Optics

Exercise 8.1 Waves

1. State a test for wave motion.

2. When a light wave travels from the air into water, state what happens to
   a) the wavelength,
   b) the frequency,
   c) the velocity.

3. A microwave oven, used to cook a steak, produces microwaves of frequency 2450 MHz.
   a) Calculate the wavelength of these microwaves in a vacuum.
   b) State how the wavelength will be affected when the microwaves enter the steak.

4. a) What are the **four** main properties of wave motion?
   b) Which of these proves wave motion is taking place?
   c) Describe how you would show experimentally that light has wave properties.

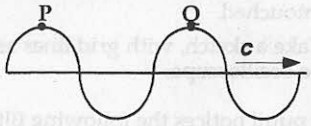
5. The audible frequency range of a boy's hearing is 30 Hz to 16 500 Hz.
   If the speed of sound in air is 340 m s^{-1}, what is the shortest wavelength of sound in air which the boy can hear?

6. Sketch a graph which shows how the frequency of sound varies with the wavelength of sound.
   Assume the speed of sound is constant for all frequencies.

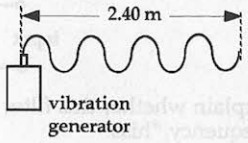
7. a) Give the electromagnetic spectrum in order of increasing frequency.
   b) State the colours of the visible spectrum in order of increasing wavelength.

8. The velocity of sound in a metal is 11 times the velocity of sound in air.
   The wavelength of a certain note in air is 2 m.
   What is the wavelength of the same note in the metal?

9. The diagram represents a wave of frequency ***f*** and wavelength λ moving with speed ***c***.
   What is the time taken for the crest of the wave shown at position **P** to reach position **Q**?
   Give your answer in terms of λ and ***c***.



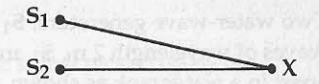
10. A generator of frequency 25 Hz produces waves as shown.
    a) What is the wavelength of the waves?
    b) Calculate the speed of the waves.
    c) If the frequency is doubled to 50 Hz, what will happen to the wavelength? State the assumption which you make.



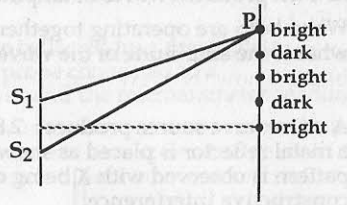
Exercise 8.2 Path Difference

1. An interference pattern is produced when two coherent waves overlap.
   a) If a minimum is produced, what are the possible values for the path difference?
   b) If a maximum is produced, what are the possible values for the path difference?

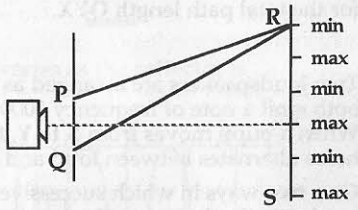
2. S_1 and S_2 are coherent sources of microwaves of wavelength λ.
   If a maximum signal is detected at **X**, suggest **two** different possibilities for the path difference.



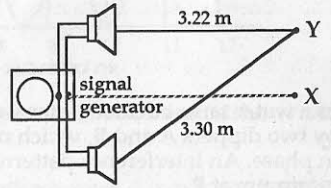
3. The figure shows the paths of light in a double slit interference experiment. Waves from two slits S_1 and S_2 produce a bright fringe at **P**.
   The figure also indicates a series of bright and dark fringes.
   The light has a wavelength of 400 nm.
   Calculate the path difference $S_1P - S_2P$.



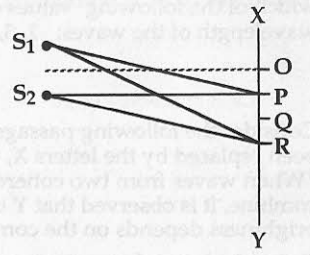
4. A microwave transmitter is directed at a metal plate which has two slits **P** and **Q** as shown. The microwave radiation had a wavelength of 3 cm. A microwave receiver is moved from **R** to **S** and in doing so detects maxima and minima of intensity at the positions shown.
   What is the path difference between **PR** and **QR**?



5. Two loudspeakers are connected to the same signal generator as shown.
   A microphone at **X** detects maximum intensity. When the microphone is moved slowly upwards, it detects the first minimum at **Y**.
   Calculate the wavelength of the sound emitted from the loudspeakers.

