How can waves explain the behaviour of light?

Properties on mechanical waves

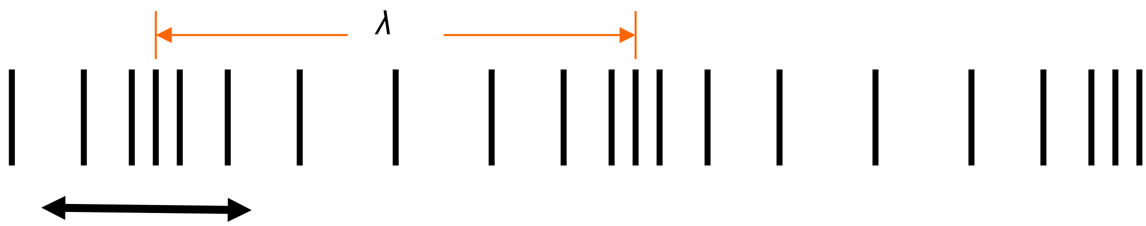
- **explain a wave as the transmission of energy through a medium without the net transfer of matter**
- **distinguish between transverse and longitudinal waves**
- **identify the amplitude, wavelength, period and frequency of waves**
- **calculate the wavelength, frequency, period and speed of travel of waves using:**

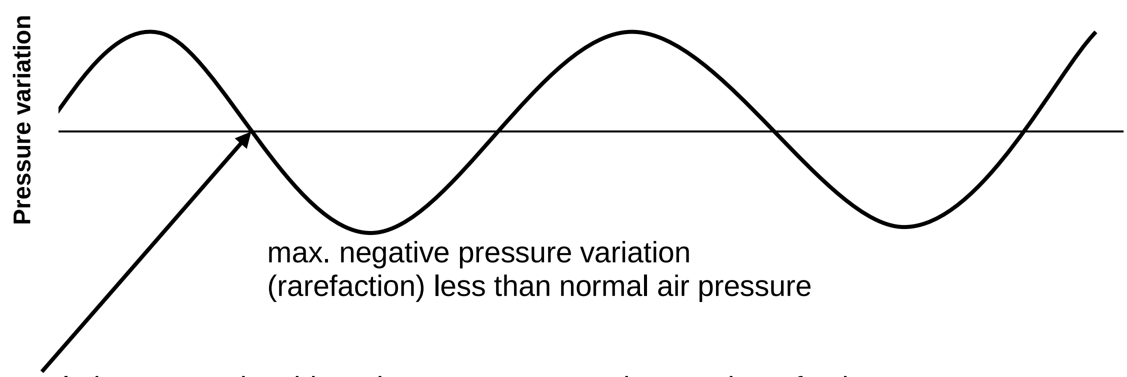
$$v = f\lambda = \frac{\lambda}{T}$$

2006 Sound	2007 Sound	2008 Sound	2009 Sound	2010 Sound	2011 Sound	2012 Sound	2013 Sound	2014 Sound	2015 Sound	2016 Sound
2, 3		2, 3	2, 3, 4	1, 2	1	1, 2	1, 9	1	1, 2	1, 2

Longitudinal waves

In longitudinal waves the vibration of the waves is in the same direction as the line of travel, the particles do not move forward, they vibrate around an equilibrium position. E.g. Sound waves.

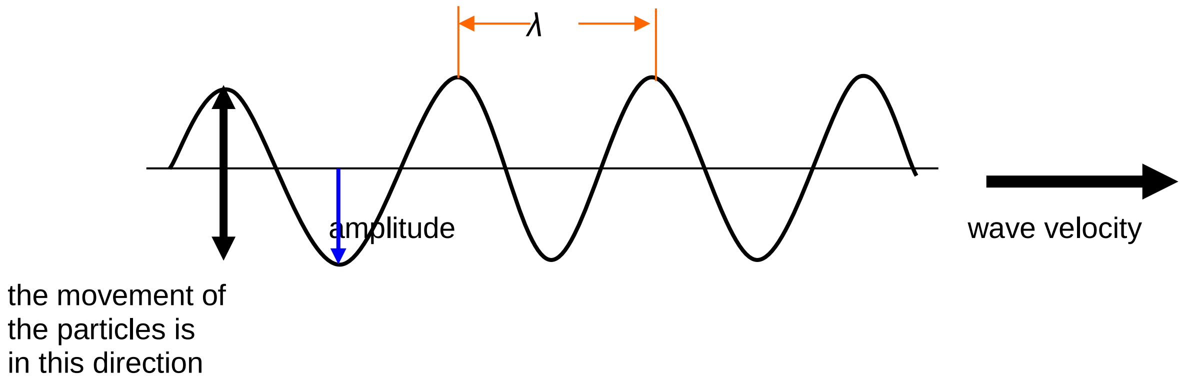




Transverse waves

When waves vibrate up and down in a direction perpendicular to the direction of motion of the wave. e.g. water waves, where the motion of the water particles is at right angles (up and down) to the direction of the wave (forward), light.

A transverse wave is modelled below



Waves can be characterised by key quantities: speed, frequency, period and wavelength.

Frequency

Frequency is a measure of how rapidly the source of the wave is vibrating. The frequency (f) is defined as the number of vibrations per second. The units for frequency are Hertz, Hz, cycles per sec.

Period (T)

The period is the length of time required for one full cycle of the wave to be complete. Frequency is the number of cycles per second, $\therefore$ $f = \frac{1}{T}$, where T is the period, the time taken for 1 cycle.

Speed (v)

The speed of the wave is obviously how fast the wave is travelling. Sound waves propagate at about 330 m s^{-1}. The speed of light in a vacuum is 3×10^8 m s^{-1}. For a uniform medium, the speed is constant. The frequency, amplitude and wavelength of a wave do not change its speed.

Wave equation

The wave equation links the velocity of the wave to the frequency and the wavelength.

$$\mathbf{v = f\,\lambda = \frac{\lambda}{T}}$$

where v is in m s^{-1}, f is in Hz, λ is in metres and T in seconds.

Example 4.1: QLD 2016 Question 7 (1 mark)

When a wave moves through a medium there is a net transfer of

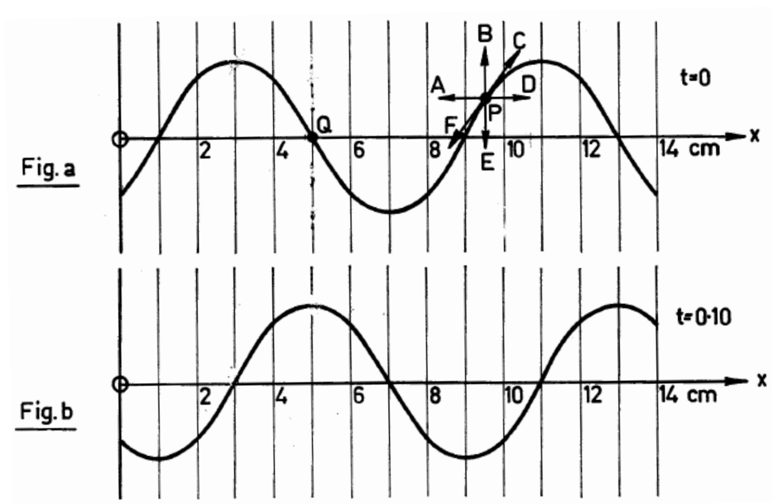
A mass only.

B energy only.

C momentum only.

D mass and energy.

Fig. a is a picture of a string with a periodic wave moving on it in the +x direction.
Fig. b shows same piece of string 0.10 sec later.



Example 4.2: 1971 Question 53 (1 mark)

What is the smallest velocity of the wave consistent with this information?

Example 4.3: 1971 Question 54 (1 mark)

What is the frequency of the wave corresponding to this velocity?

Example 4.4: 1971 Question 55 (1 mark)

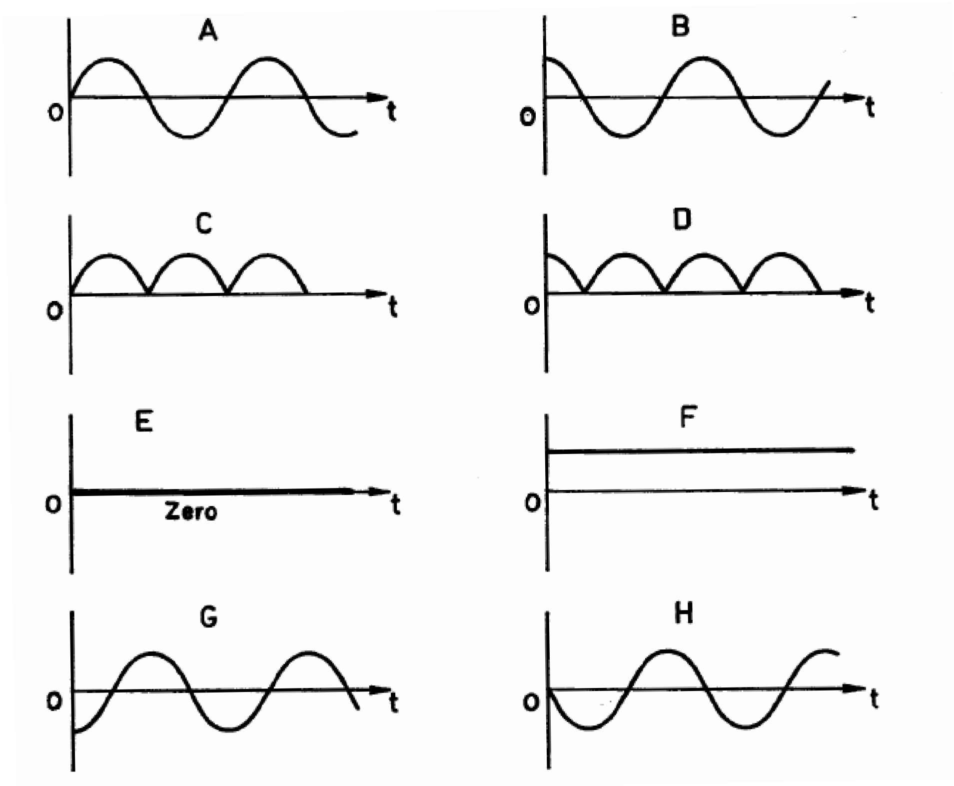
What is the next highest velocity of the wave consistent with the information on the diagram?

Example 4.5: 1971 Question 56 (1 mark)

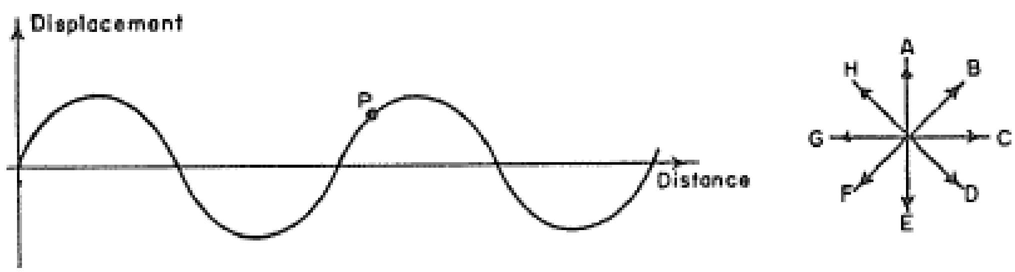
Which of the arrows on Fig. a shows the velocity of point P on the string?

Example 4.6: 1971 Question 57 (1 mark)

Which of the following graphs best represents the velocity-time graph of point Q?



The figure below represents a flash photograph, taken at the time $t = 0$, of a rope, along which a wave is *moving to the right.* Axes have been added indicating displacement (vertical) as a function of distance along the rope.

