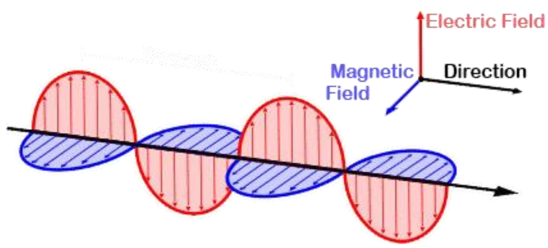
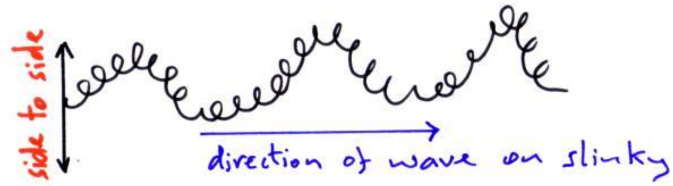
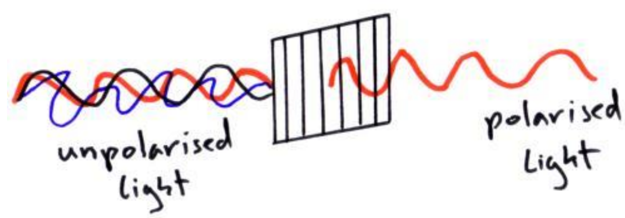
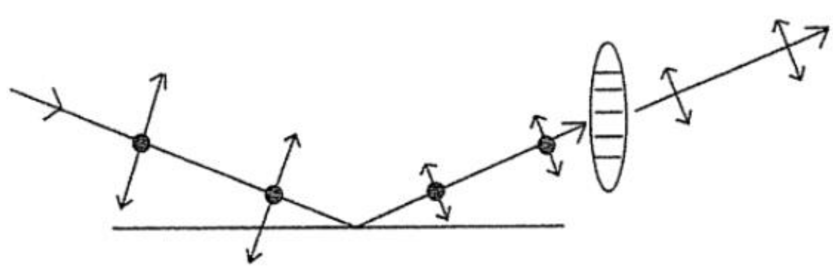
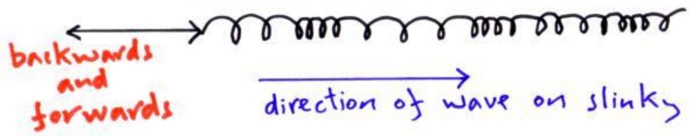
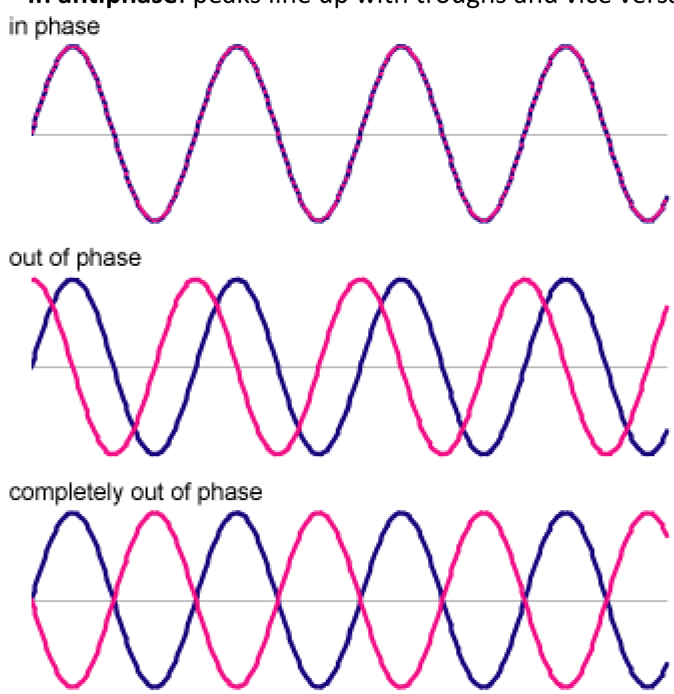
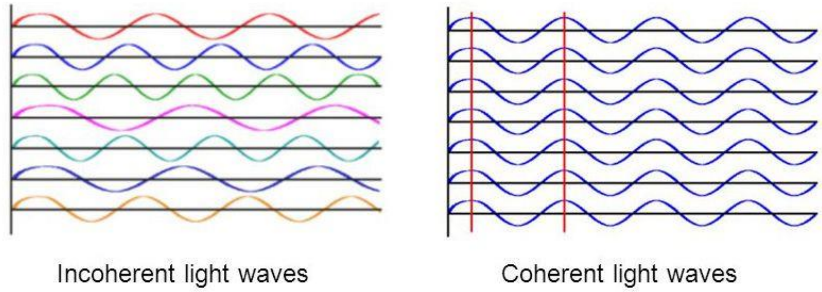
U3 - Waves

