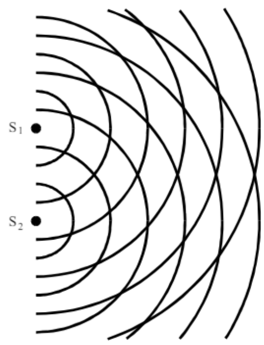
Topic 5: Wave and Particle Nature of Light

0.5 Specification notice:

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include determining the refractive index of solids and liquids, measuring the focal length of a lens, and using models of structures to investigate stress concentrations.
Mathematical skills that could be developed in this topic include using calculators to handle sin x, identifying uncertainties in measurements and using simple techniques to determine uncertainty when data are combined.
This topic may be studied using applications that relate to waves and light, for example medical physics.

5.Q Exam questions

7. The diagram shows wavefronts spreading out from two identical sources, S_1 and S_2.



Describe how such a pattern could be produced and observed using a ripple tank. (5)

- Two connected dippers above the water (1)
- Vibrated electrically (1)
- Shallow water (1)
- Illuminate using stroboscope (1)

7. Description:

Either	*Or*
Two connected dippers just touching/above the water	Dipping beam or single source **(1)** reaches two slits **(1)**

Vibrated electrically **(1)**
Level tank/shallow water/sloping sides **(1)**

Either	*Or*
Illuminate project on to screen	Use stroboscope **(1)** to freeze the pattern **(1)**

Max 5

On the diagram draw the following:

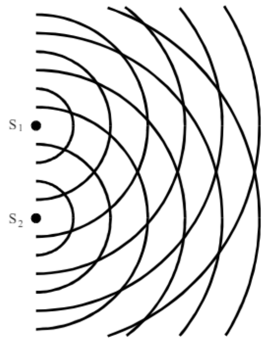
(i) a line labelled A joining points where the waves from S_1 and S_2 have travelled equal distances,

(ii) a line labelled B joining points where the waves from S_1 have travelled one wavelength further than the waves from S_2.

(iii) a line labelled C joining points where the waves from S_2 have travelled half a wavelength further than the waves from S_1.

(4)

7. The diagram shows wavefronts spreading out from two identical sources, S_1 and S_2.



On the diagram draw the following

1. **A line labelled A joining points where the waves from S1 and S2 have travelled equal distances**
2. **A line labelled B joining points where the waves from S1 have travelled one wavelength further than the waves from S2**
3. **A line labelled C joining points where the waves from S2 have traveleed half a wavelength further than the waves from S1**

Diagram:

(i) Correct line A - centre line **(1)**

(ii) Correct line B (above or below A) **(1)**

(iii) Correct line C (between A and B) **(1)**

both B and C correct **(1)**

4

Complete each of the sentences below by selecting an appropriate term from the following:

increase
decrease
stay the same

If only the separation of the sources were increased, the angle between lines A and B would..

If only the wavelength of the waves were increased, the angle between lines A and B would..

If only the depth of the water in the ripple tank were increased, the angle between lines A and B would..

(3)

If only the separation of the sources were increased, the angle between lines A and B would *decrease* **(1)**

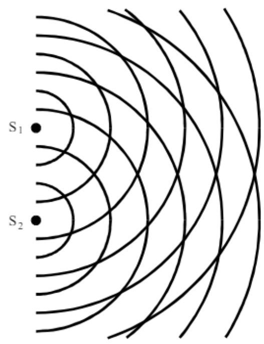
If only the wavelength of the waves were increased, the angle between lines A and B would *increase* **(1)**

If only the depth of the water in the ripple tank were increased, the angle between lines A and B would *increase* **(1)**

3

1. Decrease
2. Increase
3. Increase

7. The diagram shows wavefronts spreading out from two identical sources, S_1 and S_2.



1. **If only the separation of the sources were increased, the angle between A and B would ___________**
2. **If only the wavelength of the waves were increased, the angle between lines A and B would___________**
3. **If only the depth of the water in the ripple tank were increased, the angle between A and B would__________**

Q9.

A monochromatic beam of light of wavelength λ from a laser is directed at a diffraction grating of line spacing *d*.

A student calculates the value of d/λ in order to determine the expected number of visible maxima.

The calculated value of d/λ is 4.7

How many maxima are visible?

☐ **A** 4

☐ **B** 5

☐ **C** 9

☐ **D** 11

A monochromatic beam of light of wavelength λ from a laser is directed at a diffraction grating of line spacing d.
A student calculates the value of d/λ in order to determine the expected number of visible maxima.
The calculated value of d/λ is 4.7
How many maxima are visible?

Q9.

Question Number	Acceptable answers	Additional guidance
	The only correct answer is C because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, and there are that many orders either side of the maximum plus a central order A is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, and there are that many orders either side of the maximum plus a central order, but this answer only gives the number of orders on one side of the central order B is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, but this order rounds 4.7 to 5 and doesn't consider the central maximum or that there are orders on either side D is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, but this order rounds 4.7 to 5 and then adds the orders on the other side and the central maximum	

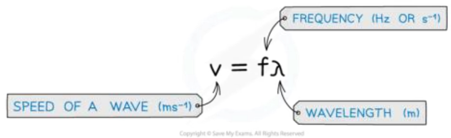
- C is answer

5.59 Understand the terms amplitude, frequency, period, speed and wavelength

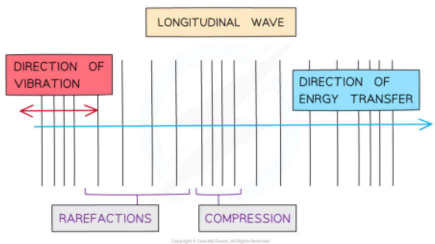
What is amplitude?	The maximum displacement of a wave from rest position
What is frequency (in terms of waves)?	The number of waves produced by a source each second

What is time period?	The time taken for one complete wavelength to pass a point
What is speed?	The distance travelled per unit time
What is wavelength?	The distance between two identical consecutive points
At what wavelengths does visible light lie?	400nm to 700nm

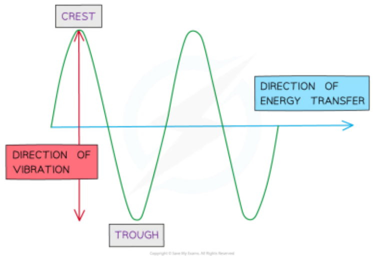
5.60 Be able to use the wave equation v = fλ

What is the wave equation?	v = fλ 

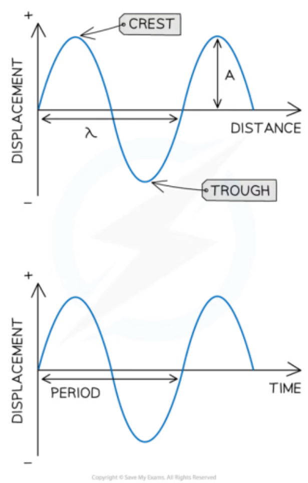
5.61 Be able to describe longitudinal waves in terms of pressure variation and the displacement of molecules

What is a longitudinal wave? And Examples	The direction of oscillations are parallel to the direction of energy propagation  *Examples: Seismic P-waves and sound*
What are areas of high pressure called on a longitudinal wave?	Compressions
What are areas of low pressure called on a longitudinal wave?	Rarefactions
What are mechanical waves (with examples)?	Waves that rely on a medium to travel through

5.62 Be able to describe transverse waves

What is a transverse wave? And examples	The direction of oscillations are perpendicular to the direction of energy propagation  *Examples: light waves, radio waves, water waves*
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

5.63 Be able to draw and interpret graphs representing transverse and longitudinal waves including standing/stationary waves

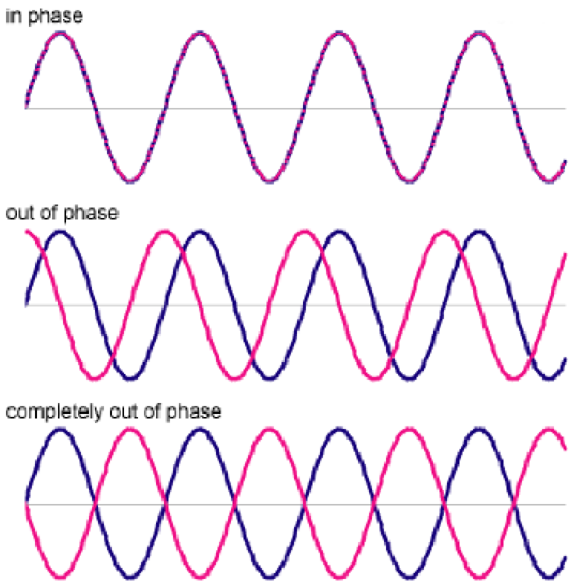
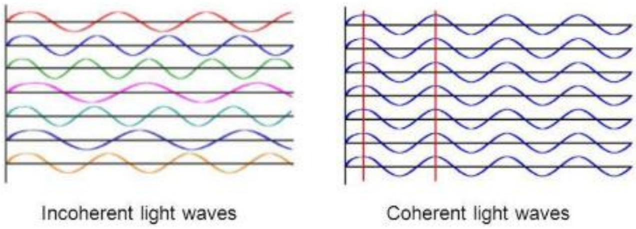
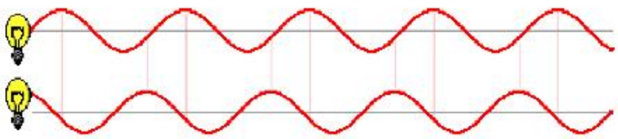
Draw a displacement-distance(with 4 labels) & displacement-time graph (with 1 label)?	

