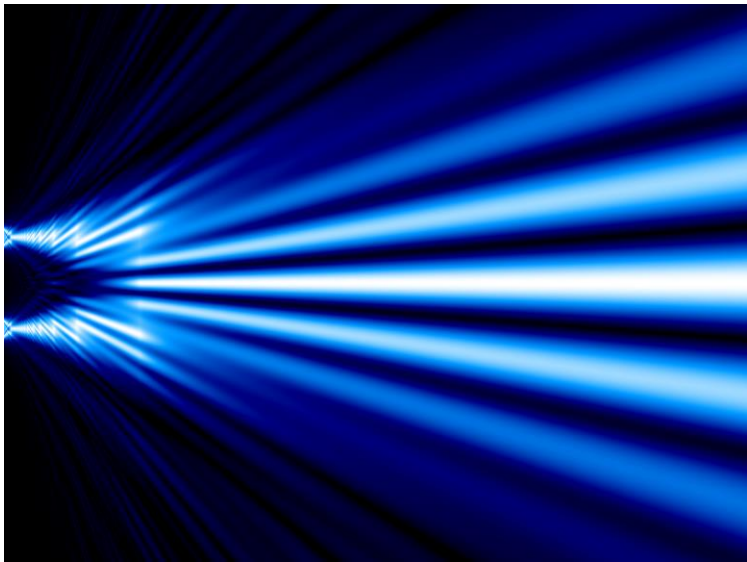
Waves & The Particle Nature of Light

2015 EdExcel A Level Physics Topic 5

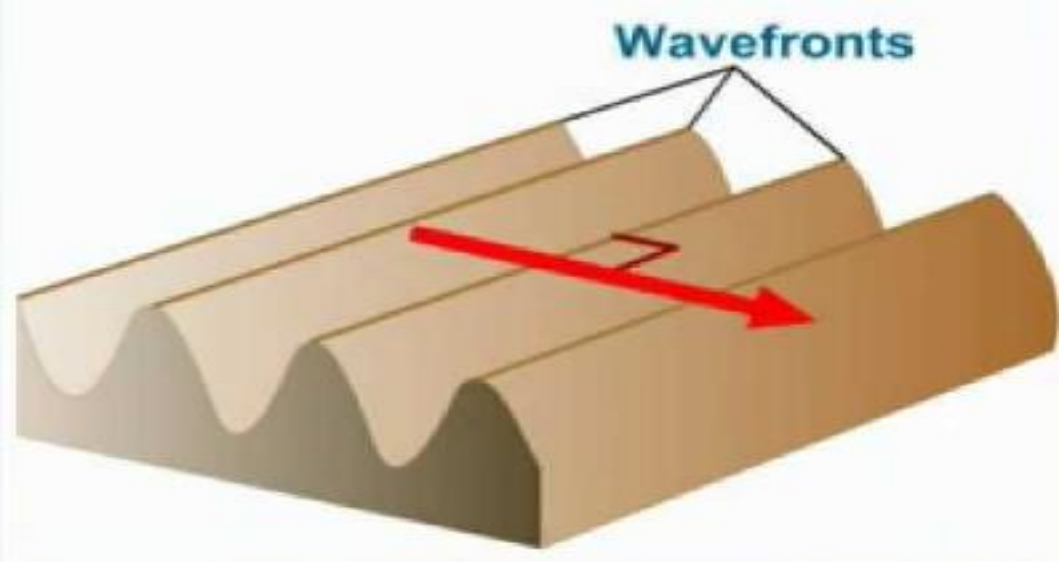
Interference



Physics Tutor Online

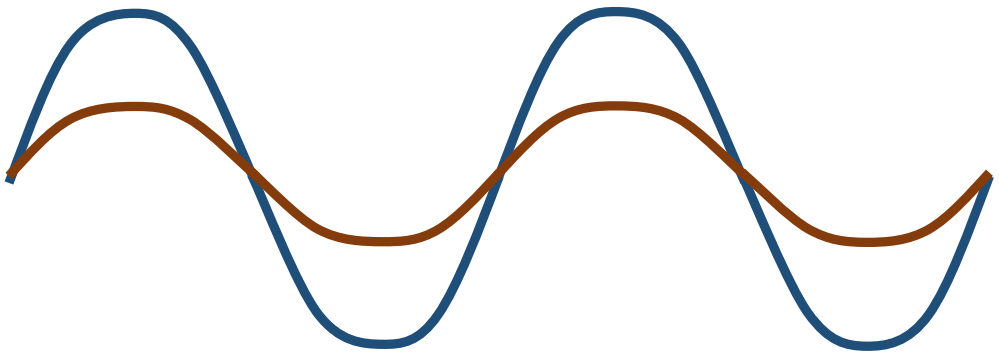
Wavefronts

A wavefront is a surface over which an optical wave has a constant phase. For example, a wavefront could be the surface over which the wave has a maximum (the crest of a water wave, for example) or a minimum (the trough of the same wave) value.

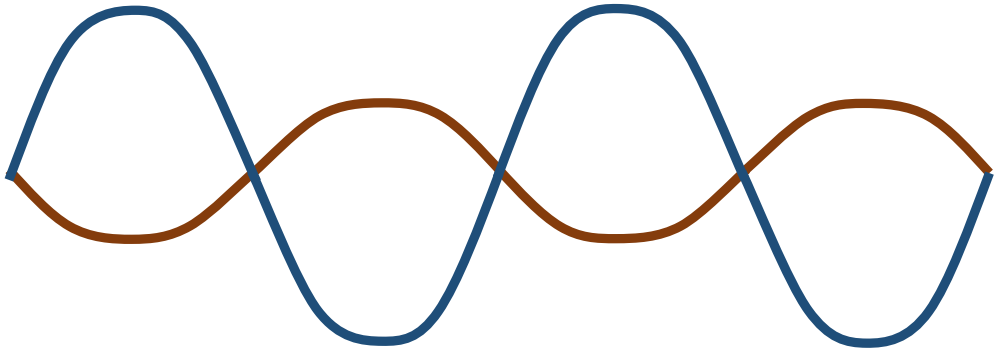


Phase Difference

Phase difference means when waves have the same frequency but oscillate differently to each other. For example:

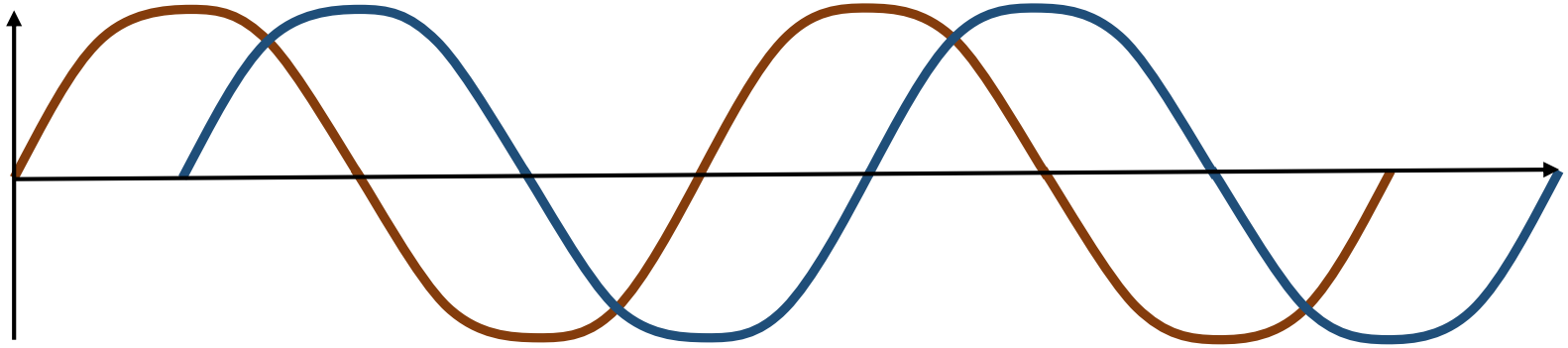


These two waves have different amplitudes but the same frequency and hit their peaks at the same time – they are “in phase”

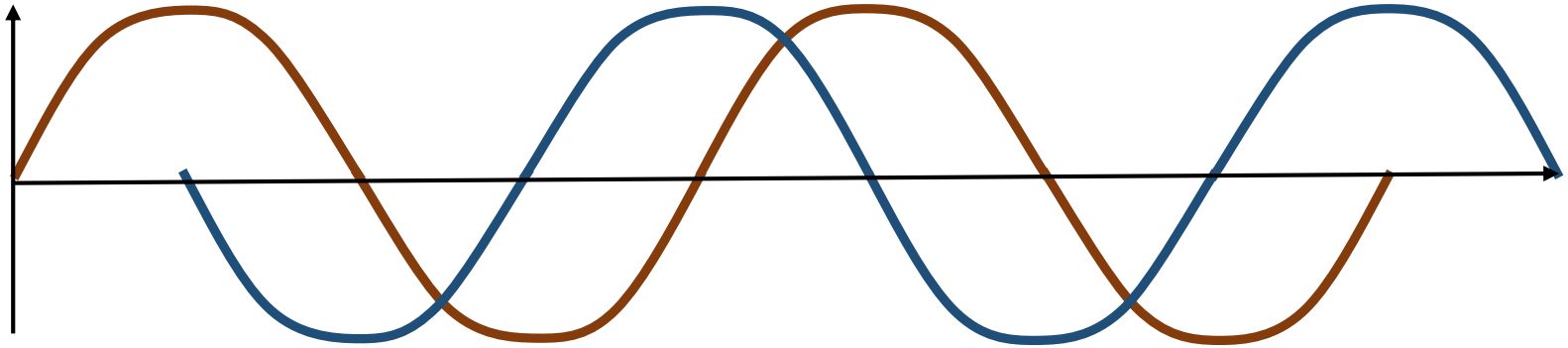


These two waves start opposite to each other – they are “in antiphase” or “out of phase by π radians”

Phase Difference

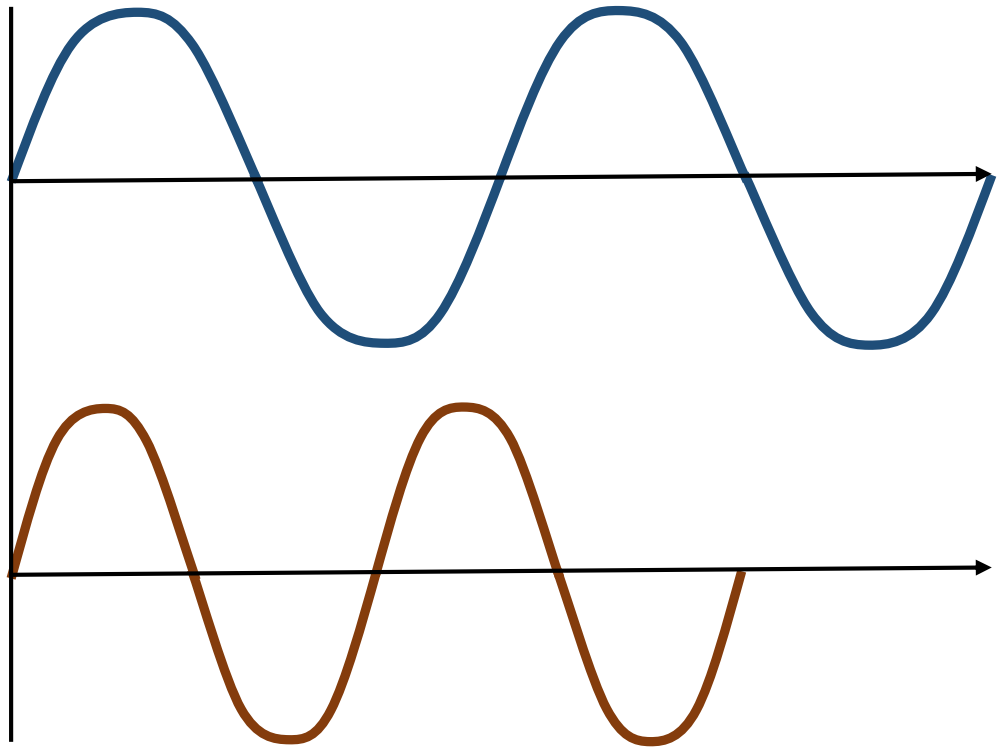


What is the phase difference between each of these waves?



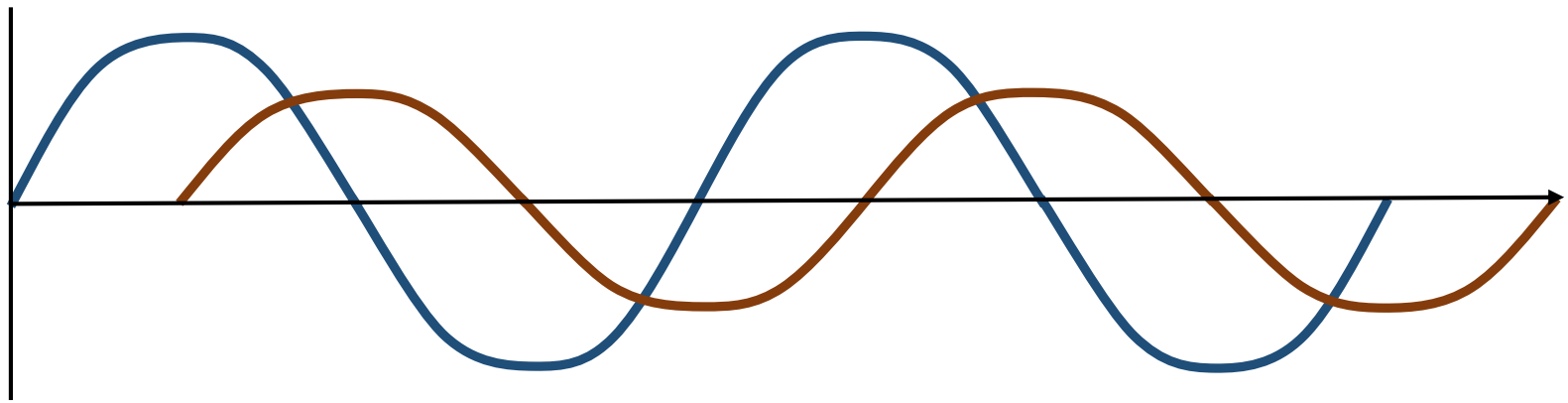
Coherence

Two waves are said to be “coherent” if they have the same frequency and the same constant phase difference. For example:



These waves have a different frequency, so phase is irrelevant.

