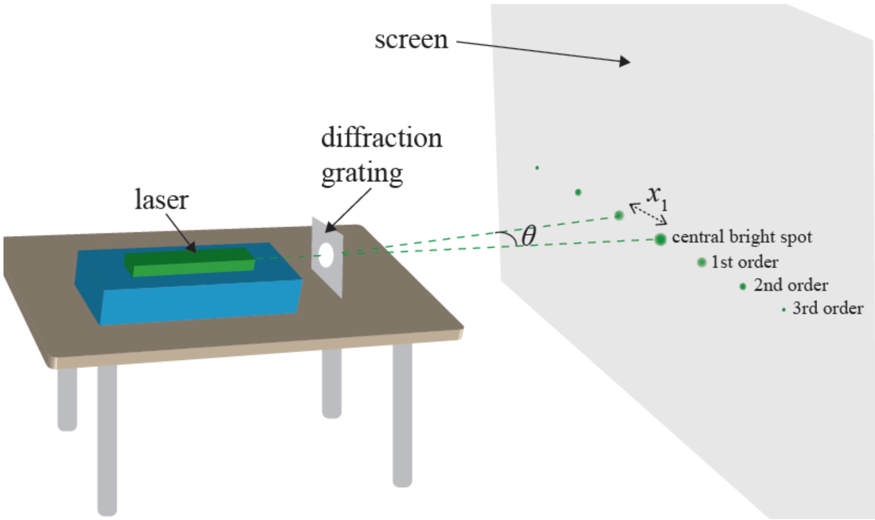
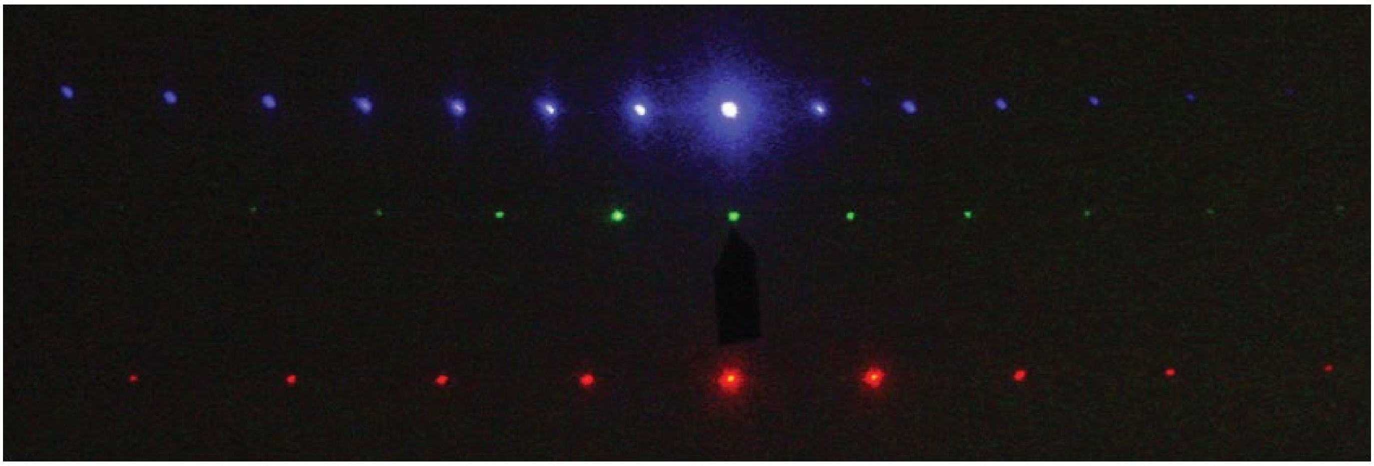
WAVES: WAVES BEHAVIOUR QUESTIONS

Waves 2019: QUESTION THREE

Lasers are used extensively in scientific research as they are point sources of monochromatic coherent light. In a lab, interference patterns can be demonstrated by shining a laser through a diffraction grating and observing the pattern on a screen.



The picture below shows three different colours (from top to bottom: violet, green, and red) of laser light shone through the same diffraction grating.



(a) Describe, using physics principles, why the violet maxima (bright spots) are closer together than the red maxima.

(b) The diffraction grating has 400 slits / mm, and the angle between the centre and second order maxima is 20.7° for the violet laser.

