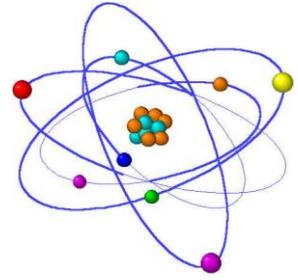


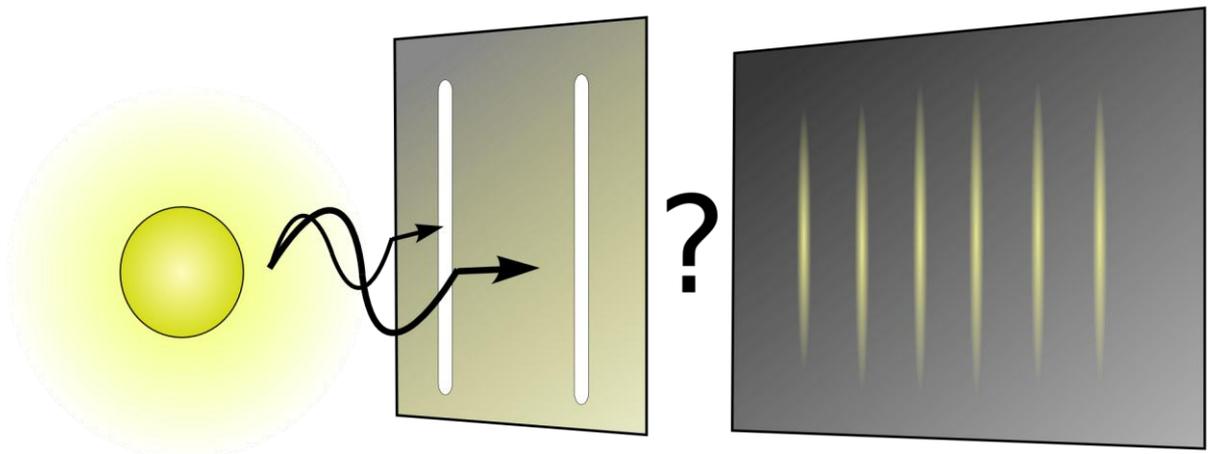


North Berwick High School



Department of Physics

## Higher Physics



### Unit 2 Particles and Waves

#### Section 5 Interference and Diffraction



## **Section 5 Interference and Diffraction**

### **Note Making**

Make a dictionary with the meanings of any new words.

### **Interference**

1. Define the term interference and explain how constructive and destructive interference is produced.
2. Show how interference can be produced from one set of waves

### **Interference of light**

1. Show how interference can be achieved using light waves.

### **Path difference and interference**

1. Describe an experiment to show the relationship between path difference and interference. Include equations and the example on pages 6 and 7.

### **The grating and monochromatic light**

1. Describe how interference is produced by a grating. Include the grating equation and an example.

### **Grating and white light**

1. Explain the pattern produced by the grating and white light.

# Section 5 Interference and Diffraction

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## Content Statements

Content	Notes	Context
<p>a) Conditions for constructive and destructive interference.</p>	<p>Coherent waves have a constant phase relationship and have the same frequency, wavelength and velocity. Constructive and destructive interference in terms of phase between two waves.</p>	<p>Interference patterns with microwaves, radio waves, sound, light and electrons. Holography. Industrial imaging of surfaces-curvature and stress analysis. Lens blooming. Interference colours (jewellery, petrol films, soap bubbles).</p>
<p>b) Interference of waves using two coherent sources.</p>	<p>Maxima and minima are produced when the path difference between waves is a whole number of wavelengths or an odd number of half wavelengths respectively. Investigations which lead to the relationship between the wavelength, distance between the sources, distance from the sources and the spacing between maxima or minima.</p>	<p>Interferometers to measure small changes in path difference. Use a spectroscope/spectrometer/spectrophotometer to examine spectra from a number of light sources.</p>
<p>c) Gratings</p>	<p>Monochromatic light can be used with a grating to investigate the relationship between the grating spacing, wavelength and angle to the maxima. A white light source may be used with a grating to produce spectra. Compare the spectra produced by gratings and prisms.</p>	