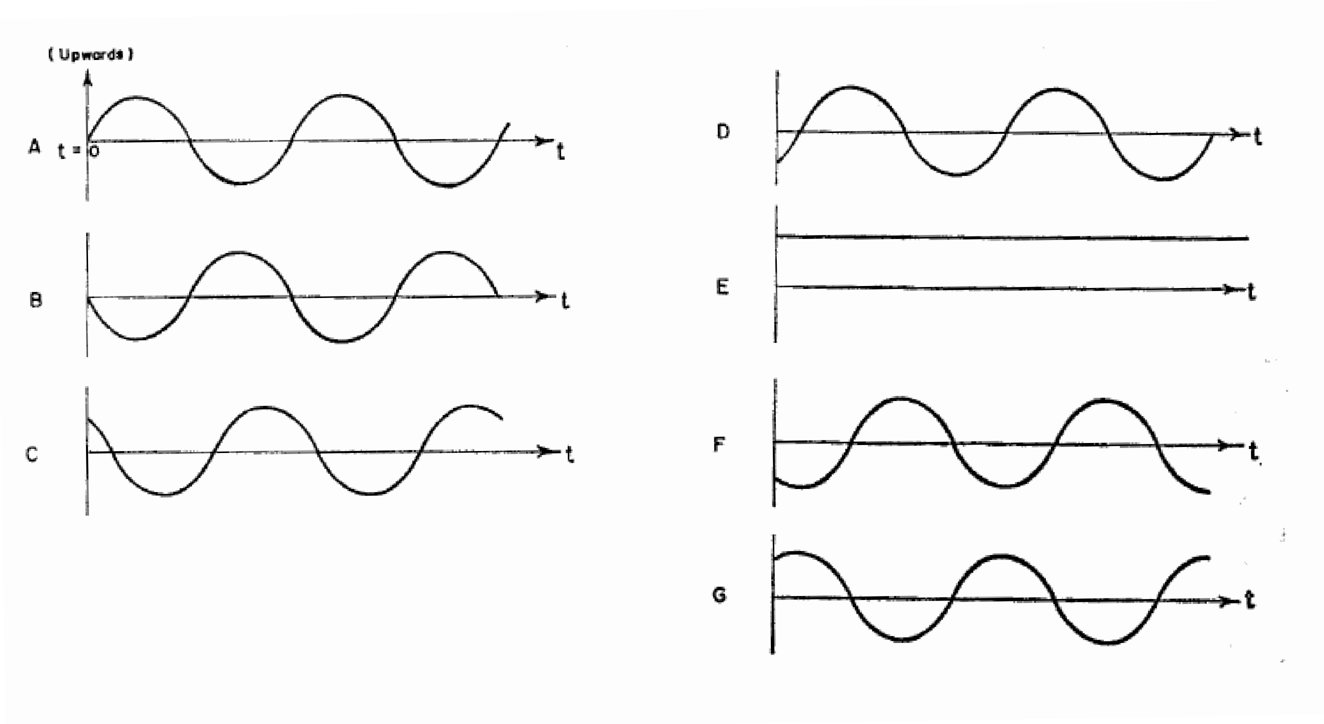


Example 4.7: 1974 Question 52 (1 mark)

What is the direction of motion of point P on the rope?
Select the correct arrow (**A** - **H**) from the key above.

Example 4.8: 1974 Question 53 (1 mark)

Which diagram below (**A** - **G**) represents the variation of the displacement of P as a function of time?



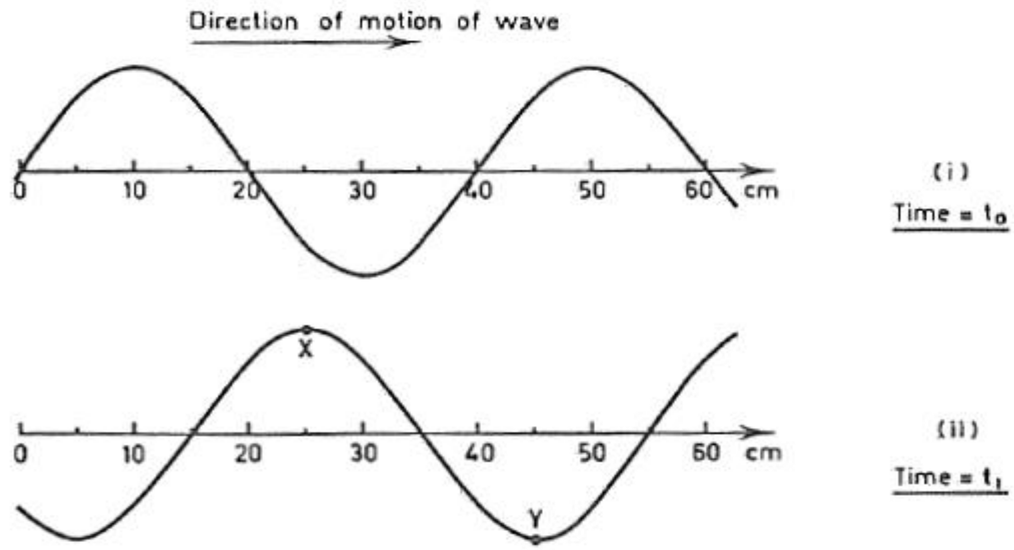


Diagram (i) represents a wave travelling along a rope in the direction indicated, at instant t_0.
Diagram (ii) represents the same wave at instant t_1, which is 0.15 seconds later.

Example 4.9: 1978 Question 33 (1 mark)

What is the slowest possible velocity of the wave for this result?

Example 4.10: 1978 Question 34 (1 mark)

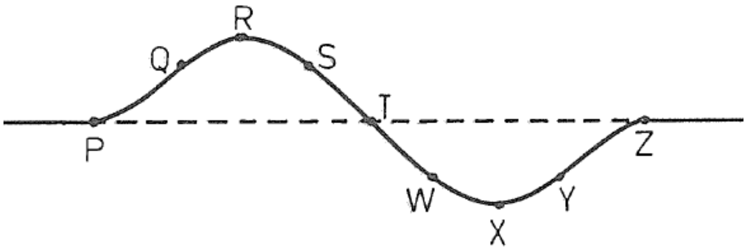
What is the lowest possible frequency of vibration of the rope which could have led to this result?

A light object is attached to the rope at point X.

Example 4.11: 1978 Question 35 (1 mark)

At the instant t_1, what is the speed of this object in the direction of travel of the wave?

A single pulse on a long coil spring is moving towards the right. A photograph of the pulse was taken and a representation of the photograph is shown below.



ANSWER KEY
A. moving up
B. moving down
C. stationary, but about to move up
D. stationary, but about to move down
E. stationary, and will remain stationary

Select from the ANSWER KEY the alternative which, at the instant the photograph was taken, described the motion

Example 4.12: 1980 Question 35 (1 mark)

of point Y.

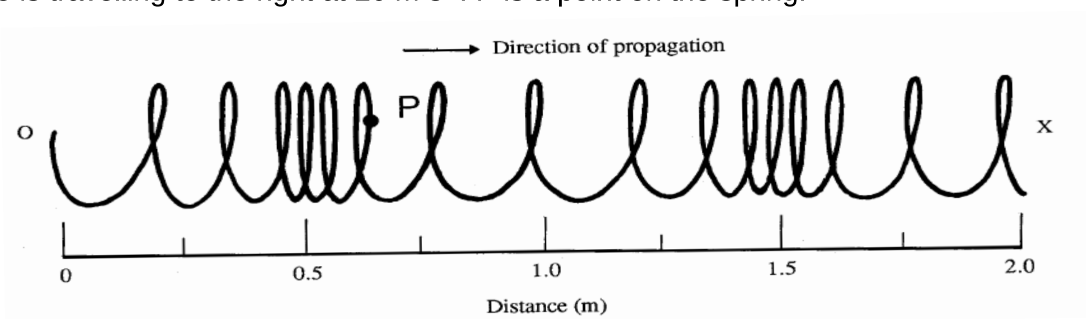
Example 4.13: 1980 Question 36 (1 mark)

of point T

Example 4.14: 1980 Question 37 (1 mark)

To which point on the spring does statement **E** in the ANSWER KEY apply?

The figure below shows a longitudinal wave travelling to the right along a 'slinky' spring. The wave is travelling to the right at 20 m s^{-1}. P is a point on the spring.



Example 4.15: 1989 Question 36 (1 mark)

What is the wavelength of the wave?

Example 4.16: 1989 Question 37 (1 mark)

Which of the statements **(A - D)** below best describes the motion of the point P on the spring?

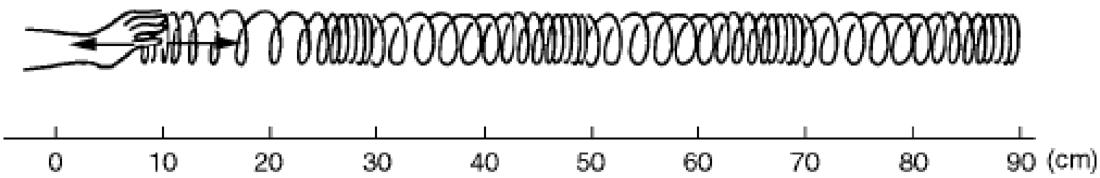
A. It is oscillating with simple harmonic motion in the direction of OX.

B. It is oscillating with simple harmonic motion in a direction at right angles to OX.

C. It is moving to the right at a constant speed of 20 m s^{-1}.

D. It is stationary and will remain so.

A teacher uses longitudinal waves on a very long spring to demonstrate travelling sound waves. The first part of the spring is shown below.



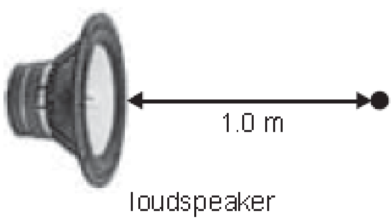
Example: 4.17: 1999 Question 1 (1 mark)

Estimate the wavelength of this wave.

Example 4.18: 1999 Question 2 (2 marks)

What is the speed of this wave if its frequency is 4.0 Hz? Give your answer in **cm s^{-1}**.

Consider a dust particle one metre in front of a loudspeaker that is producing a constant tone sound wave.



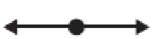
Example 4.19: 2006 Question 2 (2 marks)

Which one of the following statements and diagrams **(A - D)** best describes the motion of the dust particle?

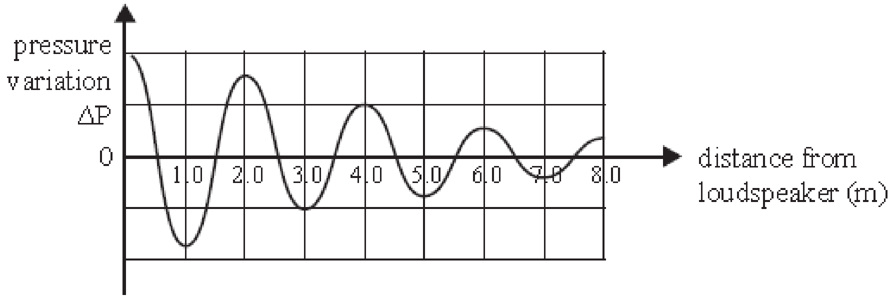
A.  The dust particle oscillates in a vertical direction.

B.  The dust particle travels away from the speaker with the wave.

C.  The dust particle remains stationary as the wave passes.

D.  The dust particle oscillates in a horizontal direction.

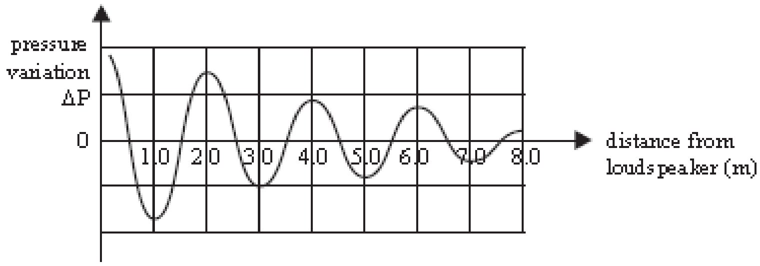
A loudspeaker is emitting sound of a fixed intensity which travels equally in all directions. The figure below shows the pressure variation plotted against distance from the loudspeaker, at a particular instant of time. Take the speed of sound to be 333 m s^{-1}.



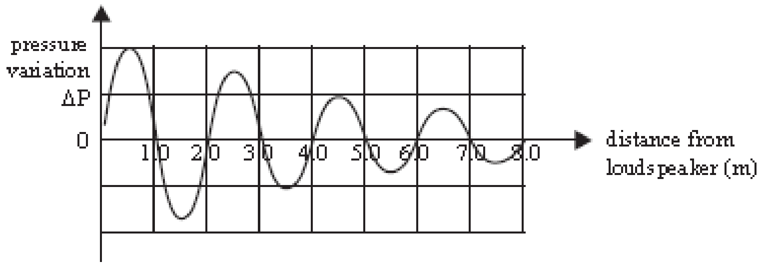
Example 4.20: 2009 Question 4 (2 marks)

Which one of the graphs shows the pressure variation as a function of distance from the loudspeaker, at a time that is a quarter of a period later than shown above?

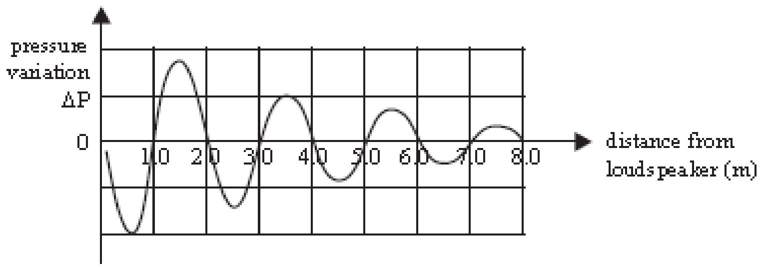
A.



