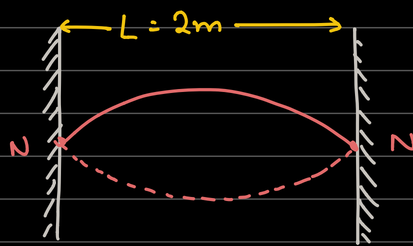
STANDING WAVES : WAVES

- To create a stationary wave using a rope, one end must be connected to a fixed point and the other end is made to vibrate continuously
- This initially gives rise to incident progressive waves
  - ↳ As they strike the fixed end, they get reflected in the opposite direction, giving rise to reflected progressive waves
- The superposition of these two waves results in the formation of stationary waves
- The incident and reflected waves have the same frequency, wavelength, amplitude, and they are travelling in opposite directions
- The wave produced is known as a stationary or a standing wave, as the wave formed does not move in the direction of the incident or the reflected wave
- In a stationary wave, there are certain points known as nodal points or nodes (N) which exhibit zero displacement
  - ↳ Midway between the nodes are the anti-nodal points or antinodes (A) which exhibit maximum displacement.

Examples :



$v = 40ms^{-1}$

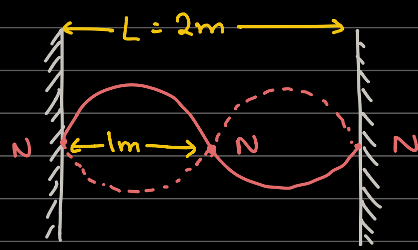
Bw. consecutive Ns = $\frac{1}{2}\lambda$

