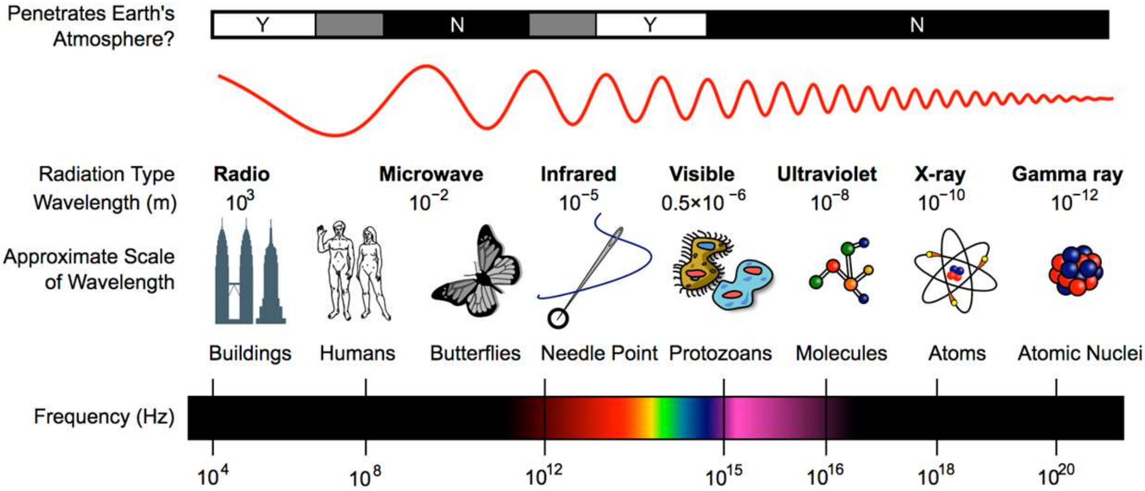
3.3.1 Progressive and stationary waves

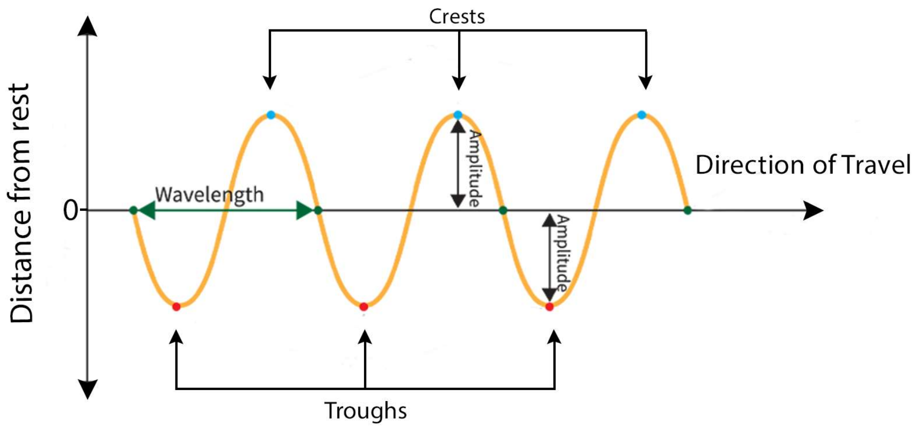
3.3.1.1 Progressive waves

- Mechanical waves
  - Involve particles in a substance vibrating
- Electromagnetic waves
  - Travel through space without the need for a substance
  - Electromagnetic spectrum



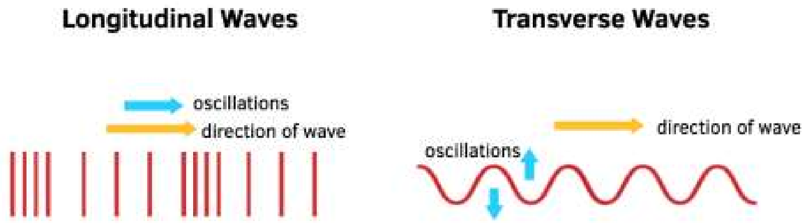
- Progressive wave
  - A wave that transfers energy and momentum from one point to another without transferring the medium itself
  - Made up of particles of an oscillating medium
- Terminologies

Term	Definition
Displacement	The vibrating particle's distance and direction from its equilibrium position
Amplitude	A wave's **maximum displacement** from the equilibrium position (unit = m)
Frequency f	The number of complete oscillations passing through a point per second (unit = Hz)
Period T	The time taken to make one oscillation (unit = s)
Wavelength λ	The length of one whole oscillation (e.g. the distance between successive peaks/troughs) (unit = m)
Speed c	Distance travelled by the wave per unit time (unit = ms^{-1})
Phase	The fraction of a cycle a vibrating particle has completed since the start of the cycle
Cycle	One complete cycle of a wave is from maximum displacement to next maximum displacement