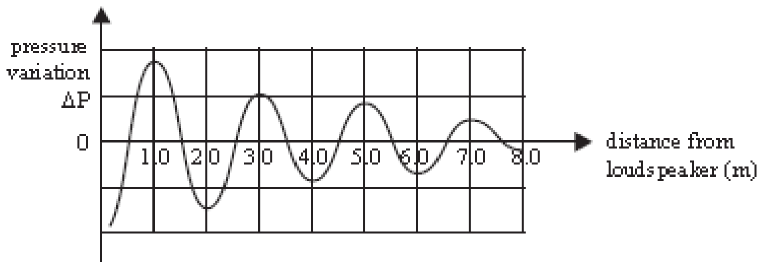
B.



C.



D.



Example 4.21: TAS 2015 Question 13a (2 marks)
Two wave types are **sound** waves and **light** waves.
For each of these two, state: whether they are **transverse** or **longitudinal**, describe what physical quantity is oscillating **and** draw vectors to show the direction of the oscillation at point **P**.

(i) Sound waves:

(ii) Light waves:

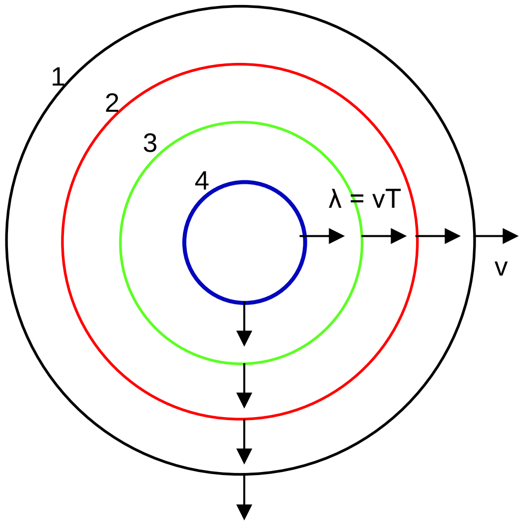
Properties on mechanical waves

- **explain qualitatively the Doppler effect**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016

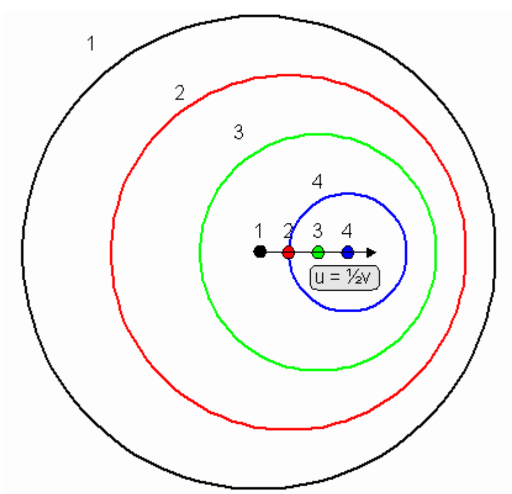
The Doppler Effect

If a wave source is stationary, then the waves will travel away from the source at the same speed in all directions. The wave fronts will be circular.



The Doppler effect is when the source of the sound wave is moving with respect to the observer.

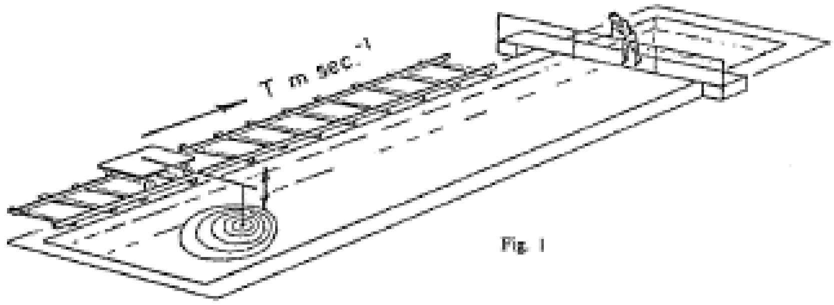
As the source moves away from the observer there is an apparent increase in the wavelength and a decrease in the frequency.



As the source moves towards the observer, there is an apparent shortening of the wavelength and hence an increase in the frequency.

Since the medium the wave is travelling in doesn't change, the speed of the wave remains constant. The wavefronts remain circular but the centre of the circle moves.

Using $v = f\lambda$, as the wavelength increases the frequency must decrease if v is constant.



A model train runs at constant speed T m sec^{-1} alongside a swimming pool. Attached to the train is a vibrating rippler which dips into the water with a frequency of H sec^{-1}. The train is moving towards a stationary observer.

If the train were not moving, the wave pattern would be as shown in figure 2.

When the train is moving, the wave pattern is as shown in figure 3. Note that the wavelength in the forward direction is now compressed to $\frac{1}{2}\lambda$.

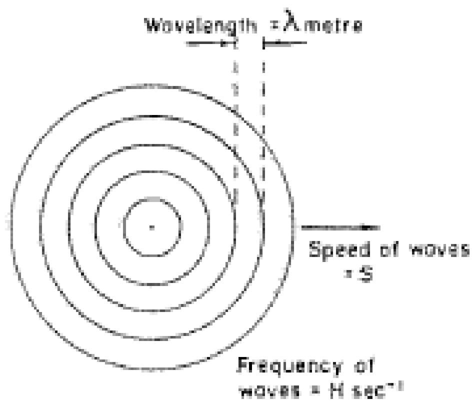


Fig. 2

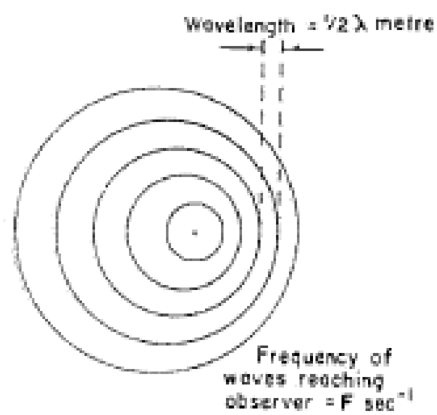


Fig. 3

Example 4.22: 1969 Question 60 (1 mark)

In Fig. 3 the speed of the waves in the forward direction is:

A. S +T. **B.** S - T. **C.** S. **D.** 2S. **E.** $\frac{S}{2}$

Example 4.23: 1969 Question 61 (1 mark)

The frequency of the waves, F sec^{-1}, reaching the observer is equal to:

A. H. **B.** 2H. **C.** $\frac{H}{2}$. **D.** $\frac{S-T}{\lambda}$. **E.** $\frac{S+T}{\lambda}$

Example 4.24: 1969 Question 62 (1 mark)

The wavelength of the waves in the backward direction is equal to:

A. $\frac{S}{H}$. **B.** $\frac{3}{2}\lambda$. **C.** λ. **D.** $\frac{S-T}{H}$. **E.** 2λ.

Properties on mechanical waves

- **explain resonance as the superposition of a travelling wave and its reflection, and with reference to a forced oscillation matching the natural frequency of vibration**

2006 Sound	2007 Sound	2008 Sound	2009 Sound	2010 Sound	2011 Sound	2012 Sound	2013 Sound	2014 Sound	2015 Sound	2016 Sound
	2, 3, 4, 5	8, 9, 10, 11	10, 11	6				5, 7, 8	5	7, 8, 9

Superposition

The displacement of two waves combining with each other is calculated by the vector addition of the two components. The two pulses pass through each other without being altered.

Constructive interference is when the two pulses pass through each other and superimpose and reinforce each other to give a maximum disturbance of the medium; this results in a louder sound. Destructive interference is when the two pulses pass through each other and superimpose and cancel each other out to give minimum or zero disturbance of the medium; this results in a quieter sound.

Resonance

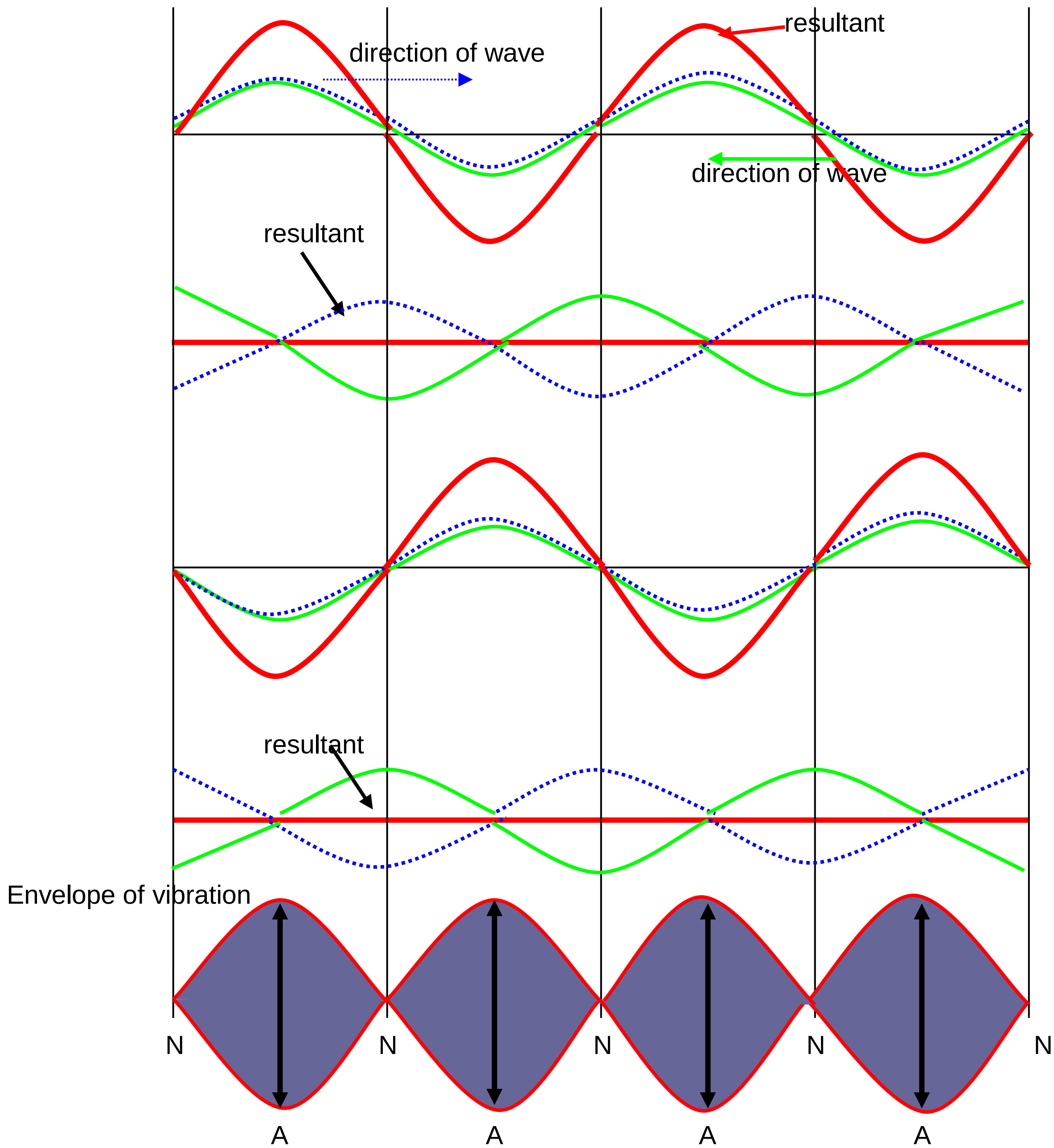
Resonance is the condition when a natural vibrating system responds to an external driving frequency, it occurs when a forcing frequency, the same as the natural frequency, is applied. Each object has its own natural or resonant frequency.

Standing waves

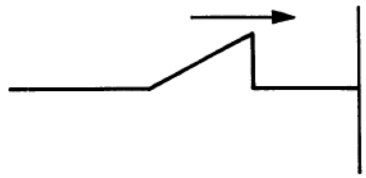
If we have two identical waves travelling in the opposite directions in one medium we get a standing or stationary wave. The superposition principle is used to obtain the waveform.

- Certain points marked N = node = point of zero displacement, a node or nodal point.
- Loops or antinodes, marked A, are points of maximum displacement, midway between the nodes.
- The wave does not progress through the medium.
- Wavelength is the same as that of the components.
- Maximum amplitude of the resultant wave is twice that of the components.
- The distance between adjacent nodes or antinodes is $\frac{\lambda}{2}$.
- Any particles between any two successive nodes are in phase. Their motions correspond at any instant. They have zero displacement and maximum displacement at the same instant.
- They can only be produced by the superposition of two waves of equal amplitude and frequency travelling in the opposite direction
- They are the result of resonance and occur only at the natural frequencies of the vibration.

Nodes are a result of destructive interference, there is little or no variation in air pressure, so it is perceived by the listener as a region of soft sound. Antinodes are a result of constructive interference, so there will be maximum variation of air pressure, which will be perceived as a region of loud sound.