$\frac{1}{2}\lambda = 2m, \quad \lambda = 4m$

$v = f\lambda$

$\frac{40}{4} = f$

$10Hz = f$ → Fundamental Frequency



$v = 40ms^{-1}$

$\frac{1}{2}\lambda = 1m$

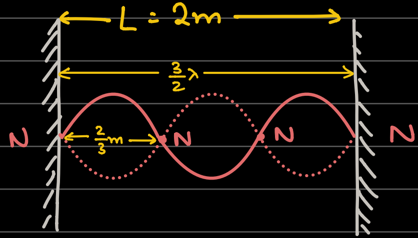
$\lambda = 2m$

$v = f\lambda$

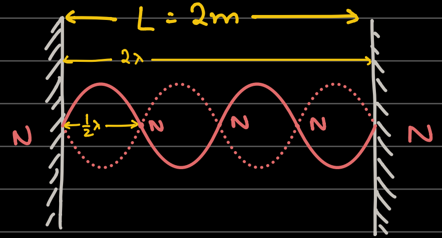
$\frac{40}{2} = \frac{f2}{2}$

$20Hz = f$

↳ First Overtone



$v = 40ms^{-1}$



$v = 40ms^{-1}$

$\frac{1}{2}\lambda = \frac{2}{3}$ m

$\frac{3}{2}\lambda = 3\left(\frac{2}{3}\right)$

$\frac{3}{2}\lambda = 2$

$\lambda = \frac{4}{3}$ m

$v = f\lambda$

$40 = f\,\frac{4}{3}$

$\frac{120}{4} = f$

$30Hz = f$ → Second Overtone

$2\lambda = 2m$

$\lambda = 1m$

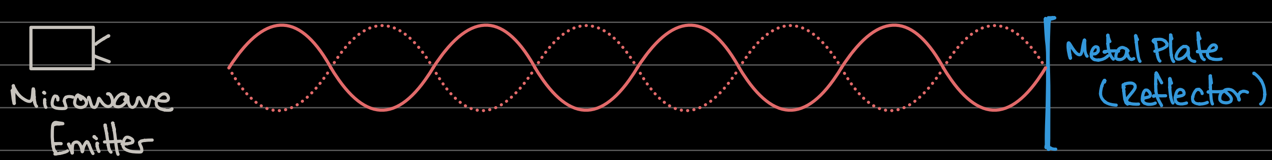
$v = f\lambda$

$40 = f1$

$40Hz = f$

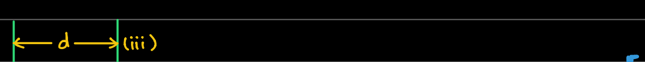
↳ Third Overtone

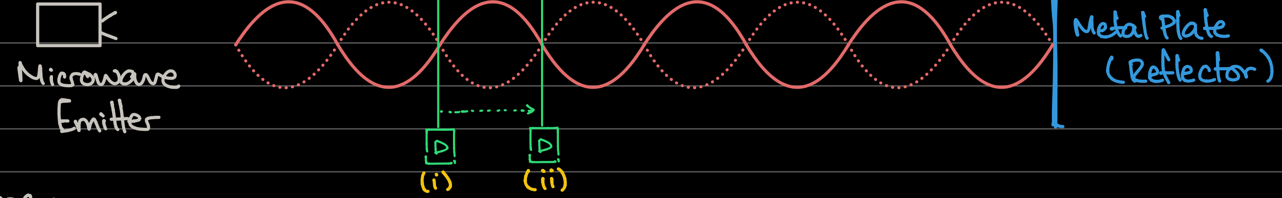
INVESTIGATING STATIONARY WAVES USING ELECTROMAGNETIC WAVES



- Microwaves of constant frequency are emitted by the source and are reflected from a point S on the reflective service (metal plate)
- The superposition will give rise to the formation of stationary waves
- If a detector is moved between the source and the reflector, the reading varies from maximum to a minimum and then back to a maximum value
- Each minimum intensity corresponds to a node
- Each maximum intensity corresponds to an anti-node
- Using the above principle, the wavelength and the frequency can be determined as shown below

Measuring the wavelength using the apparatus above





Steps :

i) Place the detector (D) at a zero-intensity point (node)

ii) Start and keep moving the detector until you reach the next node

iii) Take a metre rule and measure the distance between the initial position and final position of the detector ($\underline{\underline{d}}$)

iv) Since the distance between two consecutive nodes is $\frac{1}{2}\lambda$, then $\boxed{\lambda = 2d}$ where d is the measured value

Calculating frequency using the wavelength calculated above :

$$v = f\lambda$$
$$3 \times 10^8 = f(2d)$$

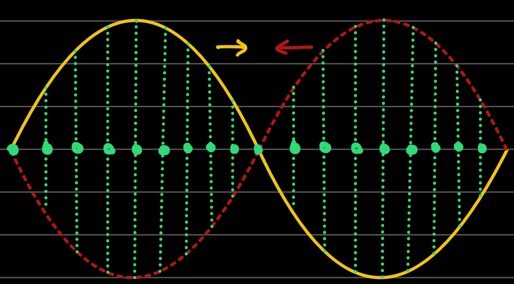
↳ speed of all EM waves

Thus... $f = \dfrac{3 \times 10^8}{2d}$

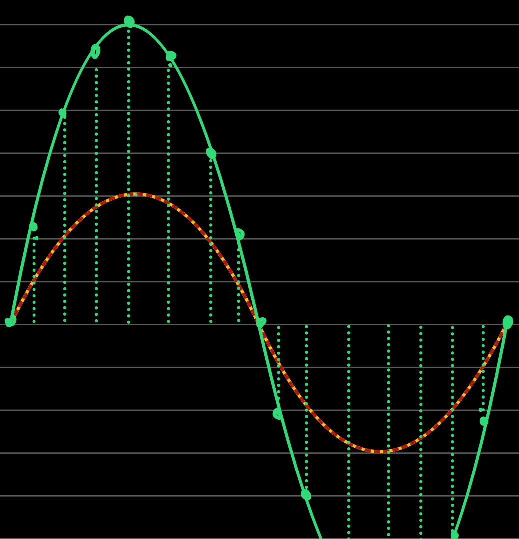
STANDING WAVES AT DIFFERENT POINTS IN TIME

↳ in terms of time period (T)

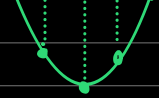
= reflected wave
= incident wave
= stationary wave