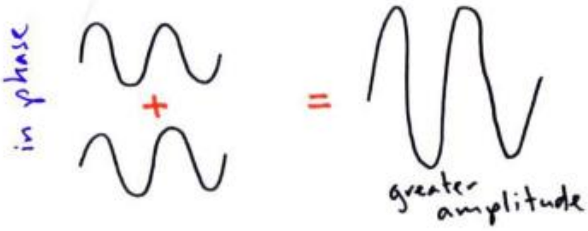
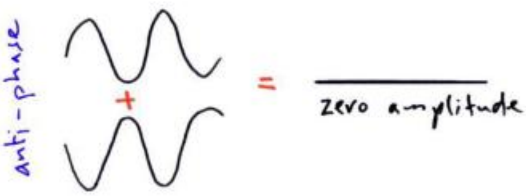
5.64 CORE PRACTICAL 6: Determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone

Describe the method to find the speed of sound using a microphone, oscilloscope and a signal generator	• Connect a microphone to an oscilloscope • Place between a speaker connected to a sig gen and a board (to reflect the sound wave back) • Move the microphone to a position where maximum amplitude is displayed on the oscilloscope • Move the microphone through a further six consecutive positions of max amplitude • Measure the distance, d, between first and last position = 6 half-wavelengths = 3 wavelengths. • d / 3 = wavelength. • Use sig gen to find frequency of sound. • Repeat with six different frequencies • Plot a graph of wavelength on the y-axis and 1/f on the x-axis • Gradient will be speed of sound

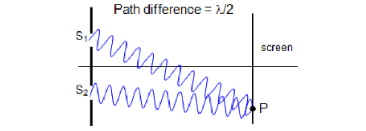
5.65 Know and understand what is meant by wavefront, coherence, path difference, superposition, interference and phase

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  Or... 
How do you convert from radians to degrees? And convert 3/2π to degrees	Radians multiply by 180/π and is 270 degrees
How do you convert from degrees to radians? And convert 315 degrees to radians?	Degrees multiplied by π/180 and is 7/4π
Define wavefront?	A line connecting points in space where the waves are all in phase
Define coherence?	Where there is a constant phase relationship
Define superposition?	● When two or more waves meet and the resultant displacement is the sum of the individual displacements from the individual waves *DO NOT ACCEPT sum of amplitude or any mention of amplitudes* Two or more waves meet (1) The (resultant) displacement (at a point) is the sum of the individual displacements from the individual waves (1) Do not accept sum of amplitudes
What happens when two waves	They **superpose** (1) meaning the resultant displacement is now the

meet? What does this mean?	**vector sum** of the **individual displacements**
When does constructive interference occur?	When **two waves of some whole wavelength, nλ, apart** (otherwise known as in phase) superpose  *The waves constructively interfere to construct a wave of greater amplitude.*
When does maximum destructive interference occur?	When **two waves of some half-wavelength apart, (n+ ½) x λ, apart (otherwise completely anti-phase) superpose**  *The waves destructively interfere to give a wave of zero amplitude.* *Depending on the question out of phase may not be allowed for anti-phase*
Define interference?	Whenever two or more waves combine to produce a resultant wave with a new amplitude

5.66 Be able to use the relationship between phase difference and path difference

What is path difference and what can it lead to?	• 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:*
What is the equation for path difference and answer the question? Two coherent sources emit waves of wavelength λ in phase. At a point where the two waves meet they have a phase difference of 90° ($\frac{\pi}{2}$ radians). Which of the following could be the path difference at this point? $\frac{1}{2}\lambda$ ☐ A 2λ ☐ B λ ☐ C $\frac{\lambda}{2}$ ☐ D $\frac{\lambda}{4}$	• ΔX= (wavelength x $\Delta\varphi$)/ 2π • ΔX = path difference • $\Delta\varphi$ = The phase difference in radians given by question • Wavelength is usually only 1λ but the question would say how many lambda or you could see from a diagram • D is answer waves meet they have a phase difference of 90° ($\frac{\pi}{2}$ radians). Which of the following could be the path difference at this point? ☐ A 2λ ☐ B λ ☐ C $\frac{\lambda}{2}$ ☐ D $\frac{\lambda}{4}$ $\Delta X=\lambda\cdot\Delta\varphi/2\pi$ $\Delta X=\frac{\lambda\frac{\pi}{2}}{2\pi}$ $\Delta X=\frac{\frac{1}{2}\lambda\pi}{2\pi}$ $\Delta X=\frac{\frac{1}{2}\lambda}{2}$ $\Delta X=\frac{\frac{1}{2}\lambda}{2}$ $\Delta X=\frac{\lambda}{4}$

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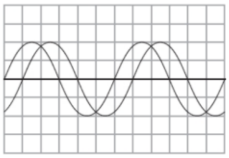
What is the equation for phase difference?

Q13.

A two-beam oscilloscope is used to display signals from two microphones as shown.



Which of the following could be the phase difference in radians between the traces?

☐ **A** $\frac{\pi}{6}$

☐ **B** $\frac{\pi}{4}$

☐ **C** $\frac{\pi}{3}$

☐ **D** $\frac{\pi}{2}$

(Total for question = 1 mark)

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- $\Delta\varphi = \Delta X \times (2\pi/\text{wavelength})$
- ΔX = path difference
- $\Delta\varphi$ = The phase difference in radians given by question
- Wavelength is usually only 1λ but the question would say how many lambda or you could see from a diagram
- C is answer (λ=1) as ⅙ x 2π/λ = π/3

Q13.

Question Number	Answer	Mark
	C $\frac{\pi}{3}$	1
	Incorrect Answers: **A** – incorrect **B** – incorrect **D** – incorrect	

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5.67 Know what is meant by a standing/stationary wave and understand how such a wave is formed, know how to identify nodes and antinodes

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<td>Explain how standing waves are set up including antinodes and nodes (you may wish to sketch a diagram)? SCRIPT</td>
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- Two coherent waves with equal frequency travel in opposite directions (this is usually due to one being reflected)
- The two waves superpose
- Where the waves are in phase constructive interference occurs which results in a maximum amplitude and maximum energy transfer
- Where the waves are in antiphase (180 degrees out of phase) destructive interference occurs which results in a minimum amplitude and minimum energy transfer

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<td>Describe standing/stationary wave?</td>
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- A wave that stores energy instead of transferring it
- The amplitude varies from zero at the nodes to a maximum at the antinodes

A common example is a string fixed at both ends. They are formed by a wave propagating and being reflected so that it comes into superposition with itself

