REVISION: WAVES, SOUND & LIGHT 11 JUNE 2013

Lesson Description

In this lesson we revise:

- the Doppler Effect, Huygens' Principle, Diffraction of Light & the Photoelectric Effect

Key Concepts

The Doppler Equation

The Doppler Effect is the change in observed frequency (pitch) as a result in a difference in the velocities of the source and listener.

When the source or observer are moving towards each other the frequency increases.

When the source or observer are moving away from each other the frequency decreases.

The Doppler Equation

The Doppler equation uses a fraction made of the velocities of the waves, the source and the listener to change the source frequency.

The fraction is:

$$\left(\frac{v \pm v_L}{v \pm v_S}\right)$$

Where "v" is the velocity of the waves, "v_L" is the velocity of the listener and "v_S" is the velocity of the source.

We choose "+" or "-" so that the fraction becomes bigger (for objects getting closer) or smaller (for objects moving away from one another).

Combining it into one equation:

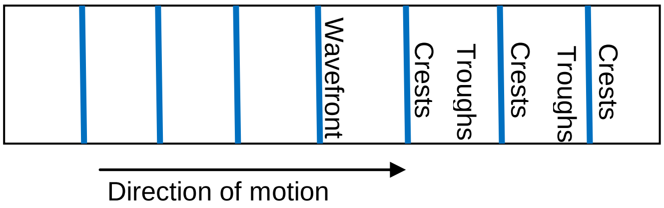
$$\therefore f_L = \left(\frac{v \pm v_L}{v \pm v_S}\right) f_S$$

Wavefront

An imaginary line that connects particles in medium that are adjacent to each other and are moving in phase as the wave moves through the medium.

Example: Water wave

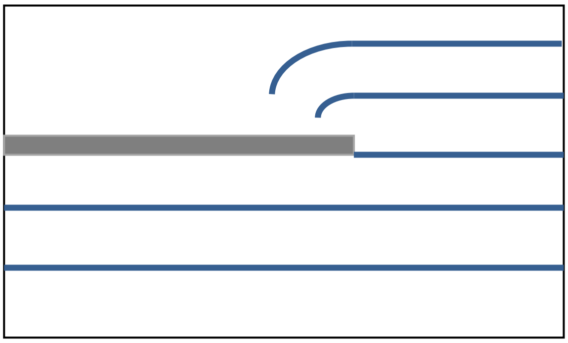
In a water wave there are many adjacent particles that form a crest. A straight line can be drawn to connect these particles which form a wavefront. Imagine looking at water waves moving through a tank of water from above. The diagram of the top view shows all the particles of a crest as a line and the trough as a space until the next crest



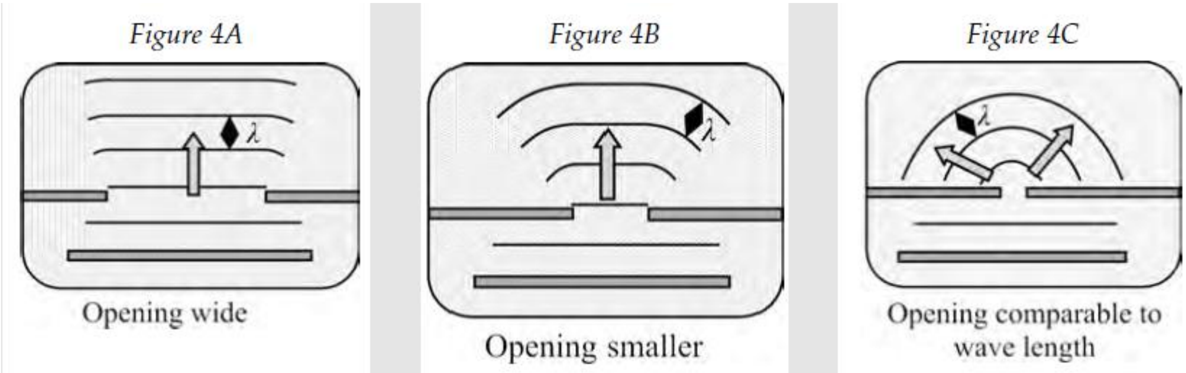
Diffraction

Diffraction is the ability of waves to spread around an edge or gap.

Diffraction of water waves around a barrier



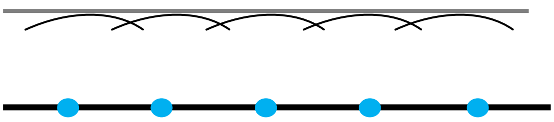
Diffraction of water waves through a gap



Notice that the amount of diffraction is greater when the size of the gap is smaller than the wavelength of the waves

Huygens' Principle

- All points on a wave front act as new point sources.
- These point sources each produce small circular wavelets with the same frequency, wavelength speed of the wave. They spread out in the forward direction.
- The new wavefront is formed by adding the all wavelets together. We draw a tangent to the wavelets to show the new wavefront.
- The parts of the wavelets that are not moving forward will cancel each other out by destructive interference



Interference

When waves from different sources move through the same medium, at the same time they will interfere with each other and then continue moving through the medium in their original directions.