<table>
<tr><td>What is amplitude?</td><td>MAXIMUM displacement from rest position.</td></tr>
<tr><td>What is frequency (in terms of waves)?</td><td>The number of waves passing through a point each second (measured in Hz or s^{-1}).</td></tr>
<tr><td>What is wavelength?</td><td>The distance between two identical consecutive points.</td></tr>
<tr><td>What is time period?</td><td>The time taken for one complete wavelength to pass a point.</td></tr>
<tr><td>What are mechanical waves (with examples)?</td><td>Waves that rely on a medium to travel through (e.g., sound waves and seismic waves).</td></tr>
<tr><td>What are electromagnetic waves?</td><td>

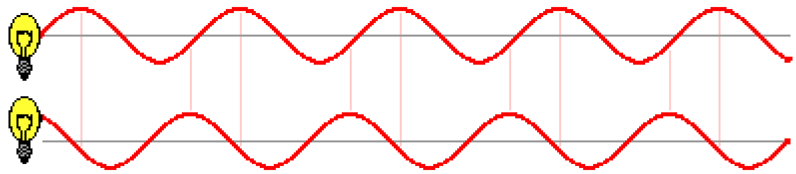
Oscillating electric and magnetic fields that are in phase and perpendicular to one another.</td></tr>
<tr><td>Give 3 properties of electromagnetic waves</td><td>Can travel through a vacuum.
Travel at the speed of light (through a vacuum).
Are all transverse.</td></tr>
<tr><td>What are the sections of the electromagnetic spectrum and the properties of either side?</td><td><table>
<tr><th>Name</th><th>Properties</th></tr>
<tr><td>Radio</td><td>Longest wavelength ⇒ lowest frequency ⇒ least penetrating.</td></tr>
<tr><td colspan="2">Microwaves, Infrared, Visible, Ultraviolet, X-ray</td></tr>
<tr><td>Gamma</td><td>Shortest wavelength ⇒ highest frequency ⇒ most penetrating.</td></tr>
</table></td></tr>
<tr><td>In what range does visible light lie?</td><td>400 nm to 700 nm.</td></tr>
</table>

Describe the motion of transverse waves	The direction of **vibrations** are **perpendicular** to the **direction of energy propagation**.  *E.g., a seagull bobbing up and down in water.*
What type of waves cannot be polarised and why?	● Longitudinal waves. ● As their oscillations always occur in one direction - in the direction of the way - so there's no need to distinguish between 'different' oscillation directions as there's only one.
What is unpolarised light?	A mixture of waves oscillating in different planes.
How can you make a wave polarised, what does this do, and how does it work?	● By passing it through a polaroid filter **WHICH ALLOWS** waves oscillating in one plane to pass **LOWERING** the new wave's intensity. ● Oscillations in the other directions are absorbed by the molecules. 
Give a use of polaroid filters	**Light is reflected** from the road surface is **partially plane polarised**. **Polaroid sunglasses** can **stop** the horizontally polarised light getting in your eyes. 
Describe the motion of longitudinal waves	The direction of **vibrations** are **parallel** to the direction of **energy propagation**.

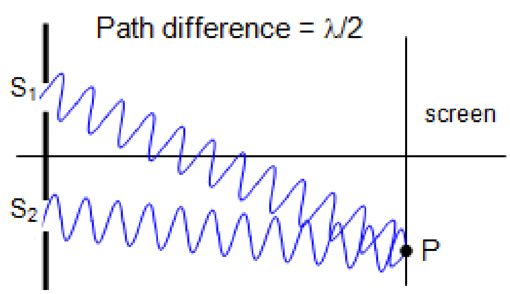
	
How is polarisation used in transmission and reception?	● TV signal transmitted horizontally or vertically and your antenna should match the signal polarisation. ● Antenna in a given area have the same polarisation to prevent interference from nearby stations.
How does changing the amplitude and wavelength affect particles on a longitudinal wave?	● **Increasing** the **amplitude** makes particles **vibrate further** from rest position. ● **Increasing** the **wavelength increases** the **distance between consecutive areas** of compression/rarefaction.
What 'in phase' and 'in antiphase' mean?	● **In phase**: peaks line up with peaks and troughs with troughs. ● **In antiphase**: peaks line up with troughs and vice versa. 
When are two waves coherent and what does this also mean?	When the **phase difference** between them is **constant**. This means they have the **same frequency**.