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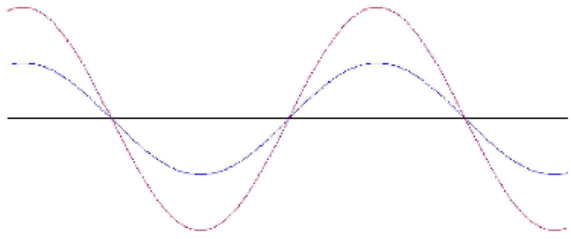
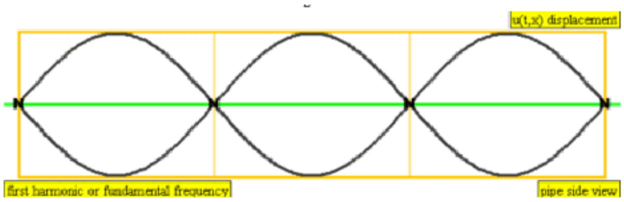
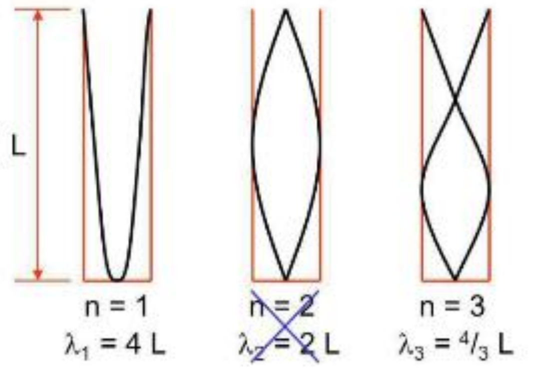
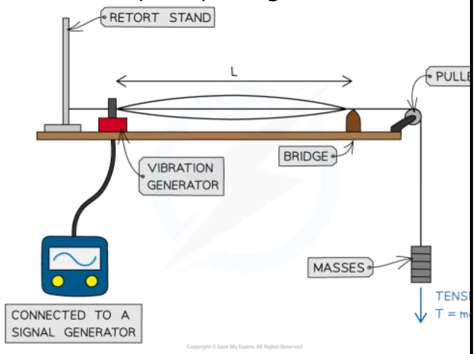
How do standing/stationary waves formed?	By an **incident wave superposing** with its **reflected wave** (essentially, two identical waves propagating in opposite directions  *It is reflected after coming in contact with some surface.*
Why do standing/stationary waves only form under specific frequencies?	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
What is the displacement at the nodes and antinodes of a stationary wave and why?	● 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*
What is 'not present' at a node and why?	Energy as it has zero amplitude
What will you always have at an open and closed end of a standing wave?	● An **antinode** at an **open** end ● A **node** at a **closed** end
What is the distance between two nodes AND a node and antinode	● Two nodes in 0.5λ ● Node and antinode is 0.25λ
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 a completely open/closed tube?	● At the 1st harmonic - l = λ/2 ● At the 2nd harmonic - l = λ ● At nth harmonic - l = n x λ/2 

What is the length of each harmonic for a tube closed at one end?	• At the 1st harmonic - l = λ/4 • At the 3rd harmonic - l = 3λ/4 • At the (2n - 1)th harmonic - l = (2n-1)λ/4 Only the odd numbered harmonics exist 
How to remember where nodes or antinodes are?	**Nod**es occurs at areas of **No d**isturbance

5.68 be able to use the equation for the speed of a transverse wave on a string v=√T/μ

What is the 2 variants of the equation for the wave speed of a transverse wave on a stretched string AND the 2 equations for 2 of the variables? And what does each quantity stand for?	• v=√(T/μ) or v²=T/μ • V = wave speed (ms-1) • T = tension in the string • μ = Density of the string (mass per unit length kg/m) • T = mg • μ = m / L (kg/m)
4 (a) A transverse wave travelling along a wire under tension has a speed v given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the wire and μ is the mass per unit length of the wire. Show that the units on both sides of the equation are the same. (3) • Show that the units on both sides of the equation are the same	• kg/ms-2/kgms-1 = ms-1 The equation for the speed of a transverse wave on a string is given by v=√T/μ, with T=mg and μ= M/L. The units for tension are in Newton's and m is the total mass of the masses in kg. μ should have the units kg/m. 4 (a) A transverse wave travelling along a wire under tension has a speed v given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the wire and μ is the mass per unit length of the wire. Show that the units on both sides of the equation are the same. $\frac{kgms^{-2}}{kgms^{-1}} = ms^{-1}$

5.69 CORE PRACTICAL 7: Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire.

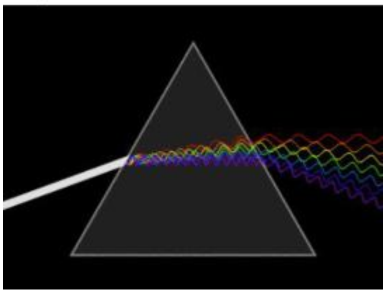
Describe an experiment to find the linear density of a string using standing waves?	● Measure the length of the string with a ruler ● Measure the mass of the string with a balance ● μ = mass / length ● Place a string under tension (using masses, clamp, pulley etc) ● Use T=W=mg to find the tension ● Set up a standing wave (1st harmonic - draw and level) using a signal generator and vibration generator to change the frequency ● Measure length of string between 3 consecutive nodes (or between clamp and pulley) = 1 wavelength ● Change tension by adding masses to the hanger use 6 different masses (100g -> 600g) and repeat the above for each ● Read frequency from signal generator ● Calculate speed of the wave from $v=f\lambda$ ● As $v = \text{sqrt}(T/\mu)$ then $v^2 = T/\mu$ ● Plot a graph with v^2 on the y-axis and T on the x-axis ● Gradient = $1/\mu$ so μ = 1/gradient 

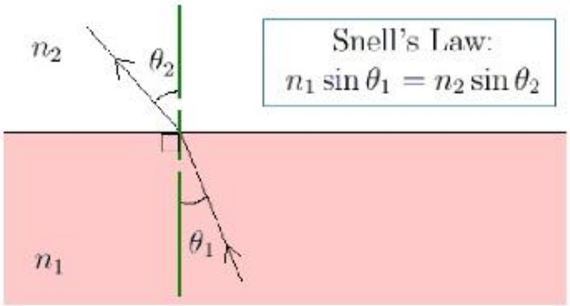
5.70 Be able to use the equation intensity of radiation I=P/A

What is the intensity equation? And units for each quantity	● I=P/A ● $I\sin(\Theta)=P/A$ (if the radiation is not perpendicular to the object)

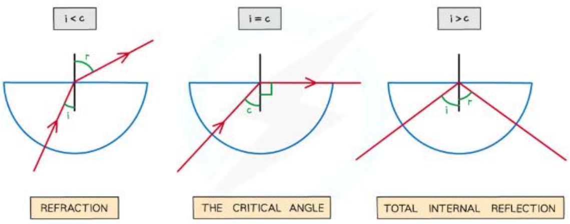
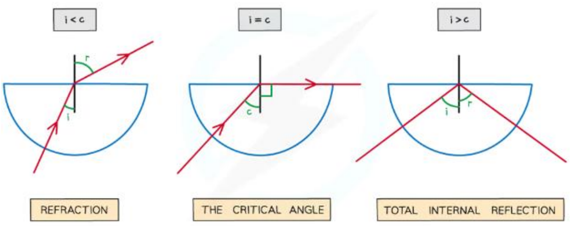
	● $Wm^{-2} = W/m^2$
What is the intensity equation for spherical waves (a wave from a point source that spreads out equally in all directions)?	$I=P/4\pi r2$
How is intensity proportional to amplitude?	Intensity is proportional to amplitude squared ($I = A^2$)
How is intensity proportional to frequency?	Intensity is proportional to frequency squared ($I = f^2$)
What are the assumptions when doing an intensity calculation?	● Inverse square law applies ● Radiation is perpendicular to object

5.71 Know and understand that at the interface between medium 1 and medium 2 $n_1\sin\theta_1 = n_2\sin\theta_2$ where refractive index is $n = c/v$

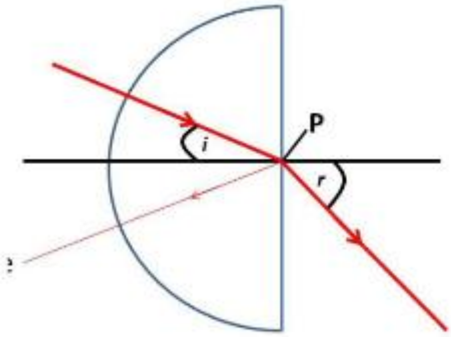
What is refraction?	● When a wave changes direction as it moves from one medium to another ● **T**owards **A**ir **G**lass **A**way **G**lass **A**ir
What remains constant under refraction	Frequency (Wavelength,Speed of light and amplitude change)
Which wavelength refracts more?	● A shorter wavelength ● (as light with higher frequency [shorter wavelength] interacts more strongly with these atoms because it is closer to the resonant frequency. As a result it is slowed down more by its interaction, and has a larger index of refraction) 

	This is for every substance you'll encounter in this course
What is Snell's law? And two arrangements	• $n_1\sin\Theta_1 = n_2\sin\Theta_2$ • $n_1/n_2 = \sin\Theta_2/\sin\Theta_1$ 
What is the refractive index of air?	Approximately one