## Section 5 Interference and Diffraction

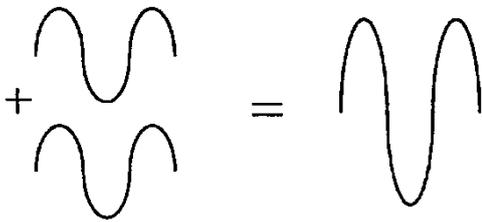
### Interference

When two sets of waves meet, they combine to produce a new pattern. This pattern can vary depending on the original wave direction, wavelength, amplitude, etc. Waves can combine in one of two ways as illustrated below.

#### Constructive interference

Two sets of waves meet in **phase**.

Two crests meet or two troughs meet to produce a larger crest or trough.

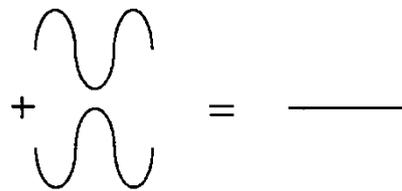


#### Destructive interference

Two sets of waves meet completely out of phase, i.e.  $180^\circ$  out of phase.

A crest meets a trough and combine to cancel each other out and produce no wave at that point.

If the waves are not of equal amplitude, then complete cancelling out does not occur.

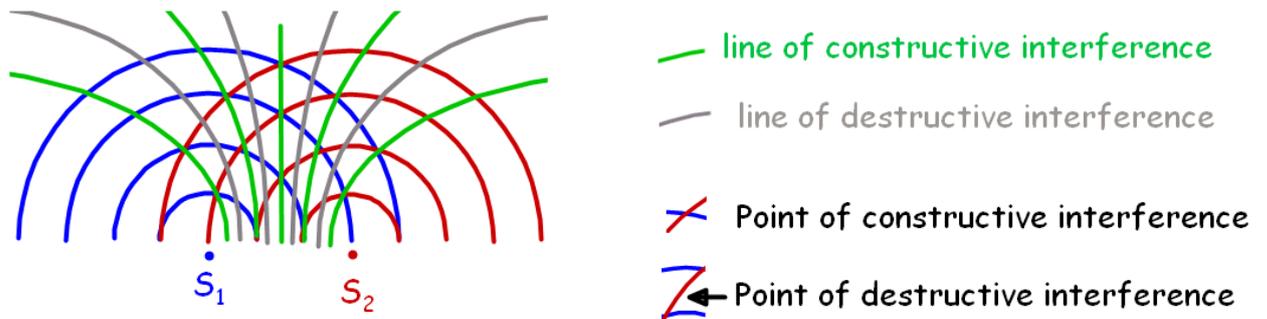


#### Coherent sources

Two sources are **coherent** if they have a constant phase difference. They will have the same frequency. They often have the same amplitude.

## Interference of water waves

If two point sources produce two sets of circular waves, they will overlap and combine to produce an interference pattern.

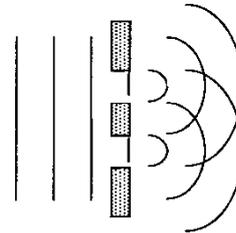


The points of **constructive** interference form waves with larger amplitude and the points of **destructive** interference produce calm water.

The positions of constructive interference and destructive interference form alternate lines which spread out from between the sources. As you move across a line parallel to the sources, you will therefore encounter alternate large waves and calm water.

## Interference from one set of waves

It is possible to produce interference from one source of waves by division of the wavefront. Plane waves are made to pass through two small gaps (similar in size to the wavelength) to produce two coherent sources of circular waves by diffraction. These will then interfere as before.