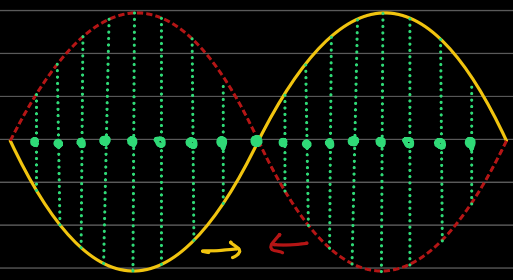


At time $t = -\frac{1}{4}T$

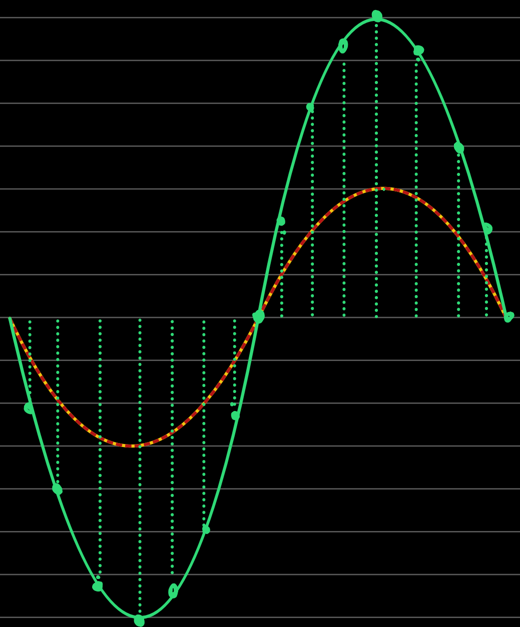


At time $t = 0T$

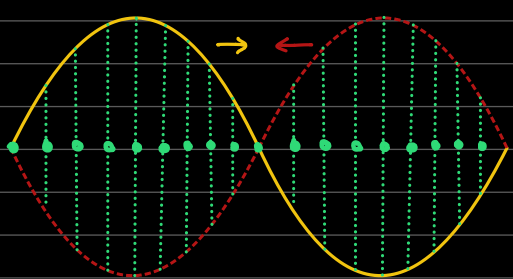




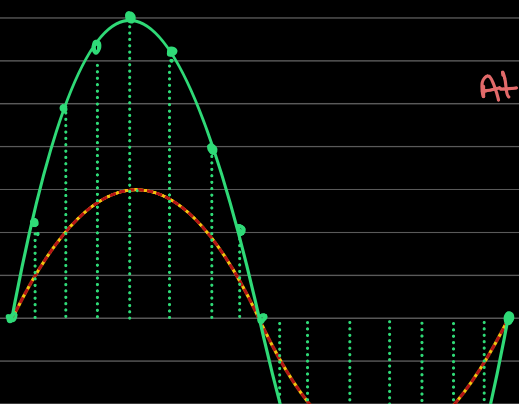
At time $t = \frac{1}{4}T$



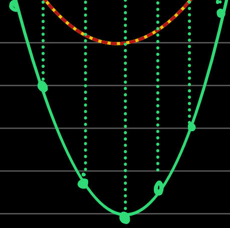
At time $t = \frac{1}{2}T$



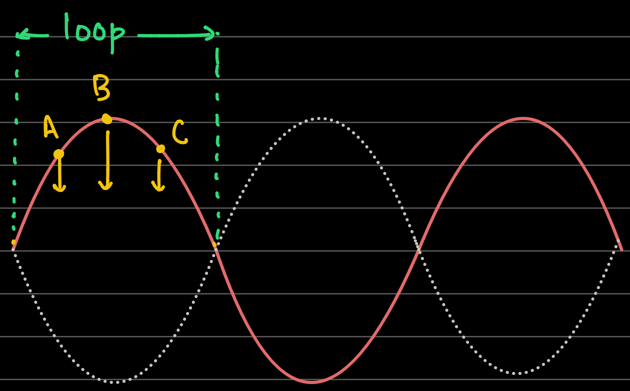
At time $t = \frac{3}{4}T$



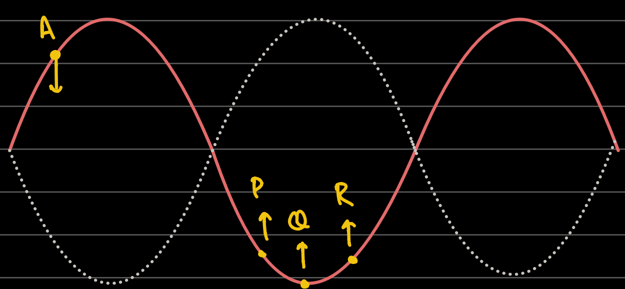
At time $t = 1T$



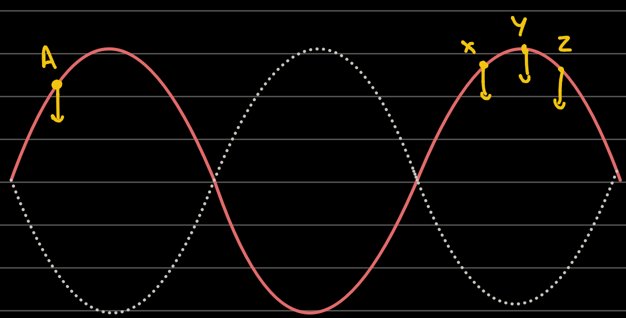
CALCULATING PHASE DIFFERENCES in a stationary wave



Points in the same "loop" are said to be in-phase with each other with a phase difference of 0.