5.72 Be able to calculate *critical angle* using sinC=1/n

Define critical angle? (1)	• The angle of incidence in an denser medium at which the angle of refraction in the less dense medium is 90 degrees (1) *The ray would travel along the boundary of the medium* 
What is the formula for the critical angle and draw the diagram to explain it	Sin(C) = 1/n • C = critical angle • n = refractive index 
What happens when the incident angle = the critical angle?	The angle of refraction is 90 degrees (so it travels along the boundary)

5.73 Be able to predict whether total internal reflection will occur at an interface

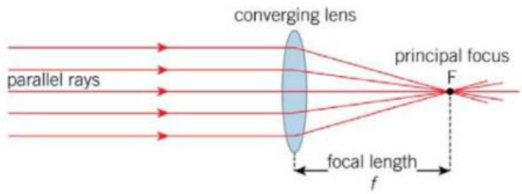
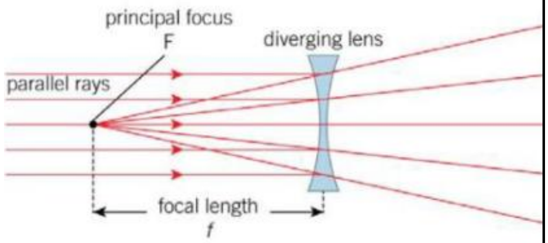
Give the two conditions needed and what happens to light for total internal reflection to occur	● Light must be travelling from a more dense to a less dense medium ● The angle of incidence is greater than or equals to the critical angle ● All of the light is reflected
Why is a semi-curricular block often used for total internal reflection? 	As you want the curved side to have an angle of incidence of 0 degrees

5.74 Understand how to measure the refractive index of a solid material

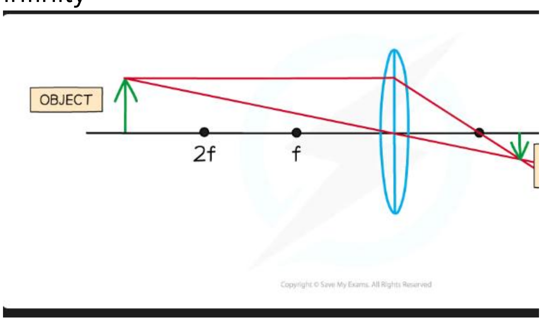
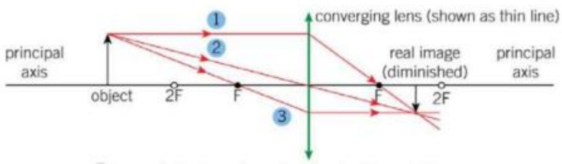
What is the absolute refractive index?	It is a ratio of speeds m/s / m/s -> has no unit $n = \frac{c}{v}$ *c is the speed of light in the substance*

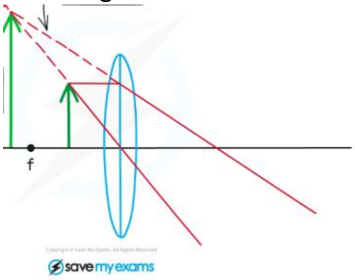
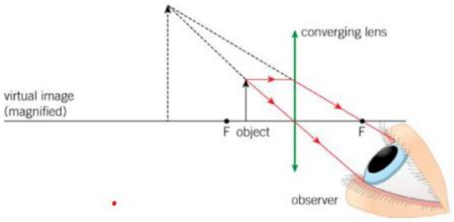
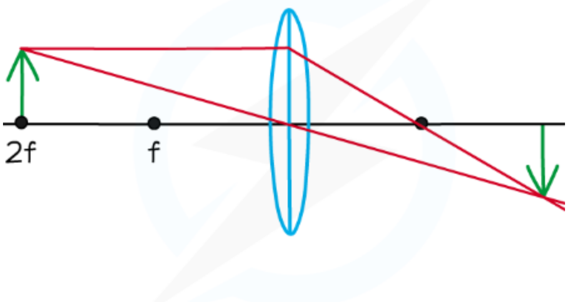
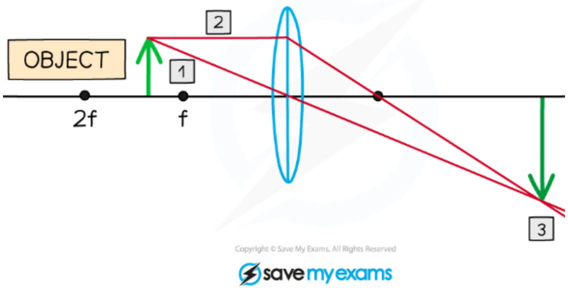
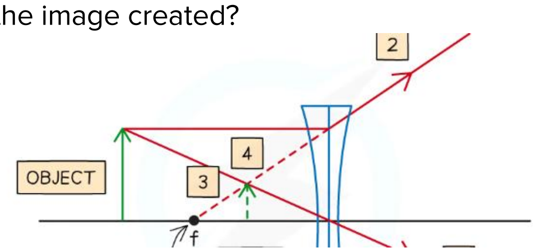
5.75 Understand the term focal length of converging and diverging lenses

Define Focal length?	The distance from the centre of the lens to the principal focus
Draw the principal focus / focal point and ray diagram for a converging lens with rays?	The point where rays parallel to the principal axis are focused to

	
Draw the principal focus / focal point in a diverging lens with rays?	The point where diverging rays from rays parallel to the principal axis appear to come from 
How does distance to lens affect image clarity?	The closer it is to the principal focus (yet is greater than > the focal length) the further a clear image is formed by the lens *This is because the lens can only bend the light so much, otherwise you need a stronger lens*

5.76 Be able to use ray diagrams to trace the path of light through a lens and locate the position of an image

What are the three descriptions to describe the image created?/ What is the ray diagram for object lying between focus and infinity 	• Real • Diminished (smaller) • Inverted 

What are the three descriptions to describe the image created?   	● Virtual ● Enlarged (magnified) ● Upright *This is essentially a magnifying glass*
What are the three descriptions to describe the image created?  	● Real ● Same size as the object ● Inverted
What are the three descriptions to describe the image created?  	● Real ● Enlarged (magnified) ● Inverted
What are the three descriptions to describe the image created?  	● Virtual ● Diminished ● Upright

5.77 Be able to use the equation power of a lens P=1/f

What is the equation for a lens's power with what each quantity is and units?	$P=1/f$ P = power (Dioptres) f = focal length (m)

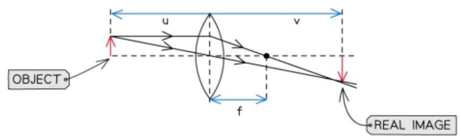
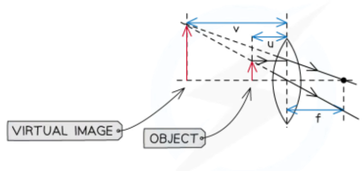
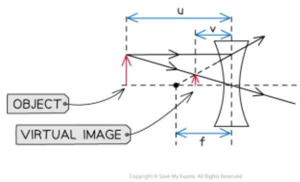
5.78 Understand that for thin lenses in combination $P=P_1+P_2+P_3+...$

Destine has the focal length and power of 3 thin lenses would you add the focal length or the power of the lenses to find the combined power/focal length and write equation	• Add the powers • $P_T=P_1+P_2+P_3$

5.79 Know and understand the terms real image and virtual image

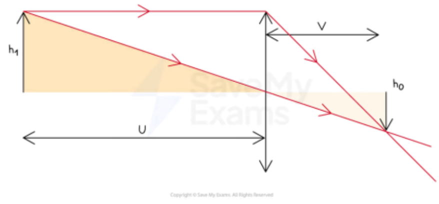
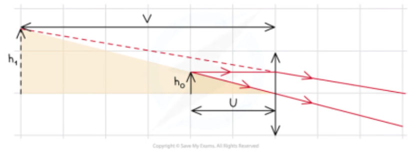
Define Real image?	A real image forms on a screen and is always on the opposite side of the lens to the object
Define Virtual image?	A virtual image cannot form an image on a screen and forms on the same side of the lens as the object
Define Upright? (1)	The image is in the same orientation as the original object (or same way up) (1) *Do not except not inverted*
Define Inverted?	The image is in the opposite orientation as the original object (or opposite way down) *Do not except upright*

5.80 Be able to use the equation 1/u + 1/v = 1/f for a thin converging or diverging lens with the real is positive convention