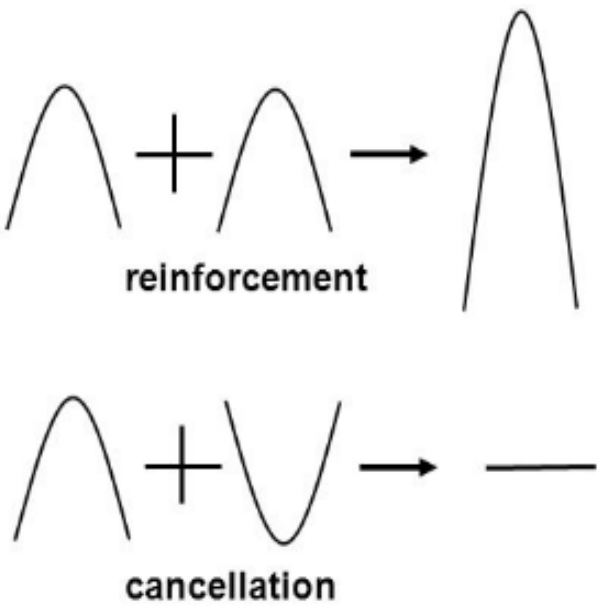
Coherence cont.



These waves have the same frequency and the same constant phase difference, so they are “coherent”

Superposition

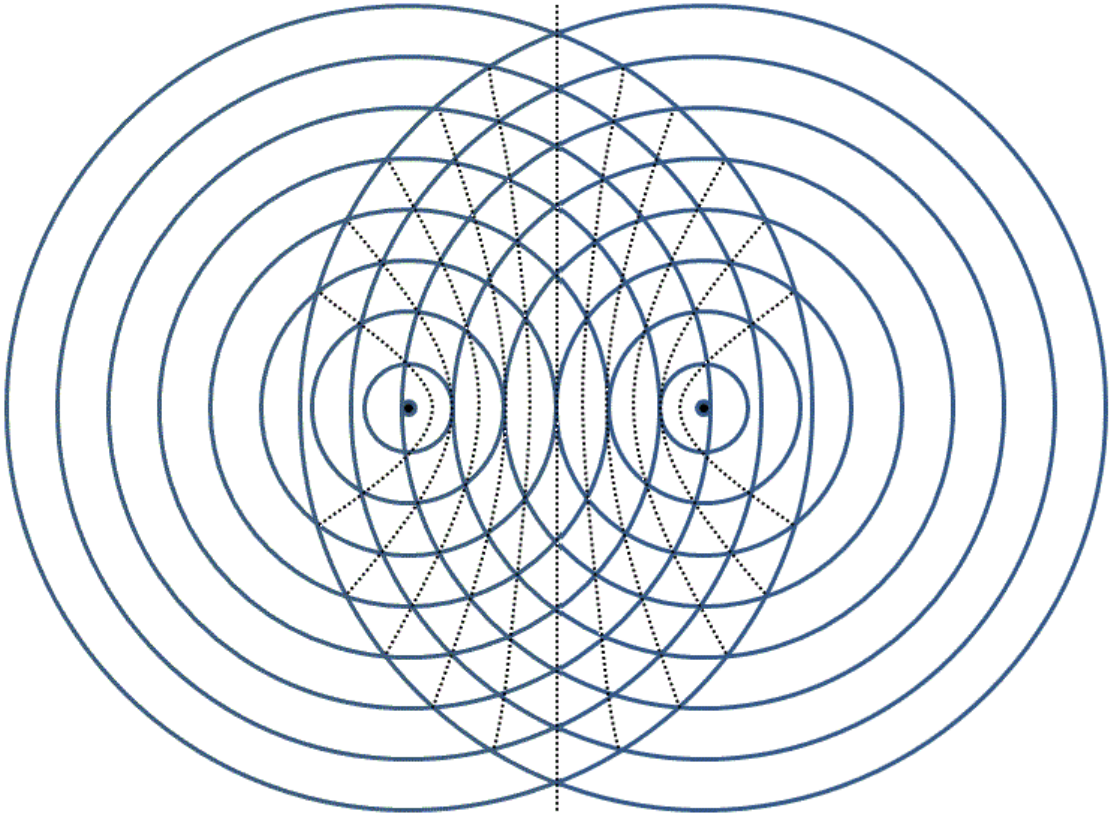
The formation of a resultant wave when two or more waves meet at the same position, at the same time is known as superposition. It is defined as “the vector sum of the two displacements of each wave”.

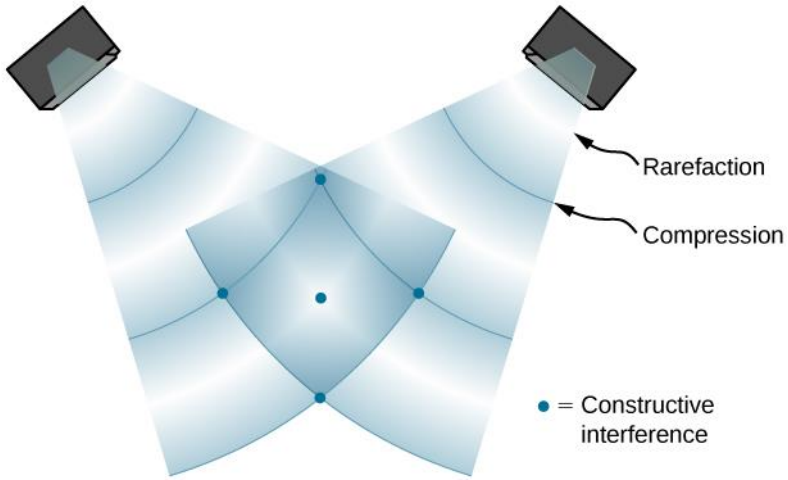


Superposition patterns

Consider two point sources (e.g. two dippers or a barrier with two holes):

Stable interference patterns happen when these waves are the same type, coherent AND have similar amplitudes at the point of superposition.




