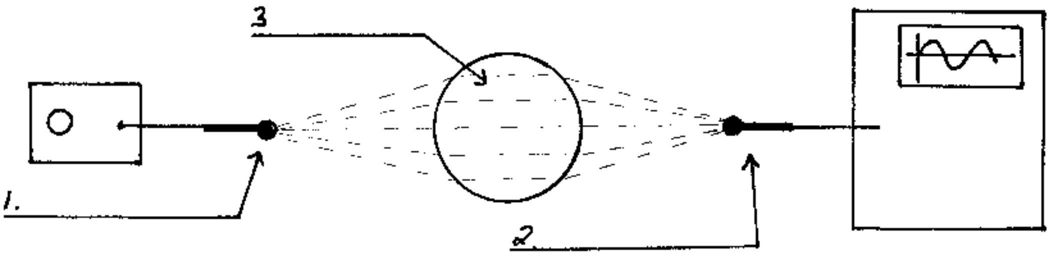
- When the switch is closes you will see the bell is ringing and you will hear the sound from the bell.
- As the air is removed from the bell jar you will notice that the sound becomes more faint.
- When all the air is removed you will hear no sound. You will see that the electric bell is still working.
- We conclude that sound cannot travel in a vacuum. **Sound requires a medium in which to travel.**

Demonstration experiment to show reflection of sound:



- A speaker is inserted into a glass tube as shown above.
- The sound travelling along the glass tube is reflected off the **smooth, flat hard** surface.
- The reflected sound is picked up by the microphone and fed to an oscilloscope.
- Checking the frequency of the display on the oscilloscope verifies it came from the signal generator.
- The sound absorbing medium reduces the sound energy travelling directly from the speaker to microphone.

Demonstration experiment to show refraction of sound:



- The speaker connected to the signal generator emits sound in all directions.
- Some of this sound is refracted by the balloon of CO_2 gas and is concentrated at a point.
- This sound energy is picked up by the microphone and displayed on the oscilloscope.

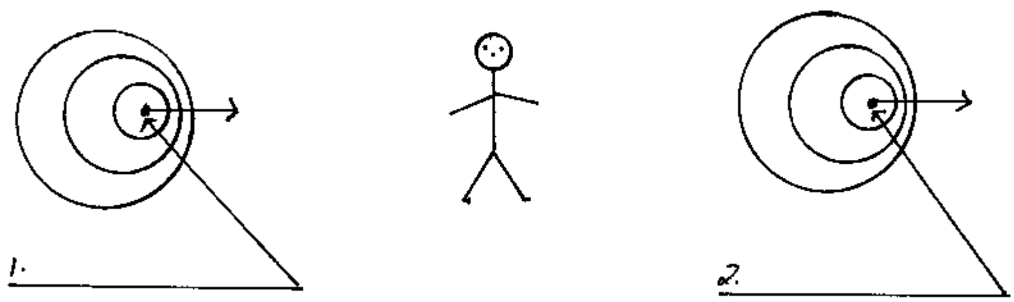
Chapter 2 **The Doppler Effect**

You are standing on the side of a road listening to the sound from a siren on the roof of a stationary car that is 500 m down the road. The car starts to move towards you and you notice that the frequency of the sound is different (higher). The car passes by you and moves away from you. The frequency of the sound is different again (lower). This is due to the Doppler effect.

Definition of Doppler effect: The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

Explanation of Doppler effect:

Source moving towards observer *Stationary observer* *Source moving away from observer*



(i) wavefronts closer together

(ii) observed **wavelength smaller**

(iii) observed **frequency higher**

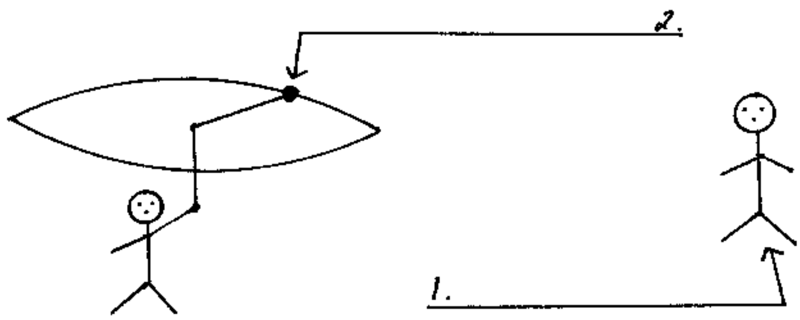
(i) wavefronts further apart

(ii) observer **wavelength longer**

(iii) observed **frequency lower**

The observed wavelength and frequency change as the source moves past observer !!!!!!!!!!

Demonstration (laboratory) experiment for the Doppler Effect:



- A battery powered electronic buzzer is attached to a string 50 cm long. The emitted frequency is set at 300 Hz.
- The buzzer is spun in circular motion on the end of the string quite fast.
- An observer standing 2 m away will notice the frequency from the buzzer change as it rotates.
- The observed frequency changes as the buzzer moves towards and then moves away from the person.

Maths of Doppler effect:

$$f' = \frac{f\,c}{c \pm u}$$ ……………………P. 59

(f'= observed frequency; f = frequency of source; c = speed of wave; u = speed of source)

Use the − when source moves towards the observer

Use the + when the source moves away from the observer

Note: It is very easy to confuse f' and f. I propose we use the following

$$f_o = \frac{f_s\,c}{c \pm u}$$

(f_o = observed frequency; f_s = frequency of source)

Sample question 1: A police car is travelling at $25ms^{-1}$ and has a siren emitting a sound at a frequency of 480 Hz. What is the frequency detected by a stationary observer

(i) as the car approaches

(ii) as the car moves from the person.

(speed of sound in air = $340ms^{-1}$)

Solution: (i)

$$f_o = \frac{f_s\,c}{c - u}$$

$$f_o = \frac{480 \times 340}{340 - 25}$$

$$f_o = 518\ Hz$$

(ii)

$$f_o = \frac{f_s\,c}{c + u}$$

$$f_o = \frac{480 \times 340}{340 + 25}$$

$$f_o = 447\ Hz$$

Sample question 2: A train's whistle emits a continuous note of frequency 640 Hz as it approaches a person standing near the track. To the person the frequency appears to be 720 Hz. Calculate the speed of the train.

(speed of sound in air = $340ms^{-1}$)

Solution: the train approaches the person so use

$$f_o = \frac{f_s\,c}{c - u}$$

$$c - u = \frac{f_s\,c}{f_o}$$

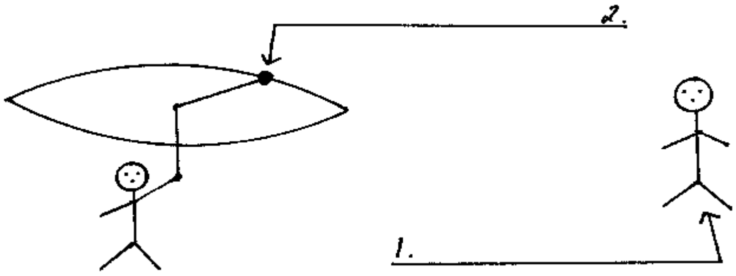
$$340 - u = \frac{640 \times 340}{720}$$

$$340 - u = 302.2$$

$$340 - 302.2 = u$$

$$37.8ms^{-1} = u$$

Sample question 3: A whistle emitting a note of 1 kHz is whirled in a horizontal circle on the end of a string 1.2 m long at a constant angular speed of $50\ rad\,s^{-1}$. What are the highest and lowest frequencies heard by a person standing some distance away. (speed of sound in air = $340 m s^{-1}$)



Solution: step 1: change angular speed to linear speed

$$v = r \times \omega$$
$$v = 1.2 \times 50$$
$$v = 60 m s^{-1}$$

Step 2: whistle moving towards the observer

$$f_o = \frac{f_s\ c}{c - u}$$
$$f_o = \frac{1000 \times 340}{340 - 60}$$
$$f_o = 1214 Hz$$

Step 3: whistle moving away from observer

$$f_o = \frac{f_s\ c}{c + u}$$
$$f_o = \frac{1000 \times 340}{340 + 60}$$
$$f_o = 850 Hz$$

Sample question 4: The yellow line emitted by a Helium discharge tube in the laboratory has a wavelength of 587 nm. The same yellow line in the helium spectrum of a star has a measured wavelength of 590 nm.

(i) what can you deduce about the motion of the star
(ii) calculate the speed of the star.

(speed of light = $3 \times 10^8 m s^{-1}$)

Solution: (i) the observed wavelength is longer therefore the star moves away from the earth.

(ii) change the wavelengths to frequencies

True frequency (source) = $f_s = \frac{c}{\lambda} = \frac{3 \times 10^8}{587 \times 10^{-9}} = 5.11 \times 10^{14} Hz$

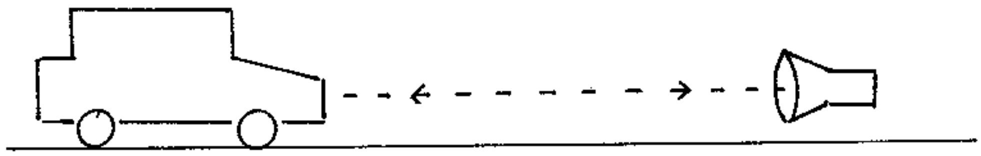
Observed frequency = $f_o = \frac{c}{\lambda} = \frac{3 \times 10^8}{590 \times 10^{-9}} = 5.0847 \times 10^{14} Hz$

Now rearrange $f_o = \frac{f_s\ c}{c + u}$ to get $c + u = \frac{f_s\ c}{f_o}$

$$c + u = \frac{5.11 \times 10^{14} \times 3 \times 10^8}{5.0847 \times 10^{14}}$$
$$3 \times 10^8 + u = 3.015 \times 10^8$$
$$1.5 \times 10^6 m s^{-1} = u$$

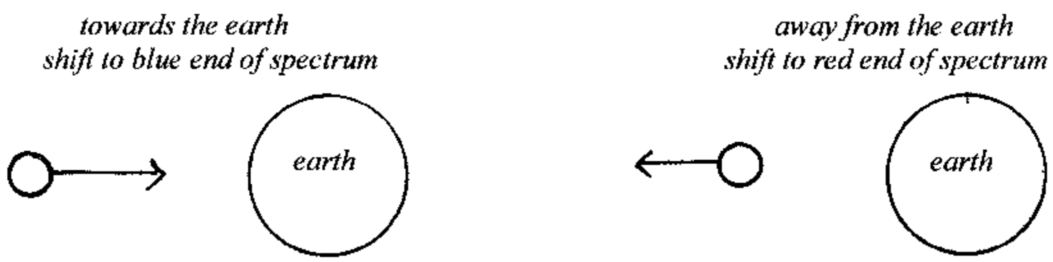
Applications of the Doppler effect:

Checking the speed of a car:



- An electromagnetic wave of **known frequency** f_s is directed at a moving car.
- The speed of this wave is also known as all electromagnetic waves the same speed. The value of the speed of the wave c is $3 \times 10^8\, ms^{-1}$
- The wave reflected off the car will have a different frequency to the incident wave. This reflected frequency f_o is measured electronically.
- The values of f_s, f_o and c are now all known. We calculate the speed of the car u using $f_o = \dfrac{f_s\ c}{c \pm u}$

Measuring the speed of a star:



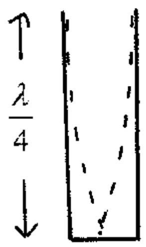
- If a star is moving towards the earth the frequency of the light from the star appears higher. The wavelength appears smaller. There is a shift towards the violet end of the spectrum
- If a star is moving away from the earth the frequency of the light from the star appears lower. The wavelength appears longer. There is a shift towards the red end of the spectrum. " **red shift**".
- The actual speed of a star can be calculated using our Doppler formula.