(i) Show that the slit separation of the diffraction grating is 2.5×10^{-6} m.

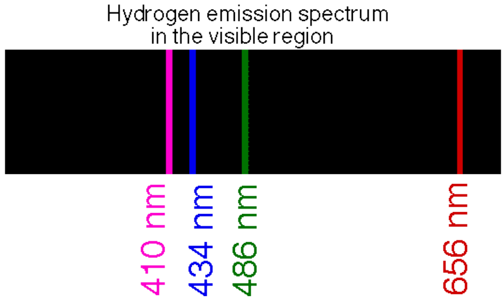
(ii) Calculate the wavelength of the laser light.

(c) Explain the role of diffraction and interference in producing interference patterns seen when light passes through a diffraction grating. (Assume the light is monochromatic.)

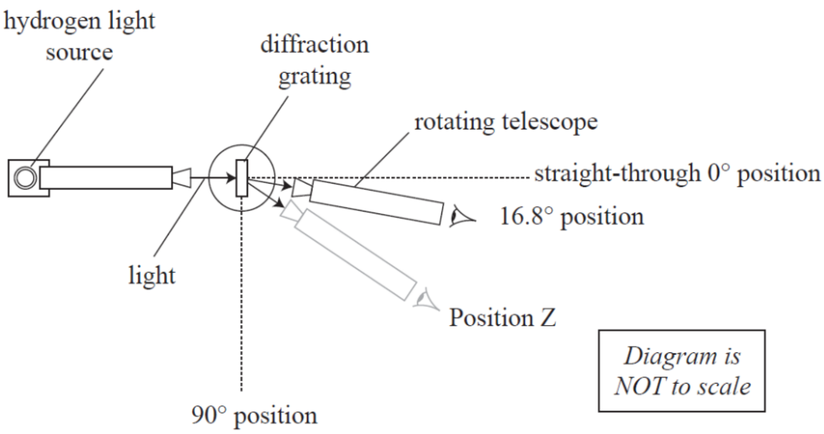
(d) The wavelength of the light from the green laser is 5.32×10^{-7} m. Describe and explain what would be seen at a point 28.6° from the centre of the green interference pattern. A calculation should accompany your discussion.

QUESTION ONE (2018;1)

All elements emit a number of distinct fixed wavelengths of light known as spectral lines that are unique to each element. Hydrogen emits four visible light lines, as shown.
[1 nm = 1 x 10^{-9} m]



Light from a hydrogen source can be passed through a diffraction grating to form an interference pattern. The wavelength of each spectral line can then be determined by measuring the angle to its first order maximum.



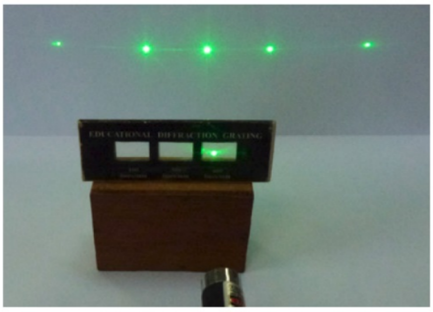
(a) The lines on a diffraction grating are spaced 1.68 x 10^{-6} m apart. Show that the wavelength of the spectral line with a first order maximum at 16.8° is 486 nm.

(b) The telescope is rotated from the 16.8° position to Position Z, the location of the next spectral line. State the wavelength of this line. Explain your reasoning.

(c) Calculate the maximum number of orders visible for the 656 nm line.

(d) The diffraction grating is replaced with a double-slit that has a slit separation of 1.68 x 10^{-6} m. Describe and explain any changes that will occur to the location, brightness, and width of the maxima for the 656 nm line.

QUESTION THREE (2017;3)



Priya wants to measure the wavelength of her green laser. She shines the laser beam through a diffraction grating. She sees an interference pattern on the wall behind the diffraction grating, as shown in the photograph. The slits in the diffraction grating are 2.00 × 10^{-6} m apart. The angle between the central anti-nodal line and the first anti-nodal line is 15.4°.

(a) Show that the wavelength of the green laser is 5.31 × 10^{-7} m.

(b) Explain what causes the bright spot at the first antinode (first order maximum).

(c) The picture shows the pattern she sees using the green laser. Priya repeats the experiment using a red laser (red light has a lower frequency than green light). Draw the pattern she would expect to see with the red laser. Explain why this pattern is different to the green laser.