Rarefaction
Compression
= Constructive interference

Interference

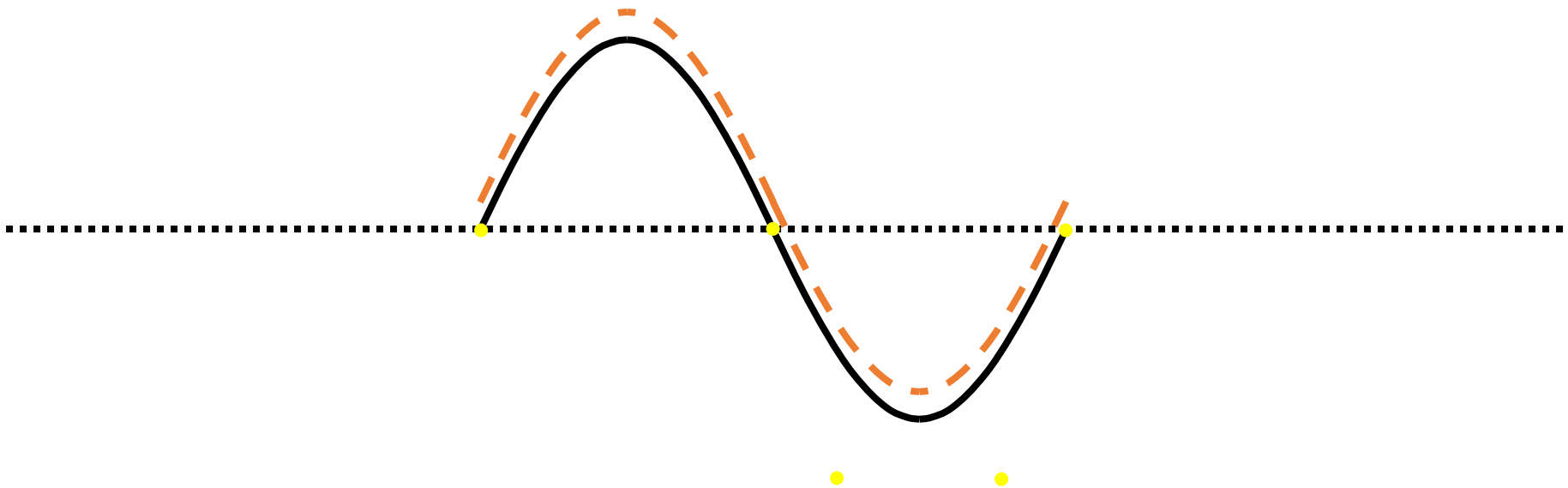
The variation with distance or time of the amplitude

of a wave which results from the superposition of two or more waves.

- Constructive Interference: Resultant amplitude is larger than either individual wave.
- Destructive Interference: Resultant amplitude is less than either individual wave.

Constructive Interference

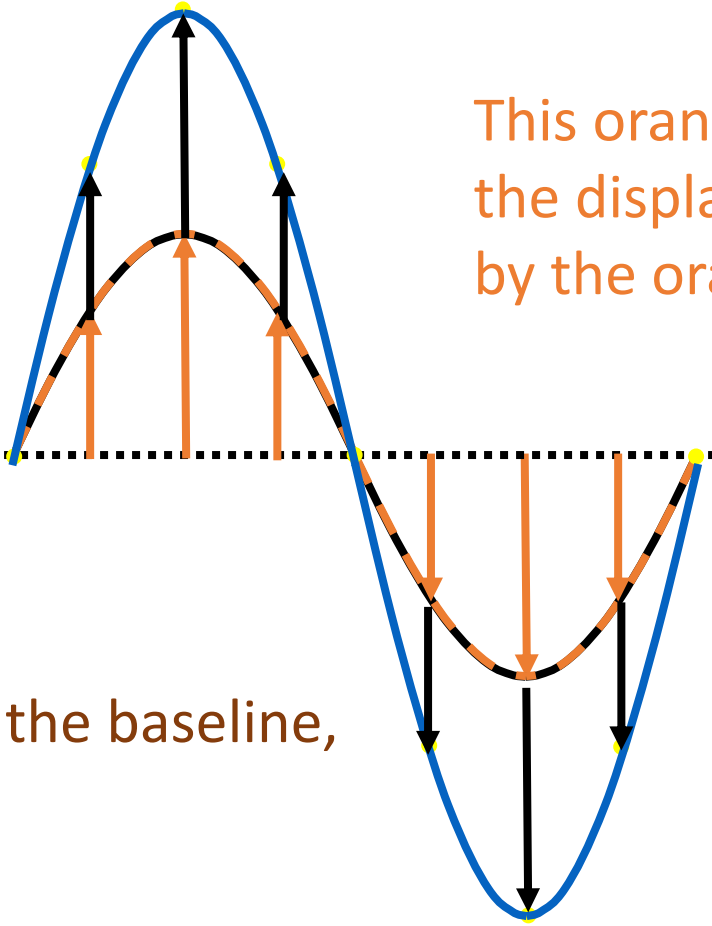
Consider 2 waves that are in phase overlapping



What will the combined wave look like?

Constructive Interference

The black arrows represents the displacement by the black wave.



This orange arrows represents the displacement by the orange wave alone.

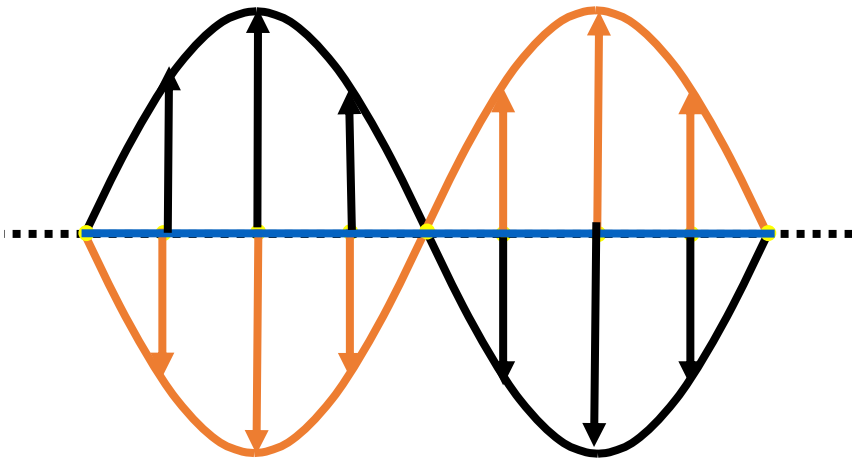
Since they are both displacements on the same side of the baseline, they add together.

The blue wave is the combined wave, which has a larger amplitude than the individual waves.

Destructive Interference

2 waves out of phase and same frequency overlap

The black arrows represent the displacement by the black wave alone.