Note: Other uses of the Doppler effect would include

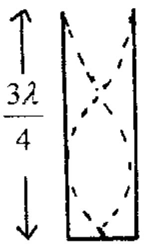
- Blood flow measurement (echocardiogram)
- Checking the heart beat of a foetus.

Chapter 3:
Resonance and columns of air

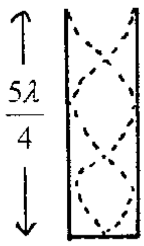
Longitudinal standing waves: (pipe closed at one end):



1st harmonic



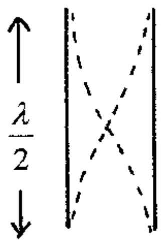
3rd harmonic



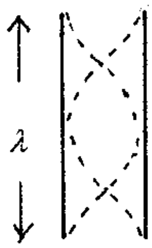
5th harmonic

- It is possible to make the air vibrate in a pipe which is closed at one end and open at the other end.
- The air can vibrate at certain frequencies and these are called the harmonics.
- There will be a node at the closed end and an antinode at the open end.
- You will notice that only the **odd harmonics** are possible for the pipe closed at one end.
- Musical instruments based on this are called **poor quality instruments** since only the odd harmonics are available.
- Examples are : clarinet, trombone, saxophone

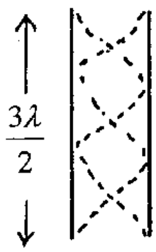
Pipe open at both ends:



1st harmonic



2nd harmonic



3rd harmonic

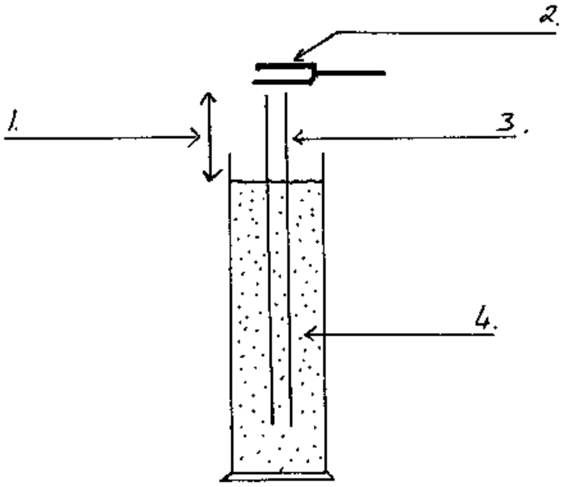
- It is possible to make the air vibrate in a pipe open at both ends
- The air can vibrate at certain frequencies and these are called the harmonics
- There is an antinode at both open ends
- You will notice that **all the harmonics** are possible.
- Musical instruments based on this are called **good quality instruments** since all the harmonics are possible.
- Examples are : tin whistle, flute, pan pipes

Sample question 1: A pipe closed at one end is 30 cm long. The air in the pipe is made vibrate at the fundamental frequency (1st harmonic). Calculate the value of this fundamental frequency. (speed of sound in air = $340\,m\,s^{-1}$)

Solution: $\frac{\lambda}{4}$ = 30 cm therefore λ = 120 cm = 1.2 m

$$f = \frac{c}{\lambda} = \frac{340}{1.2} = 283.3 \text{ Hz}$$

Mandatory experiment: To measure the speed of sound in air:



- A tall graduated cylinder almost filled with water and a hollow glass tube open at both ends are arranged as shown in the diagram.
- A vibrating tuning fork is placed over the open end of the tube and the tube is raised out of the water until the **first resonance** between tuning fork and column of air is observed.
- When resonance happens the frequency of the vibrating column of air equals the frequency of the tuning fork.
- The resonance in the column of air is detected by hearing, i.e. the sound gets louder.

Data:

- Note and record the frequency that is stamped on the tuning fork
- Measure the length of the tube over the water level when first resonance happens.
- Measure the internal diameter of the glass tube (column of air) with a sliding callipers.

Calculations:

- Record the frequencies of several different tuning forks and the corresponding values of the length of the tube (length of air column) above the water level
- Since you are dealing with the first harmonic for a tube open at one end (the water acts as a closed end) $\frac{\lambda}{4} = l + d$

$$\lambda = 4 \times \{l + d\}$$

Now since $c = f \times \lambda \quad \Rightarrow \quad c = f \times 4\{l + d\}$

(l = length of tube above water level; d = end correction)

- Repeat the above calculation for each different frequency of tuning fork and calculate an average value of the speed of sound in air.

Accuracy:

- Avoid the error of parallax when measuring the length of the tube (length of air column) above the water level
- Avoid tuning forks of very high frequency as they correspond to small values of length and small values of length result in greater percentage errors.
- Make sure you always work with the first position of resonance and not the higher harmonics. As you lift the tube the first resonance detected is the first harmonic.
- The **end correction "*d*"** takes account of the gap between the end of the tube and the vibrating tuning fork. The vibrating column of air extends a little beyond the end of the tube. **End correction $\approx$ internal diameter of tube $\times$ 0.3**

Sample question 2: In an experiment to measure the value of the speed of sound in air a student recorded the frequency f of several tuning forks and the corresponding values of the length of tube l above the water level. The internal diameter of the tube was 3 cm.

f / Hz	256	288	320	341	384	480	512
l / cm	32	29	26	24	21	17	16

Calculate the value of the speed of sound in air

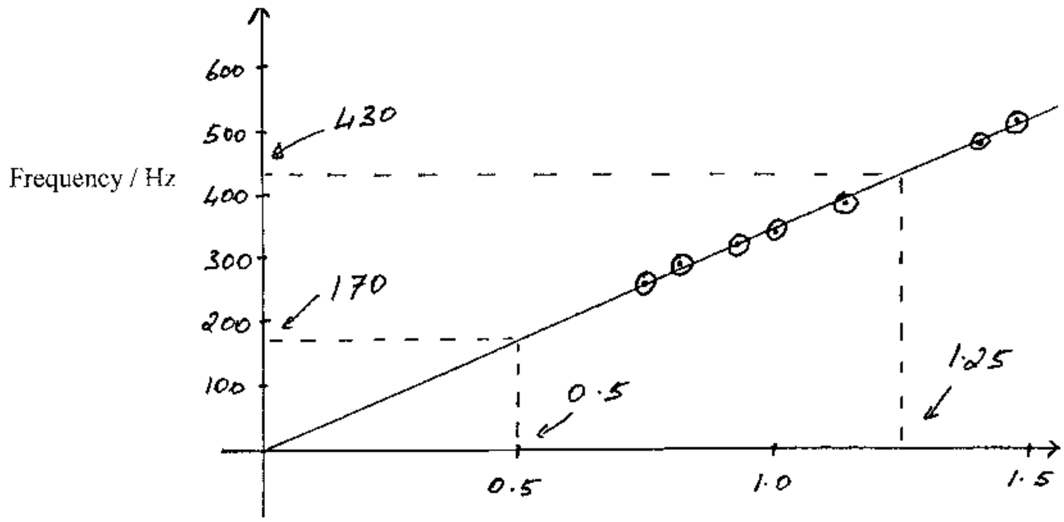
Solution: **Method 1:** the end correction = 3 × 0.3 = 0.9 cm

f / Hz	256	288	320	341	384	480	512
l / cm	32	29	26	24	21	17	16
$\{l+d\}/cm$	32.9	29.9	26.9	24.9	21.9	17.9	16.9
$\lambda = 4\{l+d\}/m$	1.316	1.196	1.076	0.996	0.876	0.716	0.676
$c = f \times 4\{l+d\}/ms^{1}$	337	344	344	340	336	344	346

The average of the seven values is $c = 341.6 ms^{-1}$

Method 2: Plot a graph of frequency on the y-axis and **reciprocal wavelength** on the x-axis.

f / Hz	256	288	320	341	384	480	512
l / cm	32	29	26	24	21	17	16
$\{l+d\}/cm$	32.9	29.9	26.9	24.9	21.9	17.9	16.9
$\lambda = 4\{l+d\}/m$	1.316	1.196	1.076	0.996	0.876	0.716	0.676
$\frac{1}{\lambda}$ / m^{-1}	0.76	0.84	0.93	1.00	1.14	1.40	1.48



$\frac{1}{\lambda}$ / m^{-1}

$$\text{Speed} = c = \frac{f}{\frac{1}{\lambda}} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{430 - 170}{1.25 - 0.5} = 347 ms^{-1}$$

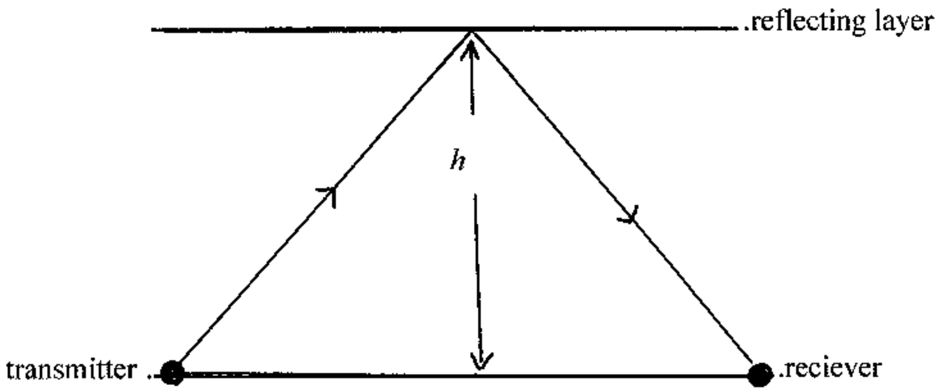
2002 Q.7:

"Constructive interference and destructive interference take place when waves from two coherent sources meet."
Explain the underlined terms in the above statement. (12)

What is the condition necessary for destructive interference to take place when waves from two coherent sources meet? (6)

Describe an experiment that demonstrates the wave nature of light. (12)

Radio waves of frequency 30 kHz are received at a location 1500 km from a transmitter. The radio reception temporarily "fades" due to destructive interference between the waves travelling parallel to the ground and the waves reflected from a layer (ionosphere) of the earth's atmosphere, as indicated in the diagram.