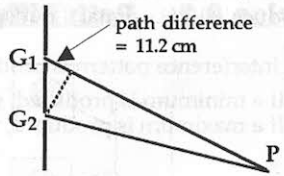


6. S_1 and S_2 are two coherent wave sources giving an interference pattern along the line **XY**. **O** is the central (zero) maximum, **P** the first maximum, **Q** the second maximum and **R** the third maximum. The first maximum **P** occurs where S_1P = 20 cm and S_2P = 18 cm.
   What is the path difference for the third maximum ($S_1R - S_2R$)?



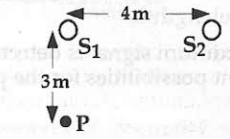
7. Microwaves of wavelength 2.8 cm pass through two narrow gaps G_1 and G_2 in an aluminium barrier. Point **P** on the far side of the barrier is 11.2 cm further from one gap than the other.

Explain whether point **P** is a maximum or a minimum.



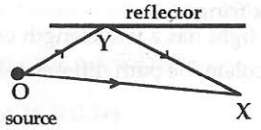
8. Two water-wave generators, S_1 and S_2, produce water waves of wavelength 2 m. S_1 and S_2 are placed 4 m apart in a water tank as shown. There is a detector on the water surface at **P**, 3 m from S_1. Each generator on its own produces waves of amplitude y at position **P**.

When both are operating together and in phase, what is the amplitude of the wave at **P**?



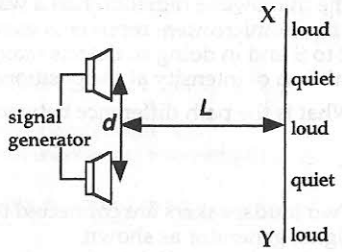
9. A microwave source produces 2.8 cm waves. When a metal reflector is placed as shown, an interference pattern is observed with **X** being on a line of **constructive interference**.

If **OX** = 40 cm, suggest **two** possible values for the total path length **OYX**.



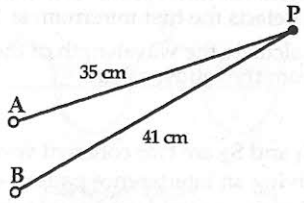
10. Two loudspeakers are arranged as shown and both emit a note of frequency 1000 Hz. When a pupil moves from **X** to **Y**, the note he hears alternates between loud and quiet.

Give **two** ways in which successive loud regions can be made closer together.



11. In a water tank, circular water waves are produced by two dippers **A** and **B**, which move up and down in phase. An interference pattern is observed with a minimum at **P**.

If the distances are as shown, explain which of the following values could be the wavelength of the waves: **2, 3, 4, 6 cm**

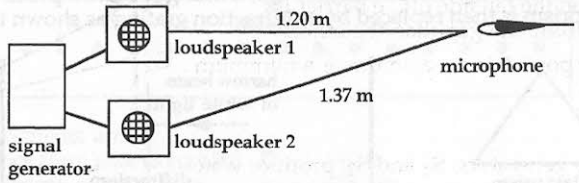


12. Consider the following passage in which **three** words are missing and have been replaced by the letters **X**, **Y** and **Z**.

"When waves from two coherent sources of **X** light (i.e. light of one frequency) combine, it is observed that **Y** occurs. The resulting pattern varies in brightness. The brightness depends on the combined **Z**"

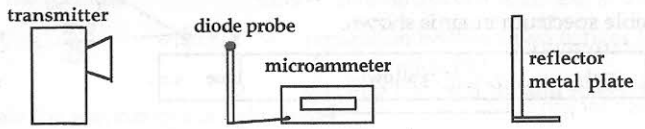
State which words are represented by the letters **X**, **Y** and **Z**.

13. Loudspeakers **1** and **2** are both connected to the same signal generator which is set to produce a 1 kHz signal. Loudspeaker **1** is switched on but loudspeaker 2 is switched off.

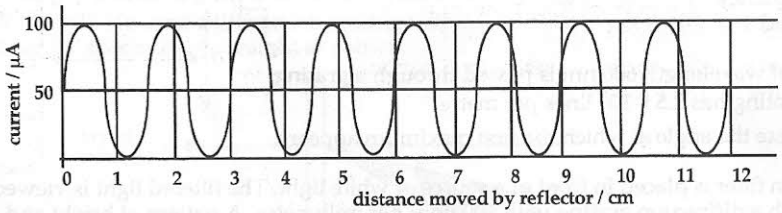


State **and** explain what happens to the amplitude of the signal picked up by the microphone when loudspeaker 2 is switched on.
Your explanation should include a calculation, taking the value of the speed of sound in air to be 340 m s^{-1}.