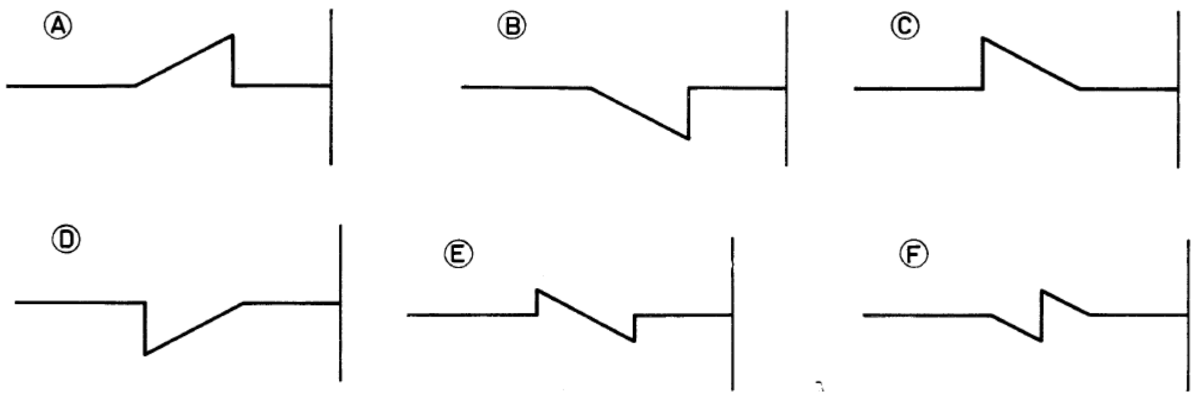

resultant
direction of wave
direction of wave
resultant
resultant
Envelope of vibration
N
N
N
N
N
A
A
A
A

A pulse in a rope approaches a solid wall and is reflected from it.

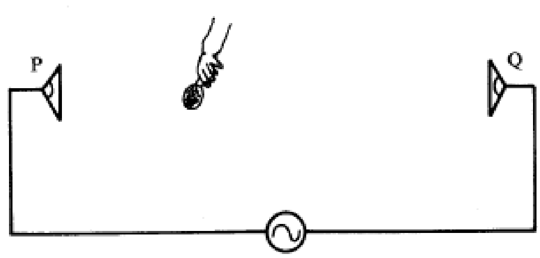


Example 4.25: 1973 Question 49 (1 mark)

Which of the following shows the pulse after reflection?



Two loudspeakers P and Q are connected in phase to an amplifier so that they emit sound of frequency 1000 Hz. A microphone is moved along the line joining P and Q and shows a series of maximum and minimum intensities. Three successive maxima are found at distances 1.27 m, 1.42 m and 1.57 m from P.



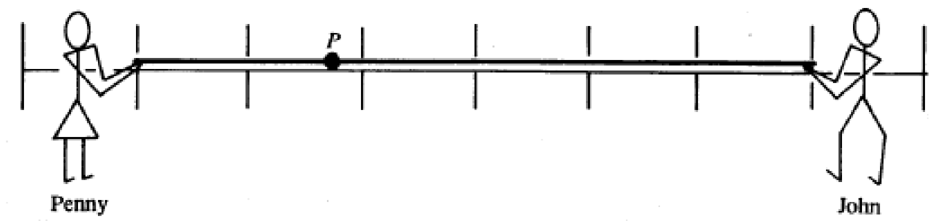
Example 4.26: 1983 Question 33 (1 mark)

What is the wavelength of the sound?

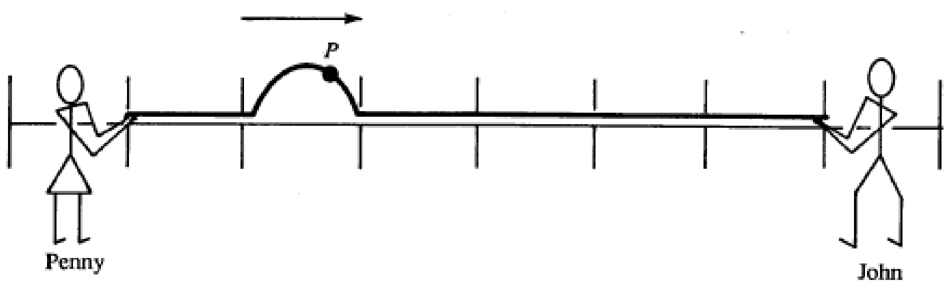
Example 4.27: 1983 Question 34 (1 mark)

What is the speed of the sound in the medium?

Two physics students, Penny and John, use a length of light spring to demonstrate waves to their class. The situation is shown below, where a scale is visible behind the spring.
P is a point on the spring.



Penny sends a single travelling pulse, moving from left to right, along the spring as shown below.



Example 4.28: 1988 Question 35 (1 mark)

Which of the statements **(A - F)**, listed in the key below, best describes the motion of the point P, at the instant shown in the second figure?
Key

A. It is moving to the right.

B. It is moving to the left.

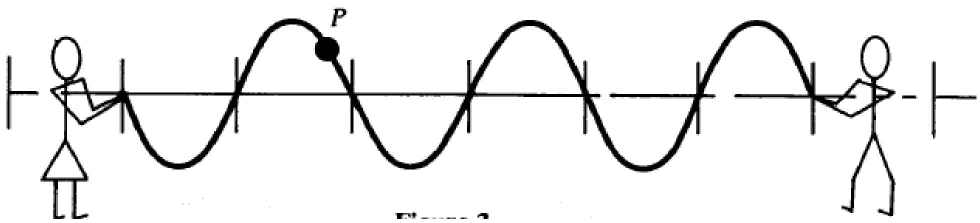
C. It is moving upwards.

D. It is moving downwards.

E. It is momentarily stationary.

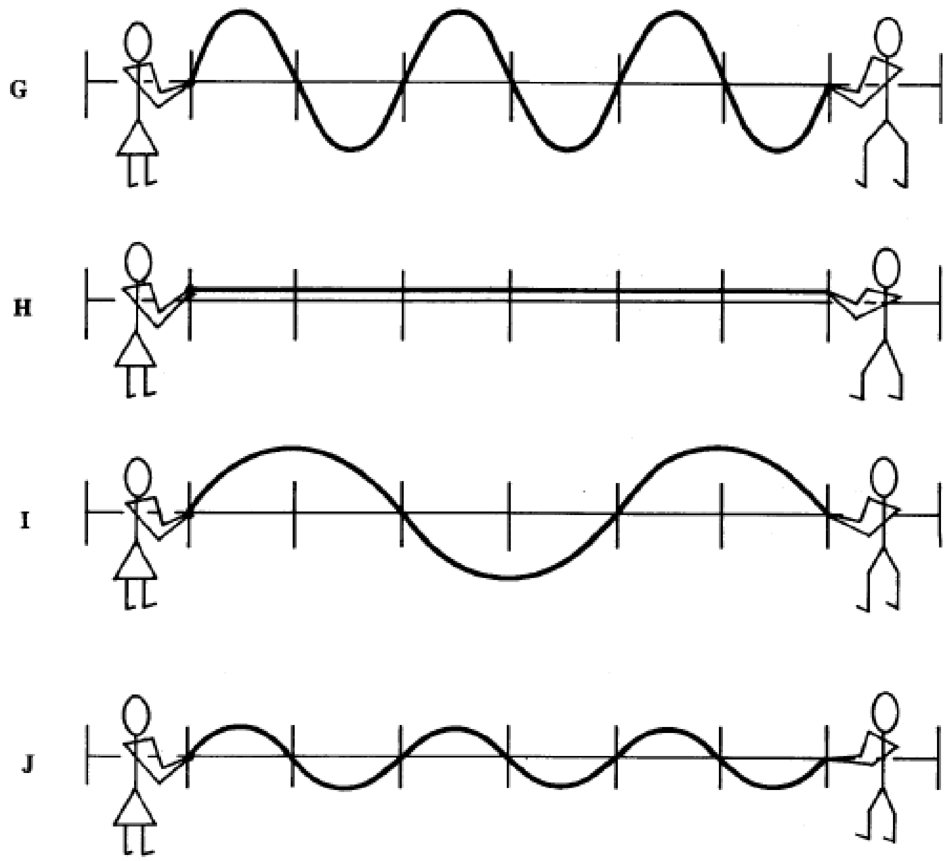
F. It is always stationary.

Penny and John now set up a standing wave pattern on the spring as shown below.
At the instant shown below the pattern is at its maximum displacement.



Example 4.29: 1988 Question 36 (1 mark)

Using the key above, which of the statements (**A - F**) best describes the motion of the point P, at the instant shown.

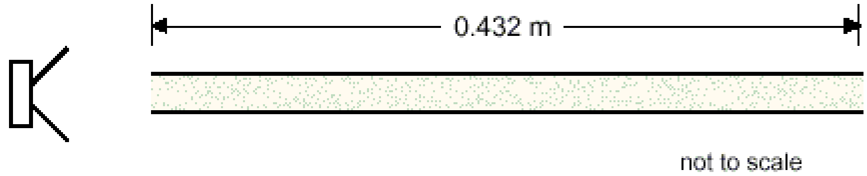


Example 4.30: 1988 Question 37 (1 mark)

Which one or more of the diagrams, **G** to **J** above, could show the standing wave pattern some time later?

(One or more answers.)

Students use a narrow tube of length 0.432 m open at both ends to model a flute. By varying the frequency of sound emitted from a small loudspeaker placed near one end, as shown below they observe resonances at several frequencies.



The wavelengths of the sound at which the resonances with the three lowest frequencies occur are 0.864 m, 0.432 m and 0.288 m. The speed of sound in air is 340 m s^{-1}.

Example 4.31: 1998 Question 10 (c/f 2009 Q10) (2 marks)

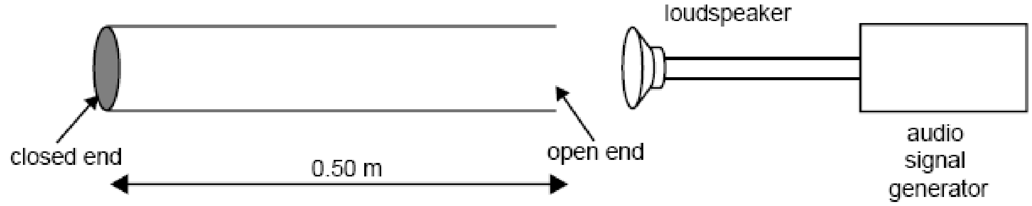
What is the lowest frequency at which resonance is observed by the students? Show your working.

The students then fill the 0.432 m tube with helium. The speed of sound in helium is 1 000 m s^{-1}, compared to 340 m s^{-1} for air.

Example 4.32: 1998 Question 11 (3 marks)

The students find the longest wavelength of sound which produces resonance in the tube filled with helium. Is this wavelength the same, longer or shorter than the longest wavelength when the tube was filled with air?

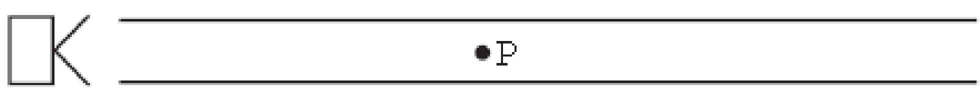
In order to study resonance in air columns, students use a narrow tube of length 0.50 m that is closed at one end and open at the other. They use a signal generator and loudspeaker as shown below.



Example 4.33: 2007 Question 4 (2 marks)

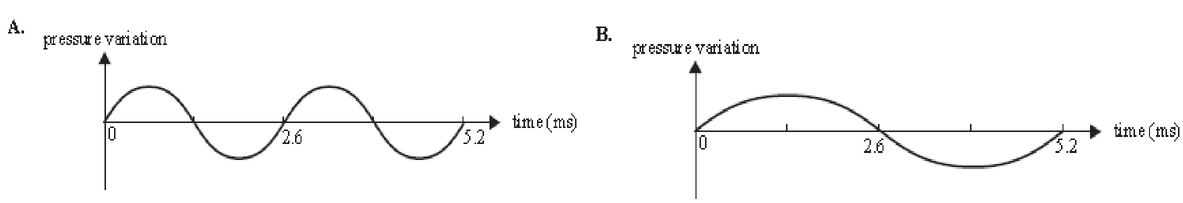
The students begin the experiment by using a sound of frequency 100 Hz. What will the students hear that will enable them to identify this resonance frequency? Explain why this occurs.

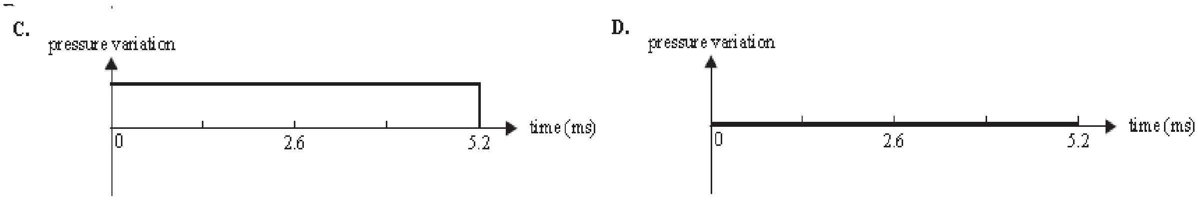
Students use a narrow tube, open at both ends, to model a flute. A frequency generator attached to a loudspeaker is placed near one end, as shown below. The fundamental frequency is measured to be 385 Hz. Take the speed of sound to be 333 m s^{-1}.