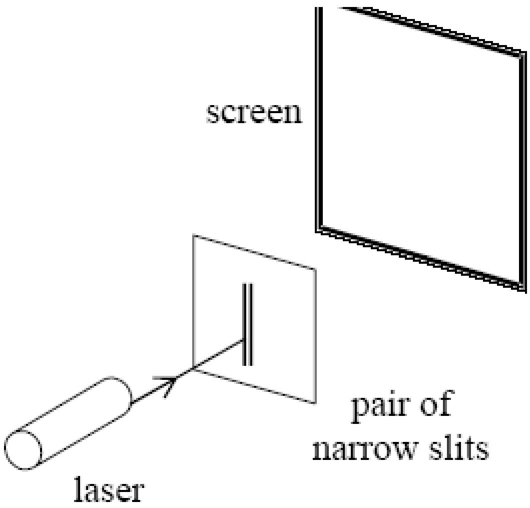
(i) Calculate the wavelength of the radio waves. (6)
(ii) What is the minimum distance that the reflected waves should travel for destructive interference to occur at the receiver? (9)
(iii) The layer at which the waves are reflected is at a height h above the ground. Calculate the minimum height of this layer for destructive interference to occur at the receiver. (11)
(speed of light, $c = 3.0 \times 10^{8}$ m s^{-1})

Solution :

Constructive interference ………. When two waves combine to give a wave of greater amplitude

Coherent ……… Coherent sources are sources which emit waves with the **same frequency** and the waves are **in phase**.

What ………. When the crest of one wave combines with the trough of another wave, i.e. when the waves meet and combine they have a phase difference of $\frac{\lambda}{2}$, $\frac{3\lambda}{2}$, … etc.

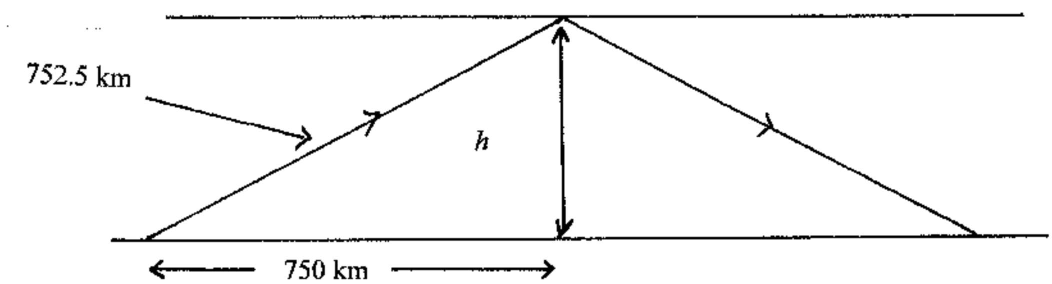


- Interference and diffraction of light both happen as light passes through the double slits.
- The pair of slits act like coherent sources of light, i.e. light beams leaving the slits have the same frequency and are in phase.
- At the screen the light waves meet and combine.
- Constructive interference gives a series of bright lines.
- Destructive interference gives a series of dark lines between the bright lines.
- Since interference can only happen for waves then it follows that **light is a wave**.

(i) $$\lambda = \frac{c}{f} = \frac{3\times10^8}{30\times10^3} = 10000\,m$$

(ii) for destructive interference there must be a path difference of at least $\frac{\lambda}{2}$ i.e. 5000 m. (5 km) . Therefore the minimum distance for the reflected wave is 1500 km + 5 km i.e. 1505 km.

(iii) Since 1505 km is the distance from transmitter to the reflecting layer to the receiver then from the transmitter to the reflecting layer is half of this value i.e. 752.5 km.



Using Pythagoras $$h^2 + 750^2 = 752.5^2$$
$$h = 61.3 \text{ km.}$$

2003 Q.7:

Describe an experiment to show that sound is a wave motion. (12)

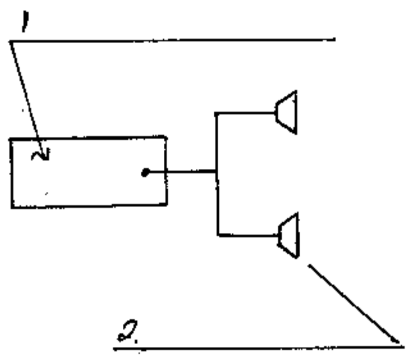
What is the Doppler effect? Explain, with the aid of labelled diagrams, how this phenomenon occurs. (14)

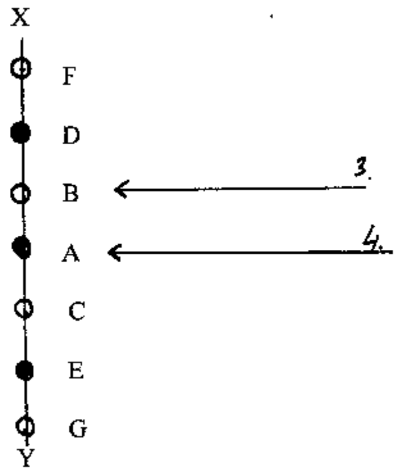
Bats use high frequency waves to detect obstacles. A bat emits a wave of frequency 68 kHz and wavelength 5.0 mm towards the wall of a cave. It detects the reflected wave 20 ms later. Calculate the speed of the wave and the distance of the bat from the wall.
(12)

If the frequency of the reflected wave is 70 kHz, what is the speed of the bat towards the wall?
. (12)

Give two other applications of the Doppler effect. (6)

Solution :



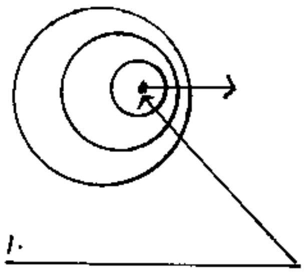


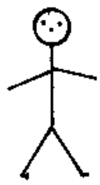
- The two speakers are connected in parallel to a signal generator and emit sounds of the same frequency and amplitude and are in phase. The speakers are coherent sources.
- A person walking along the line X Y will notice the sound intensity vary from loud to faint in a regular manner. **Constructive and destructive interference is taking place**.
- Interference is a phenomenon associated with waves, so if sound exhibits interference then we conclude that sound is a wave.

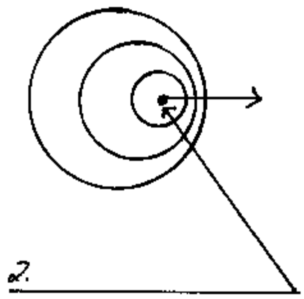
Definition of Doppler effect: The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

Explanation of Doppler effect:

Source moving towards observer | *Stationary observer* | *Source moving away from observer*







(i) wavefronts closer together

(ii) observed **wavelength smaller**

(iii) observed **frequency higher**

(i) wavefronts further apart

(ii) observer **wavelength longer**

(iii) observed **frequency lower**

The observed wavelength and frequency change as the source moves past observer !!!!!!!!!!

Calculate …… $c = f \times \lambda = 68000 \times 5 \times 10^{-3} = 340 ms^{-1}$

If it takes 20 ms for the wave to travel from the bat to the wall and back to the bat then it takes 10 ms to travel from the bat to the wall. To get the distance use

$$s = ut + \frac{1}{2}at^2$$ no acceleration

$$s = 340 \times 0.01 + 0$$

$$s = 3.4 m$$

If ………. $f_o = \frac{f_s \; c}{c - u}$ therefore $70000 = \frac{68000 \times 340}{340 - v}$

$$340 - v = \frac{68000 \times 340}{70000}$$

$$340 - v = 330.3$$

$$9.7 ms^{-1} = v$$

Give …… (a) to measure the speed of a car

(b) to measure the speed of stars (red shift)

2006 Q.3:

A cylindrical column of air closed at one end and three different tuning forks were used in an experiment to measure the speed of sound in air. A tuning fork of frequency *f* was set vibrating and held over the column of air.
The length of the column of air was adjusted until it was vibrating at its first harmonic and its length *l* was then measured. This procedure was repeated for each tuning fork. Finally, the diameter of the column of air was measured. The following data was recorded.

f/Hz	512	480	426
l/cm	16.0	17.2	19.4
Diameter of column of air = 2.05 cm			

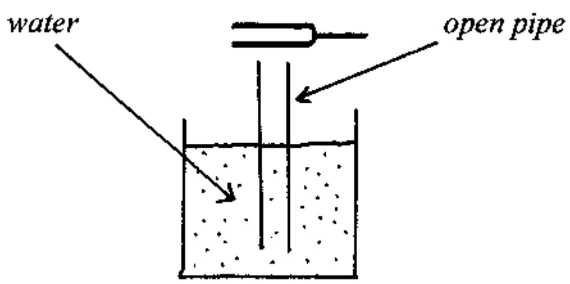
Describe
(i) how the length of the column of air was adjusted;
(ii) how the frequency of the column of air was measured;
(iii) how the diameter of the column of air was measured. (16)

How was it known that the air column was vibrating at its **first** harmonic? (9)

Using all of the data, calculate the speed of sound in air. (15)

Solution :

(i) The open pipe can be raised or lowered in the water to change the length of the column of air.



(ii) When the column of air is vibrating at its first harmonic the frequency of the column of air equals the frequency of the tuning fork (resonance). Read the frequency written on the tuning fork

(iii) The diameter of the column of air is the internal diameter of the open pipe. This can be measured using a vernier calipers.

How ….. Start with the open pipe fully immersed in the water. Position the vibrating tuning fork over the open mouth of the pipe. Slowly lift the pipe upwards until you hear the first resonance (the sound gets louder). This first resonance corresponds to the first harmonic.

The **end correction “*d*”** takes account of the gap between the end of the tube and the vibrating tuning fork. The vibrating column of air extends a little beyond the end of the tube.

. **End correction $\approx$ internal diameter of tube $\times$ 0.3**

$$0.3 \times \text{diameter} = 0.3 \times 2.05\,cm = 0.615 \text{ cm}$$

Calculate ….

From the notes $c = f \times \lambda$

$$c = f \times 4(l + d)$$

1st attempt : $c = 512 \times 4(0.16 + 0.00615) = 340.3\ ms^{-1}$

2nd attempt : $c = 480 \times 4(0.172 + 0.00615) = 342\,ms^{-1}$

3rd attempt : $c = 426 \times 4(0.194 + 0.00615) = 341.1\,ms^{-1}$

The average value is $c = 341.13\,ms^{-1}$

2007 Q.7:

What is the Doppler effect?
Explain, with the aid of labelled diagrams, how this phenomenon occurs. (18)

The emission line spectrum of a star was analysed using the Doppler effect.
Describe how an emission line spectrum is produced. (12)

The red line emitted by a hydrogen discharge tube in the laboratory has a wavelength of 656 nm. The same red line in the hydrogen spectrum of a moving star has a wavelength of 720 nm. Is the star approaching the earth? Justify your answer. (8)

Calculate:

(i) the frequency of the red line in the star's spectrum
(ii) the speed of the moving star. (18)

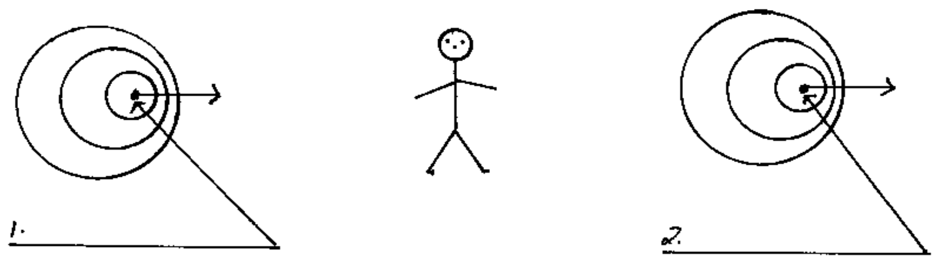
(speed of light = 3.00 × 10^8 m s^{-1})

Solution :

Definition of Doppler effect: The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

Explanation of Doppler effect:

Source moving towards observer *Stationary observer* *Source moving away from observer*



(i) wavefronts closer together

(ii) observed **wavelength smaller**

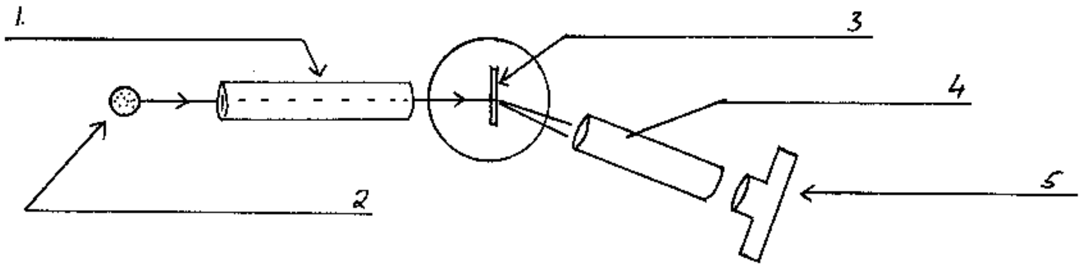
(iii) observed **frequency higher**

(i) wavefronts further apart

(ii) observer **wavelength longer**

(iii) observed **frequency lower**

The observed wavelength and frequency change as the source moves past observer !!!!!!!!!!