14. In an experiment, microwaves from a transmitter are reflected by a metal plate. Between the transmitter and the reflector is a diode probe connected to a microammeter. The diode probe picks up microwaves and the microammeter reading is a measure of the intensity of the microwaves.



The graph shows how the microammeter reading varies as the **reflector** is moved to the right.



a) Explain why movement of the reflector causes the maxima and minima shown on the graph.
b) What is the wavelength of the microwaves?
c) In another experiment with a different source of microwaves, a maximum reading was found with the reflector at 22.5 cm from the detector and a further ten maxima were found as the reflector was moved to a maximum reading at 36.5 cm from the detector.
   i) Calculate the wavelength of these microwaves.
   ii) What was the frequency of these microwave?

Exercise 8.3 Prisms and Diffraction Gratings

1. A narrow beam of white light is passed through a triangular glass prism as shown in diagram 1. The prism is then replaced by a diffraction grating as shown in diagram 2.

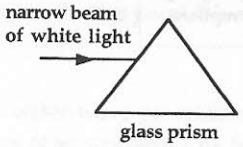


Diagram 1

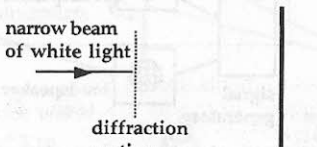
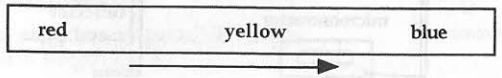


Diagram 2

a) Describe in detail what would be seen on the screen in diagram 1.
b) Describe in detail what would be seen on the screen in diagram 2.

2. State a possible wavelength for
a) red light,
b) green light,
c) blue light.

3. Part of the visible spectrum in air is shown.



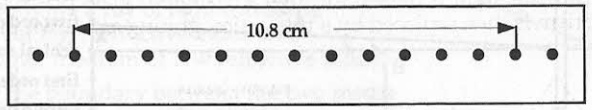
How do the following wave characteristics vary as the light changes from red to blue (in the direction of the arrow)?
a) wavelength
b) frequency
c) speed

4. Light of wavelength 600 nm is passed through a grating.
The grating has 2.5×10^5 lines per metre.
Calculate the angle at which the first maximum appears.

5. A green filter is placed in front of a source of white light. The filtered light is viewed through a diffraction grating with 100 lines per millimetre. A pattern of bright and dark fringes is observed but they are too close together for accurate measurement.
For each of the following changes, explain whether the fringe separation would increase or decrease.
a) increasing the distance between the grating and the screen
b) using a blue filter instead of a green one
c) using a more intense light source
d) using a grating with 300 lines per millimetre

6. During an experiment, white light is dispersed into its constituent colours and the red light is deviated the most.
a) What has been used to cause the dispersion?
b) How many spectra will be produced, only one or several pairs?

7. Red light from a laser is passed through double slits. The diagram shows the pattern of dots produced on a screen. Each pair of dots are x apart.



Other measurements are:
Distance from slits to screen, $D = 3.02$ m
Wavelength of laser light $\lambda = 633$ nm

a) Using the expression $\lambda = \frac{x\,d}{D}$ calculate the separation of the slits d.

b) What change in the spacing of the dots will take place if a laser emitting green light is used instead?

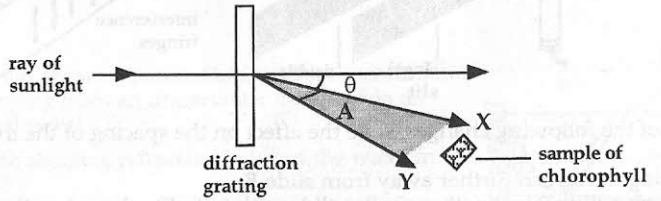
8. a) Using monochromatic light, interference fringes are produced on a screen which is 2 m from a pair of narrow slits. The slits are 0.5 mm apart and the fringe separation is 1.6 mm.
Given the formula

$$\lambda = \frac{x\,d}{D}$$

where x = separation between two fringes (m)
d = slit separation (m)
D = distance between slit and screen (m)

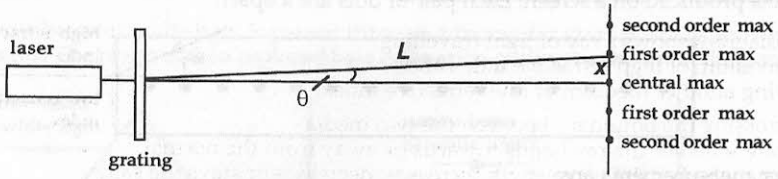
calculate the wavelength of light used.
b) The screen is now placed 4 m from the slits and the slit separation is reduced to 0.1 mm. Calculate the new fringe separation.