## Interference of light

Two sources of coherent light are needed to produce an interference pattern. Two separate light sources such as lamps cannot be used to do this, as there is no guarantee that they will be coherent (same phase difference).

The two sources are created by producing two sets of waves from one monochromatic (single frequency) source using the principle above. A laser is a good source of this type of light.

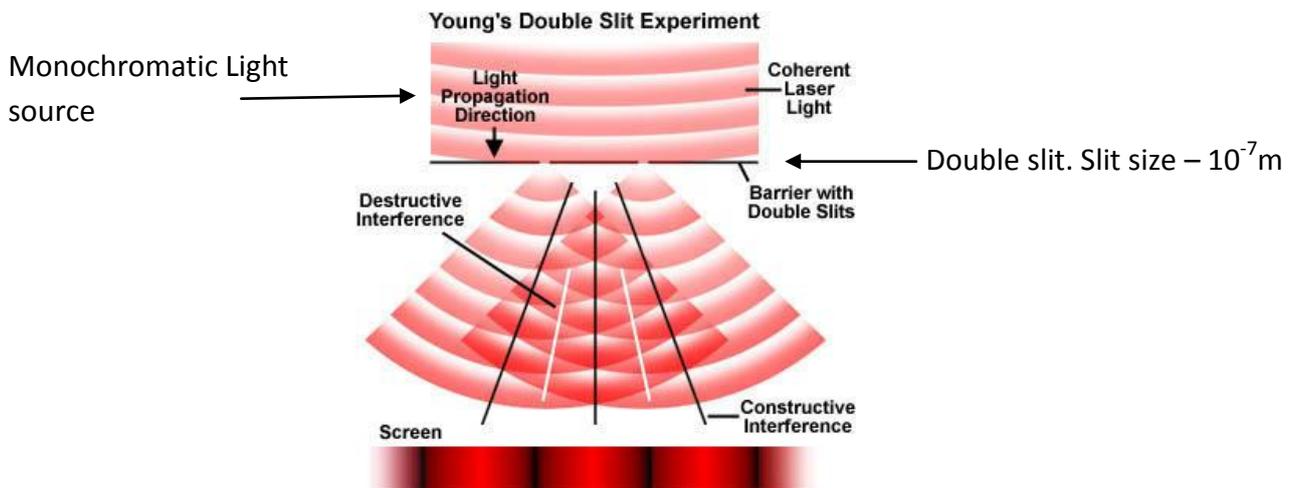


Figure 4 Intensity Distribution of Fringes

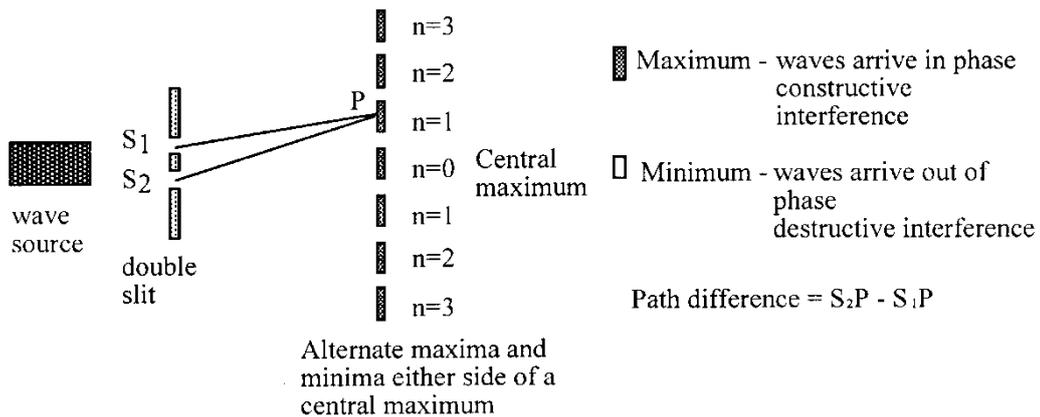
Alternate series of light and dark lines (fringes).  
Light fringe, waves arrive in phase, constructive.  
Dark fringe, waves arrive out of phase, destructive.