1 = collimator; 2 = sodium lamp; 3 = diffraction grating; 4 = telescope; 5 = camera

- The source of light is positioned in front of the slit of the collimator.
- The light passes through a diffraction grating (or a prism) and the colours of the light separate.
- A camera is attached to the telescope to obtain a permanent record of the spectrum.

- You will observe that line spectra consist of separate bright lines of definite wavelength on a dark background.

Is ….. No !!! The wave length has increased / frequency has decreased, i.e. the source is moving away from the observer.

Calculate ….. (i) $$f = \frac{c}{\lambda} = \frac{3\times10^{8}}{720\times10^{-9}} = 4.167\times10^{14}\,Hz$$

Or $$f = \frac{c}{\lambda} = \frac{3\times10^{8}}{656\times10^{-9}} = 4.573\times10^{14}\,Hz$$

The question was unclear as to whether the star was to be considered as moving or stationary when calculating the frequency of the red line, hence two acceptable answers!

(ii) $$f_o = \frac{f_s\, c}{c+u}$$ therefore $$4.167\times10^{14} = \frac{4.573\times10^{14}\times3\times10^{8}}{3\times10^{8}+u}$$

$$3\times10^{8}+u = \frac{4.573\times10^{14}\times3\times10^{8}}{4.167\times10^{4}}$$

$$3\times10^{8}+u = 3.292\times10^{8}$$

$$u = 2.92\times10^{7}\,ms^{-1}$$

2008 Q.12(b):

The pitch of a musical note depends on its frequency.
On what does (i) the quality, (ii) the loudness, of a musical note depend? (6)

What is the Doppler effect? (6)

A rally car travelling at 55 m s^{-1} approaches a stationary observer. As the car passes, its engine is emitting a note with a pitch of 1520 Hz. What is the change in pitch observed as the car moves away? (12)

Give an application of the Doppler effect. (4)
(Speed of sound in air = $340 ms^{-1}$)

Solution :
(i) Quality depends on the number of overtones (harmonics) present in a note.
(ii) The loudness of a note depends on the amplitude of a sound wave.

What …… The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

Source moving away $$f_o = \frac{f_s\, c}{c + u}$$

$$f_o = \frac{1520 \times 340}{340 + 55}$$

$$f_o = 1308.35\ Hz$$

Therefore change in frequency = 1520 – 1308.35 = 211.65 Hz

Give …… To estimate the speed of stars or to calculate the speed of a moving car.

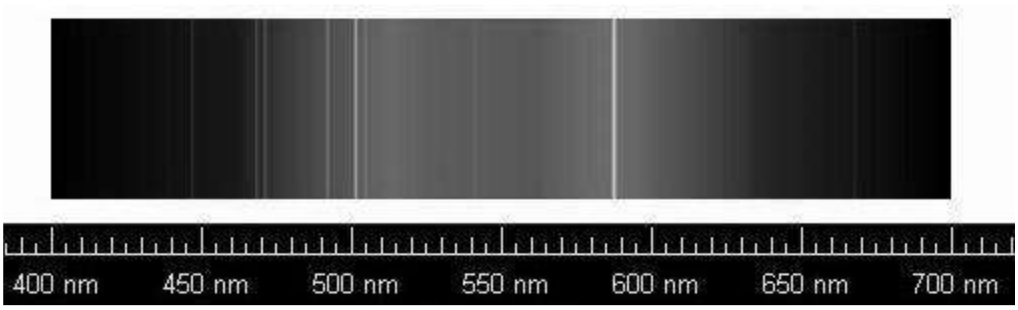
2010 Q.7:

The Doppler effect applies to all types of waves and is named after Christian Johann Doppler, an Austrian scientist who explained this phenomenon in 1842.

What is the Doppler effect?
Explain, with the aid of labelled diagrams, how this phenomenon occurs. (18)

Describe a laboratory experiment to demonstrate the Doppler effect. (9)

In the early part of the twentieth century, Hubble and other astronomers made the first measurements on the spectra from distant stars. They observed that these spectra were shifted and they used the Doppler effect to explain these shifts.
What causes the red shift in the spectrum of a distant star? (6)



The yellow line emitted by a helium discharge tube in the laboratory has a wavelength of 587 nm as shown in the diagram. The same yellow line in the helium spectrum of a star has a measured wavelength of 590 nm.
What can you deduce about the motion of the star?
Calculate the speed of the moving star. (18)

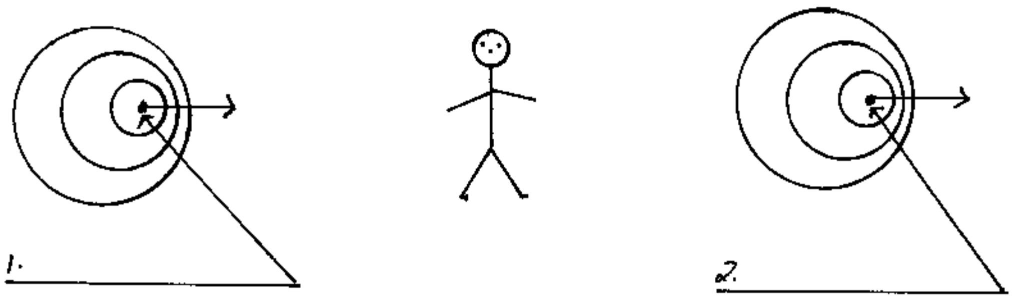
Give another application of the Doppler effect. (5)
(speed of light = 3.00 × $10^8\ m s^{-1}$)

Solution:

Definition of Doppler effect: The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

Explanation of Doppler effect:

Source moving towards observer | *Stationary observer* | *Source moving away from observer*



(i) wavefronts closer together

(ii) observed **wavelength smaller**

(iii) observed **frequency higher**

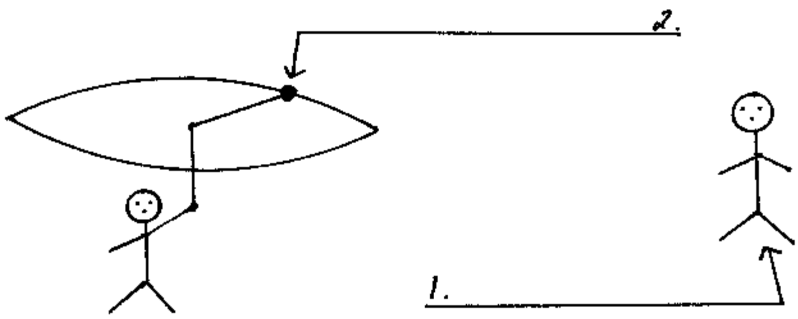
(i) wavefronts further apart

(ii) observer **wavelength longer**

(iii) observed **frequency lower**

The observed wavelength and frequency change as the source moves past observer !!!!!!!!!!

Describe ……



- A battery powered electronic buzzer is attached to a string 50 cm long. The emitted frequency is set at 300 Hz.
- The buzzer is spun in circular motion on the end of the string quite fast.
- An observer standing 2 m away will notice the frequency from the buzzer change as it rotates.
- The observed frequency changes as the buzzer moves towards and then moves away from the person.

What causes ….. The star was moving relative to the earth.
A longer wavelength is observed if the star moves away from the earth.
A shorter wavelength is observed if the star moves towards the earth.

What can …… the longer wavelength tells us the star is moving away from the earth.

Calculate …. First change the wavelength values to frequency values

In the lab. $f = \frac{c}{\lambda} = \frac{3\times10^{8}}{587\times10^{-9}} = 5.11073\times10^{14}$ Hz

From the star $f = \frac{c}{\lambda} = \frac{3\times10^{8}}{590\times10^{-9}} = 5.08475\times10^{14}$ Hz

$$f_o = \frac{f_s \times c}{c + u}$$

$$5.08475\times10^{14} = \frac{5.11073\times10^{14} \times 3\times10^{8}}{3\times10^{8} + u}$$

$$3\times10^{8} + u = \frac{5.11073\times10^{14} \times 3\times10^{8}}{5.08475\times10^{4}}$$

$$3\times10^{8} + u = 3.01533\times10^{8}$$

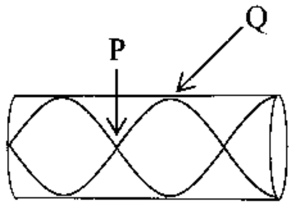
$$u = 1.533\times10^{6}\, ms^{-1}$$

Give …..

- Measuring the speed of a car
- Blood flow measurement
- Medical imaging ……………

2011 Q.8:

(a) Destructive interference can occur when waves from <u>coherent sources</u> meet.
Explain the underlined term.
Give two other conditions necessary for total destructive interference to occur. (14)



The diagram shows a standing wave in a pipe closed at one end.
The length of the pipe is 90 cm.
(i) Name the points on the wave labelled P and Q.
(ii) Calculate the frequency of the standing wave.
(iii) What is the fundamental frequency of the pipe?

The clarinet is a wind instrument based on a pipe that is closed at one end.
What type of harmonics is produced by a clarinet? (24)

(*b*) An audio speaker at a concert emits sound uniformly in all directions at a rate of 100 W.
Calculate the sound intensity experienced by a listener at a distance of 8 m from the speaker.

The listener moves back from the speaker to protect her hearing. At what distance from the speaker is the sound intensity level reduced by 3 dB? (18)
(speed of sound in air = 340 m s^{-1})

Solution:

Coherent ……… Coherent sources are sources which emit waves with the **same frequency** and the waves are **in phase**.