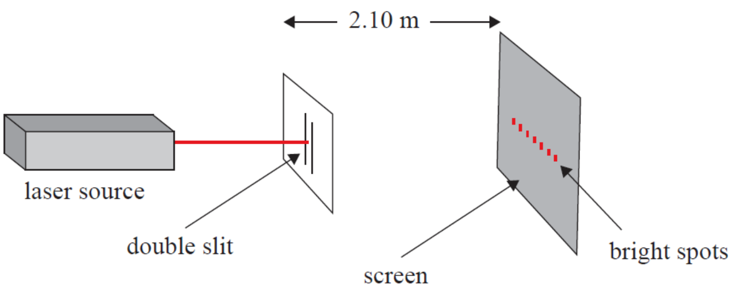
(d) Priya shines white light through another diffraction grating. There are three complete spectra of visible light produced each side of the central antinodal line. Calculate the minimum slit separation on this diffraction grating. Explain your reasoning.

The frequency of violet light is 7.70×10^{14} Hz.

The frequency of red light is 4.30×10^{14} Hz.

DIFFRACTION GRATINGS (2016;3)

Moana is doing an experiment in the laboratory. She shines a laser beam at a double slit and observes an interference pattern on a screen. The diagram below shows the experiment. Moana measures the distance between adjacent bright spots (maxima) and finds they are 0.0100 m apart. The slits are 1.28×10^{-4} m apart. The screen is 2.10 m from the slits.



(a) Show that the wavelength of the laser light is 6.10×10^{-7} m.

(b) Moana replaces the double slit with a diffraction grating in the same position. The diffraction grating has 500 lines per mm. Calculate the angle between the central antinodal line and the first antinodal line.

(c) Explain what would happen to the distance between the bright spots on the screen if the laser source is changed to one with a shorter wavelength.

(d) Moana then shines white light through a diffraction grating. The pattern she sees is shown. Explain the pattern Moana observes. Your explanation should include:

- why the centre of the pattern is white
- why there is a coloured spectrum on each side
- why there are dark regions between the white and coloured regions.

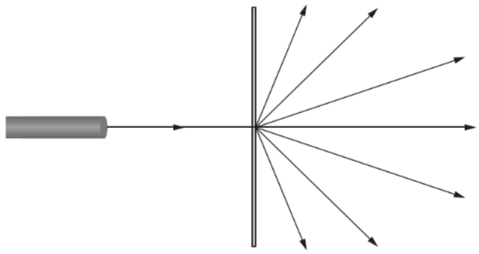
INTERFERENCE (2015;2)

Rianne uses a pair of novelty glasses to produce a laser show. When she shines a laser through the centre of one of the eyepieces, the laser light splits up into a number of beams. She suspects that the novelty glasses contain a diffraction grating. Rianne measures the angle between the bright central beam of light and the 1st order maximum in the horizontal direction to be 26.0°. The laser light has a wavelength of 532 x 10^{-9} m.

Calculate the slit spacing of the novelty glasses.

(a) Rianne experiments by shining her laser light through different parts of the glasses. There are more lines per metre in the middle of each eyepiece (smaller slit spacing) than there are at the edges. Describe the differences in the patterns Rianne would see when she shines the laser light through the two different sections of the glasses.

(b) Rianne visits a physics laboratory where she replaces the novelty glasses with a 600 000 lines per metre diffraction grating. Calculate the spacing in degrees between the central maximum and the 2nd order maximum for her laser light when it passes through the diffraction grating.