<table>
<tr>
<td></td>
<td>


Or…

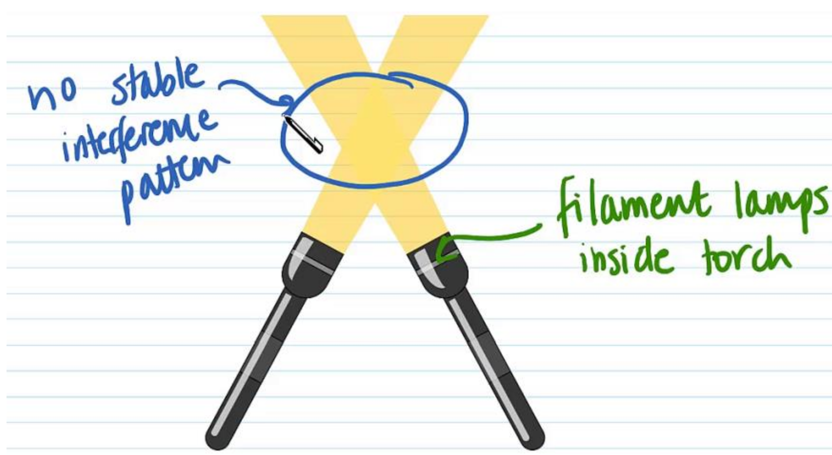

</td>
</tr>
<tr>
<td>What is path difference and what can it lead to?</td>
<td>

- Path difference is the difference in distances travelled by two coherent waves.
- Path difference leads to phase difference.



E.g., S_1 has travelled half a wavelength more than S_2 so they're now completely-out-of-phase.

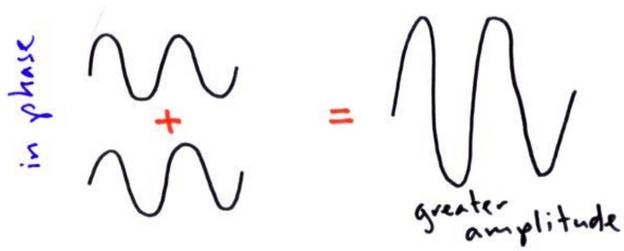
Without coherent waves, there is no stable interference pattern as shown below:

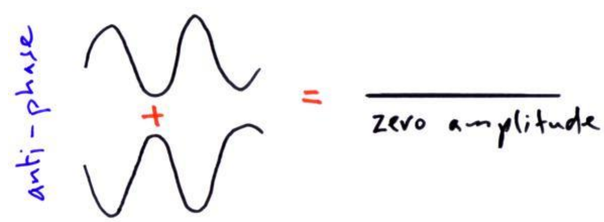


</td>
</tr>
</table>

<table>
<tr>
<td>What is phase difference for both stationary and progressive waves?</td>
<td>

For standing waves, the phase difference can only ever be $\pi/2$, π, $3\pi/2$ or 2π radians.
For progressive waves, the phase difference is the fraction of a cycle between the two vibrating particles. Hence, (distance between points) / (wavelength) * 2π.

This is the case for progressive waves because each point will undergo maximum displacement from equilibrium position. The two points will always remain however much out of phase when the wave passes through them (imagine them being an equal distance apart constantly on a circle).
</td>
</tr>
<tr>
<td>What happens when two waves meet? What does this mean?</td>
<td>They superpose (1) meaning the resultant displacement is now the vector sum of the individual displacements.</td>
</tr>
<tr>
<td>When does constructive interference occur?</td>
<td>When two waves some whole wavelength, nλ, apart (otherwise known as in phase) superpose.


The waves constructively interfere to construct a wave of greater amplitude.</td>
</tr>
<tr>
<td>When does maximum destructive interference occur?</td>
<td>When two waves some half-wavelength apart, (n + 1/2) x λ, apart (otherwise completely-out-of-phase/anti-phase) superpose.


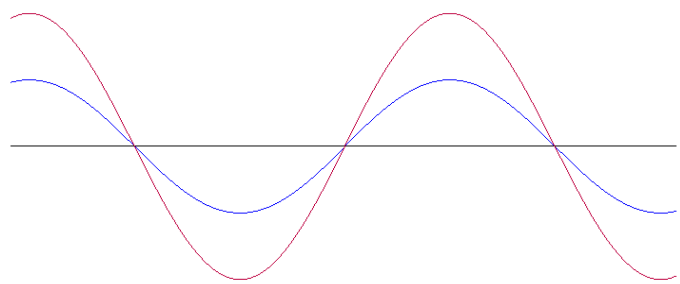
The waves destructively interfere to give a wave of zero amplitude.</td>
</tr>
<tr>
<td>Compare both progressive and stationary/standing waves</td>
<td>
<table>
<tr><th>Property</th><th>Stationary</th><th>Progressive</th></tr>
<tr><td>Energy & Momentum</td><td>No net transfer between points.</td><td>Net transfer - moving with speed $c = f\lambda$.</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr><td></td><td>
<table>
<tr><td>Amplitude of Particles</td><td>Varies from zero at nodes to maximum at</td><td>Same for all particles.</td></tr>
<tr><td>Frequency</td><td colspan="2">Same for all particles oscillating.</td></tr>
<tr><td>Wavelength</td><td></td><td></td></tr>
<tr><td>Phase Difference</td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Describe progressive waves</td><td>

Waves that transfer energy from one point to another (1) without transferring material (1).
The amplitude is the same for all particles.