Points in the neighbouring loop are said to be out-of-phase with a phase difference of $180°$ / π



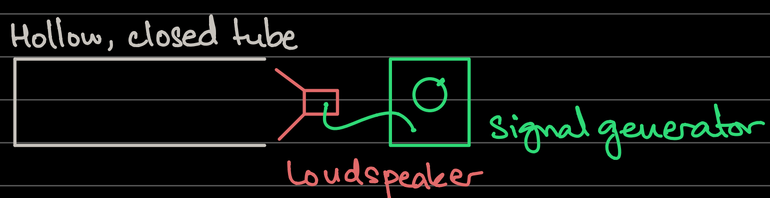
Points in alternate loops are said to be in-phase with a phase difference of $360°$/ 2π

PROGRESSIVE VS. STATIONARY

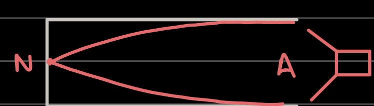
Progressive Wave	Stationary Wave
Energy is transfered along the direction of propagation	No energy is transfered along the direction of propagation
The wave profile moves in the direction of propagation	The wave profile does not move in the direction of propagation
Every point along the direction of propagation is displaced at different instants	There are points known as nodes where where no displacement occurs
Every point has the same amplitude	Points between two successive nodes have different amplitudes
Neighbouring points are not in-phase	All points between two sucessive nodes vibrate in phase with one another

INVESTIGATING STATIONARY WAVES USING A SOUND SOURCE

- A hollow tube can be used to investigate stationary waves in sound. The tube is closed at one end and open at the other end. A loudspeaker connected to the Signal Generator is placed near the open end of the tube as shown

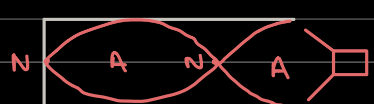


- when the frequency is adjusted, a stationary wave is formed in the tube. The lowest frequency (fundamental frequency) representation is shown below

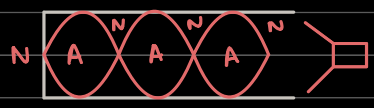


where N : node
A : anti-node

- when the frequency is further increased, a loud sound is observed near the opening of the tube (first overtone)



· And second overtone :



Calculating the frequencies in the cases above

Given : Length of tube = 2m
Speed of Sound = $320ms^{-1}$

Fundamental Frequency

$N \longrightarrow A = \frac{1}{4}\lambda$

$2m = \frac{1}{4}\lambda$

$8m = \lambda$

$v = f\lambda$

$320 = f(8)$

$40Hz = f$ → Fundamental Frequency

First Overtone

$N \longrightarrow N \longrightarrow A = \frac{3}{4}\lambda$

$2 = \frac{3}{4}\lambda$

$\frac{8}{3}m = \lambda$

$v = f\lambda$

$320 = \frac{f 8 \lambda}{3}$

$120Hz = f$ → First Overtone

Second Overtone

$N \longrightarrow N \longrightarrow N \longrightarrow A = \frac{5}{4}\lambda$

$2m = \frac{5}{4}\lambda$

$\frac{8}{5}m = \lambda$

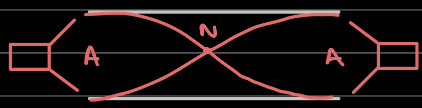
$320 = f \frac{8}{5}$

$200Hz = f$ → Second Overtone

.... And so on and so forth

Example 2 : length of tube = 4m , speed of sound = 320 ms^{-1}

Fundamental Frequency :



$A \rightarrow N \rightarrow A = \frac{1}{2}\lambda$

$4m = \frac{1}{2}\lambda$

$8m = \lambda$

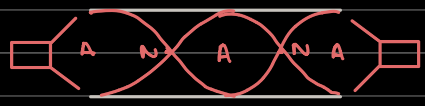
$v = f\lambda$

$320 = f\,8$

$40Hz = f$

Fundamental Frequency

First Overtone :



$A \rightarrow N \rightarrow N \rightarrow A = \lambda$

$4m = \lambda$

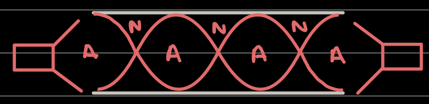
$v = f\lambda$

$320 = f\,4$

$80Hz = f$

First Overtone

Second Overtone :



$\overset{\frac{1}{4}}{A \rightarrow N} \overset{\frac{1}{2}}{\rightarrow N} \overset{\frac{1}{2}}{\rightarrow N} \overset{\frac{1}{4}}{\rightarrow A} = 1.5\lambda$

$4 = \frac{3}{2}\lambda$

$\frac{8}{3}m = \lambda$

$v = f\lambda$

$320 = f\,\frac{8}{3}$

$120 = f$

Second Overtone