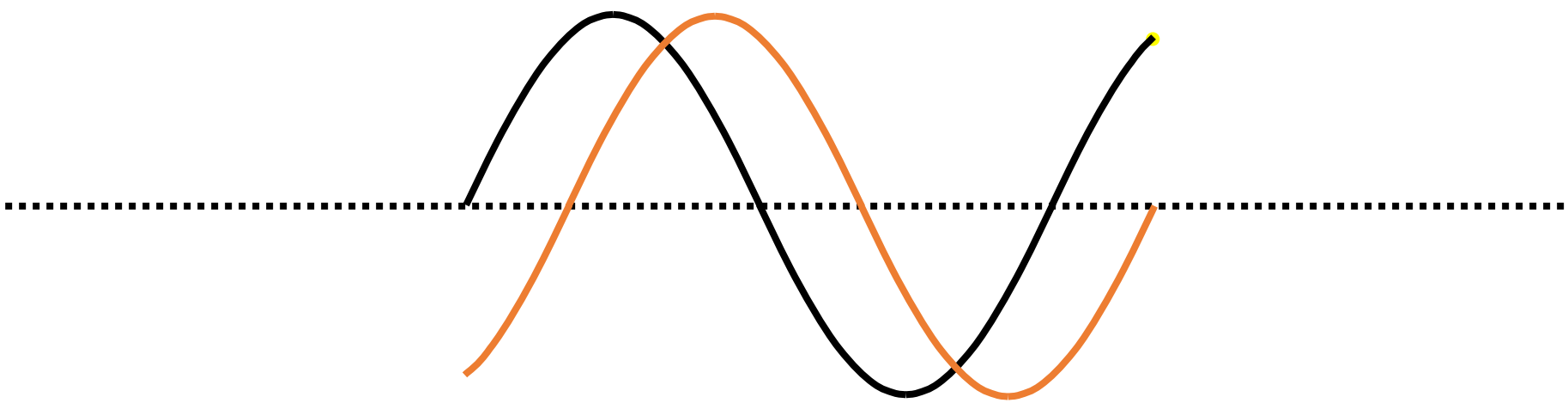


The orange arrows represent the displacement by the orange wave alone.

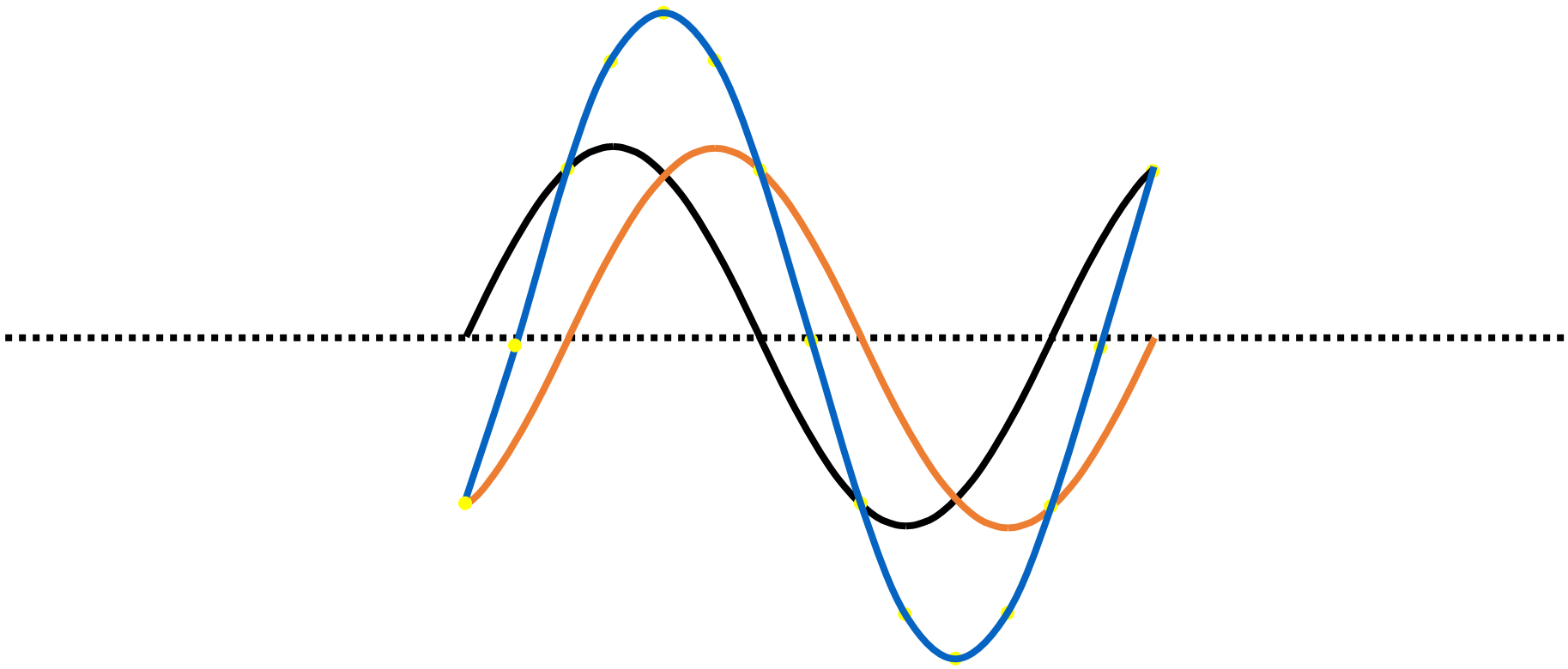
Since the two displacements are on opposite sides of the baseline, the top one should be considered positive and the bottom one negative.

Just add the positive and negatives together to give the flat blue line
This shows complete cancellation.

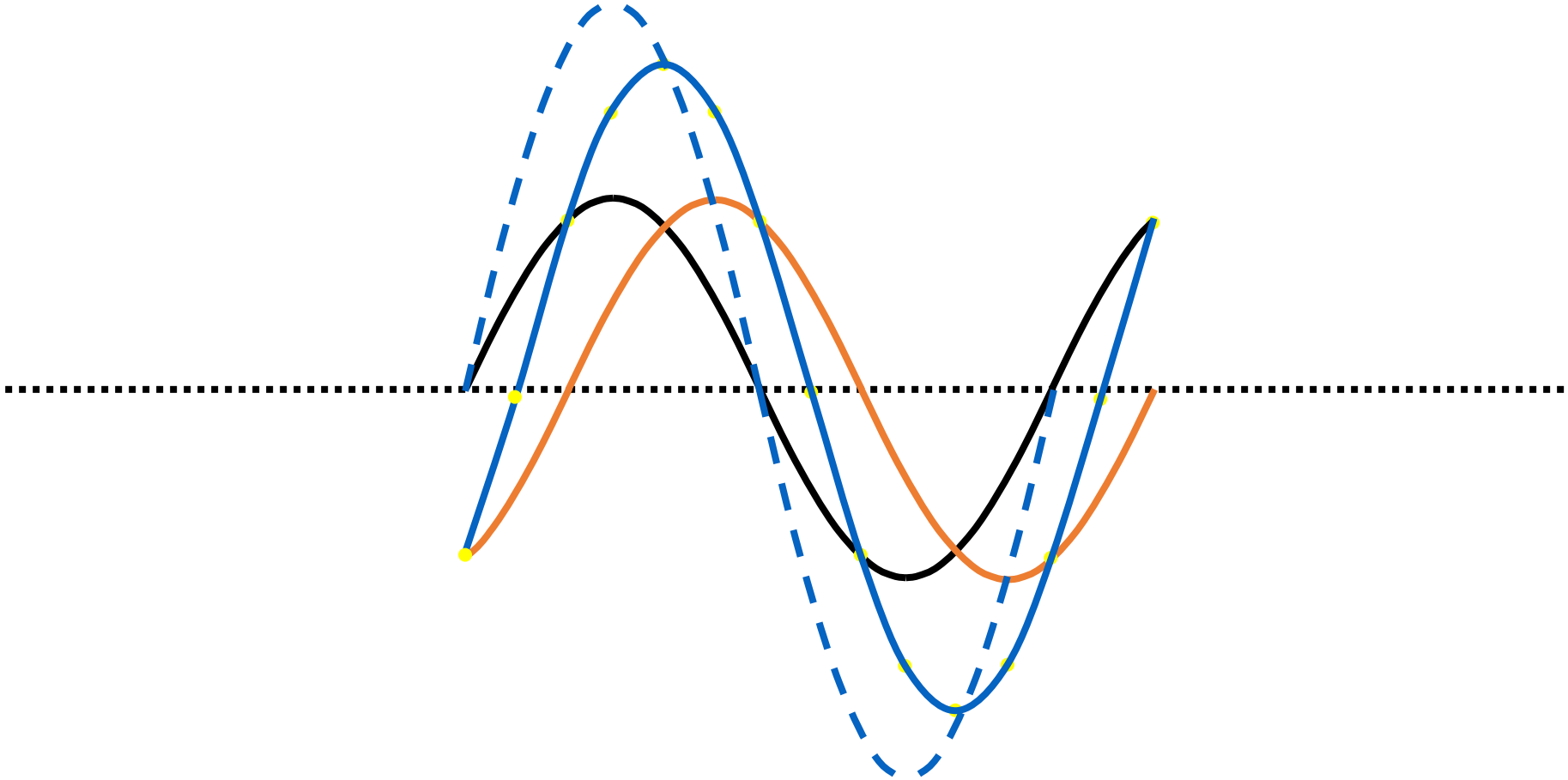
Interference where there is a 90° ($\pi/2$) phase difference