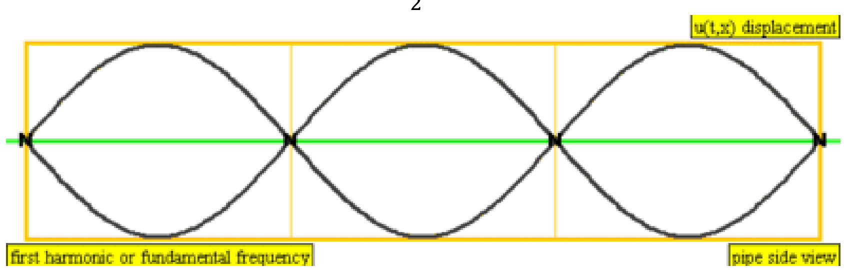
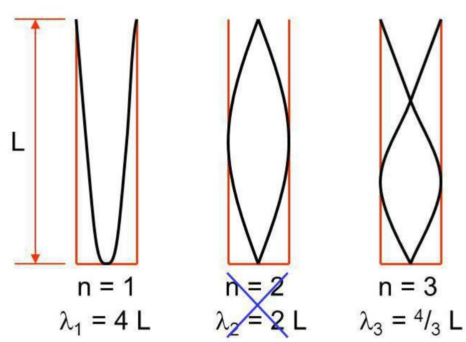
</td></tr>
<tr><td>Describe standing/stationary waves</td><td>

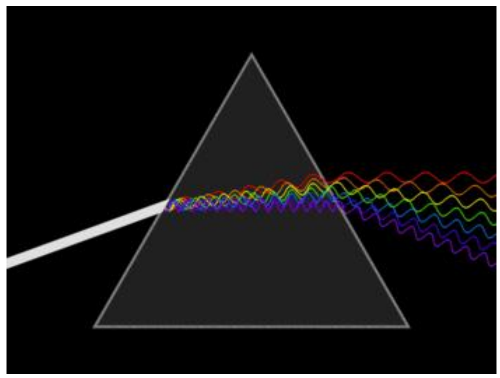
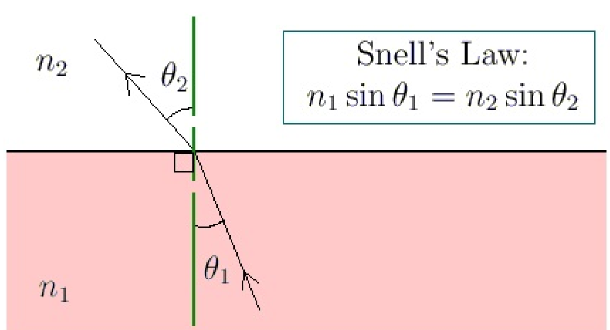
Waves that have no net transfer of energy from one point to another.
The amplitude varies from zero at the nodes to a maximum at the antinodes.

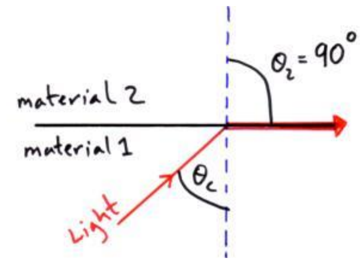
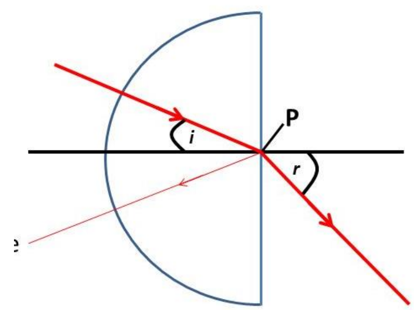
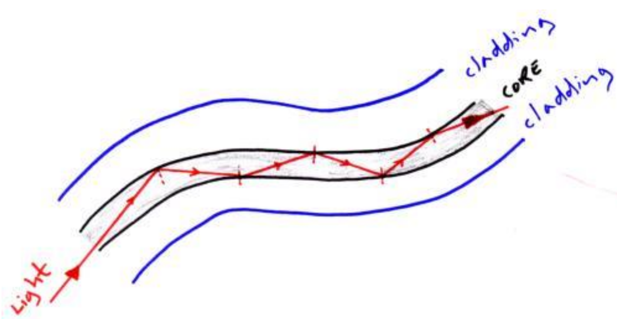
</td></tr>
<tr><td>How do standing/stationary waves formed?</td><td>
By an incident wave superposing with its reflected wave (essentially, two identical waves propagating in opposite directions).