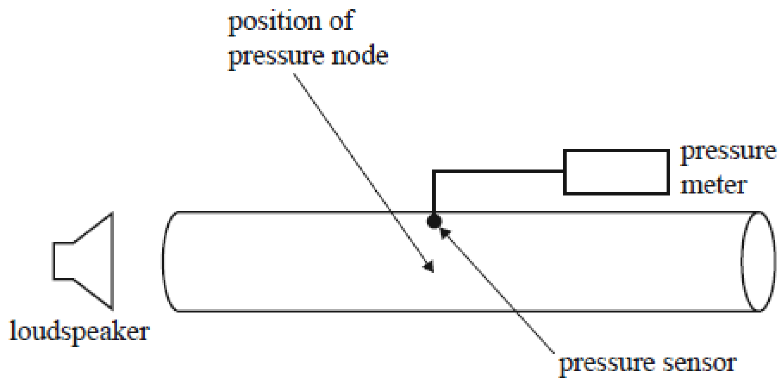
Example 4.34: 2009 Question 11 (2 marks)

P is at the middle of the tube and the sound of 385 Hz is still being emitted.
Which one of the following graphs best shows the pressure variation at P as a function of time?





The students now investigate the variation of pressure in a sound standing wave in another tube. A standing wave is set up at 80 Hz.
One student has a pressure sensor that measures the pressure above atmospheric pressure (a positive reading) or below atmospheric pressure (a negative reading).
The apparatus is shown below. The sensor is placed at a pressure node.



Example 4.35: 2014 Question 8 (2 marks)

Which one of the following best describes the pressure the student will measure?

A. The reading will remain at a constant and positive value.

B. The reading will go from zero to a positive value 80 times per second.

C. The reading will go from a negative to a positive value 80 times per second.

D. The reading will be a constant zero.

Properties on mechanical waves

- **analyse the formation of standing waves in strings fixed at one or both ends**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016

Reflection in strings

When a wave reaches a free end, or yielding boundary, it will reflect with crests as crests and troughs as troughs. Strings in musical instruments are always fixed at both ends.

The wavelength of the standing waves corresponding to the natural harmonics is $\lambda_n = \frac{2L}{n}$ or $f = \frac{nv}{2L}$.

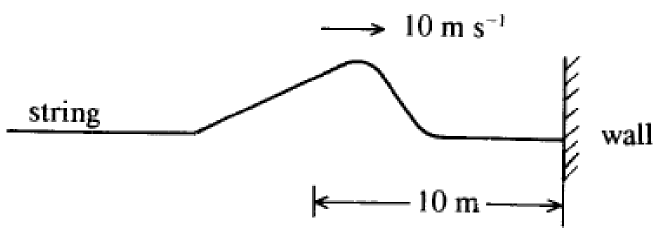
All harmonics (n = 1,2,3, …) may present, the ratio of frequencies $f_1 : f_2 : f_3 = 1 : 2 : 3$.

The fundamental frequency of a stretched wire depends on: length, tension and mass per unit length.

This gives $f = \frac{1}{2L}\sqrt{\frac{T}{m}}$ where: f = fundamental frequency in Hertz (Hz), L = length in metre (m),

T = tension in Newton (N), and m = mass per unit length in kg/m.

A heavy string is anchored to a wall and a pulse travels along it at a speed of 10 m s^{-1} towards the wall. The figure below shows the string at time t = 0.



Example 4.36: 1985 Question 38 (1 mark)

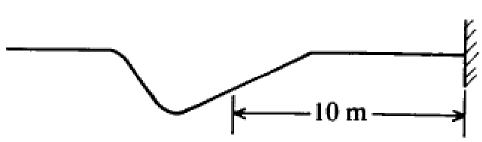
Which of the diagrams (**A - E**) below best represents the shape of the string at time t = 2 s?

A.

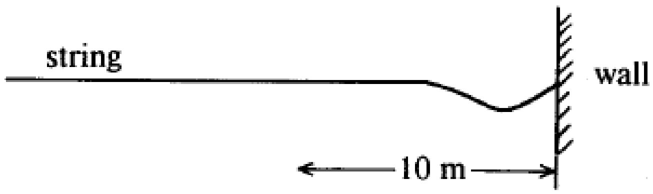

B.


C.


D.


E.


At time t = 1 s, the string appears as shown below.



Example 4.37: 1985 Question 39 (1 mark)

Which of the following statements (**A - D**) is a correct statement about the energy shown in contained in the pulse in the second figure compared with the same pulse shown in the first figure?

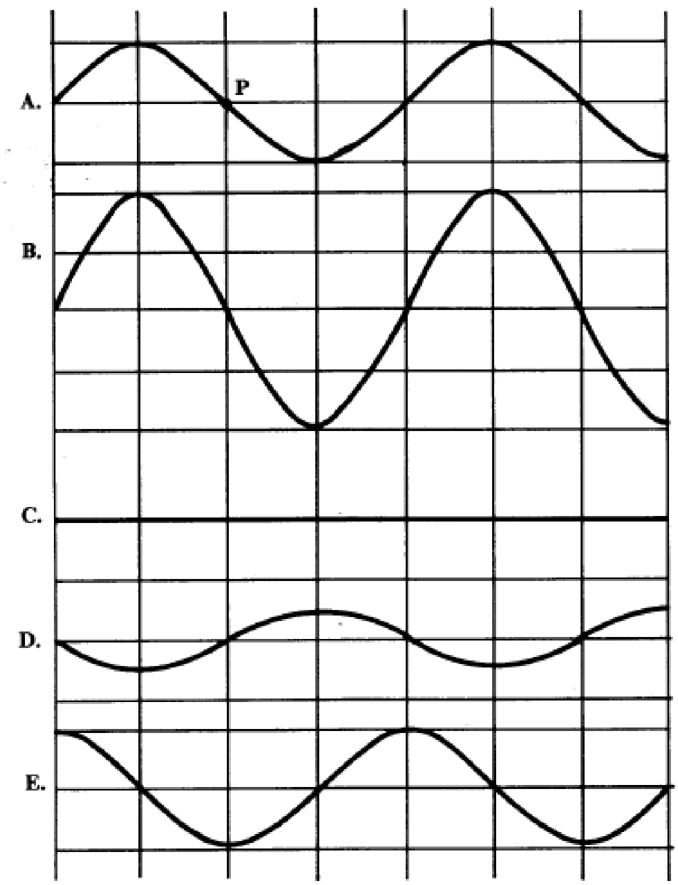
A. The energy has been lost to the wall.

B. The energy is mostly in the form of elastic potential energy.

C. The energy is mostly associated with transverse motion of the string.

D. The energy has been cancelled by superposition with the reflected pulse from the wall.

In a school laboratory there is a long string used for demonstrations, on which one can set up either standing waves or travelling waves. The diagrams (**A - E**) below show several flashlight photographs, taken at different times, of a particular section of the string.



Example 4.38: 1986 Question 41 (1 mark)

If diagram A above is a picture of a standing wave, which one or more of the diagrams **(B - E)** above, could show the same section of the string at some other time?

(one or more answers)

Example 4.39: 1986 Question 42 (1 mark)

If diagram A is a picture of a standing wave, which statement below **(A - E)** best describes the motion of point P on the string, at the moment the photograph was taken?

A. It is moving upward.

B. It is moving downward.

C. It is at rest.

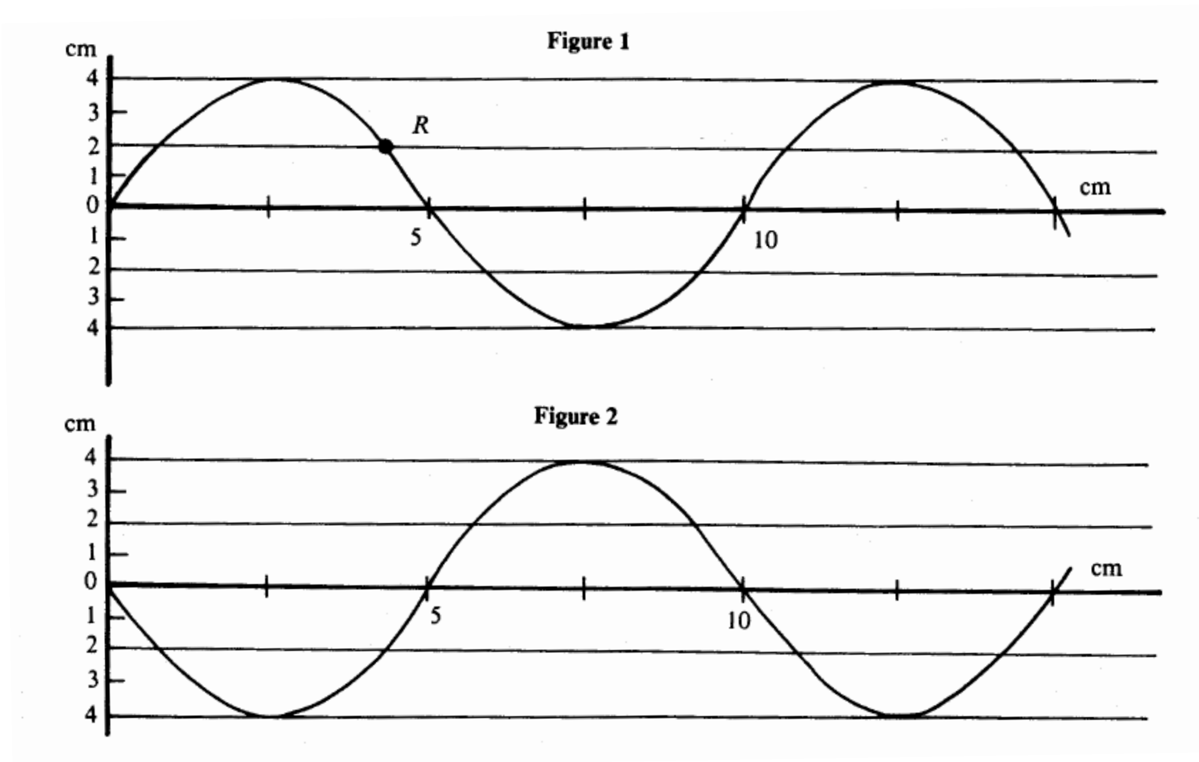
D. It is moving to the left.

E. It is moving to the right.

Example 4.40: 1986 Question 43 (1 mark)

If diagram A is a picture of a travelling wave moving to the right, which statement, **(A - E)** above, best describes the motion of point P on the string at the moment the photograph was taken?

A standing wave is set up in a long string. The amplitude of the wave is 4.0 cm and the wavelength is 10 cm. Figure 1 represents a section of the string at a particular time t_0, and Figure 2 represents the same section of the string 1.0 s later.



Example 4.41: 1987 Question 41 (1 mark)

What is the longest possible period of oscillation of the standing wave?

Example 4.42: 1987 Question 42 (1 mark)

Which of the statements **(A - F)** below best describes the motion of the point R at time t_0 (Figure 1)?

A. It is moving upward.

B. It is moving downward.

C. It is moving to the right.

D. It is moving to the left.

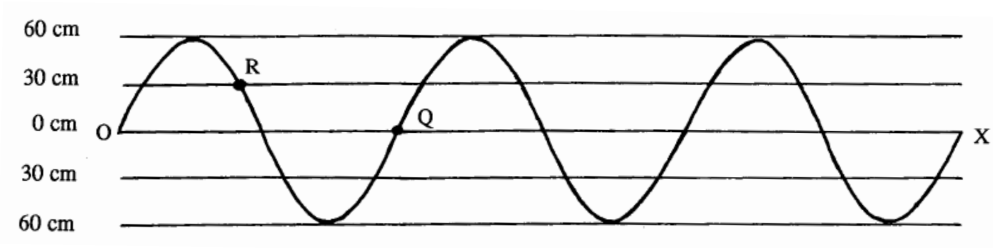
E. It is stationary.

F. There is insufficient information to tell.

Example 4.43: 1987 Question 43 (1 mark)

If instead the wave was a travelling wave with the same amplitude, wavelength and period, moving to the right which of the statements **(A – F)** would best describe the motion of the point R at time t_0?

In a second situation, shown in below, a standing wave is formed on the spring. The wave pattern is shown at the instant of **maximum displacement** from the centre line OX. R and Q are points on the spring.



Example 4.44: 1989 Question 34 (1 mark)

Which of the statements **(A - E)** below best describes the motion of the **point Q**, at the instant shown.

A. It is moving upwards.

B. It is momentarily stationary and about to move upwards.

C. It is stationary and will remain so.

D. It is moving downwards.

E. It is moving to the right.

Example 4.45: 1989 Question 35 (1 mark)

Which of the statements **(A - E)** below best describes the motion of the point R with time?