Interference can only be explained in terms of wave behaviour and as a result, **interference is taken as proof of wave motion.**

Historically, the original version of this experiment with two slits by Thomas Young proved that light did, in fact, travel in the form of waves.

## Path difference and interference

An interference pattern is more easily explained in terms of path difference. Consider an interference pattern produced by two coherent wave sources as below.



Take a point **P** in the interference pattern.

The central, or **zero order maximum** has **zero path difference**, as it is equidistant from each source.

As you move across the pattern away from the zero order, the **first order maximum** is reached. This is the next point where the waves arrive in phase; the waves here have a path difference of  $1\lambda$ , the waves from one source have travelled  $1\lambda$  further than the waves from the other source.

Similarly, the path difference to the second order maximum would be  $2\lambda$  and so on.

The **zero order minimum**, the minimum next to the central maximum, is reached at the first point the waves arrive out of phase; the waves here have a path difference of  $\frac{1}{2}\lambda$ .

Similarly, the path difference to the next minimum would be  $\frac{3}{2}\lambda$  and so on.

In general:

For a maximum path difference,  $S_2P - S_1P = n\lambda$

Whole number of  $\lambda$

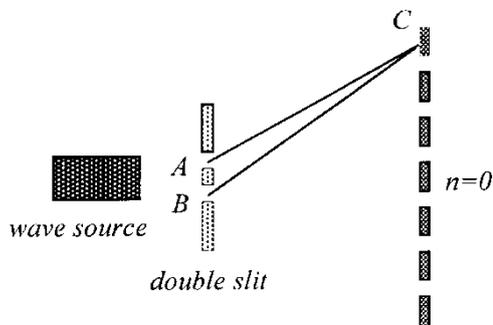
For a minimum path difference,  $S_2P - S_1P = (n + \frac{1}{2})\lambda$

Odd number of  $\frac{1}{2}\lambda$ .

The term 'order' for a maximum or minimum is simply the value of  $n$  in the above equations. For a maximum this is straightforward. When  $n = 1$  we have the first maximum. However, for a minimum some care is required. The first minimum, the minimum next to the central bright band, is the 'zero order minimum' with  $n = 0$ . In most cases a simple diagram is useful.

### Example

If distances  $AC$  and  $BC$  are 51 cm and 63 cm respectively, and point  $C$  is the third order maximum, determine the wavelength of the source.



Path difference  $BC - AC = 12$  cm.

For third order maximum, path difference =  $3\lambda$ .

$$3\lambda = 12 \text{ cm,}$$

so  $1\lambda = \underline{4 \text{ cm}}$

If the above source was replaced by another with wavelength 8 cm, what effect would be produced at point C?

Path difference  $BC - AC = 12$  cm, as before.

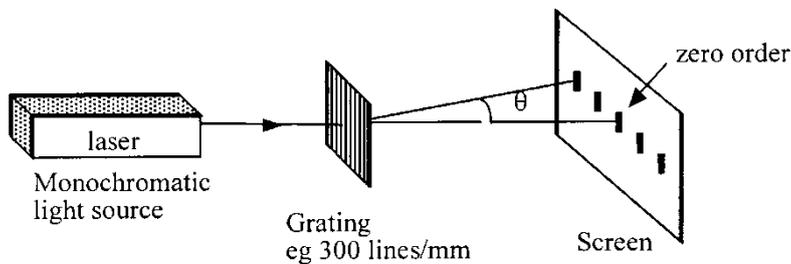
If  $\lambda = 8$  cm:  $\frac{12}{8} = \frac{3}{2}$  Therefore the path difference =  $\frac{3}{2}$  or  $1\frac{1}{2}\lambda$ .