The displacement amplitudes for each wave would combine. What will the resultant wave look like?



The blue wave show the combined wave

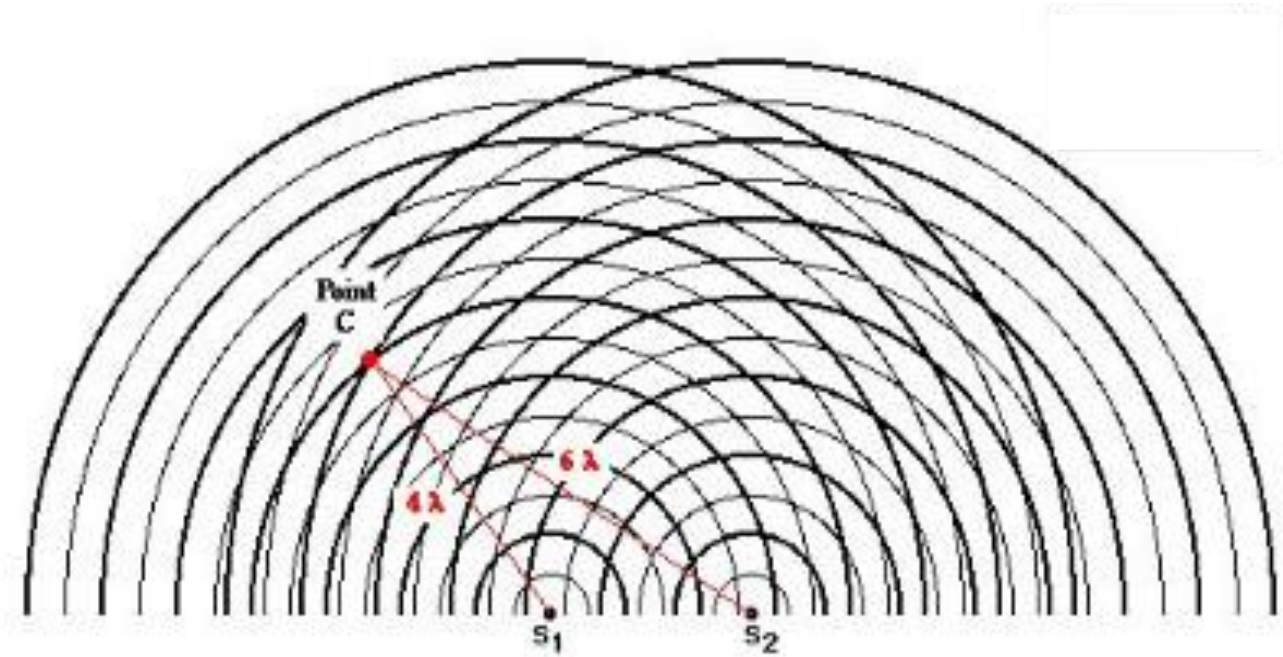


By overlaying the constructive interference curve from a previous slide you can tell that the curve of this slide is not fully constructive interference.

Path Difference

Path difference is the difference between the distance travelled for each wave from the origin to the point of interference.

For example for point C the path difference is 2λ.



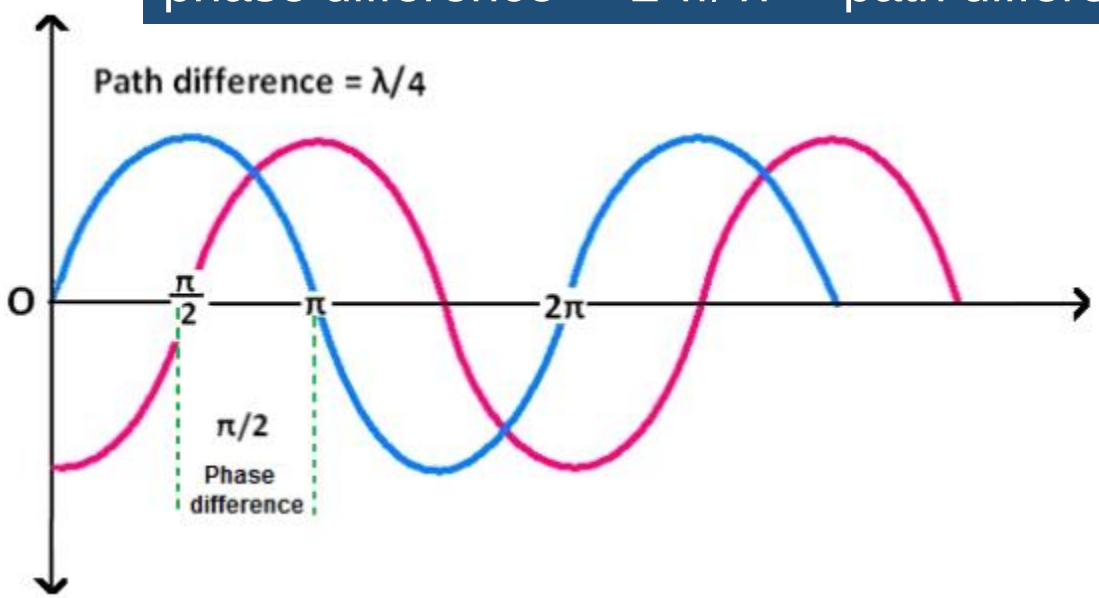
Path Difference related to Phase Difference

In general, constructive interference happens when path difference = nλ (n=1,2,3…) and phase difference = 2π radians