There are two types of interference:

Constructive Interference

When two waves of the same frequency meet at the same position and are in phase with each other, constructive interference takes place. We determine the amplitude of the wave produced by constructive interference by the principle of superposition. We add the amplitudes of the individual waves together to form a wave with a larger amplitude than either of the original waves.

Destructive Interference

When two waves of the same frequency meet at the same position and are out of phase with each other, destructive interference takes place. The amplitude of the new wave will be less than the amplitude of the larger original wave.

Interference can take place with water waves, waves on a string, sound waves and electromagnetic waves including light.

Interference is a wave property. Particles never interfere with each other.

Diffraction of light

Single slit experiment

When monochromatic light from a laser passes through a single slit a pattern of coloured and dark bands appears on a screen. There is a bright central coloured band then a small dark band, followed by a smaller dimmer coloured band and then another dark band and another smaller coloured band.

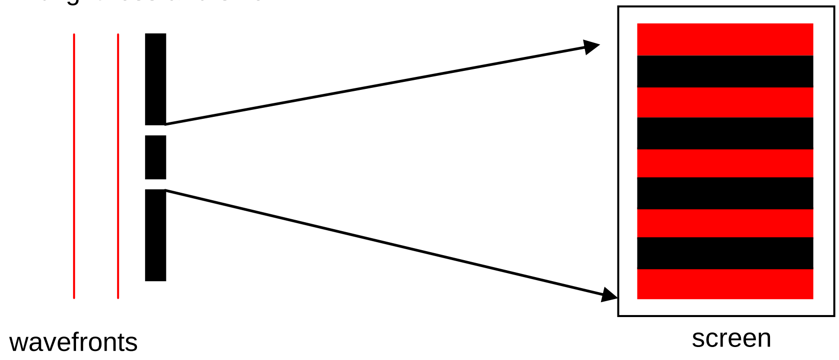
We can only explain this pattern by applying Huygens' Principle. Each point in the slit is a treated as a source of light. The light produced by these sources is of the same frequency and they are in phase. The light waves interfere with each other constructively to form the bright coloured bands and interfere destructively to form the dark banks.

The relationship between the slit width (a), wavelength and angle to the dark bands is approximately:

$a \sin \theta = m.\lambda$ where $m = \pm 1; \pm 2$ ..... (the number of dark band)

Young's Double Slit Experiment

Thomas Young passed sunlight through a barrier containing two small slits positioned close to each other. A series of bright and dark bands formed on a screen. The bright bands were of similar brightness and size.



The interference pattern observed in Young's Experiment is evidence that light has a wave nature.

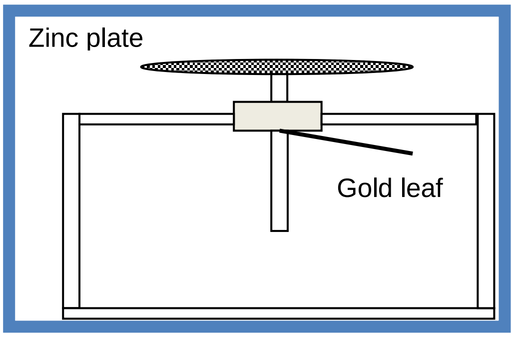
Photoelectric Effect

Photoelectric effect is a phenomenon observed when electromagnetic radiation of a certain frequency falls onto a metal surface and causes electrons to be ejected from the surface.

Electrons are not ejected from metal surfaces when electromagnetic radiation with a low frequency of falls on them.

Threshold frequency is the minimum frequency needed to cause electrons to be ejected from a metal surface. Different metals have different threshold frequencies.

Demonstration of photoelectric effect



- Charge a gold leaf electroscope negatively.
- Allow red light of different intensities to shine on the zinc metal of the gold leaf electroscope and observe what happens.
- Allow Ultraviolet radiation of different intensities to shine on the negatively charged electroscope and observe what happens.
- Use a specific intensity of UV for a long time onto the zinc plate and observe further what happens.

Discussion of Observations

- When red light of different intensities is shone onto the zinc surface of the negatively charged gold leaf electroscope, nothing happens to the leaves. This is because the frequency of red light is less than the threshold frequency of the zinc metal. When the frequency of electromagnetic radiation is less than the threshold frequency, no electrons will be ejected even if the intensity is increased.