What is the thin lens equation? And what does each quantity mean?	$1/f=1/u+1/v$ • f = focal length (which is positive for real images and negative for virtual images) • u = object distance from lens • v = image distance from lens    *This equation only work for a thin converging or diverging lenses* *If the values are positive then the image is real and vice versa* ***THE ANSWER FOR FOCAL LENGTH CAN BE NEGATIVE***

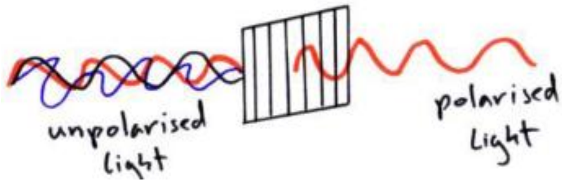
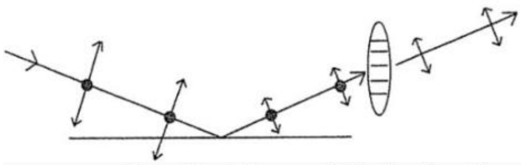
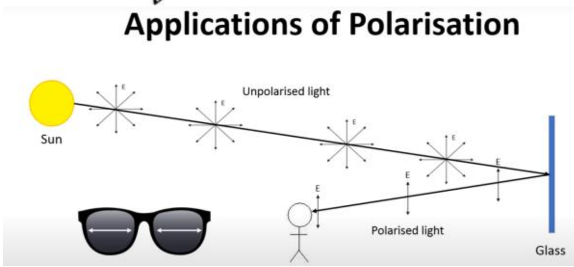
5.81 Know and understand that magnification = image height/object height and m = v/u

What are the 2 equations for the ratio of magnification?	$m=v/u$ $m=h_i/h_o$ • v = distance from lens to image • u = distance from lens to object • h_i = image height • h_o = object height *When subbing v or u into equation and its a virtual image you do need negative*

	 *sign* 

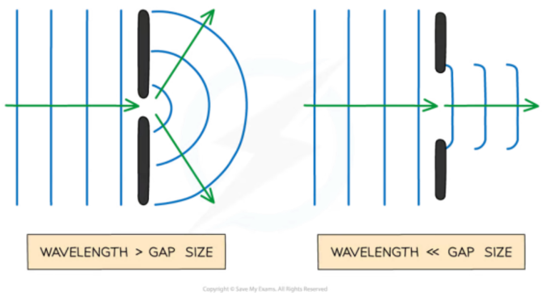
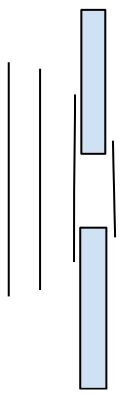
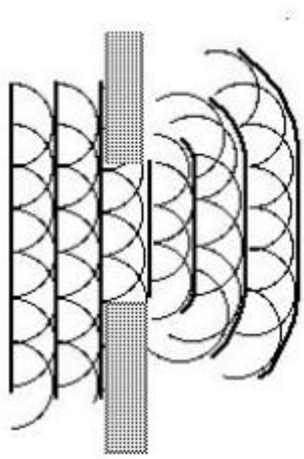
5.82 Understand what is meant by plane polarisation

Define plane polarisation? (2)	Where the oscillations of a wave occur only in a single plane (1) which includes the direction of propagation (1) *Unpolarised - where the oscillations of a wave occur in all planes*
Explain what is observed when two plane-polarising filters are rotated on top of each other?	• When unpolarised light passes through the first filter it becomes plane polarised with oscillations only in the plane of polarisation of the filer • The rest of the light is absorbed • If the second filter is orientated in the same way as the first filter then the polarised light is transmitted and maximum intensity is observed • As the second filter is rotated to 90 degrees the polarised light is no longer transmitted through the second filter and a minimum intensity is observed • A further 90 degrees rotation would result in maximum intensity gain and so on
What type of waves cannot be polarised and why?	• Longitudinal waves • As there oscillations always occur in one direction - parallel in the direction of the way - so there is no need to distinguish between ‘ different’ oscillation directions as there is 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 then new waves 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  

5.83 Understand what is meant by diffraction and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle

What are laser's sources of?	Coherent monochromatic light
What is monochromatic light?	Light of a single frequency/wavelength

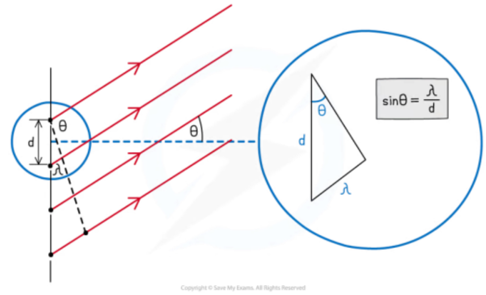
What wavelengths diffract more and why	● **Longer wavelengths** because they have a lower frequency so less energy The **more energy** a wave has the **greater** its **tendency** to travel in a **straight line** *Think of p = mv*
State the conditions for maximum diffraction to occur?	When the wavelength and aperture (size of gap) /object are approximately equal sized
What are the factors that effect diffraction?	Diffraction is most effected when the gap sized or obstacle is approximately the same or smaller than the wavelength of the wave ● *As the size of the gap or obstacle increases, the effect gradually gets less pronounced* ● *When the gap is much larger than the wavelength the waves are not longer spread out* 
Illustrate diffraction through the gap below using Huygen's construction? And draw three more wavefronts? 	

5.84 Be able to use nλ = dsinθ for a diffraction grating

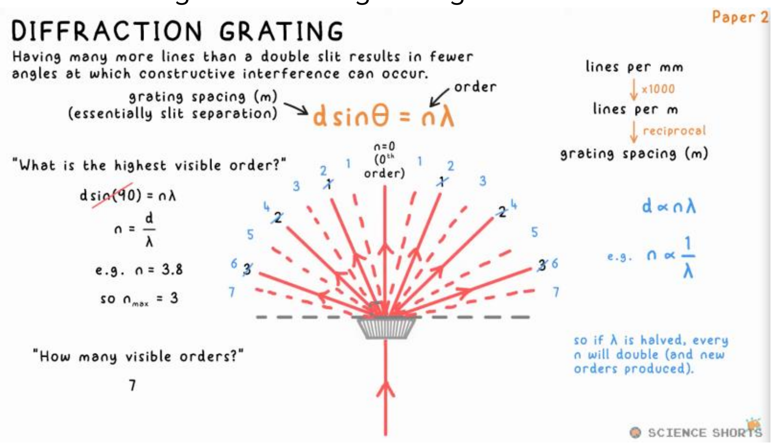
What is each variable in the formula for diffraction gratings?	See list below

What is each variable in the formula for diffraction gratings?

$$d \sin(\theta) = n\lambda$$

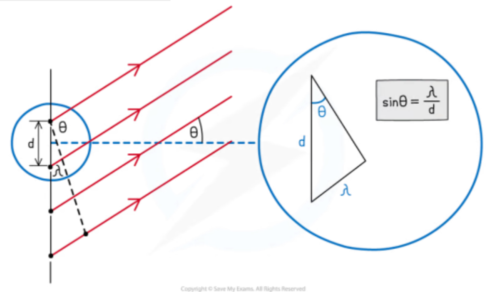


- nλ = dsinθ
- d being the distance between two adjacent slits
- Θ being the angle to maxima of interest from central maxima
- n being the order of maxima
- λ being the wavelength of light