It is reflected after coming in contact with some surface.
</td></tr>
<tr><td>Why do standing/stationary waves only form under specific frequencies?</td><td>As there has to be a node/antinode on either side ∴ you need a wavelength that is a specific fraction of the length of the wire.</td></tr>
<tr><td>What is the displacement at the nodes and antinodes of a stationary wave and why?</td><td>

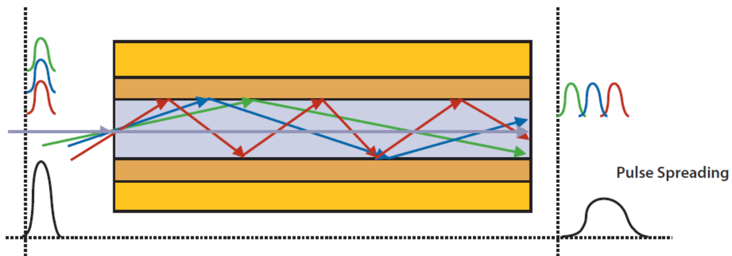
At the node, no displacement because maximum destructive interference occurs.
At the antinode, maximum displacement because constructive interference occurs.

Less destructive interference occurs as you move towards the rest position. This is partial destructive interference.
</td></tr>
</table>

What is 'not present' at a node and why?	Energy as it has zero amplitude.
What will you always have at a closed and an open end of a standing wave?	● A **node** at a **closed** end. ● An **antinode** at an **open** end.
What is the distance between two nodes AND a node and antinode?	● Two nodes is ½ λ. ● Node and antinode is ¼ λ.
What is the first, second, and third harmonics also known as and how are they related?	● First - fundamental mode. ● Second - first overtone (double the frequency of first, half the wavelength). ● Third - second overtone (triple the frequency of first, a third the wavelength).
What is the length of each harmonic for an completely open/closed tube?	● At the 1st harmonic, $l\ =\ \frac{\lambda}{2}$. ● At the 2nd harmonic, $l\ = \lambda$. ● At nth harmonic, $l = n \times \frac{\lambda}{2}$. 
What is the length of each harmonic for a tube closed at one end?	● At the 1st harmonic, $l = \frac{\lambda}{4}$. ● At the 3rd harmonic, $l\ = \frac{3\lambda}{4}$. ● At the (2n - 1)th harmonic, $l\ = (2n - 1)\frac{\lambda}{4}$. Only the odd numbered harmonics exist. 

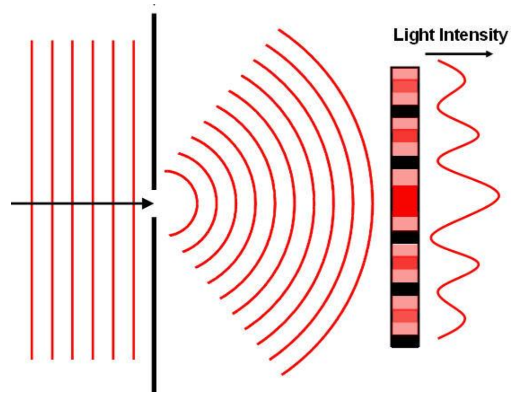
What is refraction?	• When a wave changes direction as it moves from one medium into another. • <u>**T**</u>owards <u>**A**</u>ir <u>**G**</u>lass <u>**A**</u>way <u>**G**</u>lass <u>**A**</u>ir
Which 'types of diffraction' occur as the gap size varies?	• When **aperture size = wavelength**, **maximum** diffraction. • When **aperture size << wavelength**, wave **reflects back**. • When **aperture size >> wavelength**, **diffraction** occurs at **edges**.
What remains constant under refraction?	Frequency.
Which wavelength refracts more?	A shorter wavelength.  *This is for every substance you'll encounter in this course.*
What is absolute refractive index?	How many times slower the **speed of light** is in a **medium** compared to the speed of light in a **vacuum**. $$n = \frac{c}{c_s}$$ *c_s is the speed of light in the substance.*
What is Snell's Law?	