Give …. (a) The waves must have the same amplitude

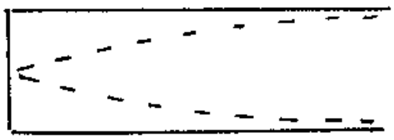
(b) The waves are out of phase by $\frac{\lambda}{2}$ (a crest meets a trough)

(i) P is a node Q is an antinode

(ii) $1\frac{1}{4}\lambda = \frac{5\lambda}{4} = 90cm$ therefore $\lambda = \frac{4 \times 90}{5} = 72cm$

$$f = \frac{c}{\lambda} = \frac{340}{0.72} = 472.2Hz$$

(iii) for a pipe closed at one end the fundamental frequency happens when the length of the pipe corresponds to one quarter of a wavelength ($\frac{\lambda}{4}$)



Therefore $\frac{\lambda}{4} = 90cm \quad \Rightarrow \quad \lambda = 360cm = 3.6m$

$$f = \frac{c}{\lambda} = \frac{340}{3.6} = 94.4Hz$$

What ….. Because the clarinet is a pipe closed at one end only the odd harmonics are available.

(b) $$sound\ intensity = \frac{energy\ per\ second}{area}$$

$$I = \frac{power}{4\pi r^2}$$

$$I = \frac{100}{4\pi \times 8^2}$$

$$I = 0.124\ W m^{-2}$$

If the sound intensity level is reduced by 3 dB then the sound intensity is halved i.e.

$$\frac{0.124}{2} = 0.062\ W\ m^{-2}$$

Therefore rearrange $I = \frac{power}{4\pi r^2}$ to get $r^2 = \frac{power}{4\pi I}$

$$r^2 = \frac{100}{4\ \pi \times 0.062}$$

$$r^2 = 128.35$$

$$r = 11.33m$$

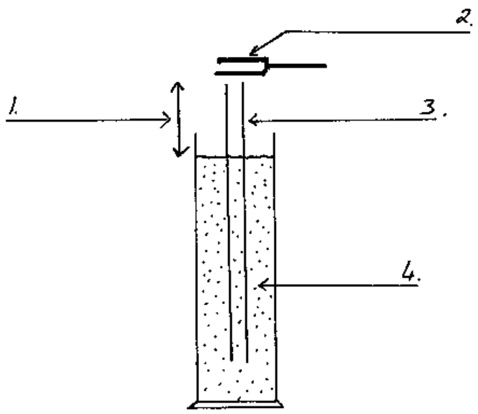
2014 Q. 3:

A student used a cylindrical column of air closed at one end and a tuning fork of frequency 512 Hz in an experiment to measure the speed of sound in air.

The following data was recorded:
Length of column of air for first position of resonance = 16.2 cm
Diameter of air column = 1.15 cm

Draw a labelled diagram of the apparatus used in the experiment. (9)
Describe how the first position of resonance was found. (9)
Using the recorded data, calculate the speed of sound in air. (9)
Why was it necessary to measure the diameter of the air column? (6)
Another student carried out the experiment. She measured the length of the column of air for each of the first two positions of resonance but she did not measure the diameter of the air column.
Explain how this second student would find the speed of sound in air. (7)

Solution:



1 = length of air column which can be varied; 2 = tuning fork of known frequency
3 = glass tube; 4 = water

Describe……
- A vibrating tuning fork is placed over the open end of the tube and the tube is raised out of the water until the **first resonance** between tuning fork and column of air is observed.
- The resonance in the column of air is detected by hearing, i.e. the sound is at its loudest.

Using….. note that the end correction $= 0.3 \times 1.15 = 0.345 cm$

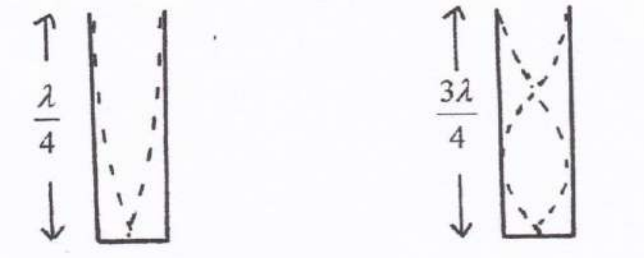
$$c = f \times 4\{l + d\} = 512 \times 4\{16.2 \times 10^{-2} + 0.345 \times 10^{-2}\}$$
$$c = 338.8 ms^{-1}$$

Why……….the vibrating column of air extends beyond the end of the tube. This is referred to as an end correction. The end correction is calculated using

End correction $\approx$ internal diameter of tube $\times$ 0.3

We therefore need to measure the internal diameter of the tube.

Explain….



1st harmonic 3rd harmonic

The student measures the length of tube above the water level corresponding to the first position of resonance. Note that this length l_1 could be written as

$$\frac{\lambda}{4} = l_1 + d \qquad \text{(a)}$$

The student measures the length of tube above the water level corresponding to the next position of resonance. Note that this length l_2 could be written as

$$\frac{3\lambda}{4} = l_2 + d \qquad \text{(b)}$$

When you subtract equation (a) from (b) you get $\frac{\lambda}{2} = l_2 - l_1$

$$\lambda = 2\{l_2 - l_1\}$$

Since $c = f \times \lambda$ it follows $c = f \times 2\{l_2 - l_1\}$

Here you do not need the value of the end correction, therefore you do not need the value of the diameter of the column of air.

2014 Q. 10:

Blood pressure can be measured in many ways. One technique uses the Doppler effect; another uses strain gauges contained in Wheatstone bridges. What is the Doppler effect?

Explain, with the aid of labelled diagrams, how the Doppler effect occurs. (18)

An ambulance siren emits a sound of frequency 750 Hz. When the ambulance is travelling towards an observer, the frequency detected by the observer is 820 Hz.

What is the speed of the ambulance? (12)

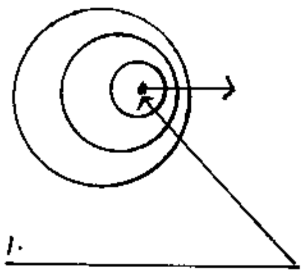
State two other practical applications of the Doppler effect. (4)

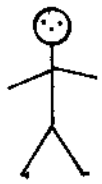
The remainder of this question is based on the Wheatstone bridge covered in Electricity!!

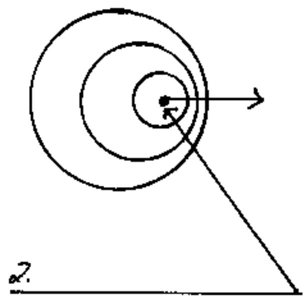
Solution:

What…… The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

Source moving towards observer | *Stationary observer* | *Source moving away from observer*







(i) wavefronts closer together | (i) wavefronts further apart

(ii) observed **wavelength smaller** | (ii) observer **wavelength longer**

(iii) observed **frequency higher** | (iii) observed **frequency lower**

The observed wavelength and frequency change as the source moves past observer !!!!!!!!!!

What …. the ambulance approaches the person so use $f_o = \dfrac{f_s\ c}{c - u}$

$$820 = \frac{750 \times 340}{340 - u}$$

$$340 - u = \frac{750 \times 340}{820}$$

$$340 - u = 310.98$$

$$29.02\,ms^{-1} = u$$

State………(i) police use speed cameras to measure speeds of cars

(ii) Astronomers use Doppler effect to measure the speeds of stars

2015 Q.9:

Musical instruments produce stationary (standing) waves.
Resonance also occurs in many instruments.
What are stationary waves? How are they produced?
What is resonance? Describe a laboratory experiment to demonstrate resonance. (24)

A guitar is a string instrument. The frequency of a stretched string depends on the tension of the string and on two other factors. What are the two other factors?
What effect does increasing the tension of the string from 36 N to 81 N have on the frequency of the string? (12)

Explain, with the aid of labelled diagrams, why a pipe open at only one end produces half the number of harmonics as a pipe open at both ends.
A tin whistle consists of a pipe which is open at both ends. A particular tin whistle has a fundamental frequency of 587 Hz when all of the holes on it are covered.
How long is the pipe? (20)
(speed of sound in air = 340 $m s^{-1}$)

Solution:

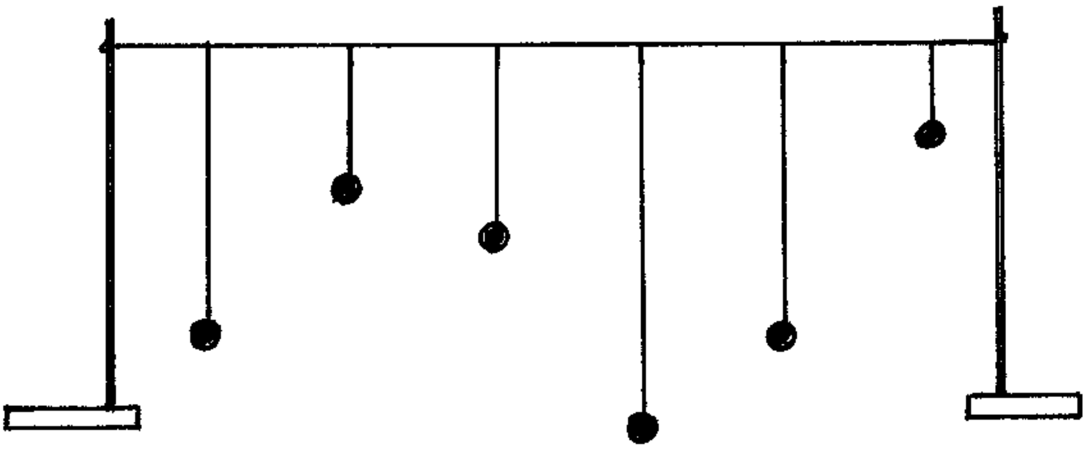
What … standing waves are waves where there is no net transfer of energy.

How … Stationary waves are produced when two progressive waves of the same amplitude, same frequency, same speed and moving in opposite directions meet.

What …. Resonance is the transfer of energy between two systems of similar natural frequencies

Describe……. **Demonstration (laboratory) of resonance**: **(Barton's pendulums)**

1 2 3 4 5 6

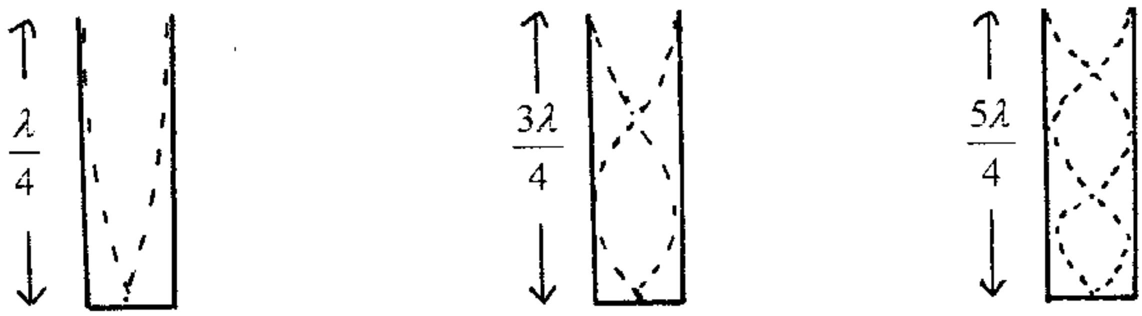


- A number of pendulums are arranged as shown above.
- Pendulum 1 is made swing in and out of the plane of the page.
- All the pendulums start to swing a little but pendulum 5 swings most.
- Pendulums 1 and 5 have the same length and therefore the same natural frequency.
- Energy is transferred back and forth between the pendulums of the same natural frequency.