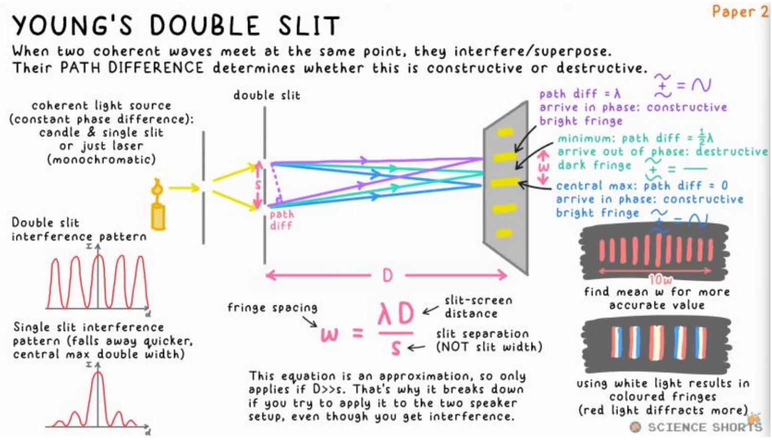


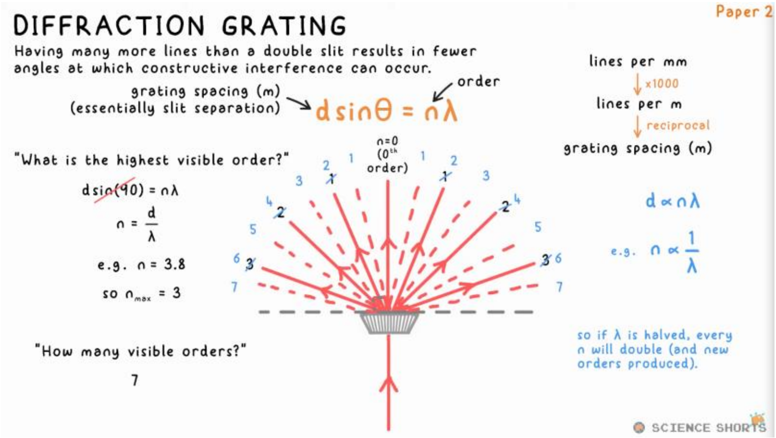
What is each variable in the formula for diffraction gratings?
For fringe distance

$$n\lambda = dx/D$$



- nλ = dx/D
- n being the order of maxima
- λ being the wavelength of light
- d being the distance between two adjacent slits
- x being the fringe distance from central maxima
- D being the distance between grating and screen



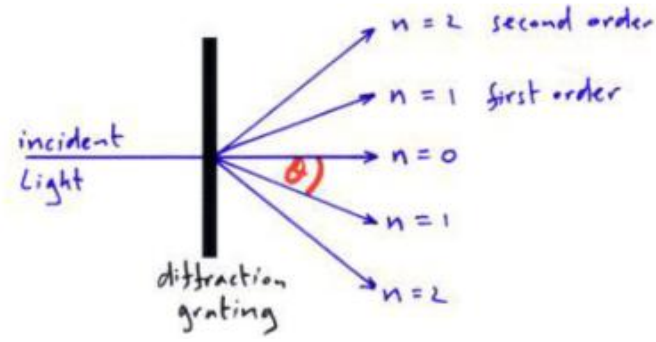
What is the equation for the spacing of slits? And calculate the spacing of slits for 100 lines per mm AND also calculate the number of lines per mm for $2x10^{-5}$ m $$d = \frac{1}{N}$$	• d being the distance between two slits • 1(x10x) being the lines per unit length (mm or nm etc = the power x) • N being the number of slits • $1x10^{-3}/100 = 1x10^{-5}$m • And • $1x10^{-3}/2x10^{-5}$ = 50 lines per mm 
How can you work out the maximum order of a diffraction grating?	By setting Θ to 90 and finding the lowest integer below n

5.85 CORE PRACTICAL 8: Determine the wavelength of light from a laser or other light source using a diffraction grating.

(b) A diffraction grating can be used to analyse the radiation emitted by a variety of sources. (i) A diffraction grating of known grating spacing is used in a school laboratory to analyse the light emitted by a laser. Describe how the diffraction grating is used and the measurements that should be taken. (3)	• set up diffraction grating at right angles to light from laser **Or** set up grating parallel to screen (1) • measure the distance between the diffraction grating and the screen (1) • measure the distance between 1st order images on the screen (1) An annotated diagram could score these marks MP3 accept between other correct specified orders.

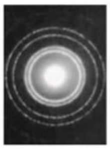
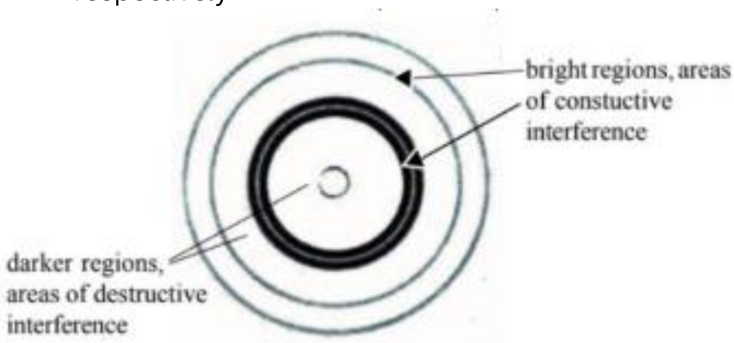
5.86 Understand how diffraction experiments provide evidence for the wave nature of electrons

Describe the evidence that suggests light is a wave, and the evidence that suggests the particle nature of light?	Interference patterns and diffraction suggest that light behaves as a wave and emission spectrum and photoelectric effect suggests that light behaves as a particle
What is diffraction grating? What does it do?	A piece of glass with closely spaced parallel lines which splits light into a spectra

	
Explain how in a double slit experiment how bright and dark fringes are produced between each maxima. You should refer to the ideas of phase, path difference and interference?	● Passing light through slits creates 2 coherent monochromatic light sources ● Each source acts as a point source and light diffracts out ● Each wave can now interfere with the others and a pattern is seen on screen produced by superposing waves ● If the waves incident on the screen superpose when in phase with a path difference of nλ = constructive interference = bright fringe ● If the waves superpose when in antiphase with path difference of nλ + λ/2 = destructive interference = dark fringe

5.87 Be able to use the de Broglie equation λ=h/p

What is the de Broglie wavelength?	The wavelength of matter
What is the de Broglie equation?	λ=h/p
Define stopping potential	The minimum voltage required to stop electrons moving and reaching the anode
What is the equation linking $E_{k\ (max)}$ to stopping potential?	$0.5mv^2 = eV = E_{k\ (max)}$ *As V = E/Q, multiplying it by the charge of an electron gives J*
What is the rearrangement of the stopping potential equation to find the velocity of the electron?	● $0.5mv^2 = eV = E_{k\ (max)}$ ● $v = \sqrt{\frac{2eV}{m}}$
What is the equation linking frequency to stopping potential?	hf = eV = E *As V = E/Q, multiplying it by the charge of an electron gives J*

5 The image shows a diffraction pattern formed when a beam of electrons passes through thin metal foil.  Which of the following would cause the diameter of the rings to increase? ☐ **A** Decreasing the number of electrons in the beam. ☐ **B** Decreasing the speed of electrons in the beam. ☐ **C** Increasing the number of electrons in the beam. ☐ **D** Increasing the speed of electrons in the beam. Which one?	● B - decreasing the speed of electrons in the beam ● As $\lambda=h/p$ therefore decreasing $p=mv$ increases wavelength increasing diameter
How can the wave-like nature of electrons be observed?	1. Fire electrons via crystalline structure causing them to diffract onto a fluorescent screen 2. An illuminated pattern of concentric bright and dark circles is formed corresponding to areas of constructive and destructive interference respectively  *These are fired by accelerating them through a potential difference. A larger potential difference would mean they're accelerated more and gain more kinetic energy leading to a smaller wavelength and thus less diffraction so closer rings*
What structure is required for electron diffraction and why?	● Crystalline structure ● The gaps between atoms is approximately equal to De Broglie wavelength of electron for maximum diffraction to occur

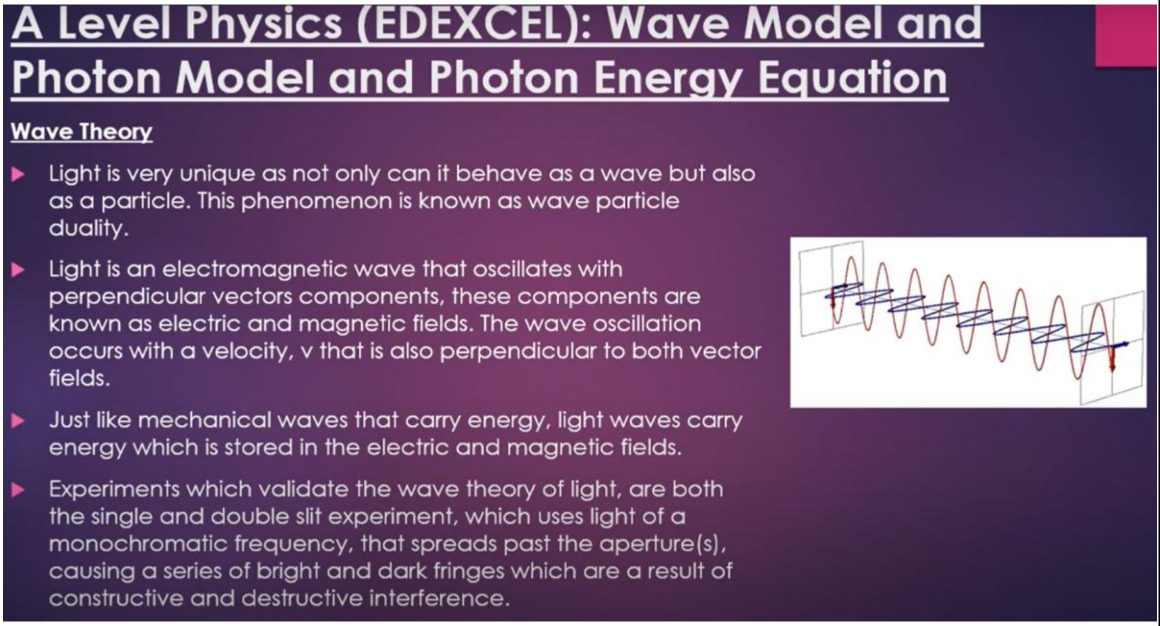
5.88 Understand that waves can be transmitted and reflected at an interface between media