- When UV radiation shines onto the zinc surface of the negatively charged electroscope, the gold leaves collapse. The gold leaves collapse because the electrons are now ejected on the surface of the zinc metal so that the force of repulsion between the leaves becomes less. The frequency of UV radiation is greater than the threshold frequency of zinc metal. Electrons are ejected even at low intensity. When the intensity of UV is increased, the number of photons bombarding the zinc surface. So more electrons absorb the energy from the photons and more electrons get ejected from the metal surface.

- When the gold leaf electroscope is exposed to the UV radiation of specific intensity for a longer period of time, the gold leaves open up again. Further exposure of the electroscope to UV radiation leads to more and more electrons ejected from the gold leaves through the zinc metal. As a result the gold leaves become positively charged and therefore begin to repel each other.

Explanation of Photoelectric Effect

The energy of a wave is related to its amplitude. For light, amplitude is related to brightness or intensity. The wave model of light **cannot** explain why brighter light does not cause electrons to be ejected from the surface of a metal.

Einstein explained the Photoelectric effect by recognizing that electromagnetic radiation has a particle nature. He proposed that the energy of the particles is quantised and not continuous. He called the particles of light **photons**. The energy of a photon is found by using the equation:

$E = hf$ where ***h*** is the ***Plank's Constant = $6{,}63 \times 10^{-34}$ Js*** and ***f*** is the frequency of the electromagnetic radiation measured in Hertz (Hz).

When photons have a frequency equal to the threshold frequency of a metal we call this energy the ***Work Function (W_o)***.

$W_o = hf_o$ where f_o is the ***threshold frequency***.

Both the threshold frequency and the Work Function are properties of a specific metal. Thus different metals will have different work functions. This is so because different metals have different ionisation energies due to the specific arrangement of electrons in their energy levels.

When the energy carried by a photon is **less than the work function** of specific metal no electrons will be ejected from such a metal surface.

When the energy of the incident photon is **greater than the work function** of the metal, electrons will be ejected from the metal surface. The electron absorbs the energy equal to the work function so that it can be ejected from the metal surface and then uses the remaining energy to move away from the surface. We say the ejected electron has gained kinetic energy. Thus:

Energy of the photon = Work function + Kinetic Energy of the photoelectron

$$(hf = W_o + K)$$

Questions

Question 1

(Adapted from Mar 2011, DOE, Question 6, Paper 1)

The whistle of a train emits sound waves of frequency 2 000 Hz. A stationary listener measures the frequency of these emitted sound waves as 2 080 Hz. The speed of sound in air is 340 $m \cdot s^{-1}$.

a.) Name the phenomenon responsible for the observed change in frequency. (1)
b.) Is the train moving AWAY FROM or TOWARDS the stationary listener? (1)
c.) Calculate the speed of the train. (4)
d.) Will the frequency observed by a passenger, sitting in the train, be GREATER THAN, EQUAL TO or SMALLER THAN 2 000 Hz? Explain the answer. (2)

[8]

Question 2

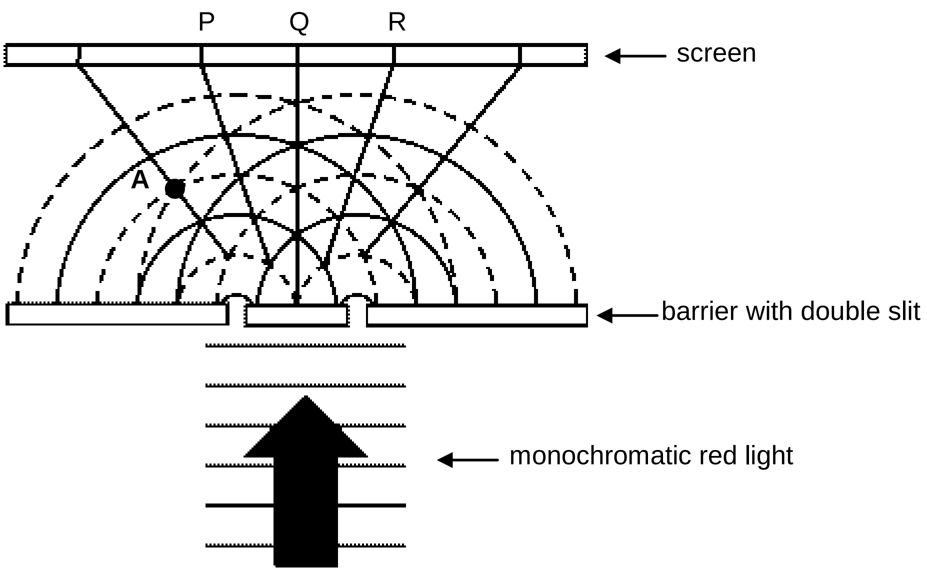
Use Huygens' Principle to explain how water waves bend around a barrier.