A. It is performing simple harmonic motion of maximum displacement from the line OX of 60 cm

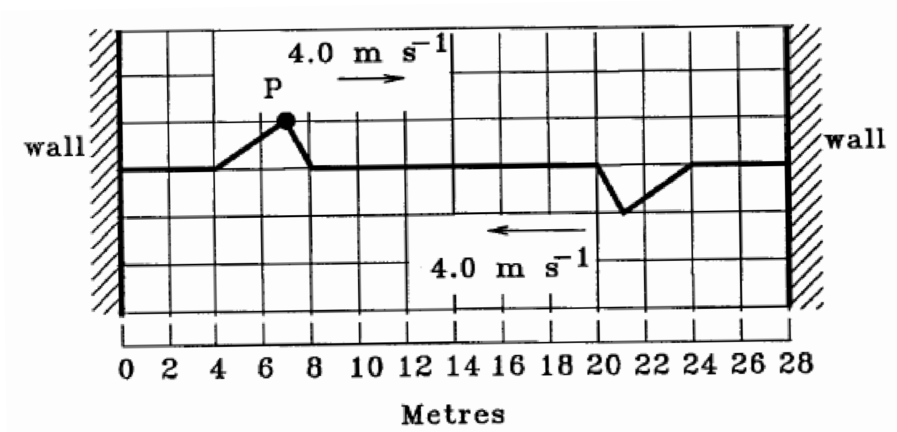
B. It is performing simple harmonic motion of maximum displacement from the line OX of 30 cm

C. It is stationary and remains so.

D. It is moving with constant velocity to the right.

E. It is moving with constant velocity to the left.

The figure below shows two triangular pulses travelling in opposite directions on a string of length 28 m. The string is attached to a wall at each end.
The speed of the pulses on the string is 4.0 m s^{-1}. A scale is shown on the diagram.



Example 4.46: 1990 Question 27 (1 mark)

Which of the statements **(A - D)** below best describes the motion of point P on the string?

A. It is stationary and about to move to the right.

B. It is stationary and about to move to the left.

C. It is stationary and about to move down.

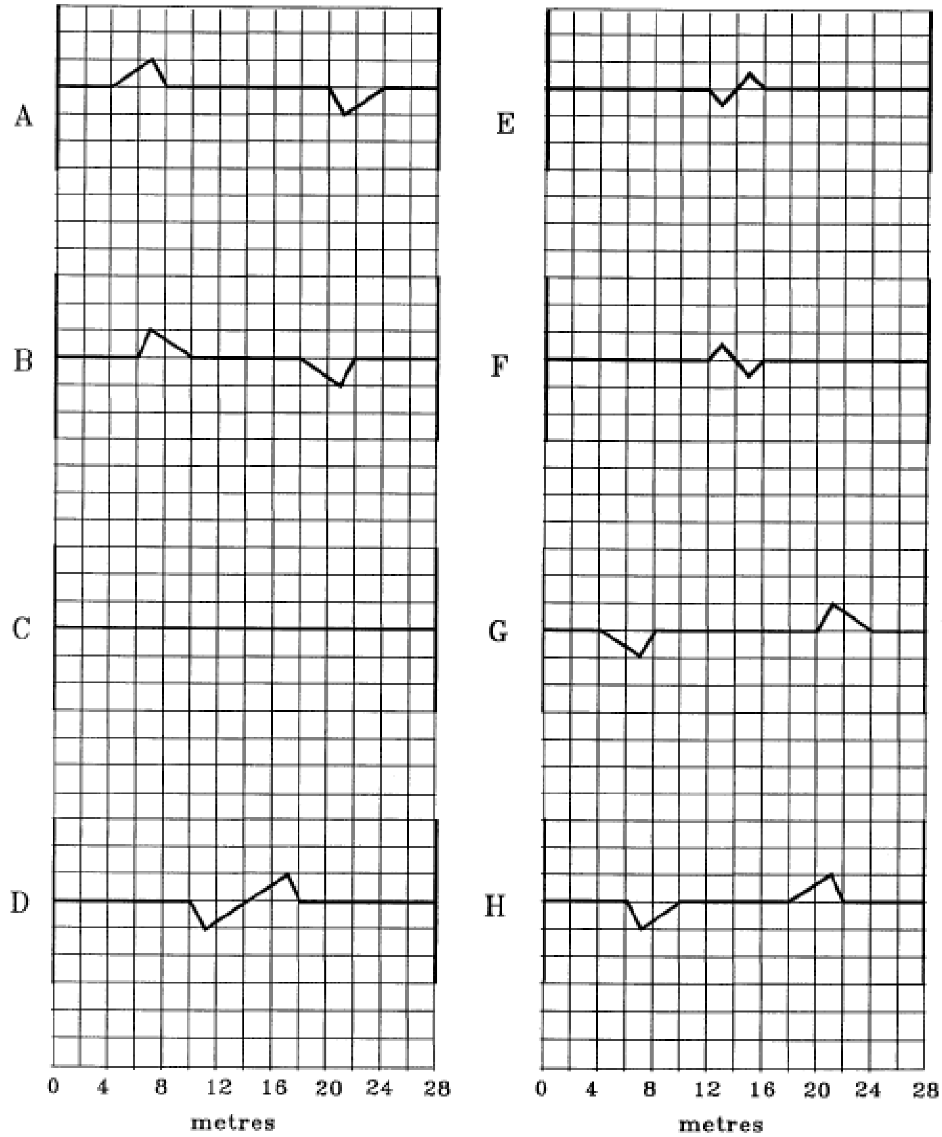
D. It is stationary and about to move up.

Example 4.47: 1990 Question 28 (1 mark)

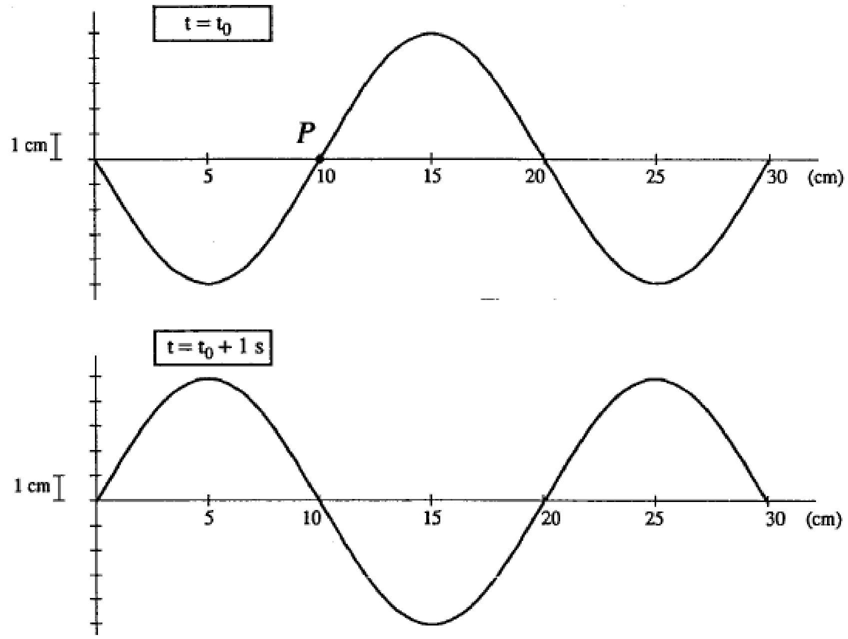
Which of the diagrams **(A - H)** in the figure below, best shows the shape of the string 2.0 seconds later?

Example 4.48: 1990 Question 29 (1 mark)

Which of the diagrams **(A - H)**, best shows the shape of the string 7.0 seconds later?


A
B
C
D
E
F
G
H
0 4 8 12 16 20 24 28
metres
0 4 8 12 16 20 24 28
metres

A travelling wave, moving to the right, is set up on a long string. The wave has a wavelength of 20 cm, and an amplitude of 5.0 cm. The first figure below shows a section of the string at a particular time t_0, and the second figure shows the same section 1.0 second later.



Example 4.49: 1991 Question 39 (1 mark)

What is the lowest frequency that the wave may have?

Example 4.50: 1991 Question 40 (1 mark)

Which of the statements (**A - G**) below best describes the motion of the string at point P at time t_0?

A. It is stationary, and will remain so.

B. It is stationary, and about to move up.

C. It is stationary, and about to move down.

D. It is moving upward.

E. It is moving downward.

F. It is moving to the right.

G. It is moving to the left.

Example 4.51: 1991 Question 41 (1 mark)

If, instead, the wave shown in the figures was a stationary wave with the same amplitude, wavelength and frequency, which of the statements (**A - G**) above would best describe the motion of the string at point P?

Example 4.52: QLD 2015 Question 7 (1 mark)

Standing waves may be created when two waves moving in opposite directions through the same medium interact. Which of the statements below is **false**?

A Standing waves can propagate energy.

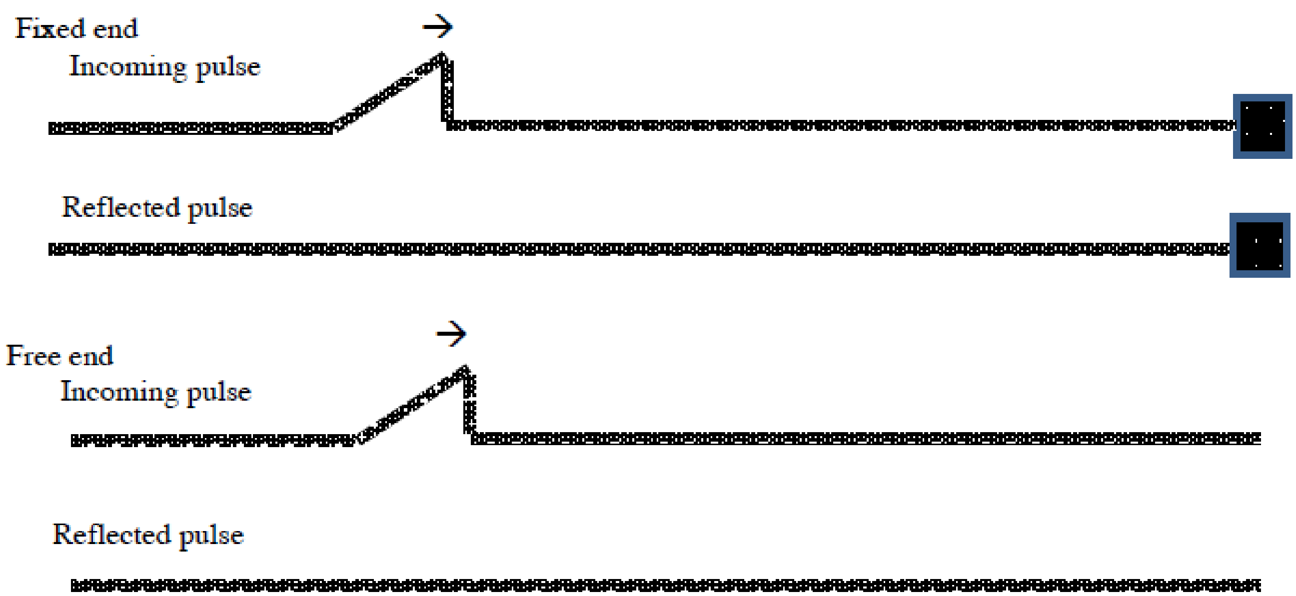
B Standing waves can occur in audio and optical phenomena.

C The waves creating the standing wave have the same amplitude.

D The waves creating the standing wave have the same wavelength.

Example 4.53: TAS 2012 Question 12a (1 mark)

An incoming pulse is shown for a string with a fixed end and for a string with a free end.
Show, on the diagrams, how each pulse will behave after it has reflected.



Properties on mechanical waves

- **investigate and explain theoretically and practically diffraction as the directional spread of various frequencies with reference to different gap width or obstacle size, including the qualitative effect of changing the $\frac{\lambda}{w}$ ratio**

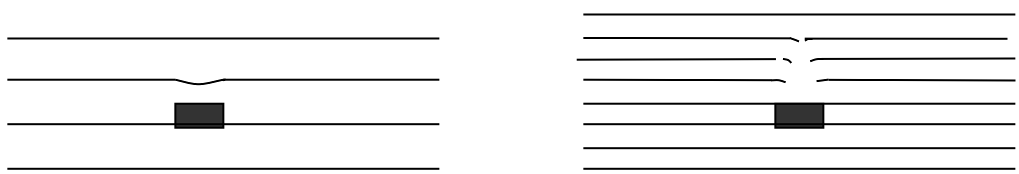
2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
10, 11	4, 5 6	9		7, 8, 9, 10	10, 11, 12	3a, b	23a, b	21a, b, c, d	20a, b 22	

2006 Sound	2007 Sound	2008 Sound	2009 Sound	2010 Sound	2011 Sound	2012 Sound	2013 Sound	2014 Sound	2015 Sound	2016 Sound
1	8, 9, 10, 11	12, 13	7	12	9, 11	8	4		10, 11	

Diffraction

When light (waves) pass through a narrow aperture, a hole, a slit or an obstacle, it spreads out, this is known as diffraction. Amount of diffraction $\propto \frac{\lambda}{d}$. To observe diffraction effects with the small wavelength of visible light, a very narrow slit must be used. Sound waves can travel around corners, they spread out when they come through an open door. When sound is diffracted there is no change in wave speed, wavelength or frequency.