5.89 understand how a pulse-echo technique can provide information about the position of an object and how the amount of information obtained may be limited by the wavelength of the radiation or by the duration of pulses

What are two uses of the pulse-echo technique?	Foetal scanning and sonar
What is the equation for calculating the wave speed or the time of a flight of a pulse and define each variable?	● 2d/v = t ● 2d being the distance to and from an object ● v being the wave speed ● t being the time of flight of a pulse
What are the limitations of ultrasound?	● The wavelength of the radiation ● The duration of the pulse (A feature can only be resolved if the pulse duration is < 2d/v) ● Duration of the pulse must be shorter than the transit time otherwise the transducer is still emitting the wave whilst at the same time tring to detect it ● Pulse repetition frequency = 1/transit time (f=1/T)

PARTICLE NATURE OF LIGHT NO!

5.90 understand how the behaviour of electromagnetic radiation can be described in terms of a wave model and a photon model, and how these models developed over time

<table>
<tr>
<td>Wave model</td>
<td>


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<tr>
<td>Photon model</td>
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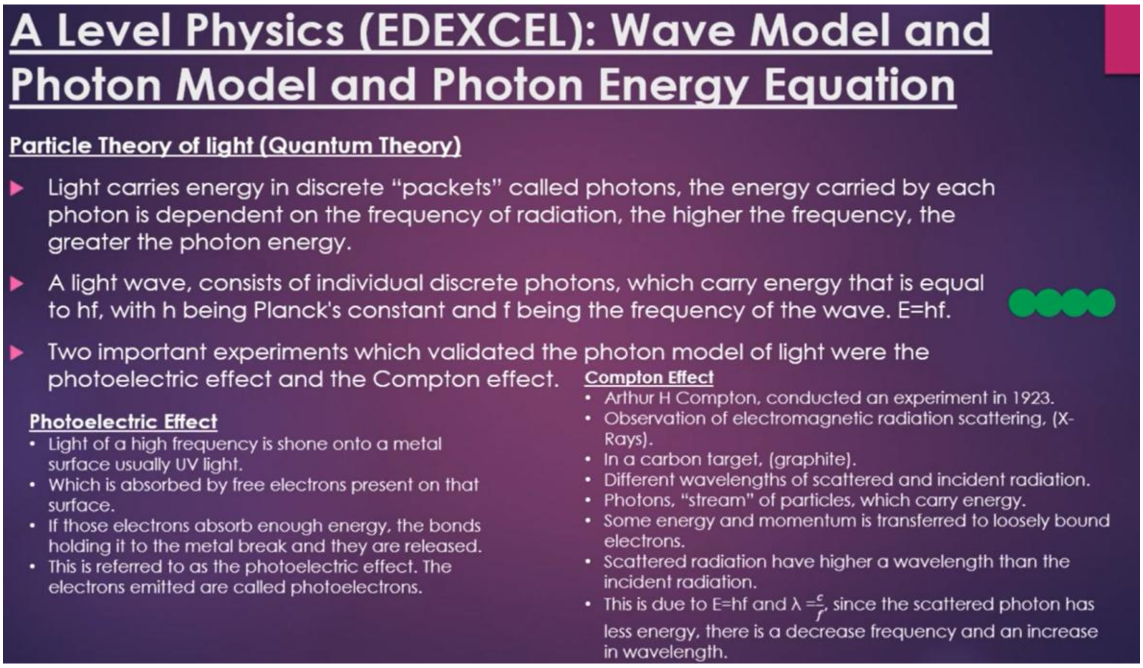

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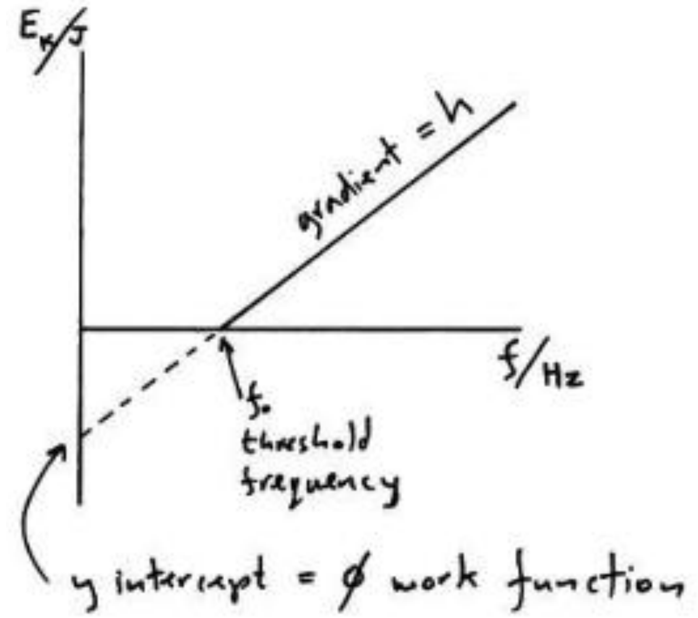
5.91 Be able to use the equation E = hf, that relates the photon energy to the wave frequency

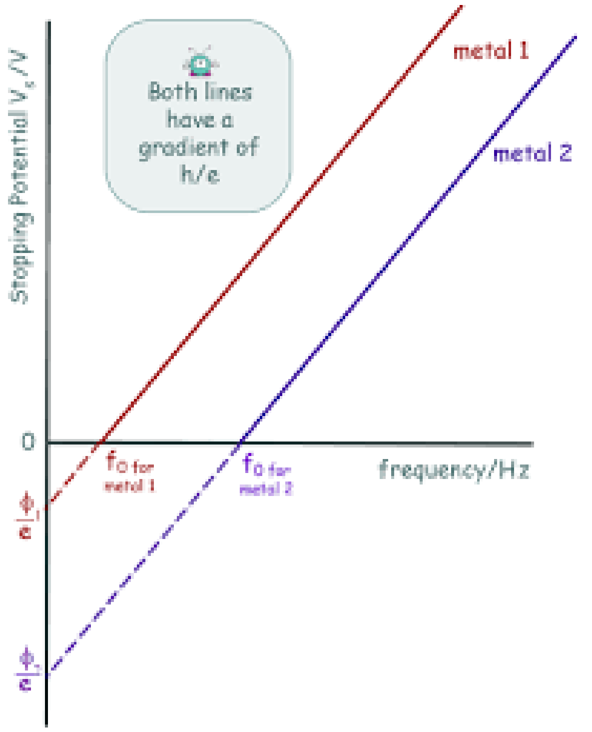
What are the equations linking energy and frequency, energy and wavelength?	• $E=hf$ • $E=hc/\lambda$

5.92 Understand that the absorption of a photon can result in the emission of a photoelectron

5.93 Understand the terms *threshold frequency* and *work function* and be able to use the equation $hf = \varphi + 1/2\ mv^2_{max}$

What is the work function?	The minimum energy required to liberate an electron from the surface of a metal
Define Threshold Frequency (f_0) under the photoelectric effect?	The minimum frequency so that the photon has energy equal to the work function
What is the work function equation and why do photoelectron kinetic energies vary to a maximum?	• $hf = \varphi + 1/2\ mv^2_{max}$ • Each photon energy is the same (due to frequency) therefore more energy is required to remove electrons further from the surface due to more attraction

<table>
<tr>
<td>How does the photoelectric effect equation look when plotted as a line? And what does the x,y intercept and gradient mean</td>
<td>