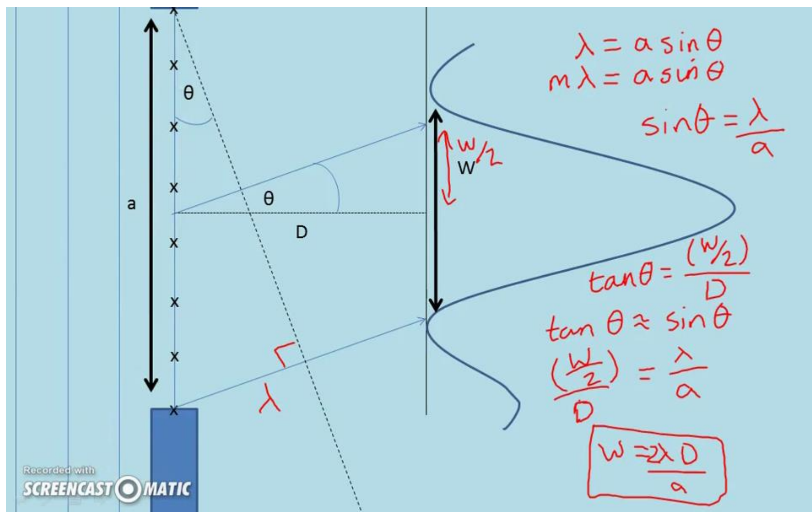
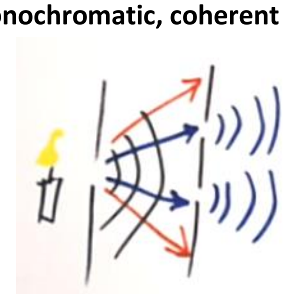
What is the refractive index of air?	Approximately one.
What happens when the incident angle = the critical angle?	The **angle of refraction** is **90°** (so travels along the boundary). 
Give two conditions needed for total internal reflection to occur	● Light must be travelling from a **more dense to a less dense** medium. ● The **angle of incidence ≥ critical angle**.
Why is a semi-curricular block often used for total internal reflection?	As you want the curved side to have an angle of incidence of 0°. 
Describe the structure of and the process of light travelling via an optical fibre	● A glass core surrounded by cladding of **lower refractive index** (1). ● Light enters, is slightly refracted at the start, is totally internally reflected when the **angle of incidence ≥ critical angle** (1). 

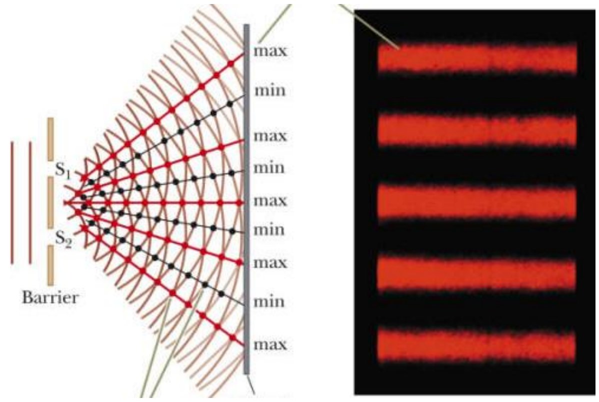
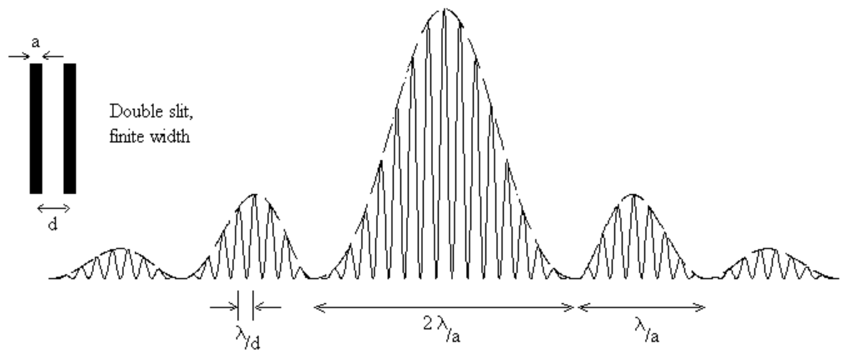
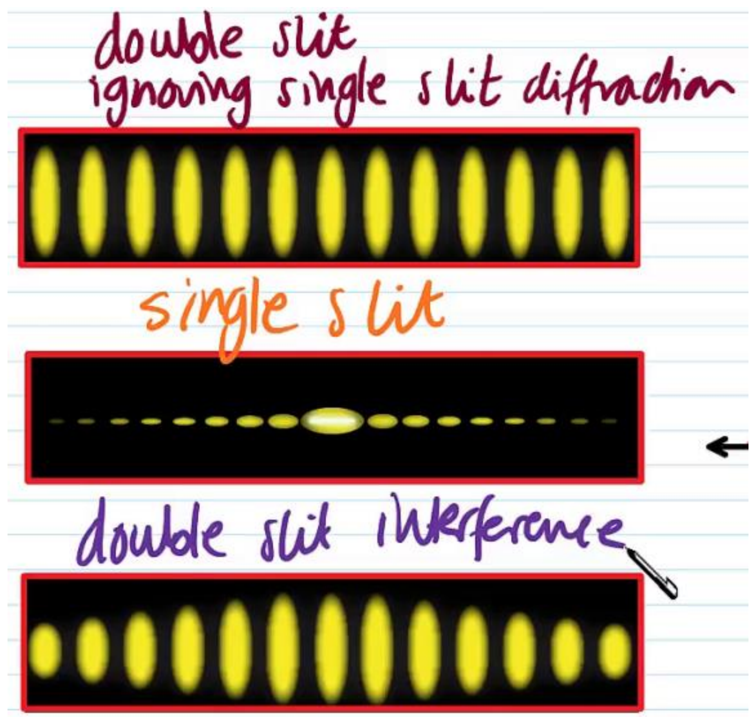
Give 3 reasons for why cladding is useful for optical fibres	● Protects the core. ● Prevents cross-talk. ● Prevents the leakage of light.
Give 2 advantages and 1 disadvantage of optical fibres compared to metal wires	+ They don't corrode + They can send more information per second. - Difficult to join fibres and make junctions.
Describe multimode/multipath dispersion and what this leads to	● **Different wavelengths enter** and are refracted to **slightly different angles**. ● They **follow slightly different paths** (some taking longer than others due to more reflections) thus **leaving at different times**. ● This leads to **pulse broadening**.  *This differs from material dispersion in that it can still occur even if a monochromatic source of light is used.*