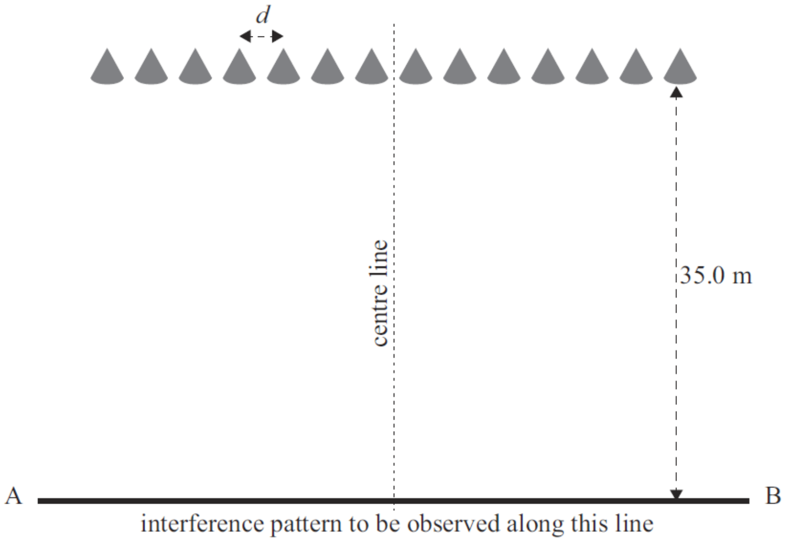


(c) Rianne wonders whether it would be possible to use the diffraction grating to create a laser light show, where a blue laser light with a wavelength of 460 x 10^{-9} m creates a pattern that overlaps with a pattern created by a red laser light with a wavelength of 690 x 10^{-9} m. Explain what the complete pattern would look like. In your answer, you should:

- calculate the number of maxima for blue laser light
- calculate the number of maxima for red laser light
- explain why there will be a limit to the number of maxima for each laser light
- show that one of the red maxima is at the same angle as one of the blue maxima

INTERFERENCE (2014;2)

The diagram shows a series of speakers connected together, and to a frequency generator producing a single frequency. The speakers act like a diffraction grating.



(a) The sound wave source is producing a note of wavelength 0.600 m. The distance between the speakers and the line AB is 35.0 m. When a person walks along the line AB, the distance between two loud positions is 7.40 m. Calculate the separation of the speakers, *d*.

(b) Explain how the path difference of the waves causes positions of constructive and destructive interference along the line AB.

(c) Explain the effect on the interference pattern of reducing the distance between the speakers.

(d) The frequency generator is now set so that several different frequencies are emitted by each speaker. Explain how the sound heard by someone walking along AB would differ from that described in part (b) of this question.

INTERFERENCE (2013;3)

Jenny is looking through a window at an orange street light outside. Many vertical scratches on the window act as a diffraction grating.

(a) Describe what Jenny would see when she looks at the orange street light.

(b) Orange light with a wavelength of 589×10^{-9} m diffracts through the window, and Jenny measures the first order maximum at an angle of 1.04°. Calculate the separation of the scratches on the window.

(c) Explain why monochromatic light shone through a diffraction grating produces a different pattern of fringes than it does when shone through a double slit of the same spacing.

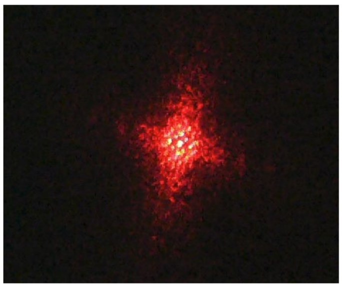
(d) Jenny now observes a white light through the same window. Explain what effect the scratches have on Jenny's view of the white light.

THE LASER POINTER (2012;3)

Mira is playing with a laser pointer. She finds that the laser spot on the wall is changed when she puts dress fabric in front of the laser.

(a) Explain why the threads in the fabric have caused the light to spread out in a pattern, as shown in the photograph.

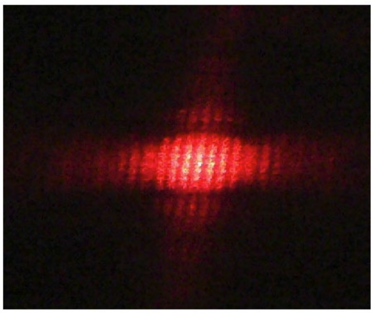

With no fabric in front of the laser pointer, the spot looks like this.


With fabric in front of the laser pointer, the spot looks like this.

Mira tries a different piece of fabric. The laser spot is spread differently because the threads, in one direction, are much closer together.

Looking carefully, Mira can see vertical stripes across the laser spot.

(b) Describe how the light passing between the threads causes this pattern.


Close-up of the spot on the wall.

Mira investigates further. She finds out that the laser has a wavelength of 650 nm (6.50×10^{-7} m). When her fabric is 40.0 cm from the screen, the stripes are 1.00 mm apart.

(c) Use this information to calculate the separation of the close-woven threads.

(d) The fabric is stretched: a 16.0 cm length of fabric is pulled to become 16.3 cm long, pulling the close-woven threads further apart. Calculate the new separation of the lines on the screen.