What …. The other factors are the length of the string and the mass per unit length of the string.

What … since $f \propto \sqrt{T}$, if the ration of the tensions are 81 : 36, then the ration of the frequencies is $\sqrt{81:36}$, i.e. 9 : 6, or the frequency is 1.5 times greater. ($\frac{9}{6} = 1.5$)

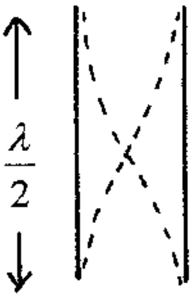
Explain ….. **pipe closed at one end**



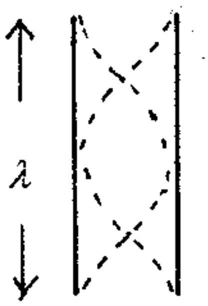
1st harmonic 3rd harmonic 5th harmonic

- You will notice that only the **odd harmonics** are possible for the pipe closed at one end.

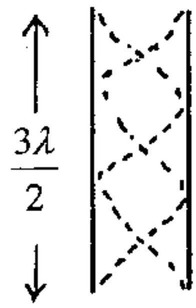
Pipe open at both ends:



1st harmonic



2nd harmonic



3rd harmonic

- You will notice that **all the harmonics** are possible.

How … if the fundamental frequency for a pipe open at both ends is 587 Hz, then the corresponding wavelength is $\lambda = \frac{c}{f} = \frac{340}{587} = 0.5792m$

From diagram above, the length of the pipe $= \frac{\lambda}{2} = \frac{0.5792}{2} = 0.29m$

2016 Q. 12(c):

What is meant by the Doppler effect?
Define centripetal force. (10)

A buzzer attached to a string of length 80 cm moves at a speed of 13 m s^{-1} in a vertical circle. The buzzer has a mass of 70 g and emits a note of frequency 1.1 kHz. An observer stands in the plane of motion of the buzzer, as shown in the diagram.
Calculate
(i) the maximum and minimum frequency of the note detected by an observer
(ii) the maximum and minimum tension in the string. (18)
(speed of sound in air = 340 ms^{-1} ; acceleration due to gravity = 9.8 ms^{-2})

Solution:

What … The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.
Define … centripetal force is the force acting towards the centre of the circle for an object undergoing circular motion.

(i). buzzer moving towards the observer

$$f_o = \frac{f_s \ c}{c - u}$$

$$f_o = \frac{1100 \times 340}{340 - 13}$$

$$f_o = 1143.7\,Hz$$ Maximum

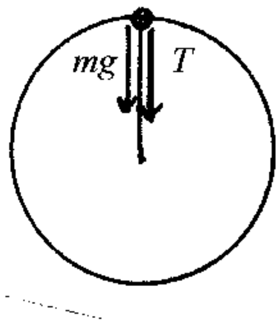
buzzer moving away from observer

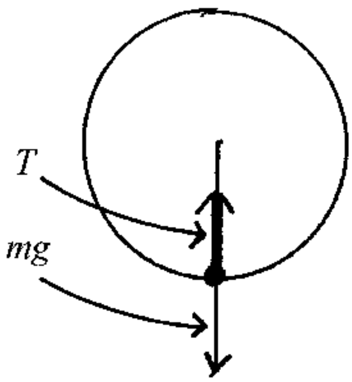
$$f_o = \frac{f_s \ c}{c + u}$$

$$f_o = \frac{1100 \times 340}{340 + 13}$$

$$f_o = 1059.5\,Hz$$ Minimum

(ii).





(i) At the top let

$$T + mg = \frac{mv^2}{r}$$

$$T + 0.07 \times 9.8 = \frac{0.07 \times 13^2}{0.8}$$

$$T + 0.686 = 14.7875$$

$$T = 14.1 \text{ N}$$

Minimum tension at top

(ii) At the bottom let

$$T - mg = \frac{m\,v^2}{r}$$

$$T - 0.07 \times 9.8 = \frac{0.07 \times 13^2}{0.8}$$

$$T - 0.686 = 14.7875$$

$$T = 15.47 \text{ N}$$

maximum tension at bottom

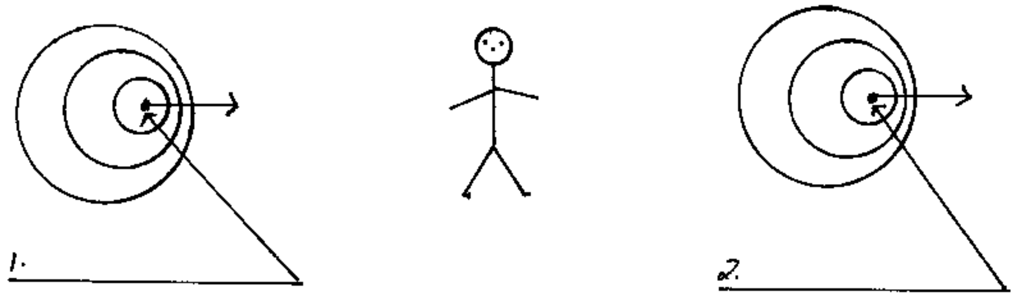
2017 Q.7:

For the start of this question see PPQ Light 2017 Q.7

Speed cameras use the Doppler effect to calculate the speed of vehicles.
Describe, with the aid of a labelled diagram, how the Doppler effect occurs.
A source that is emitting a sound wave of a certain frequency is approaching an observer.
The frequency observed is 15% more than the frequency of the sound wave emitted.
What is the speed of the source? (23)
(speed of sound in air = 340 m s^{-1})

Solution:

Source moving towards observer *Stationary observer* *Source moving away from observer*



(i) wavefronts closer together (i) wavefronts further apart

(ii) observed **wavelength smaller** (ii) observer **wavelength longer**

(iii) observed **frequency higher** (iii) observed **frequency lower**

1 = source moving towards observer; 2 = source moving away from observer

Note: you were expected to label the "**non concentric circular wavefronts**" in the diagram.

What …..

$$f_o = \frac{f_s \; c}{c - u}$$

$$1.15 f_s = \frac{f_s \; 340}{340 - u}$$

$$1.15\{340 - u\} = 340$$

$$340 - u = 295.7$$

$$44.3 m s^{-1} = u$$

2019 Q. 10 :

For start of this question see PPQ for light 2019 Q 10 (39 marks)

A certain musical instrument can be modelled as a cylindrical pipe that is closed at one end and whose length can be changed. The air column in the pipe vibrates at a frequency of 512 Hz.

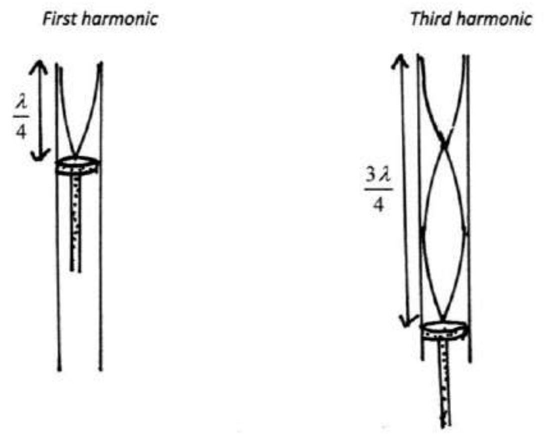
Draw diagrams to show the first two harmonics of this instrument.

The lengths of the pipe at the first two positions of resonance are 16.7 cm and 49.8 cm.

Calculate (i) the wavelength of the sound wave, (ii) the speed of sound in air. (17)

Solution :

Draw .....



Calculate (i) From the above diagrams $\frac{3\lambda}{4} = 49.8 + d$

$\frac{\lambda}{4} = 16.7 + d$

Subtracting gives $\frac{\lambda}{2} = 33.1$

Therefore $\lambda = 66.2\,cm$ = 0.662 m

(ii) speed = $c = f\lambda$

$c = 512 \times 0.662$

$c = 339 ms^{-1}$

2020 Q. 3 :

In an experiment to determine the speed of sound in air a student determined the lengths l of an air column when it was vibrating at different fundamental frequencies f.
The following data were recorded.

F (Hz)	250	300	350	400	450	500
l (cm)	34.0	28.3	24.0	20.5	19.1	17.0

(i) Draw a labelled diagram of how the apparatus was arranged in this experiment.

(ii) How did the student determine the length of the air column for a particular frequency?

(iii) How did the student ensure that the fundamental frequency, not an overtone, was observed? (18)

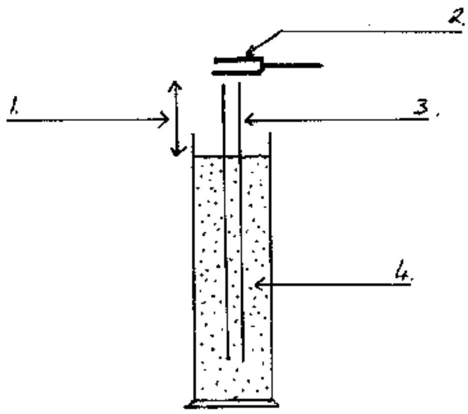
(iv) Use the data to draw a graph of f against $\frac{1}{l}$

(v) Calculate the slope of your graph.

(vi) Hence or otherwise calculate the speed of sound in air. (22)

Solution:

(i)



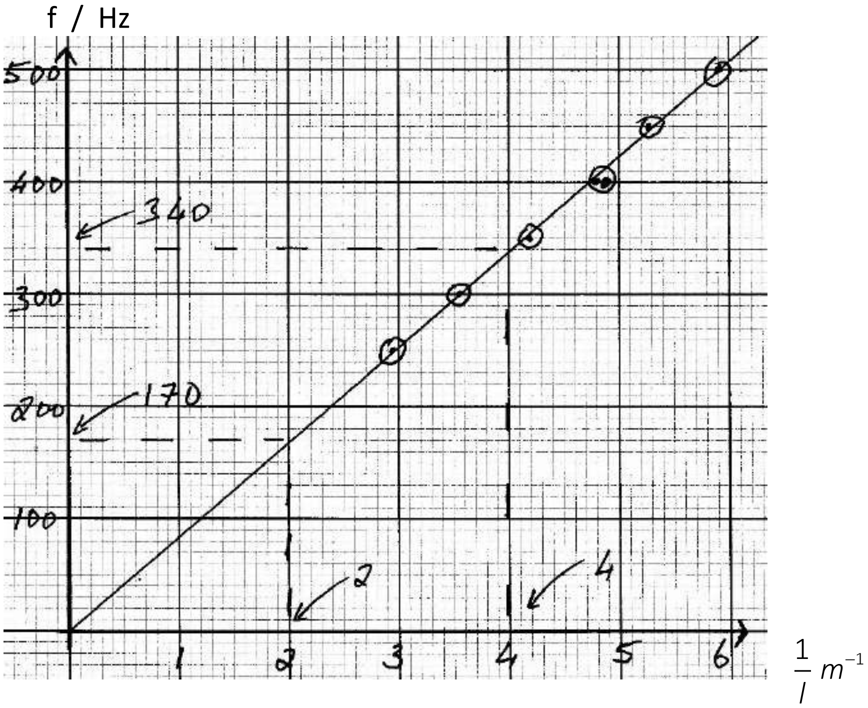
1 = length of air column which can be varied; 2 = tuning fork of known frequency
3 = glass tube; 4 = water

(ii) A vibrating tuning fork is placed over the open end of the tube and the tube is raised out of the water until the **first resonance** between tuning fork and column of air is observed.
The resonance in the column of air is detected by hearing, i.e. the sound is at its loudest.