Point C would be the second minimum above the central bright band (or the 'first order minimum').

The pattern is now more spaced out.

## The grating and monochromatic light

A grating consists of many equally spaced slits positioned extremely close together (e.g. 300 lines per mm). Light is diffracted through each slit and interference takes place in a similar fashion to the double slit. The advantage of the grating is that much more light is transmitted through and a clearer interference pattern is seen.



## Grating equation

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

For a grating,

Where:

n	=	order of the maximum
$\lambda$	=	wavelength of light
d	=	separation of slits
$\theta$	=	angle from zero order to nth maximum.

$\lambda$  and d must be in metres.

If the above formula is rearranged to  $\sin\theta = \frac{n\lambda}{d}$ ,

then it can be seen that to increase  $\theta$ , the separation of the maxima, you can:

increase the wavelength,	i.e. move from blue towards red light
decrease the slit separation,	i.e. have more lines per mm.

Also notice that moving the screen further away will also increase the distance between the maxima.

## Example

A diffraction grating with 300 lines per mm is used to produce an interference pattern.

The second order maximum is obtained at a diffracted angle of  $19^\circ$ . Calculate the wavelength of the light.

Using the formula:  $n\lambda = d \sin\theta$

$$d = 1/300\text{mm} = 3.33 \times 10^{-3}\text{mm} = 3.33 \times 10^{-6}\text{m}$$

$$n = 2$$

$$\theta = 19^\circ$$

$$2 \times \lambda = 3.33 \times 10^{-6} \sin 19^\circ$$

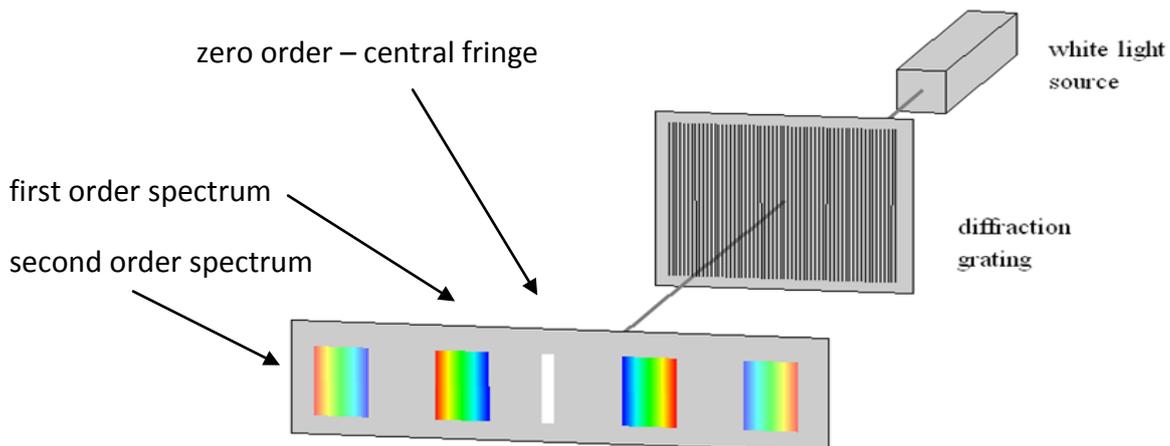
$$= \underline{\underline{5.4 \times 10^{-7} \text{ m or } 540 \text{ nm}}}$$

## Approximate values of wavelengths

Red	700 nm	=	$7 \times 10^{-7} \text{ m}$
Green	540 nm	=	$5.4 \times 10^{-7} \text{ m}$
Blue	490 nm	=	$4.9 \times 10^{-7} \text{ m}$

## Grating and white light

It is possible to use a grating to observe the interference pattern obtained from a white light source. Since white light consists of many different frequencies (wavelengths), the fringe pattern produced is not as simple as that obtained from monochromatic light.



Each fringe appears as a visible spectrum, apart from the central white fringe. Red is deviated the most, violet is deviated the least.