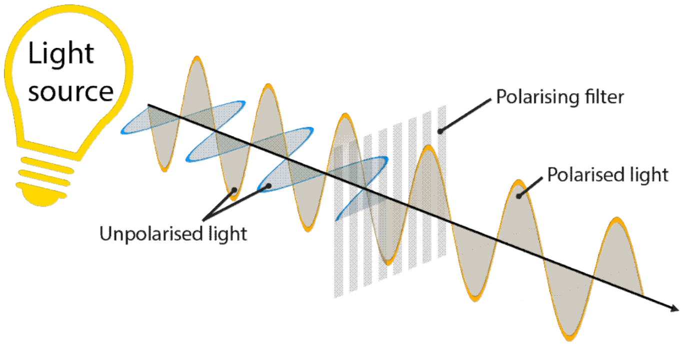
- 

- Phase difference
    - The fraction of a cycle between the vibration of two particles
    - $\text{phase difference in radians} = \frac{2\pi d}{\lambda} = \frac{2\pi \times \text{distance between two points}}{\text{wavelength}}$
- In phase
    - Two points on a wave are in phase if they are both at the same point of the wave cycle
    - Same displacement and velocity
    - Phase difference is a multiple of 360° / 2π
- Completely out of phase / in anti-phase
    - $(2n + 1)\pi$ apart in phase
- Wave speed
    - $c = f\lambda$
- Frequency / period conversion
    - $f = \frac{1}{T}$
    - $T = \frac{1}{f}$
- Properties of waves
    - Reflection
    - Refraction
    - Diffraction

3.3.1.2 Longitudinal and transverse waves

- Longitudinal and transverse waves
    - Transverse waves
        - The particles oscillate **perpendicular** to the direction of travel of the wave
        - **Can be polarised**
        - e.g. EM waves, waves on a string
    - Longitudinal waves
        - The particles oscillate **parallel** to the direction of travel of wave
        - The particles get compressed so they have more energy than the particles around them
        - When they vibrate they transfer energy to particles nearby → more compressions
        - **Cannot be polarised**
        - Cannot travel in vacuums (require a medium to propagate)
        - e.g. sound waves
- 

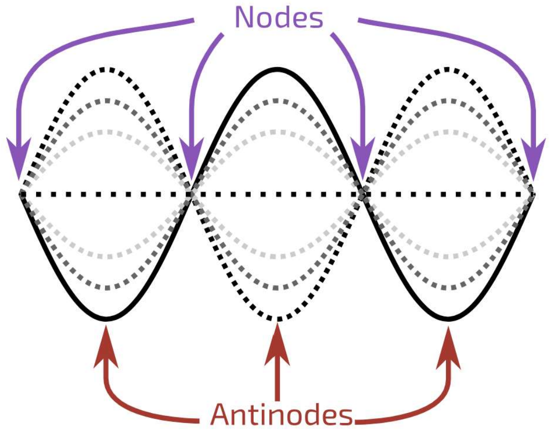
- Types of waves
    - Mechanical waves
        - Oscillations of the particles of the medium

- Electromagnetic waves
  - Oscillating electric and magnetic field that progress through space without the need for a substance
  - Transverse waves
  - All have the same speed in vacuum (3×10^8 ms^{-1})
- Polarisation
  - Can only happen when transverse waves travel in one plane only
  - Particle oscillations occur in **only one of the directions** perpendicular to the direction of wave propagation (vibrations stay in 1 plane only)
  - Cannot occur on longitudinal waves as it does not oscillate perpendicular to the direction of travel
  - (Transverse waves are called plane-polarised if the vibrations occur in one plane only, more than one plane = unpolarised)
- Polarising filter
  - 

  - Only the wave along the transmission axis can completely pass through
  - Greater angle between wave + axis = lower light intensity
  - Waves perpendicular to the transmission axis cannot pass through = 0 intensity
- Why only transverse waves can be polarised
  - Transverse waves oscillate perpendicular to direction of travel of wave
    - They initially oscillate in many different planes
    - Intensity is reduced due to oscillations being limited to one plane only
  - Longitudinal waves oscillate parallel to direction of travel of wave
    - There is no perpendicular plane to restrict the oscillations to
- Applications of polarisation
  - Polaroid sunglasses
    - Reduce glare by blocking partially polarised light reflected from water and glass
    - Only oscillations in the plane of the filter is allowed
    - Easier to see
  - EV and radio signals
    - Plane-polarised by the orientation of the rods on the transmitting aerial
    - The receiving aerial must be aligned in the same plane of polarisation to receive the signal at full strength