Diffraction around obstacles.

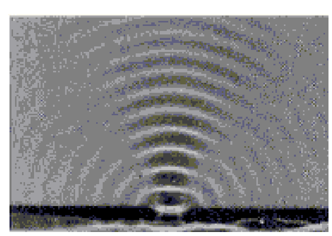


long wavelengths, low frequencies short wavelengths, high frequencies

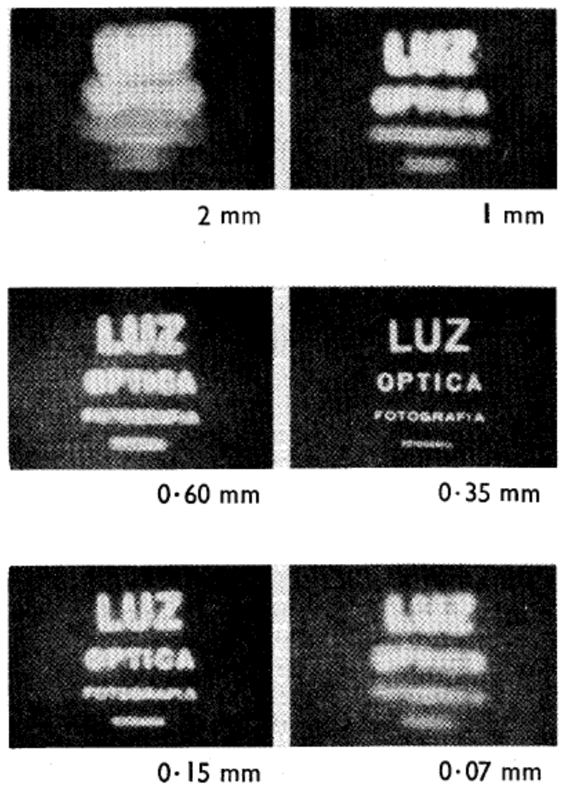
When the obstacle is small compared with the wavelength, there is very little disturbance. Larger 'shadows' occur when the obstacle is much larger than the wavelength of the incident wave.

Diffraction through gaps.

When sound travels through a narrow opening, such as a door, the waves bend around both sides of the opening and are diffracted into the region beyond the barriers on both sides of the doorway. So a narrow gap acts just like to obstacles. The amount of diffraction is given by the value of the ratio $\frac{\lambda}{w}$ where w is either the width of the object or the opening. As the value of $\frac{\lambda}{w}$ increases, so does the amount of diffraction (bending). If $\frac{\lambda}{w}$ << 1, very little diffraction occurs, if the ratio $\frac{\lambda}{w} \geq 1$, then it is complete diffraction, i.e. bending through 180^0.



The picture shows the images obtained with a pinhole camera in sunlight. The diameter of the pinhole used to obtain each image is shown beneath the image.



Example 4.54: 1978 Question 40 (1 mark)

There is an optimum size of hole that gives the sharpest image.
The reason the image gets fuzzier for very small holes is:

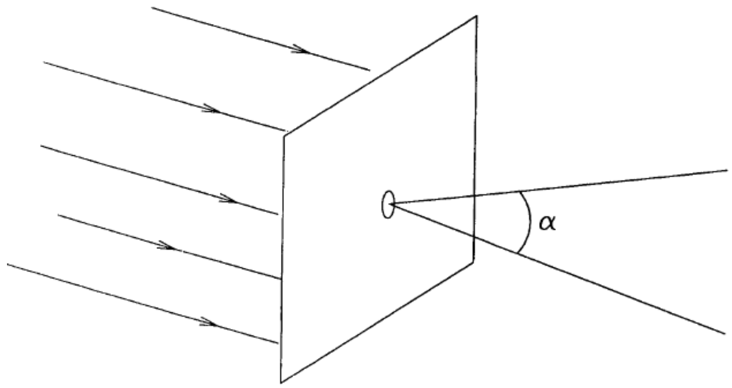
A. It is difficult to make a small hole with sharp edges; there is a burring around the hole.

B. Diffraction effects become important with small holes.

C. Small holes let less light pass through.

D. Only short wavelengths can pass through the hole.

A parallel beam of red light is shone onto a sheet of cardboard in which there is a very small hole. The light shining through the hole spreads out into a cone as shown in the diagram below. The angle of the cone is α, and the wavelength of the light in the cone is λ.



Example 4.55: 1990 Question 30 (1 mark)

Which one or more of the statements below best describes what happens when a smaller hole is used?

A. The angle of the cone decreases.

B. The angle of the cone increases.

C. The angle of the cone is unchanged.

D. The wavelength of the light coming out of the hole decreases.

E. The wavelength of the light coming out of the hole increases.

F. The wavelength of the light coming out of the hole is unchanged.

(One or more answers)

Example 4.56: 1990 Question 31 (1 mark)

Instead of red light, a beam of white light is shone onto the cardboard. Which of the statements below best describes the cone of light emerging from the very small hole?

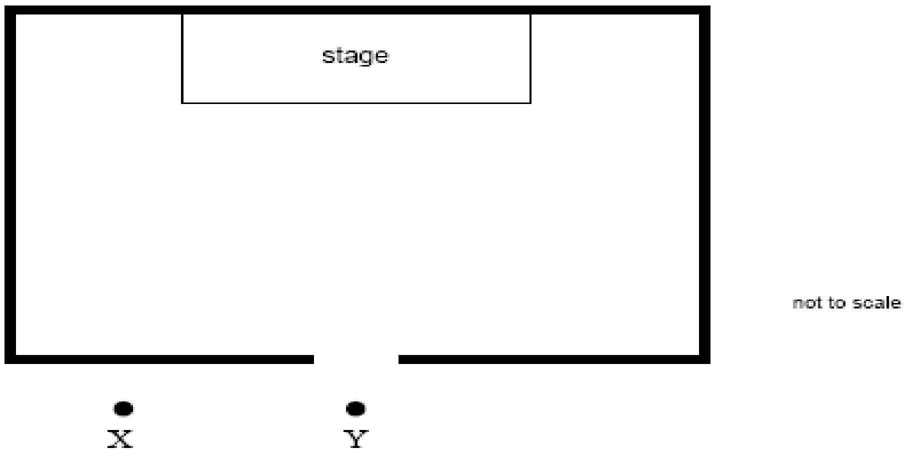
A. No cone of light is formed.

B. The light along the central axis of the cone has a blue tinge.

C. The light at the edge of the cone has a red tinge.

D. The light at the edge of the cone has a blue tinge.

Alexandra and Gary arrived at a pop concert that had already started. While waiting at point X in a queue, Alexandra commented that the sound quality was poor. Although they could hear sound of low frequency, high frequency sound was relatively much weaker. They were pleased to find that the sound quality improved when they reached point Y in front of the hall entrance.



Example 4.57: 1999 Question 13 (2 marks)

Circle the letter (**A – D**) of the wave phenomenon that best explains their observations.

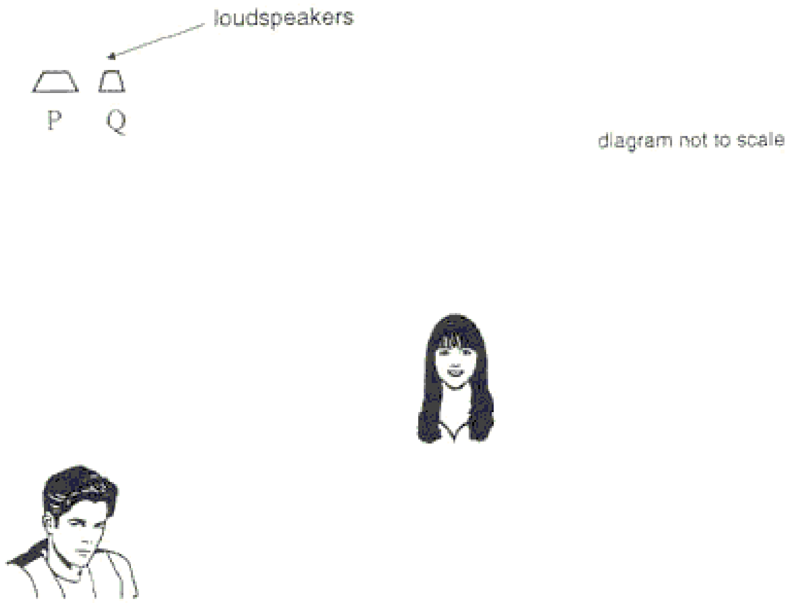
A. reflection

B. refraction

C. resonance

D. diffraction

Max and Michelle are buying loudspeakers for their hi-fi. They are choosing between two models, a 35-cm diameter speaker (P), and a 5-cm one (Q). Both speakers operate equally well over the complete audible frequency range. Max is standing in front of the speakers, and Michelle is the same distance away, but to one side, as shown below.



As a test of the speakers they play sounds of 10 000 Hz and 200 Hz, and compare the intensity that they each hear.

Example 4.58: 2000 Question 11 (2 marks)

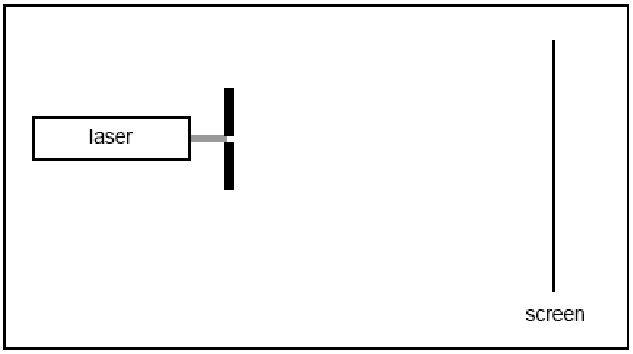
The wavelength of sound of frequency 200 Hz is 1.65 m. What is the wavelength of sound of frequency 10 000 Hz?

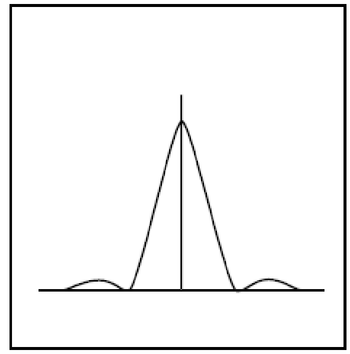
Max comments that the intensity of the sound of both frequencies seems the same from either speaker. However Michelle says that for the larger speaker, the 10 000 Hz sound is significantly softer than the low frequency sound.

Example 4.59: 2000 Question 12 (4 marks)

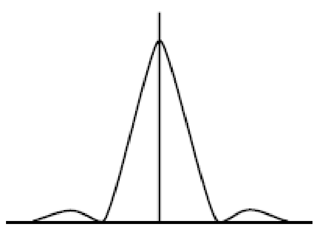
Explain these observations. Include relevant calculations and/or diagrams to support your reasoning.

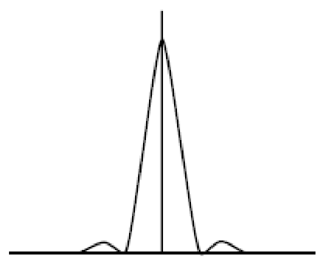
Example 4.60: 2007 Question 6 (2 marks)
In an experiment, monochromatic laser light of wavelength 600 nm shines through a narrow slit, and the intensity of the transmitted light is recorded on the screen some distance away as shown below. The intensity pattern seen on the screen is also shown below.

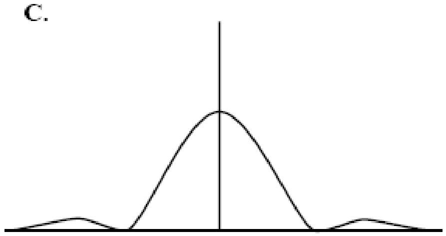


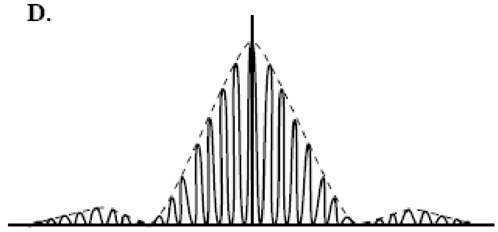


Which one of the intensity patterns **(A - D)** below best indicates the pattern that would be seen if a wider slit was used?

A.


B.


C.


D.