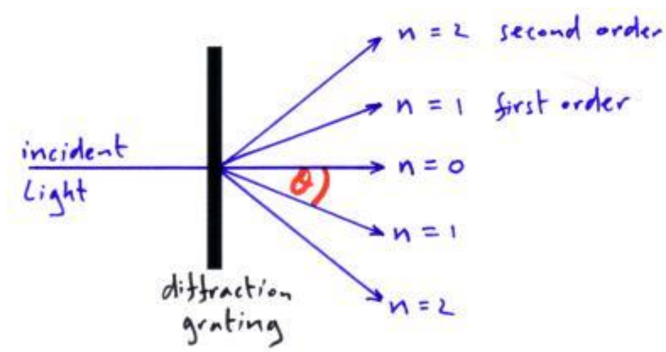
What affects multimode/multipath dispersion, why, and how can it be reduced?	● **Cable length** - the light has more time to disperse.
	    ○ Use relays for longer cables.
	● **Cable thickness** - the light is more likely to take a different path.
	    ○ Make the cable as thin as possible.

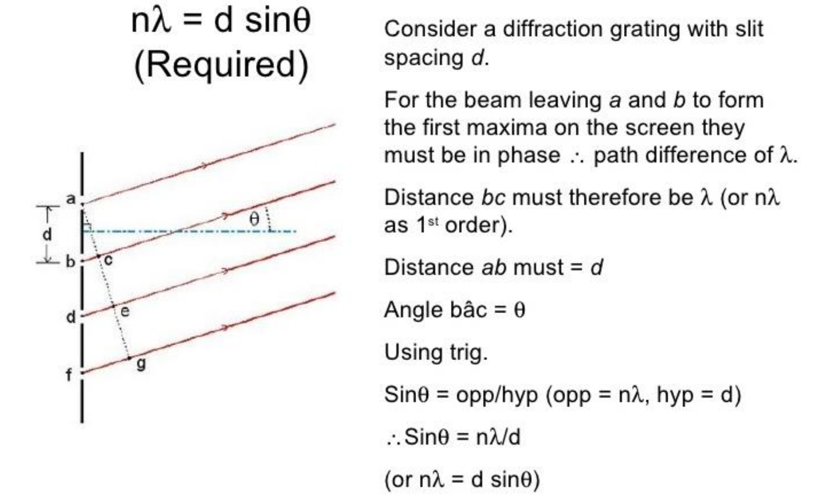
What is material dispersion and its effects?	**Different wavelengths** of light travelling at **different speeds** via an optical fibre leading to **pulse broadening**.
Why is pulse broadening bad?	Leads to a less coherent signal.
What is pulse absorption and how is it minimised?	● Less transparent a material, more light is absorbed so the shorter a pulse with given energy can travel. ● It's minimised by using a very pure transparent material in optical fibres.