9. A biologist is studying the effect of different colours of light on a sample of chlorophyll. He used a diffraction grating with 6.0×10^5 lines per metre to produce a first order spectrum of sunlight as shown.



a) i) Explain briefly how a diffraction grating produces a continuous spectrum from a ray of sunlight.
ii) The wavelength of the light at the end X of the spectrum is 410 nm.
Calculate the value of the angle θ.
iii) The angle A in the diagram above is 9°.
Calculate the wavelength at end Y of the spectrum.
b) The biologist now uses a triangular glass prism to produce a continuous spectrum from a ray of sunlight.
State **two** differences between this spectrum and the spectrum produced by the grating.

10. The apparatus shown is set up to determine the wavelength of light from a laser.

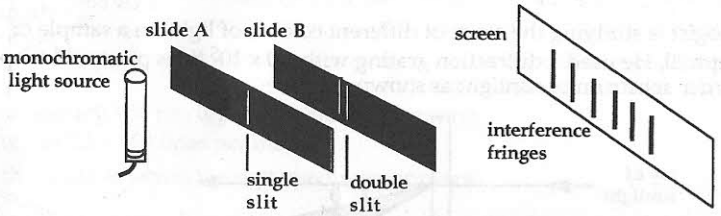


The separation of lines in the grating $d = 1.693 \times 10^{-5}$ m.
The wavelength of light is calculated using the diffraction grating equation and $\sin\theta = \frac{x}{L}$ where angle θ and distances x and L are shown above.

Seven students measure the distance L with a tape measure.
Their results are as follows:
2.402 m, 2.399 m, 2.412 m, 2.408 m, 2.388 m, 2.383 m, 2.415 m

a) i) Calculate the mean value for L.
ii) Calculate the approximate random uncertainty in the mean of L.
b) The best estimate of the distance x is 91 ± 1 mm.
Show by calculation whether L or x has the larger percentage uncertainty.
c) Calculate the wavelength, in nanometres, of the laser light.
Give your answer in the form **final value ± absolute uncertainty**.
d) Suggest an improvement which could be made so that a more accurate estimate of the wavelength could be made.
Use only the same equipment and make the same number of measurements.

11. The sketch illustrates one method of producing interference fringes.

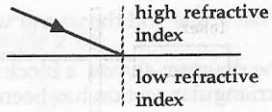


a) For each of the following changes, state the effect on the spacing of the interference fringes.
i) moving the screen further away from slide **B**
ii) replacing slide **B** by another similar slide with two slits closer together
iii) replacing the monochromatic light source with one of longer wavelength

b) The monochromatic light source is replaced by a tungsten filament lamp and slide **B** is replaced by a diffraction grating.
i) Explain in terms of waves why the red colour of the observed spectrum is seen further away from the central band than the blue colour.
ii) Explain why the central band, known as the zero order spectrum, is white.

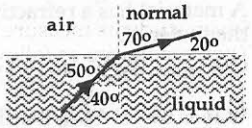
Exercise 8.4 Refractive Index

1. The diagram shows a ray of light travelling in a medium of high refractive index and meeting another medium of low refractive index.



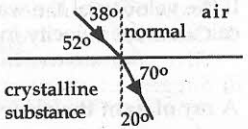
On crossing the boundary between the two media
a) state whether the ray bends towards or away from the normal,
b) state whether the wavelength increases, decreases or stays the same,
c) state whether the frequency increases, decreases or stays the same,
d) state whether the velocity increases, decreases or stays the same.

2. The diagram shows a ray of light passing from liquid into air.



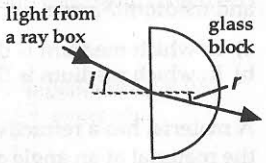
Calculate the refractive index of this liquid relative to air.

3. The diagram shows a ray of light going from air into a crystalline substance



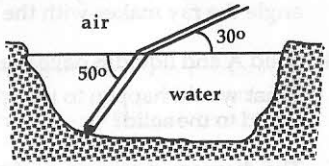
Calculate the refractive index of this crystalline substance relative to air.

4. A pupil sets up the apparatus shown to investigate the relationship between the angle of incidence i, and the angle of refraction r, for a ray passing from air into glass.



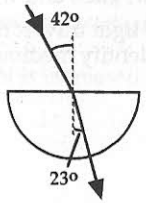
a) Sketch the graph she would obtain for sin i against sin r.
b) Explain why a semi-circular glass block was used.