Destructive interference happens when path difference

= (2n+1) λ/2 and phase difference = (2n+1)π radians

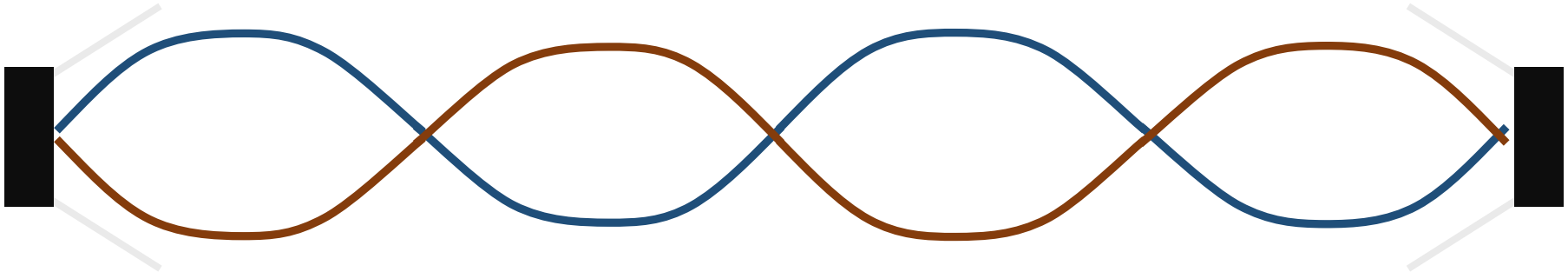
phase difference = 2 π/ λ × path difference



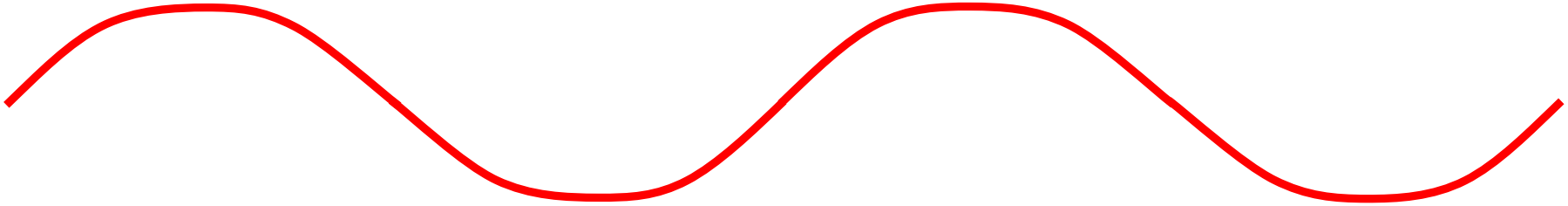
Stationary (Standing) Waves

Usually waves are described as “travelling” or “progressive” waves, i.e. there is a net movement of energy.

However, it is possible to set up a standing wave using “two progressive waves of equal frequency and wavelength incident upon each other at opposite directions”::



These 2 waves superpose and give a single wave with fixed points (NODES) and moving points with maximum displacement (ANTINODES)

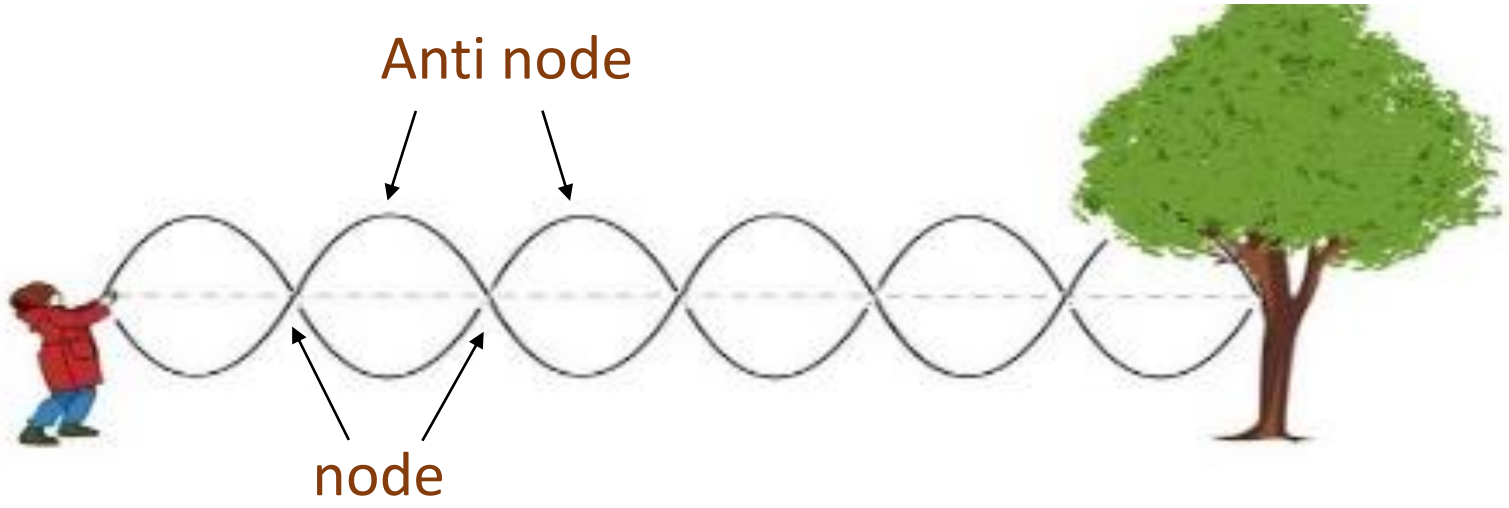


Stationary (Standing) Waves cont.

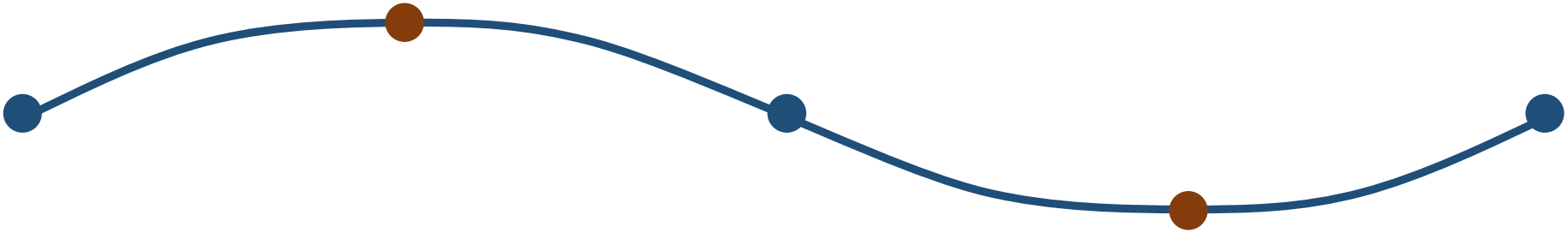
ANTINODES: Constructive interference of waves gives maximum displacement