INTERFERENCE (2011;2)

Seed-shrimps live in the soil in New Zealand forests. Male seed-shrimps have an unusual type of mating signal. The hairs on their antennae act as a diffraction grating, and during courting, a male seed-shrimp will move his antennae, causing other seed shrimps to see a flash of coloured light.

(a) When white light is incident on a diffraction grating, the light is split into several spectra, with higher order spectra occurring at larger deviations.

(i) State why white light is split into a spectrum when it goes through a diffraction grating.

(ii) Explain which end of the spectrum is furthest out from the central position.

(b) The diffraction gratings of different shrimp species have different slit separations. Explain the effect of decreasing the slit separation on the number of spectra produced by a diffraction grating.

(c) The hairs on the antennae on a particular shrimp create a diffraction grating with a slit separation of 6.6×10^{-7} m. By attempting to calculate the angle through which light of frequency 4.25×10^{14} Hz is diffracted in the first order spectrum, explain why this colour will not be present in the spectrum produced.

(d) For a different species of shrimp, the "flash" is only produced if the light that is to be diffracted contains some wavelengths that are **less** than 5.2×10^{-7} m.

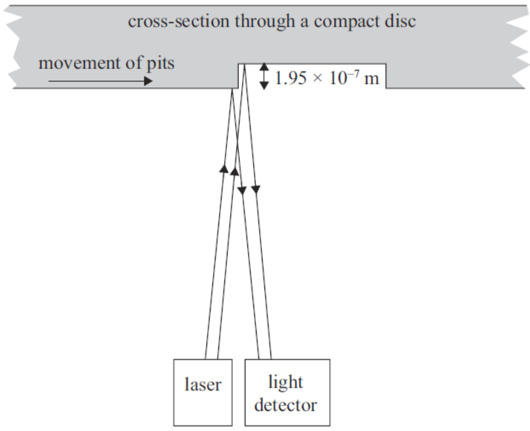
(i) Explain this observation.

(ii) Calculate the number of slits per **mm** for the hairs of this shrimp species.

CD SPECTRUM (2010;3)

A compact disc (CD) is read with a laser light of wavelength 7.80×10^{-7}m.

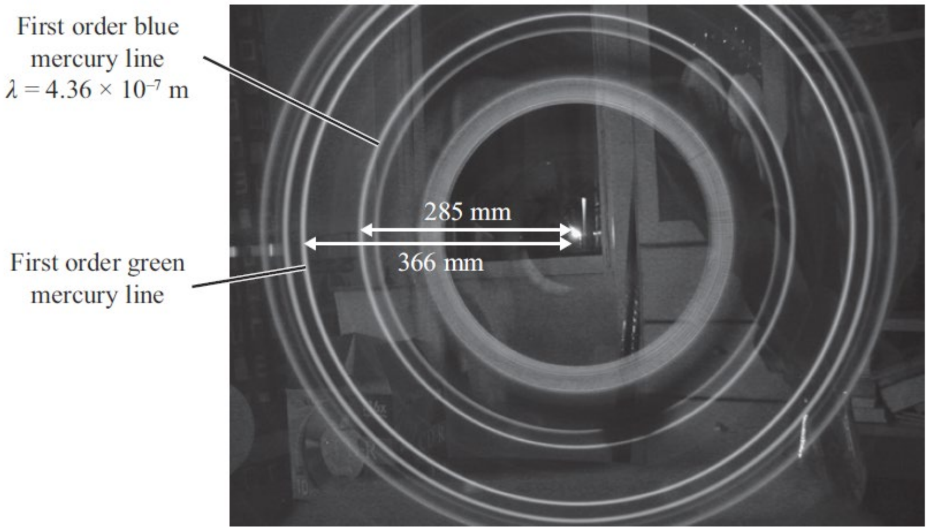
The recorded surface, on the bottom of the CD, has pits in it, which are 1.95×10^{-7}m deep. The CD rotates, moving the pits over a laser beam and varying the intensity of the reflected light. Consider a beam consisting of just two rays of light which reflect off the bottom of the CD.



(a) Explain how the intensity of the detected beam depends on whether the reflected rays are in phase or out of phase with each other when they arrive at the detector.

(b) The movement of the pits makes the intensity of the reflected beam vary between high and low so the detector receives a digital signal. Explain why the pits are made exactly 1.95×10^{-7} m deep.