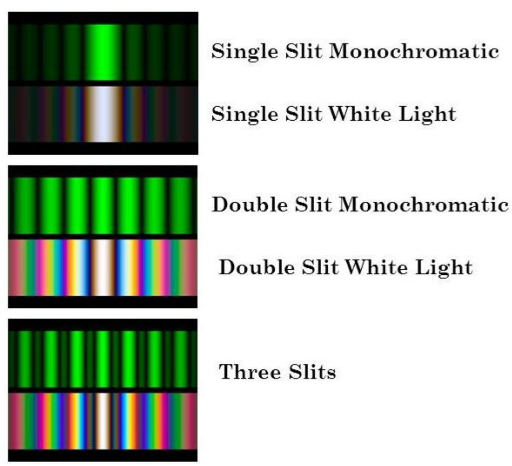
	A given fraction of a pulse is absorbed per unit distance so it follows an exponential decay. The more transparent, the lower the decay rate.
How can material dispersion be resolved?	By using monochromatic light.
What does absorption cause a loss of for a wave?	A loss in amplitude/intensity.
What is intensity?	Power per unit area (w/m^2).
Explain why the minimum intensity is not zero between 2 maxima when the intensity of light coming through each slit is the same	• Intensity of the wave decreases with distance (1) as waves are travelling further. • Some waves will travel further than others (1). • The amplitudes/intensities aren't equal so they don't cancel out completely (1).
What are lasers sources of?	Coherent, monochromatic light.
What is monochromatic light?	Light of a single frequency/wavelength.
What wavelengths diffract more and why?	**Longer wavelengths** because they have a lower frequency so less energy. The **more energy** a wave has, the **greater** its **tendency** to travel in a **straight line**. *Think of p = mv.*
Describe what appears on the screen under single slit diffraction	• A **diffraction pattern** of alternating light and dark fringes. • The **central fringe** is **brighter** and **double in size**. • The **fringes** get **dimmer** as you move from the centre. 

What will always be in the centre of a diffraction pattern and why?	● The **maximum bright fringe**. ● As the **centre** is **symmetric** to all the slits so light from each slit will travel a whole number of waves to reach it, **arrive in phase** and **constructively interfere**.
What is the equation for determining the width of the central fringe?	This isn't in the formula book. $W = \frac{2\lambda D}{a}$ *Where **W** is the width of the central maximum, **D** is the distance between the single slit, **a** is the length of the opening of the single slit.*
How can you derive the equation for the width of the central fringe for single slit diffraction?	 *This involves small angle approximation.*
Give 2 reasons Young used a single slit in his double-slit experiment	● To diffract light to both slits. ● To create **monochromatic, coherent** light.  *Blue light diffracts the least and thus comes out the other two slits.*
What occurs at each type of fringe under Young's Double Slit?	● At the light fringes, constructive interference. ● At the dark fringes, destructive interference.

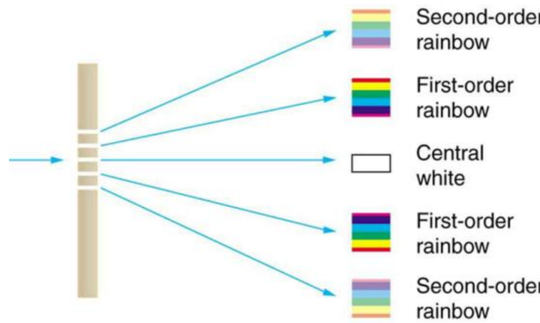
	
What appears on a screen under double slit diffraction?	An interference pattern enclosed by a single-slit envelope (of double the width in the centre).  Since… 

What is each variable n the equation for Young's Double Slit? $$w = \frac{\lambda D}{s}$$	**w** is fringe spacing (m), **D** is distance between the double slits and the screen, **s** is the split separation (m).
What is a diffraction grating? What does it do?	A piece of glass with **closely spaced parallel lines** which splits light into a spectra. 
What makes the analysis of a diffraction grating is better than Young's Double Slit?	• It's easier to measure the fringe separation as more light passes through leading to brighter and sharper fringes. • It doesn't rely on small angle approximation (thus you have to find the angle of each order yourself).
What is each variable in the formula for diffraction gratings? $$\sin\theta = \frac{n\lambda}{d}$$	**d** being the distance between two slits, **θ** being the angle of diffraction (i.e., the angle from the normal of the screen), **n** being the order number.

<table>
<tr>
<td>How can the formula for diffraction gratings be derived?</td>
<td>


If you consider Δade with ad as 2d and de as 2λ, you'll get sinϑ = λ/d where n = 1. However, for the second order, bc is 2λ so de is 4λ will give you sinϑ = 2λ/d where n = 2
</td>
</tr>
<tr>
<td>How can you work out the maximum order of a diffraction grating?</td>
<td>By setting θ to 90 and finding the lowest integer below n.</td>
</tr>
<tr>
<td>What appears on a screen when using white light with a single slit, double slit, and diffraction grating?</td>
<td>
A central white fringe with a rainbow repeated at every other order of lower intensities when further from the centre.


Central fringe has double the with for a single slit.
</td>
</tr>
</table>

	 *White light isn't diffracted in the centre as the angle of diffraction is 0°.*