(iii) Start with the open pipe fully immersed in the water. Position the vibrating tuning fork over the open mouth of the pipe. Slowly lift the pipe upwards until you hear the first resonance (the sound gets louder). This first resonance corresponds to the first harmonic (fundamental frequency)

(iv) the data needs to be adjusted

F (Hz)	250	300	350	400	450	500
$\frac{1}{l}$ (m^{-1})	2.94	3.53	4.17	4.88	5.24	5.88



(v) slope of the graph $= \dfrac{y_2 - y_1}{x_2 - x_1} = \dfrac{340 - 170}{4 - 2} = 85$

(vi) Recall that for the fundamental frequency with a pipe open at one end, $\dfrac{\lambda}{4} = l$

Therefore $\lambda = 4l$

The slope of the above graph $= \dfrac{f}{\frac{1}{l}} = f \times l$

Speed of sound $c = f \times \lambda = f \times 4l = 4(f \times l) = 4 \times slope$

$c = 4 \times 85 = 340 ms^{-1}$

2020 Q 12(c):

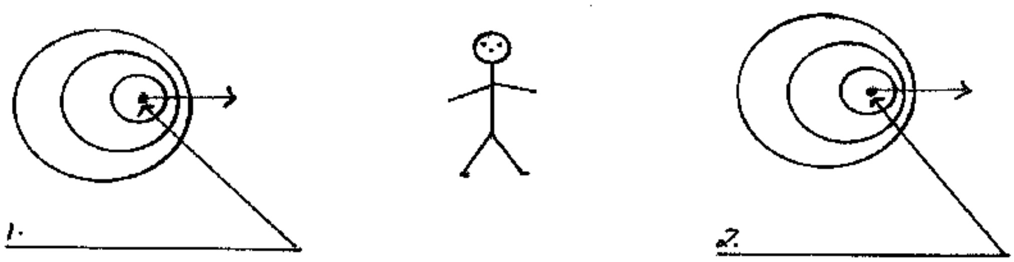
Speed cameras make use of the Doppler effect.

(i) What is the Doppler effect?
(ii) Explain, with the aid of labelled diagrams, how the Doppler effect occurs. (14)
A source of sound approaches a stationary observer.
The source appears to have a frequency that is 20% greater than its frequency at rest.
(iii) Calculate the speed of the source.
(iv) The Doppler effect is also used to detect the red-shift of galaxies.
What does the red-shift tell us about the universe? (14)
(speed of sound in air = 340 ms^{-1})

Solution:

(i) The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

(ii) *Source moving towards observer* *Stationary observer* *Source moving away from observer*



(i) wavefronts closer together (i) wavefronts further apart

(ii) observed **wavelength smaller** (ii) observer **wavelength longer**

(iii) observed **frequency higher** (iii) observed **frequency lower**

1 = source moving towards observer; 2 = source moving away from observer

Note: you were expected to label the “**non concentric circular wavefronts**” in the diagram.

(iii)

$$f_o = \frac{f_s \; c}{c - u}$$

$$1.2\, f_s = \frac{f_s \times 340}{340 - u}$$

$$340 - u = \frac{340}{1.2}$$

$$340 - u = 283.3$$

$$56.6\, ms^{-1} = u$$

(iv) the red-shift implies the galaxies are moving away from the earth, i.e. the universe is expanding.

2021 Q.14(b) :

Hydroacoustics is the study of sound in water. The Doppler effect is observed in hydroacoustics.

(i) What is the Doppler effect?
(ii) Describe how the Doppler effect can be demonstrated in the laboratory. (14)

A moving underwater source emits a sound of frequency 800 kHz while travelling towards an underwater detector, which detects a frequency of 806 kHz.
(iii) Calculate the speed of the source.

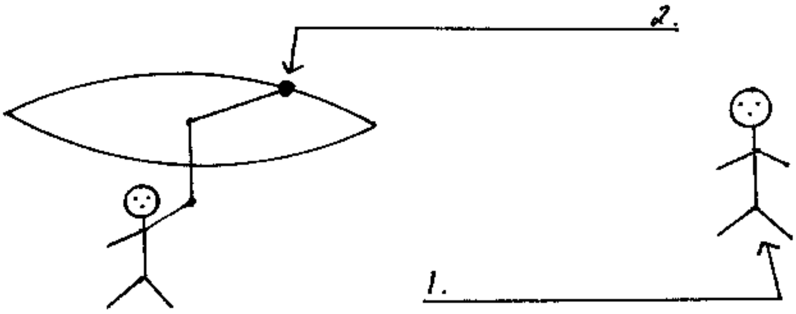
Sound travels faster in water than in air. When a sound wave travels from water into air, it undergoes refraction.
(iv) Draw a ray diagram to show the refraction of a sound wave as it travels from water into air. (14)

(speed of sound in water = 1480 $m\,s^{-1}$)

Solution :

(i) The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

(ii)



1 = stationary observer *2 = rotating (moving) buzzer*

- A battery powered electronic buzzer is attached to a string 50 cm long. The emitted frequency is set at 300 Hz.
- The buzzer is spun in circular motion on the end of the string quite fast.
- An observer standing 2 m away will notice the frequency from the buzzer change as it rotates.
- The observed frequency changes as the buzzer moves towards and then moves away from the person.

(iii)

$$f_o = \frac{f_s \; c}{c - v}$$

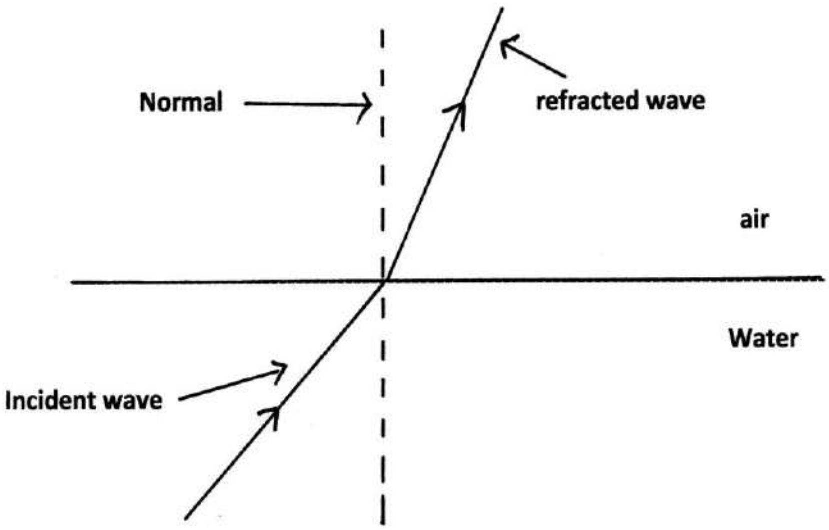
$$806\times10^3 = \frac{800\times10^3 \times 1480}{1480 - v}$$

$$1480 - v = \frac{800\times10^3 \times 1480}{806\times10^3}$$

$$1480 - v = 1468.98$$

$$11.02\, m s^{-1} = v$$

(iv)



Note that the wave bends towards the normal in the air !!!!!

2022 Q4:

In an experiment to determine the speed of sound in air a student measured the length l of a column of air when it was vibrating at its fundamental frequency f. This process was repeated for six different values of f.
The following data were recorded.

f (Hz)	256	288	320	341	384	480
l (cm)	29.2	25.5	22.6	20.9	18.1	13.7

(i) Draw a labelled diagram of how the apparatus was arranged in this experiment.

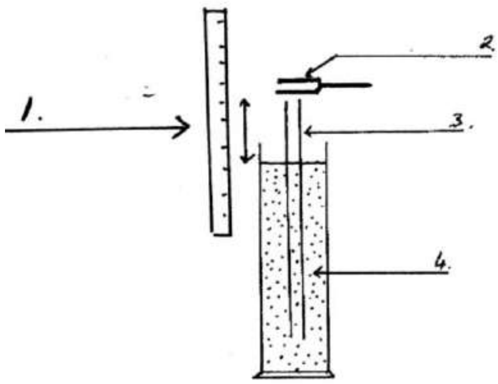
(ii) How did the student determine the length of the column of air for a particular frequency? (18)

(iii) Draw a graph to show the relationship between l and $\frac{1}{f}$.
(Note: the line of best fit on your graph should not go through the origin.)

(iv) Use your graph to calculate the speed of sound in air.

(v) Explain why the line of best fit on the graph does not go through the origin. (22)

Solution:
(i)



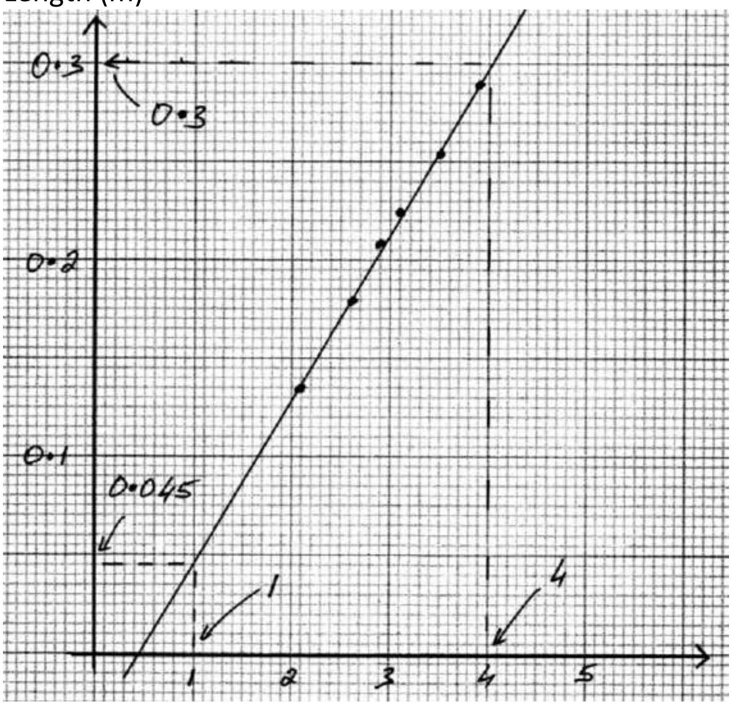
1 = metre stick to measure length of air column which can be varied;
2 = tuning fork of known frequency *3 = glass tube;* *4 = water*

(ii)
- A vibrating tuning fork is placed over the open end of the tube
- the tube is raised out of the water until the **first resonance** between tuning fork and column of air is observed.
- The resonance in the column of air is detected by hearing, i.e. the sound is at its loudest.
- Measure the length from the closed end of the pipe (water level) to the open end of the pipe.