- The y-intercept being the work function
- The x-intercept being the threshold frequency
- The gradient being planck's constant
- Straight line with positive gradient
- KE_{max} = hf - φ (y=mx+c)
</td>
</tr>
<tr>
<td>What does the photoelectric effect equation look like when stopping potential is on the y axis and frequency on the x axis</td>
<td>


- The y-intercept being the work function
- The x-intercept being the threshold frequency
- The gradient being planck's constant
- Straight line with positive gradient
- V = (h/e)f - φ/e (y=mx+c) from eV=hf-φ
</td>
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</table>

What is the equation energy change of energy levels in the eV equation? / What is the excitation/de-excitation amount determined by? Lets say the ground state = -7.3eV and n=1 -3.5eV what is the energy that a photon needs to absorb to jump from the ground state to n=1	● $E_1 - E_2 = hf$ ● -3.5 - (-7.3) = 3.8eV *Tip: when dealting with these question minus the higher eV from the lower eV to get a positive difference*

5.94 Be able to use the electronvolt (eV) to express small energies

How would you convert from 1eV to J?	1eV x $1x10^{-19}$ = $1x10^{-19}$ J
How would you convert from 10J to eV?	10J / $1x10^{-19}$ = $1x10^{20}$ eV
What are the wavelengths of the EM spectrum radiations?	● Radio | 1mm - 100km ($1x10^{-3}$ to $1x10^{3}$) | ● Micro | 30cm - 1mm ($3x10^{-3}$ to $1x10^{-3}$)| ● Infrared | 780nm - 1000µm ($7.8x10^{-7}$ to 1x10-3 | ● Visible light | 400-700nm ($4x10^{-7}$ to $7x10^{-7}$) | ● UV light | 100-380nm ($1x10^{-7}$ to $3.8x10^{-7}$) | ● X-Rays | 0.03-3nm ($3x10^{-11}$ to $3x10^{-9}$ | ● Gamma rays | less than 0.01nm ($1x10^{-11}$) |

5.95 Understand how the photoelectric effect provides evidence for the particle nature of electromagnetic radiation

<table>
<tr>
<td>Explain the photoelectric effect? (7 points)</td>
<td>

- A photon (a packet of energy) is absorbed by an electron on the surface of a metal in a 1:1 interaction
- If the photon has energy greater than the work function then the electron is liberated from the surface of the metal
- This only occurs if the frequency of light is greater than the threshold frequency as E=hf
- Any remaining energy is transferred to the photoelectron as kinetic energy
- $E_{photon} = \varphi + E_k$
- $hf = \varphi + 0.5mv^2$
- If the frequency of light is below the threshold frequency then the photon has energy less than the work function and no electrons are liberated
- Changing the intensity of the light has no effect on the energy of the photon and only affects the rate of release of the photoelectrons and not their kinetic energy

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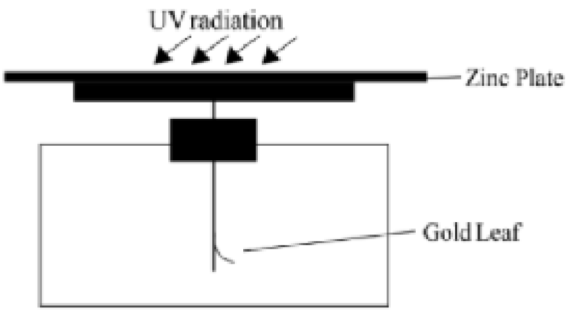
<tr>
<td>What happens during the gold leaf experiment?



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<td>

- The zinc rod/plate is negatively charged -> gold lead hangs tilted
- Shining UV light causes it to discharge -> leaf falls down

</td>
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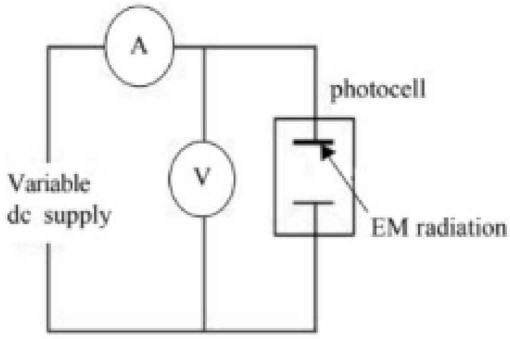
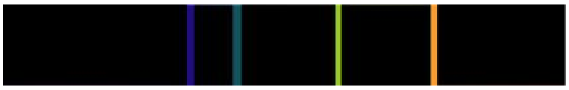
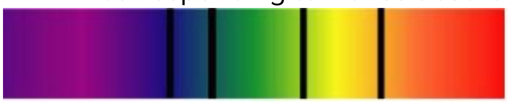
</table>

What 4 observations made under the photoelectric effect support the particle theory over the wave theory?	- Electrons are only emitted above a threshold frequency (f_0); irrespective of intensity - The KE(max) of emitted electrons depends on the frequency of EM radiation - The no. of photoelectrons emitted per second depends on the intensity of EM radiation - Low intensity EM radiation (above f_0) results in the immediate emissions of electrons
Why does ' electrons being emitted above f_0 despite intensity' support the particle theory over the wave theory?	- Wave theory - light consists of waves with energy ∝ intensity -> greater intensity should cause emission of photoelectrons regardless of frequency - Particle theory - light consists of photons with energy E=hf and the metal emits photoelectrons when f >= f_0 *For the wave theory, imagine shining a lot of light onto one square metre*
Why is '$K_{E(max)}$ depending on the frequency of EM' support the particle theory over the wave theory?	- Wave theory - energy ∝ intensity -> greater intensity means higher K_E electrons - Particle theory - the $K_{E\ (max)}$ depends on frequency and work function as defined by $K_{E(max)} = hf - \phi$
Why does ' the no. of photoelectrons per second depends on the intensity of the EM radiation' support the particle theory over the wave theory?	- Wave theory - greater frequency to which that are more waves arriving per second -> intensity should have no effect - Particle theory - the no of photons arriving per second depends on intensity -> each photon has a fixed energy and one electron absorbs a photon in a one to one interaction

Why does 'low intensity EM radiation (above f_0) resulting in immediate emission of electron' support the particle theory over the wave theory?	• Waves theory - energy ∝ intensity -> lower intensity means it must take time for energy to accumulate to free an electron • Particle theory - no of electrons emitted ∝ intensity -> whilst few arrive for low intensity they still have sufficient energy during immediate electron emission
Describe the vacuum photocell	 • The metal surface is the anode (-> positively charged so can attract e^-'s back) • Light with frequency > f_0 is shone on the anode so that photoelectrons are emitted • Applying a sufficient p.d will cause electrons to be attracted back -> current flows • The photocell is evacuated to prevent photoelectrons colliding with air molecules

5.96 Understand atomic line spectra in terms of transitions between discrete energy levels and understand how to calculate the frequency of radiation that could be emitted or absorbed in a transition between energy levels.

Definition for a photon?	• Discrete quantity of energy *Packet/quantum are accepted*

Define ground state?	Lowest energy level
What is de-excitation?	When an electron moves from a higher energy level to a lower energy levels whilst emitting a photon of a fixed frequency
Explain why energy levels are given negative values (e.g. the ground state of hydrogen (Miss Hartley script)	● Electrons that are unbound have 0 potential energy ● When electrons enter into lower energy states they lose potential energy ● Therefore as they are below 0 they must have negative values
What is an emission spectrum and an absorption spectrum?	● An emission spectrum is a spectrum of electromagnetic radiation emitted from electrons de-exciting  ● An absorption spectrum is a spectrum of electromagnetic radiation transmitted via a substance with dark vertical lines corresponding to waves absorbed 
Explain how emission/absorption lines form and how this is evidence for electrons existing in certain energy levels in the atom? 5 points	● Electrons exist in discrete energy levels ● Electrons when excited jump up to a higher energy level by absorbing a photon in a 1:1 interaction ● When an electron falls down to a lower energy level it emits a photon with energy in the visible light region proportional to the frequency of light via $\Delta E=hv$ ● The photon has energy/frequency equal to the difference in energy levels ($E_{photon} = E_2 - E_1$) ● Limited number of possible energy levels transitions and so only specific frequencies/wavelengths are emitted (N.b. the same argument can be used for absorption lines, but the electron moves up energy levels and absorbs photons/light)

	(N.b. this argument can also be used to show that light behaves as a particle - however, the starting point is that electrons exist in discrete energy levels) *N.B is used in writing to indicate that something is important, and that the reader should take notice of it*
What can you use to view the spectrum of light (emission/absorption) source using?	A diffraction grating or a spectrometer