The pits on a CD are in lines along one long spiral track. The tracks are essentially circles, 1.60×10^{-6} m apart. A teacher uses a CD to make a transparent plastic disc with this track pattern to use as a diffraction grating. He photographs a street lamp through the disc and obtains the picture.



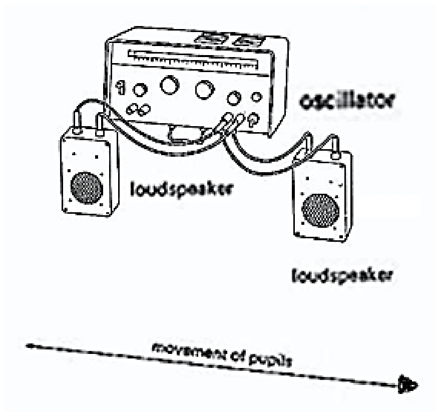
(c) Show that the first order blue mercury line ($\lambda = 4.36 \times 10^{-7}$ m) occurs at a diffraction angle of 15.8°.

(d) Use the distances marked on the photograph to calculate the wavelength of the first order green mercury line.

INTERFERENCE OF SOUND WAVES (2009;3)

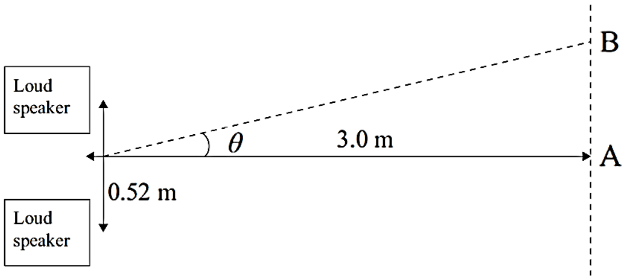
The speed of sound in air = 3.40×10^2 m s^{-1}

A teacher demonstrates interference of waves by connecting two speakers to a signal generator. The signal generator produces a single frequency. The instructions recommend that this demonstration is set up outdoors.



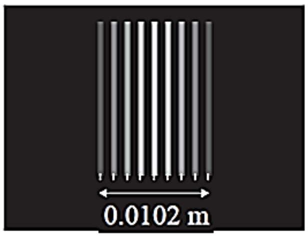
(a) Explain why the students hear regular quiet spots as they walk slowly in front of the loudspeakers (as shown in the diagram) and why the demonstration is not so effective in a typical classroom.

Two microphones are used to detect the loudness of the sound and to identify nodes and antinodes. Microphone A is placed on the central antinode and microphone B is placed on an adjacent node. The loudspeakers are 0.52 m apart. The microphones are placed 3.0 m from the loudspeakers and the frequency is set to 1.30 kHz.



(b) Calculate:
  (i) The wavelength of the sound waves.
  (ii) The angular separation, θ, between microphones A and B.

INTERFERENCE (2008;3)



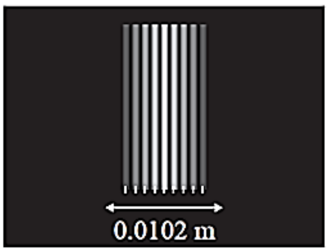
Interference techniques can be used in the quality control of the weaving process used to manufacture fabrics. This can be demonstrated in the laboratory by shining a narrow beam of laser light through a piece of fine gauze. The gaps between the woven threads of the gauze create multiple point sources of light and these interfere to produce a pattern of bright spots on a screen. A student uses the vertical threads to make a diffraction grating and shines light from a laser through the threads to form a pattern of fringes on a screen, as shown below.

The grating is 2.14 m from the screen and the distance between the two outside bright lines is measured to be 0.0102 m. The wavelength of the laser light is 6.3×10^{-7} m. The student marks the lines on the screen.

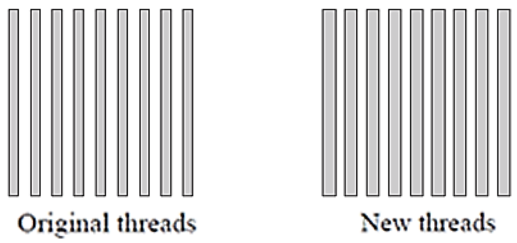
(a) Calculate the average distance between two adjacent bright lines. Give your answer to the correct number of significant figures.