(iii) **the data has to be adjusted**

f (Hz)	256	288	320	341	384	480
l (m)	0.292	0. 255	0. 226	0.209	0.181	0. 137
$\frac{1}{f}\,(Hz^{-1})$	0.0039	0.0035	0.0031	0.0029	0.0026	0.0021
$\frac{1}{f}\times 10^{-3}\,(Hz^{-1})$	3.9	3.5	3.1	2.9	2.6	2.1

Length (m)



$\frac{1}{f}\times 10^{-3}\,(Hz^{-1})$

(iv) slope of the graph $= \dfrac{y_2 - y_1}{x_2 - x_1} = \dfrac{0.3 - 0.045}{(4 - 1)\times 10^{-3}} = 85$

Recall that for the fundamental frequency with a pipe open at one end, $\dfrac{\lambda}{4} = l$

Therefore $\lambda = 4l$

The slope of the above graph $= \dfrac{l}{\frac{1}{f}} = f \times l$

Speed of sound $c = f \times \lambda = f \times 4l = 4\left(f \times l \right) = 4 \times slope$

$c = 4 \times 85 = 340 ms^{-1}$

(v) No allowance was made for the end correction. The values of length "l" were all incorrect. Hence the line of best fit on the graph does not go through the origin.

2022 Q 14(b) :

(i) What is the Doppler effect?

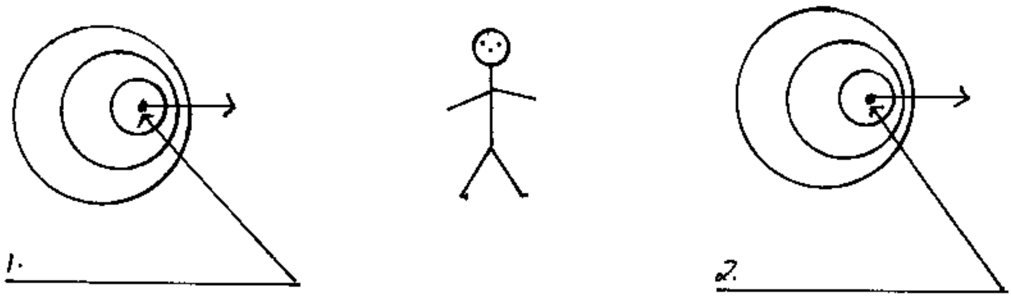
(ii) Describe, with the aid of labelled diagrams, how the Doppler effect occurs. (16)

Pierre drops a child's toy which emits sound of fixed frequency 500 Hz from the top of the Eiffel tower.
(iii) Calculate the frequency Pierre observes after 3 seconds. (12)

(speed of sound in air = 340 m s–1; acceleration due to gravity = 9.8 m s–2)

Solution:
(i) The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

(ii) *Source moving towards observer* *Stationary observer* *Source moving away from observer*



Note: the wavefronts are non-concentric as the source approaches the observer and as the source moves away from the observer

(i) wavefronts closer together	(i) wavefronts further apart
(ii) observed **wavelength smaller**	(ii) observer **wavelength longer**
(iii) observed **frequency higher**	(iii) observed **frequency lower**

(iii) "get speed after 3 seconds" : $v = u + at = 0 + 9.8 \times 3 = 29.4\,m\,s^{-1}$ **away** from Pierre

$$f_0 = \frac{f_s\, c}{c + v} = \frac{500 \times 340}{340 + 29.4} = 460.2\,Hz$$

2022 Deferred Q.8:

(i) What is the Doppler effect?

(ii) Explain how the Doppler effect occurs. (15)

(iii) What is meant by the emission line spectrum of an element?

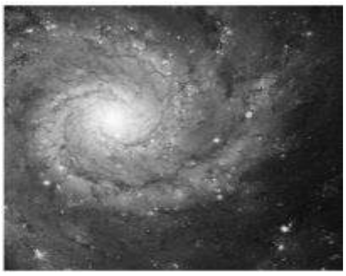
(iv) How is the emission line spectrum of an element related to the energy levels of the electrons in an atom of that element?

(v) Describe how you would show the emission line spectrum of hydrogen in the laboratory. (18)

(vi) The wavelength of the red line in the emission line spectrum of hydrogen was measured in the laboratory as 656 nm. Calculate its frequency. (6)

In the 1920s, American astronomer Edwin Hubble, pictured, used the Doppler effect to study distant galaxies. He found that most galaxies were moving away from Earth. He also found that the galaxies which were furthest away from Earth were the oneswhich were moving with the fastest speeds. A certain galaxy is moving at a speed of $3\times10^{7}\ m\,s^{-1}$ away from the Earth. Astronomers on Earth analysed the light from this galaxy and measured the frequency of the red line in the hydrogen emission line spectrum.

(vii) Calculate the frequency they observed. (9)

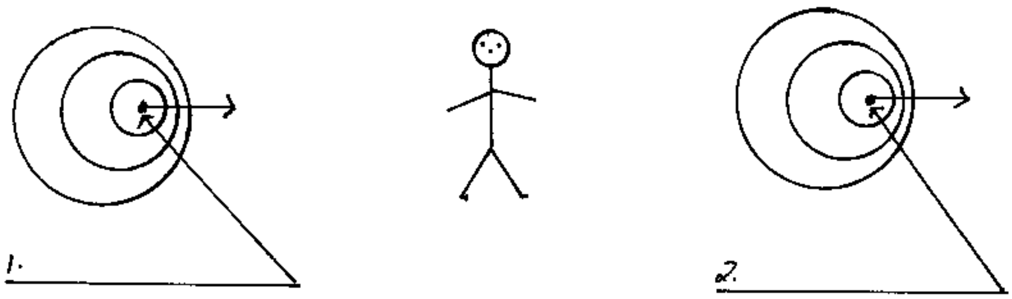


From their observations, astronomers have also calculated that the Sun is orbiting the centre of the Milky Way galaxy with a speed of 220 $km\,s^{-1}$
The Sun takes 240 million years to complete one orbit of the galaxy.

(viii) Use this data to calculate a value for the radius of the orbit of the Sun about the centre of the galaxy. (8)

Solution:
(i) The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

(ii) *Source moving towards observer* *Stationary observer* *Source moving away from observer*



Note: the wavefronts are non-concentric as the source approaches the observer and as the source moves away from the observer

(i) wavefronts closer together

(ii) observed **wavelength smaller**

(iii) observed **frequency higher**

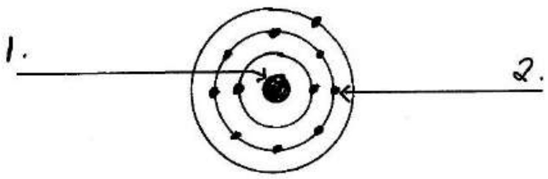
(i) wavefronts further apart

(ii) observer **wavelength longer**

(iii) observed **frequency lower**

(iii) The specific frequencies (or wavelengths) of electromagnetic radiation emitted by an element.

(iv)

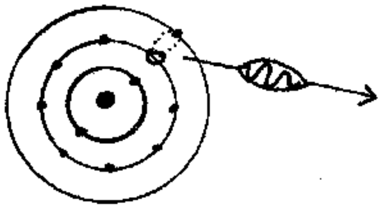


1 = central nucleus 2 = orbiting elctrons

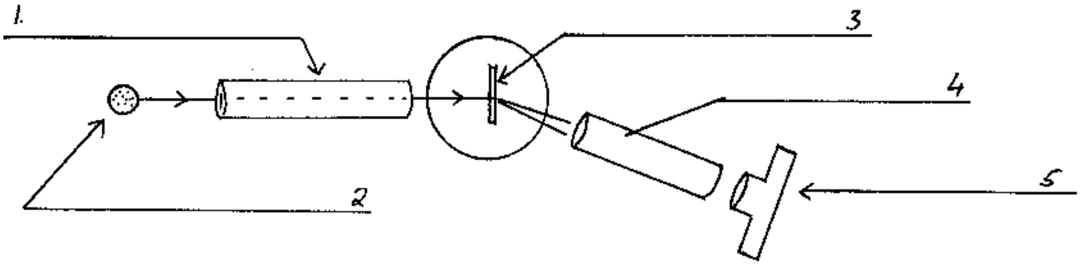
- Electrons only move in allowed orbits (energy levels)around a central nucleus.
- If an electron is given energy it moves to a higher energy level and the atom is in an excited state
- If the electron returns to its lower energy level a photon of energy is emitted.
- The energy of the photon is given by

$$h f = E_2 - E_1$$

The energy of the photon is equal to the difference in the two energy levels.



(v)



1 = collimator; 2 = hydrogen vapour lamp; 3 = diffraction grating; 4 = telescope; 5 = camera

- The source of light is positioned in front of the slit of the collimator.
- The light passes through a diffraction grating (or a prism) and the colours of the light separate.
- A camera is attached to the telescope to obtain a permanent record of the spectrum.

- You will observe that line spectra consist of separate bright lines of definite wavelength on a dark background.

Note: Parts (iii), (iv) and (v) were worth 3 marks, 9 marks and 6 marks. The answers above were too detailed but you would not have known the division of the 18 marks on the day of the exam.

(vi) $$f = \frac{c}{\lambda} = \frac{2.9979\times10^{8}}{656\times10^{-9}} = 4.57\times10^{14}\ Hz$$

(vii) $$f_0 = \frac{f_s\ c}{c + u} = \frac{4.57\times10^{14} \times 2.9979\times10^{8}}{2.9979\times10^{8} + 3\times10^{7}} = 4.154\times10^{14}\ Hz$$

(viii) recall $\omega = \frac{2\pi}{T} = \frac{v}{R}$,

therefore $R = \frac{T\ v}{2\ \pi}$

$$R = \frac{(240\times10^{6} \times 365 \times 24 \times 60 \times 60\ ) \times 220\times10^{3}}{2\ \pi}$$

$$R = 2.65\times10^{20}\ m$$

2023 Q. 14 (b) :

A speaker emits a sound of fixed frequency. The speaker is moving at a constant velocity towards an observer. The observer hears a frequency which is 20% greater than the frequency emitted.
(i) Name the effect which causes this increase in frequency.

(ii) Calculate the speed of the speaker.

(iii) Red shift in astronomy is also due to this effect. What does red shift tell us about our universe? (16)

A fixed speaker of power P is emitting sound. At a certain distance from the speaker, an observer can measure both the sound intensity and the sound intensity level due to the speaker.

(iv) Distinguish between sound intensity and sound intensity level.

(v) The speaker of power P is replaced by a speaker of power 4P.
Calculate the increase in sound intensity level measured. (12)

(speed of sound in air = 340 $m\,s^{-1}$)

Solution:

(i) the Doppler effect

(ii)

$$f_o = \frac{f_s \; c}{c - u}$$

$$1.2 \; f_s = \frac{f_s \times 340}{340 - u}$$

$$340 - u = \frac{340}{1.2}$$

$$340 - u = 283.3$$

$$56.6\,m\,s^{-1} = u$$

See 2020 Q.12(c) !!!!!!!

(iii) the universe is expanding

(iv) Sound intensity = $\dfrac{\textit{sound energy per}\sec}{\textit{area energy passes through}}$ and is measured in *watt* m^{-2}

Sound intensity is a comparative scale where the sounds are compared to a standard of $1\times10^{-12}\ W\,m^{-2}$. The scale uses logs (logarithmic) and is measured in decibels.

(v) If the power increases by a factor of 4, (double and double) the sound intensity increases by 6 decibels. (3 dB and 3 dB)