3.3.1.3 Principle of superposition of waves and formation of stationary waves

- The principle of superposition
  - When two or more waves arrive at one point, the resultant displacement is the sum of the displacement of each wave
- Constructive interference
  - Occurs when 2 waves have displacement in the same direction (arrives in phase)
- Destructive interference
  - Occurs when one wave has positive displacement and the other has negative displacement (arrives out of phase)
  - If the waves have equal but opposite displacements (π rad out of phase), total destructive interference occurs (zero amplitude)
- Stationary waves

- Waves where there is no net transfer of energy and momentum from one point to another
- 

- Formation of stationary waves
  - Formed by the **superposition** of two or more **progressive waves** of the **same frequency and wavelength** and pass through each other in **opposite directions in the same medium**
    - (The waves are emitted by …, **reflected through 180°** by …)
  - Formed as a result of the **superposition** of the progressive waves
  - Amplitudes of the two waves do not need to be the same
  - Constructive interference occurs at where the waves meet in phase so antinodes are formed
  - Destructive interference occurs at where the waves meet completely out of phase so nodes are formed
- Nodes
  - Fixed points in a stationary wave where the amplitude is **minimum** (usually zero)
  - Distance between 2 nodes = $\frac{\text{wavelength}}{2}$
- Antinode
  - Fixed point in a stationary wave pattern where the amplitude is **maximum**
  - The particles have **maximum energy** at the antinode
- Progressive waves + stationary waves comparison

	Stationary	**Progressive**
Energy & momentum	**No net transfer** of energy from one point to another through space	Energy is transferred through space
Wavelength	Wavelength = 2 × distance between adjacent nodes	Wavelength = distance between 2 particles at the same phase
Frequency	All particles expect the particles at the nodes vibrate at the same frequency	All particles vibrate at the **same frequency**
Amplitude	The amplitude varies from **minimum (0) at the nodes to maximum at the antinode** Particles immediately on either side of a node are moving in opposite directions	The amplitude is the **same for each point along wave**
Phase difference between 2 particles (rad)	Between nodes all particles are **vibrate in phase** $\text{phase difference} = m\pi$ $= \text{number of nodes between 2 particles} \times \pi$	$\text{phase difference} = \frac{2\pi d}{\lambda}$ Adjacent points vibrate with different phase

- Examples of stationary waves
  - Transverse stationary waves
    - String fixed at one end and fixed to a driving oscillator at the other end / plucked
      - Wave reflected at the end of the string
      - Two waves superpose with each other
      - Both ends are fixed so both ends of the string are always nodes
    - Stationary microwaves

- Reflected on a soft surface
      - The reflected end is an antinode, the emitter end is a node
      - A microwave probe can be used to find the nodes and antinodes
- Longitudinal stationary waves
  - Sound waves
    - Speaker causes the wave → antinode
    - Open end: when air leaves the tube the pressure around it is lower so it expands → air pushed back to the tube → **antinode**
    - Close end: reflects the wave which reverses its displacement → cancelled out by upcoming wave → **node**

- Harmonics
  - The number of **antinodes** on the string
- First harmonic frequency / fundamental frequency
  - The lowest frequency at which a stationary wave forms
  - Forms a stationary wave with two nodes and a single antinode
  - Distance between adjacent nodes = half a wavelength
  - $\lambda = 2L$
  - $f = \frac{c}{2L} = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$ $(T = \text{tension in the wire}, \mu = \frac{m}{L} = \text{mass per unit length})$
  - $n\text{th harmonic frequency} = n \times \text{first harmonic frequency} = nf_1$
  - nth harmonic frequency = nodes at a distance of $\frac{1}{n}L$
- Factors affecting the fundamental frequency
  - Mass per unit length
  - Tension
  - Length
  - Temperature

Required Practical 1 - Stationary Waves

- Frequency vs length / tension / mass per unit length
  - Keep other variables constant
  - Use a signal generator + vibrator connected to signal generator to produce the vibrations
  - Measure length using ruler / tension by hanging mass at one end / mass per unit length by changing the wire
  - Graph of f vs. $\frac{1}{l}$ / f vs $\sqrt{T}$ / f vs $\frac{1}{\sqrt{\mu}}$
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