## Explanation

The central fringe is white because, at that position, the **path difference** for all wavelengths present is **zero**, therefore all wavelengths will arrive in phase. The central fringe is therefore the same colour as the source (in this case, white).

The first maximum occurs when the **path difference** is  $1\lambda$ . Since blue light has a shorter wavelength than red light, the path difference will be smaller, so the blue maximum will appear closer to the centre. Each colour will produce a maximum in a slightly different position and so the colours spread out into a **spectrum**.

These effects can also be explained using the formula  $d\sin\theta = n\lambda$ .

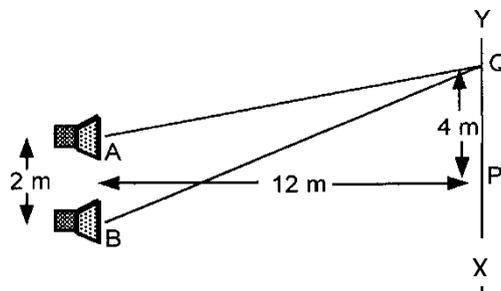
If  $d$  and  $n$  are fixed, the angle  $\theta$  depends on the wavelength. So, for any given fringe number, the red light, with a longer wavelength, will be seen at a greater angle than the blue light.

The higher order spectra overlap.

## Problems

### Interference and diffraction

1. Explain how it is possible for interference to occur in the following situations:  
  
a single loudspeaker emitting sound in a room with no other objects in the room  
  
receiving radio reception in a car when passing large buildings.
2. In an experiment on interference of sound, two loudspeakers A and B are connected in such a way that they emit coherent sound waves.

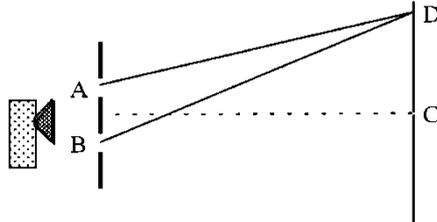


The loudspeakers are placed 2 m apart.

As a girl walks from X to Y she hears a point of maximum loudness at point P and the next maximum of loudness at point Q.

Calculate the distances AQ and BQ.  
Calculate the wavelength of the sound.  
Calculate the frequency of the sound.  
(speed of sound in air is  $330 \text{ ms}^{-1}$ )

3. A microwave transmitter is placed in front of a metal plate that has two slits A and B as shown.



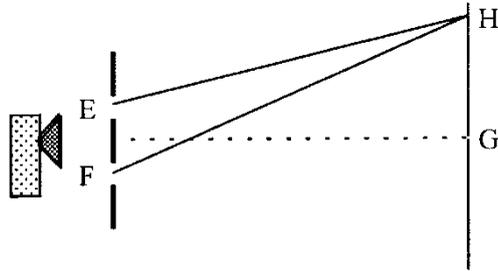
A microwave detector is moved along the line from C to D.

The zero-order maximum of radiation is detected at C and the first-order maximum is detected at D.

$AD = 0.52 \text{ m}$  and  $BD = 0.55 \text{ m}$ .

- Calculate the path difference between paths AD and BC.
- What is the wavelength of the microwaves?
- Calculate the path difference from slits A and B to the second-order maximum.
- Calculate the path difference from slits A and B to the minimum of intensity between C and D.
- Calculate the path difference from slits A and B to the next minimum after D.
- What is the path difference from slits A and B to point C?

4. A microwave interference experiment is set up as shown.



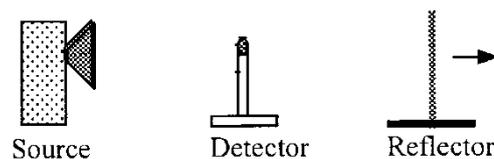
E and F are two slits in a metal plate. A microwave detector is moved along the line GH.