NODES: Destructive interference of waves gives zero displacement

Distance between successive nodes/antinodes = $\lambda/2$

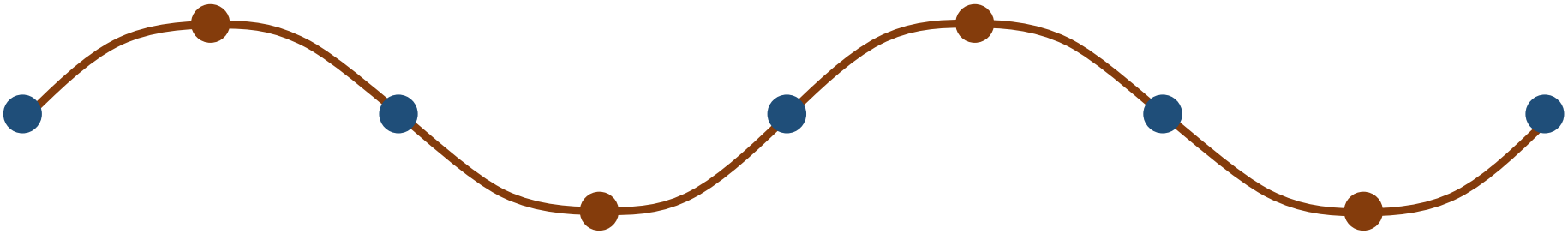


Stationary (Standing) Waves cont.



3 nodes

2 antinodes



5 nodes

4 antinodes

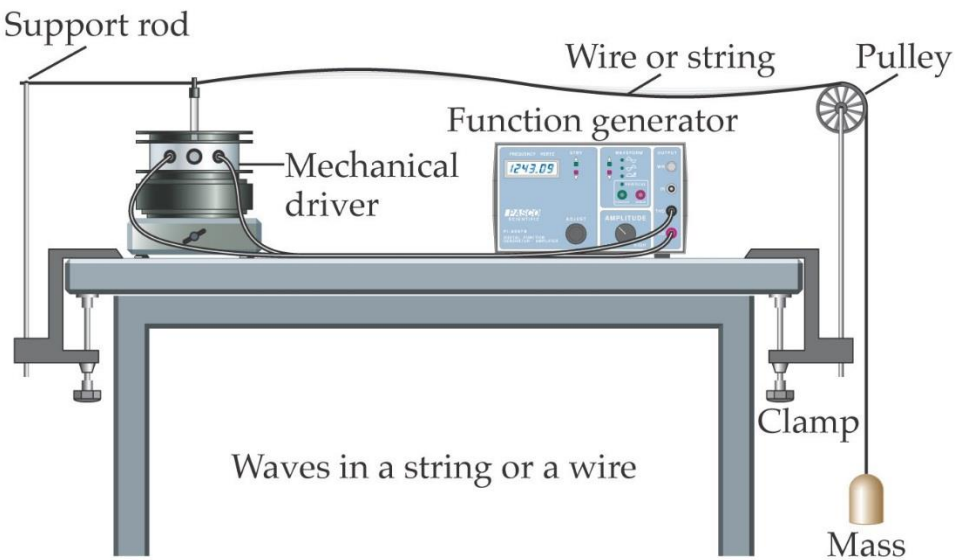
Speed of waves along a string

Here's a wave vibrating along a string:

The speed of this wave can be calculated using this equation:

$$v = \sqrt{\frac{T}{\mu}}$$

where:
v=velocity
T=tension
μ= mass per unit length



Question - Speed of waves along a string

Q.A guitar string has a mass per unit length of $0.005 kgm^{-1}$ and is held under a tension of 150N. What is the speed along the string when it is plucked?

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Solution:

$T = 150\ N$

$\mu = 0.005 kgm^{-1}$

$v = ?$

$$v = \sqrt{\frac{T}{\mu}}$$

$$v = \sqrt{\frac{150}{0.005}} = 173.205081\ ms^{-1}$$

Question - tension in a string

Q. Another string has half of the mass and the speed along it is $250ms^{-1}$. What tension is this wire under?

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Q. Another string has half of the mass and the speed along it is $250ms^{-1}$. What tension is this wire under?

Solution:

$v = 250\,ms^{-1}$

$\mu = 0.025kgm^{-1}$

$T = ?$

$$v = \sqrt{\frac{T}{\mu}}$$

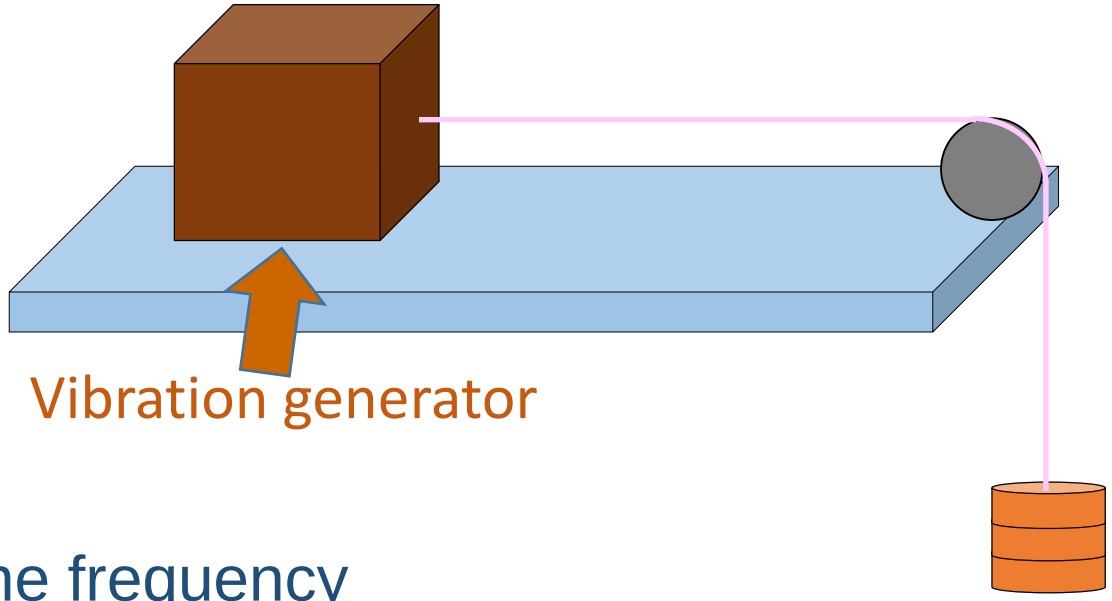
$$250 = \sqrt{\frac{T}{0.025}}$$

$T = 1562.5\,N$

Core Practical 9

Task: Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire.

Using a set up like this, how will you vary these three factors?



How will you measure the frequency of vibration?

Travelling Waves

A travelling wave (or "progressive wave") is one which travels out from the source that made it and transfers energy from one point to another.

Energy dissipation

Clearly, a wave will get weaker the further it travels. Assuming the wave comes from a point source and travels out equally in all directions we can say that the intensity at a point r metres away is given by:

$$\text{Intensity (in Wm}^{-2}\text{)} = \frac{\text{Power (in W)}}{\text{Area (in m}^2\text{)}} \qquad I = \frac{P}{4\pi r^2}$$

An "inverse square law"