(b) Calculate the spacing of the threads.

(c) The threads that produced the pattern in the diagram on the opposite page are replaced with a new set of threads and the pattern shown in the diagram is obtained. Explain what this would tell you about the spacing of the threads in the new gauze.



(d) The original threads are now replaced with thicker threads, with the same spacing as the original threads. The new interference pattern is in some ways the same, but in other ways it is different. Explain how the thicker threads will affect the pattern on the screen, and what will be unchanged.

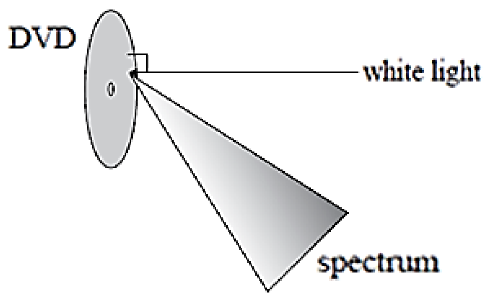


(e) Light from a red laser (wavelength 6.70×10^{-7} m) is shone at a new diffraction grating. The light forms a pattern showing nine bright fringes spread across a distance of 4.0 cm. When the laser is replaced with a green laser, the interference pattern shows nine fringes spread out over a distance of 3.2 cm. Calculate the wavelength of the green laser.

DIFFRACTION GRATING (2007;3)

The band Carlie plays in has produced a DVD of its performances. When looking at the DVD, Carlie sees a spectrum "reflected" from the surface of the DVD. The diagram shows a first order spectrum being produced when white light is shone on to the DVD perpendicular to its surface.

The DVD can be modelled as a diffraction grating. On a DVD, lines are drawn on the surface. The distance between the lines is called the track spacing. The track spacing on the DVD is equivalent to the slit spacing of a diffraction grating.

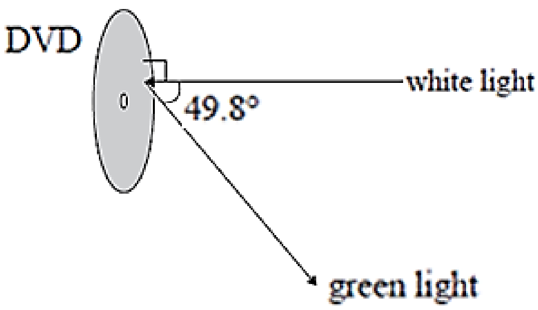


(a) Which colour light is seen "reflected" at the smallest angle in the spectrum?

The smallest angle at which green light is seen is 49.8°.

Green light has a wavelength of 5.65×10^{-7} m.

(b) Show that the spacing of the tracks on the DVD has an unrounded value of 7.3973×10^{-7} m. Round this answer to the correct number of significant figures.



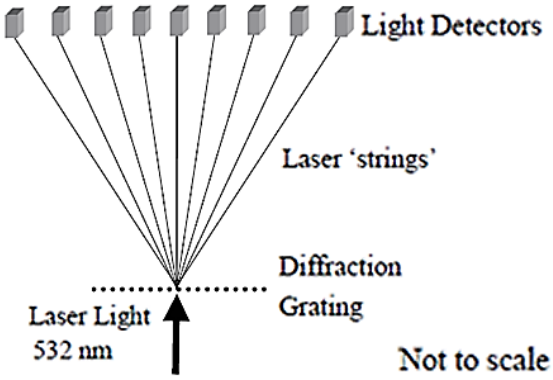
A CD produces spectra in the same way that a DVD produces spectra. The track spacing on a DVD is less than that on a CD.

(c) The angle at which violet light (wavelength 438×10^{-9} m) forms its first bright fringe when "reflected" from a CD is 20.4° less than the angle of the first bright fringe of violet light "reflected" from a DVD. Calculate the track spacing on a CD.

(d) More spectra are produced using a CD than a DVD. Explain why. (Calculations are not required.)

LASER HARP (2006;3)

The harp 'strings' are the beams of light produced by shining green laser light, of wavelength 5.32×10^{-7} m, through a diffraction grating. Each beam is detected by a light sensor connected to an electronic circuit. When a beam is broken by the person playing the harp, the electronic circuit produces a note for that string.