H is the second minimum from the straight through point at G. (This is sometimes called the first-order ( $n = 1$ ) minimum, the first minimum being the zero order  $n = 0$ )

Measurement of distances EH and FH gives:  $EH = 0.421$  m and  $FH = 0.466$  m.

Calculate the wavelength and frequency of the microwaves used.

5. A microwave experiment is set up as shown.



The waves reflected from the metal reflector plate interfere with the incident waves from the source. As the reflector is moved away from the detector, a series of maxima and minima are recorded by the detector.

A maximum is found when the reflector is at a distance of  $0.25$  m from the detector. A further eight maxima are found as the reflector is moved to a distance of  $0.378$  m from the detector.

- a) Calculate the average distance between the maxima.
- b) Calculate the wavelength of the microwaves.
- c) Calculate the frequency of the microwaves.

6. A grating has 400 lines per millimetre.

Calculate the spacing between the lines on this grating.

7. A grating with 600 lines per millimetre is used with a monochromatic source of light. The first-order maximum is produced at an angle of  $20.5^\circ$  to the straight through position.

Calculate the wavelength of the light from the source.

A grating with 1200 lines per millimetre is now used.

Calculate the angle between the zero maximum and the new first-order maximum.

8. Light of wavelength 600 nm is shone onto a grating having 400,000 lines per metre.

Calculate the angle between the zero maximum and first-order maximum.

9. Light of wavelength  $6.50 \times 10^{-7}$  m is shone onto a grating. The angle between the zero- and third-order maxima is  $31.5^\circ$ .

- (a) Calculate the spacing between the slits on the grating.
- (b) Calculate the number of lines per mm on the grating.

10. Light of wavelength 500 nm is used with a grating having 500 lines per millimetre.

Calculate the angle between the first- and second-order maxima.

11. White light, with a range of wavelengths from 440 nm to 730 nm, is shone onto a grating having 500 lines per millimetre. A screen is placed behind the grating.
- Describe the pattern seen on the screen.
  - Explain the type of pattern produced.
  - Calculate the angle between the extremes of the first-order maximum, ie the angle between violet and red.
12. A source of white light is set up in front of a grating. A green filter is placed between the source and the grating. The grating has 300 lines per millimetre.
- A pattern of bright and dark bands is produced on a screen.
- What is the colour of the bright bands produced on the screen?
- Explain what happens to the spacing between the bright bands on the screen when each of the following changes is made:
- using a blue filter instead of a green filter
  - using a grating with 600 lines per millimetre
  - using a source producing a greater irradiance of light
  - moving the screen closer to the grating.

## Solutions

2. (a)  $AQ = 12.4 \text{ m}$ ,  $BQ = 13 \text{ m}$   
(b)  $0.6 \text{ m}$   
(c)  $550 \text{ Hz}$
3. (a)  $3.0 \times 10^{-2} \text{ m}$   
(b)  $3.0 \times 10^{-2} \text{ m}$   
(c)  $6.0 \times 10^{-2} \text{ m}$   
(d)  $1.5 \times 10^{-2} \text{ m}$   
(e)  $4.5 \times 10^{-2} \text{ m}$   
(f)  $0 \text{ m}$
4. Wavelength =  $3.0 \times 10^{-2} \text{ m}$   
Frequency =  $1.0 \times 10^{10} \text{ Hz}$
5. (a)  $0.016 \text{ m}$   
(b)  $3.2 \times 10^{-2} \text{ m}$   
(c)  $9.4 \times 10^9 \text{ Hz}$
6.  $0.03 \text{ m}$
6.  $2.5 \times 10^{-6} \text{ m}$
7. (a)  $5.84 \times 10^{-7} \text{ m}$   
(b)  $44.5^\circ$
8.  $13.9^\circ$
9. (a)  $3.73 \times 10^{-6} \text{ m}$   
(b)  $268$
10.  $15.5^\circ$
11. (c)  $8.7^\circ$