Question 3

(Adapted from NCS Nov 2010 Paper 1, Question 7)

Monochromatic red light passes through a double slit, as shown in the diagram below. Circular wave fronts, advancing towards the screen, are shown between the slits and the screen as dotted lines and solid lines. The solid lines represent crests and the dotted lines troughs.

Interference of the circular wave fronts results in an interference pattern observed on the screen. **P**, **Q** and **R** represent the centres of different bands in the interference pattern.



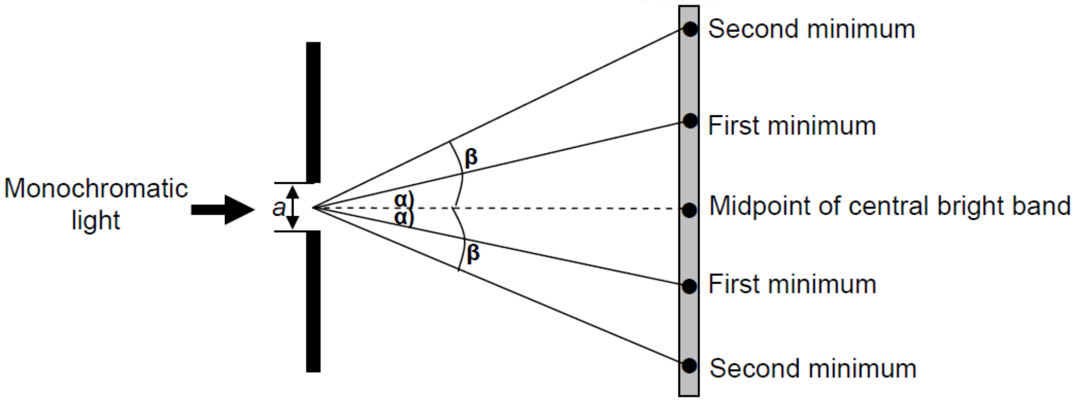
a.) What type of interference takes place at point **A**? Give a reason for the answer.

b.) Is band **P** a dark band or a red band? Refer to the type of interference involved to explain how you arrived at the answer.

Question 4

(Adapted from NCS Nov 2010 Paper 1, Question 8)

Monochromatic light of wavelength 410 nm is passed through a single slit at a *fixed distance* from a screen. The angles at which the first minimum (α) and the second minimum (β) occur are measured.



The experiment is repeated using the same light source but a slit of different width. The results obtained from the two experiments are represented in the table below.

	ANGLE OF 1ST MINIMUM (α)	**ANGLE OF 2ND MINIMUM (β)**
Slit 1	10°	20°
Slit 2	5°	10°

a.) Which ONE of **Slit 1** or **Slit 2** is the narrower slit? Explain the answer.

b.) Use the data in the table to calculate the width of **Slit 2**.

Question 5

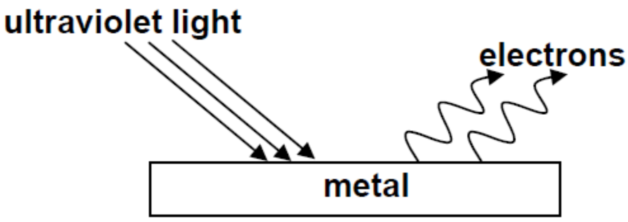
Calculate the energy of a photon of a photon of visible light which has

a.) A frequency of 3.0×10^{14} Hz
b.) A wavelength of 700 nm

Question 6

(Adapted from Nov 2011, NSC, Paper 1, Question 12)

A metal surface is illuminated with ultraviolet light of wavelength 330 nm. Electrons are emitted from the metal surface. The minimum amount of energy required to emit an electron from the surface of this metal is $3{,}5 \times 10^{-19}$ J.



a.) Give ONE word or term for the underlined sentence in the above paragraph.
b.) Calculate the frequency of the ultraviolet light.
c.) Calculate the kinetic energy of a photoelectron emitted from the surface of the metal when the ultraviolet light shines on it.

The intensity of the ultraviolet light illuminating the metal is now **increased**. What effect will this change have on the following:

d.) Kinetic energy of the emitted photoelectrons
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)
e.) Number of photoelectrons emitted per second
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)

Links

- http://www.mindset.co.za/learn/xtra
- http://www.education.gov.za/Examinations/PastExamPapers/tabid/351/Default.aspx
- http://en.wikipedia.org/wiki/Doppler_effect
- http://www.webmd.com/a-to-z-guides/doppler-ultrasound