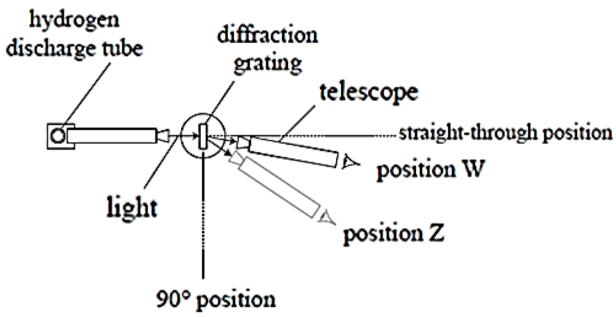
(a) The angle to the detector for the first order beam is 6.00°. Show that the slit spacing on the diffraction grating is 5.09×10^{-6} m.

(b) To be able to play the harp easily, the maximum horizontal spread of the strings at a height of 1.00 m above the grating is 0.68 m (each outside string is 0.34 m horizontally out from the centre at this height). Calculate the number of 'strings' on the harp.

(c) Explain, in terms of constructive and destructive interference, why narrow beams of light are produced when light shines through a diffraction grating.

EMISSION SPECTRA (2005;2)

When a high voltage electrical discharge is applied to hydrogen at low pressures, light is emitted. This light is passed through a diffraction grating that has 6.1×10^{3} lines per cm, and a spectrum of coloured lines is viewed through the telescope of a spectrometer. There are several different order spectra that can be viewed. Each order is made up of 4 coloured lines; red, green / blue, purple and violet. The following is a diagram of a spectrometer from above, showing how the telescope rotates about the position of the diffraction grating.



As the telescope is rotated from W to Z, each of the 4 lines of the first order spectrum is seen in turn.

(a) Explain which colour line would be seen first as the telescope rotates from W to Z.

(b) Show that the spacing of the slits in the diffraction grating is 1.6×10^{6} m.

(c) The wavelength of the green / blue line is 4.86×10^{7} m. Calculate the diffraction angle for this line in the first order spectrum.

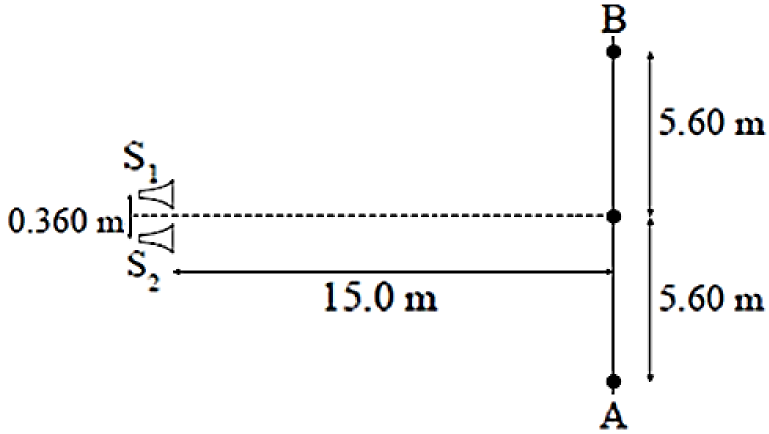
(d) There are also several higher order spectra observed for hydrogen. It was found that the 3rd order purple line coincides with the 2nd order red line. If the angle for the red line in the 1st order spectrum is 23.5°, calculate the wavelength of the purple line.

(e) The diffraction grating was replaced with one that had half as many lines per cm. When the spectrometer telescope was rotated from the straight-through position to the 90° position, in order to see all the orders of hydrogen spectra, ONE difference that was seen was that the lines in the spectra were closer together than before. TWO other differences were seen. Assuming there is no change in the amount of light transmitted, describe and explain BOTH of the other two differences.

ANOTHER EXPERIMENTAL VALUE (2004;3)

The students were then asked to design an interference experiment to measure the speed of sound. One of the windows of the laboratory faced out over the playing fields. The students set the signal generator to a frequency of 2680 Hz, connected two speakers S_1 and S_2, and aimed the sound from them out of this window.

Each student walked along the line AB and marked the positions at which the sounds were loudest. From these marks, they estimated that the distance between adjacent positions of loud sound was 5.60 m. The diagram (not to scale) shows the distances they used.



(a) Explain why the sound the students heard varied in loudness.

(b) Using information from the diagram, show that the students calculated the wavelength of sound to be 0.126 m.

(c) From this wavelength, calculate the speed of sound.