5. The diagram shows a parallel beam of monochromatic light emerging from an underwater spotlight in an ornamental pond.



What is the absolute refractive index of the water in this pond?

6. The diagram shows the path of a ray of light through a semicircular block of glass. The direction of the ray is shown by the arrows.



Draw a diagram to show the path of the ray travelling in the reverse direction.

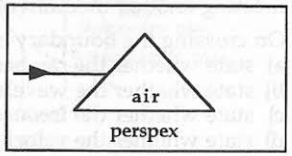
7. Light passes from air into a liquid.
Give expressions for the refractive index in terms of the angle to the normal, the wavelength and the velocity of the light in the air compared to that in the liquid.

8. Sound waves travel 4.5 times faster in water than they do in air. Sound waves from an undersea earthquake strike the surface of the water at 45° to the normal.

   What angle will the sound waves make to the normal in air?

9. The diagram shows a block of perspex out of which a triangular section has been cut.

   Copy and complete the diagram to show the path of the ray of light.

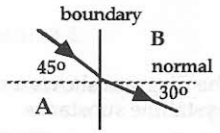


10. A material has a refractive index of 1.5. Light of frequency 6×10^{14} Hz is incident on the material.

    Calculate the speed, wavelength and frequency of the light in the material.

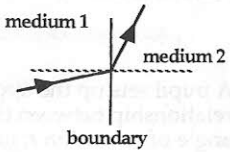
11. Waves travel from medium A to medium B. In A their direction is 45° to the normal and in B it is 30° to the normal.

    If the velocity of the waves in medium A is 0.283 m s^{-1}, calculate the velocity in medium B.



12. A ray of light travels with speed v_1 through medium 1 as shown and then passes into another medium 2, where it travels at speed v_2. The refractive indices for medium 1 and medium 2 are n_1 and n_2 respectively.

    a) In which medium is the refractive index the greater?
    b) In which medium is the speed of light the greater?



13. A material has a refractive index of 1.4. Light of wavelength 6×10^{-7} m is incident on the material at an angle of 60° to the normal.

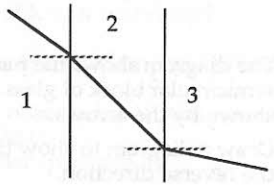
    Calculate the speed, wavelength and frequency of the light in the material and the angle the ray makes with the normal in the material.

14. Solid A and liquid B have the same refractive index.

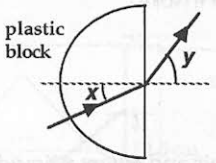
    What would happen to the speed and wavelength of a light wave passing from the liquid to the solid?

15. The diagram shows a ray of light travelling through air, glass and water, **not** necessarily in that order.

    If light travels faster in water than in glass, then identify medium 1, medium 2 and medium 3.



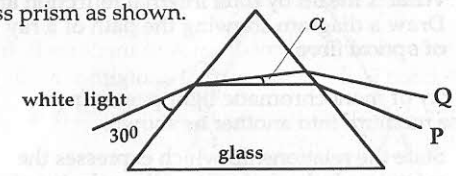
16. The table gives the results of an experiment on the refraction of light travelling through a semi-circular plastic block into air.



angle **x** / °	angle **y** / °
15	23
20	31
31	50
35	61
40	76

    a) State the mathematical relationship between the two angles **x** and **y** and show that the results are in agreement with this relationship.
    b) Calculate the refractive index of the plastic.

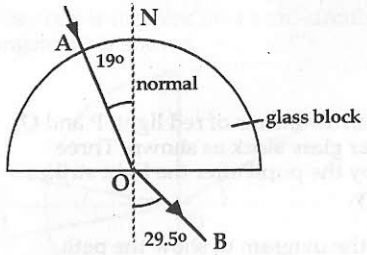
17. A ray of white light is incident on a glass prism as shown.



    The refractive index of the glass is 1.53 for blue light and 1.51 for red light.

    a) If P and Q represent the ends of the visible spectrum, which is the blue end?
    b) Calculate angle α.
    c) From the refractive indices, deduce whether red or blue light travels faster through the glass. Give your reasoning.

18. The diagram (**not** to scale) shows the ray **AOB** traced by a pupil investigating the refraction of red light using a semi-circular glass block.



    a) Use the information given in the diagram to calculate the refractive index of glass for red light.
    b) Draw an accurate diagram to show the path of the ray if angle **AON** is increased to 30°.
    c) Calculate the speed of red light in glass.