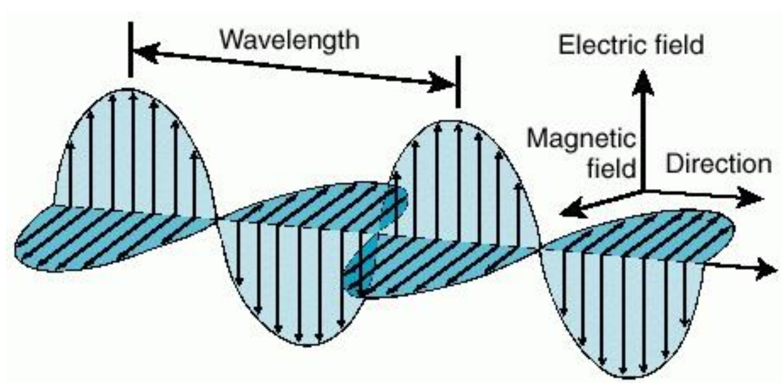
Light as a wave

- **describe light as an electromagnetic wave which is produced by the acceleration of charges, which in turn produces changing electric fields and associated changing magnetic fields**
- **identify that all electromagnetic waves travel at the same speed, *c*, in a vacuum**
- **compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and identify the distinct uses each has in society**

2006 Synchrotron	**2007** Synchrotron	**2008** Synchrotron	**2009** Synchrotron	**2010** Synchrotron	**2011** Synchrotron	**2012** Synchrotron	**2013** Synchrotron	**2014** Synchrotron	**2015** Synchrotron	**2016** Synchrotron
										1

Maxwell discovered that light was an EM radiation in the frequency range of 4.3×10^{14} to 7×10^{14} Hz. He understood that light of any kind is energy-carrying waves of electric and magnetic fields that continually regenerate each other and travel at a single fixed speed, the speed of light.

An accelerating charge creates a changing current. Every current is surrounded by a magnetic field, so every changing current is surrounding by a changing magnetic field. We also know that every changing magnetic field will induce an EMF, in other words, generates an electric field. This is electromagnetic induction.



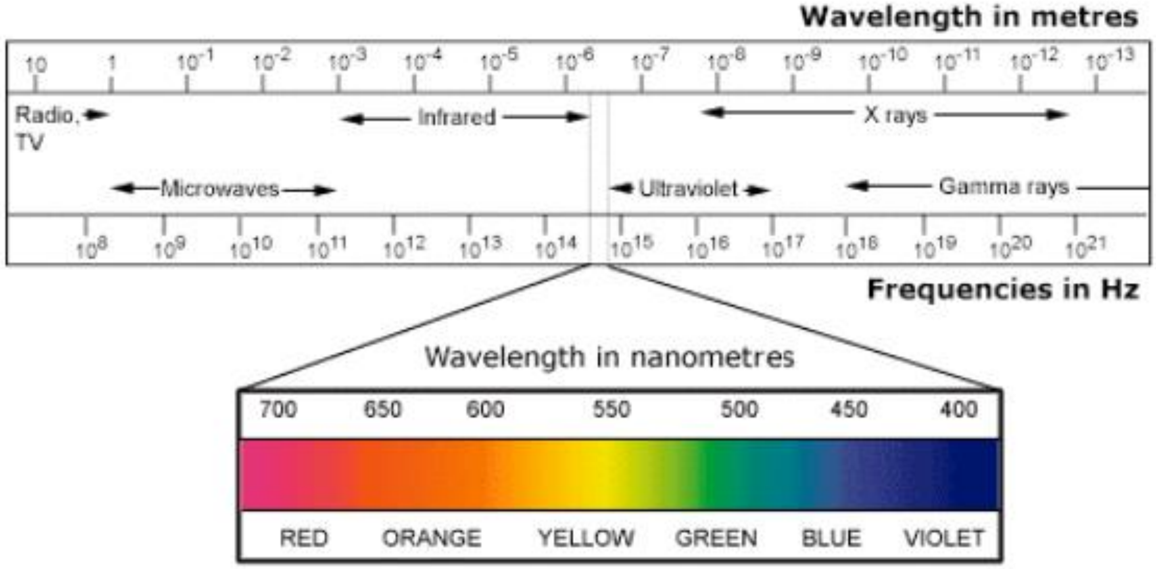
If the magnetic field is oscillating, the electric field that it generates will be oscillating, too. This oscillating electric field induces an oscillating magnetic field. The vibrating electric and magnetic fields regenerate each other to make up an **electromagnetic wave**, which emanates from the vibrating charge.

In summary, light is an energy carrying electromagnetic wave that emanates from vibrating electrons in atoms.

Speed of Light

There is only one speed for which the electric and magnetic fields remain in perfect balance, reinforcing each other as they carry energy through space. If light were to slow down, its changing electric field would generate a weaker magnetic field, which in turn, would generate a weaker electric field, and so on, until the wave dies out. This would result in a loss of energy, which is incompatible with the law of conservation of energy. So light can’t slow down (or speed up).

Electromagnetic spectrum



Creation of Electromagnetic Waves

Name	Generated by	Detected by	Properties
Gamma-rays	Changes of energy levels in the nucleus	a) Photography b) Ionisation chamber	a) Penetrates matter b) Ionise gases c) Causes photo-electric emission
X-rays	Rapid deceleration of fast moving electrons (e.g. by tungsten target)		
UV	Orbital electrons of atoms. E.g. the Sun	a) Photography b) Photoelectric cell	a) Absorbed by glass b) Can cause many chemical reactions (e.g. the tanning of human skin) c) Ionise atoms in the atmosphere resulting in the ionosphere
Visible light	Re-arrangement of outer orbital electrons in atoms and molecules. (e.g. incandescent solids)	a) Eye b) Photography c) Photocell	Can cause chemical action
Infra-red	Outer electrons in atoms and molecules	a) Photography by special plate b) Heating effect	a) Useful for ‘seeing’ molecular structures b) Less scattered than visible light by atmosphere
Micro-waves	Micro-wave generators	Micro-wave receivers	a) Microwave ovens b) Radar communication
Radio Waves	Oscillating electrons in radio aerials	Tuned electric circuit	Different wavelengths find specialised uses in radio communications

Example 4.61: 1989 Question 27 (2 marks)

Which of the following **(A - C)** below is greater for red light travelling through a vacuum, than for blue light travelling through a vacuum?

A. Frequency.

B. Speed of propagation.

C. Wavelength.

(One or more answers)

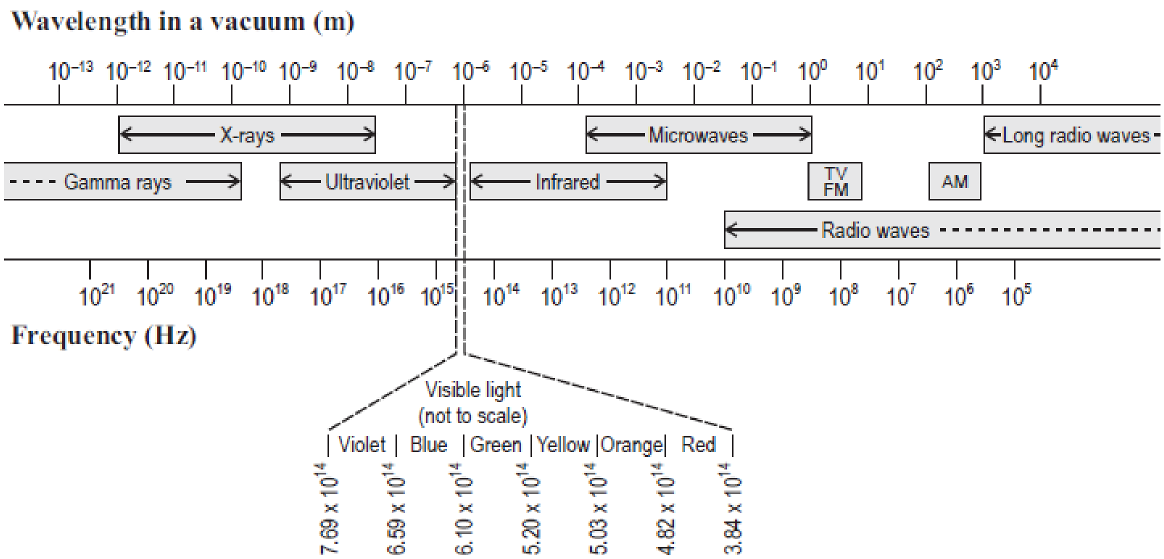
Example 4.62: SA 2009 Question 13a (2 marks)

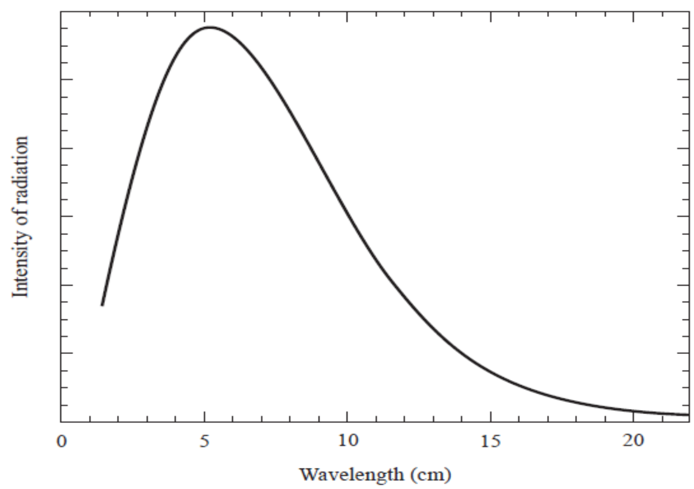
Describe the relation between the oscillating electric and magnetic fields and the direction of travel of an electromagnetic wave.

Example 4.63: QLD 2012 Question 9a (2 marks)

Red light has a longer wavelength than violet light. Which light colour has the higher frequency? Justify your response.

Consider the diagram and graph below.





The diagram shows the wavelengths and frequencies for the electromagnetic spectrum, including visible light.

The graph shows the intensity vs wavelength for the cosmic background radiation, which comes from all areas of space.

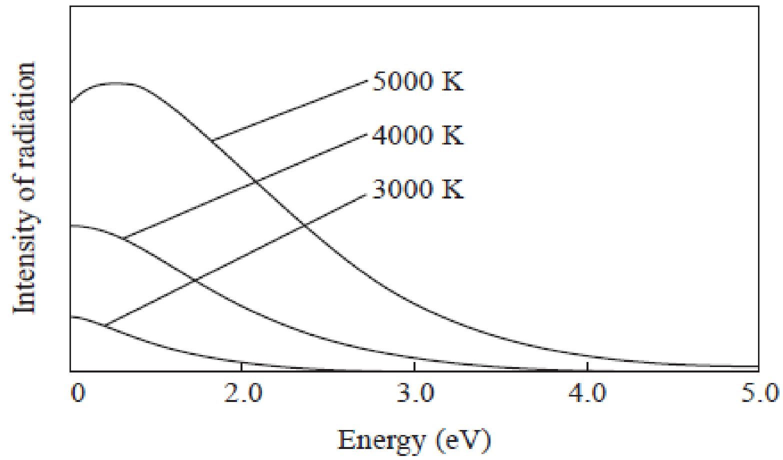
Example 4.64: QLD 2013 Question 7a (1 mark)

To which of the categories in the diagram (X-rays, radio waves, etc.) does the maximum intensity radiation of the cosmic background radiation belong?

The temperature of a star is related to its peak wavelength intensity (or the energy of the peak intensity photons) as shown in the graph below. The energy of the photons is related to their frequency by the equation $E = hf$.

Example 4.65: QLD 2013 Question 7b (4 marks)

To which of the categories in the diagram would the peak wavelength intensity belong for a star of temperature 5000 K? (Note: 1 eV = 1.6×10^{-19} J)



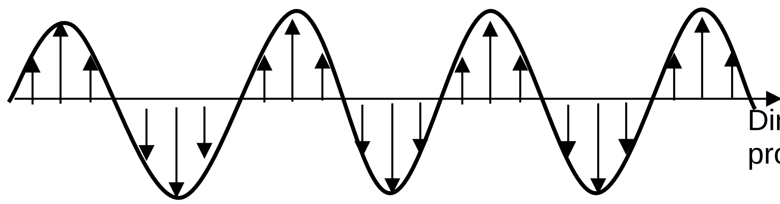
Light as a wave

- **explain polarisation of visible light and its relation to a transverse wave model**

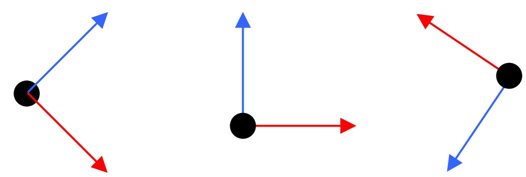
2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016

Polarisation

Light is a transverse electromagnetic wave. The diagram below is a snapshot of an electromagnetic wave. As the light propagates to the right, the electric field oscillates up and down as shown. There is a magnetic field oscillating into and out of the page, which is not shown.

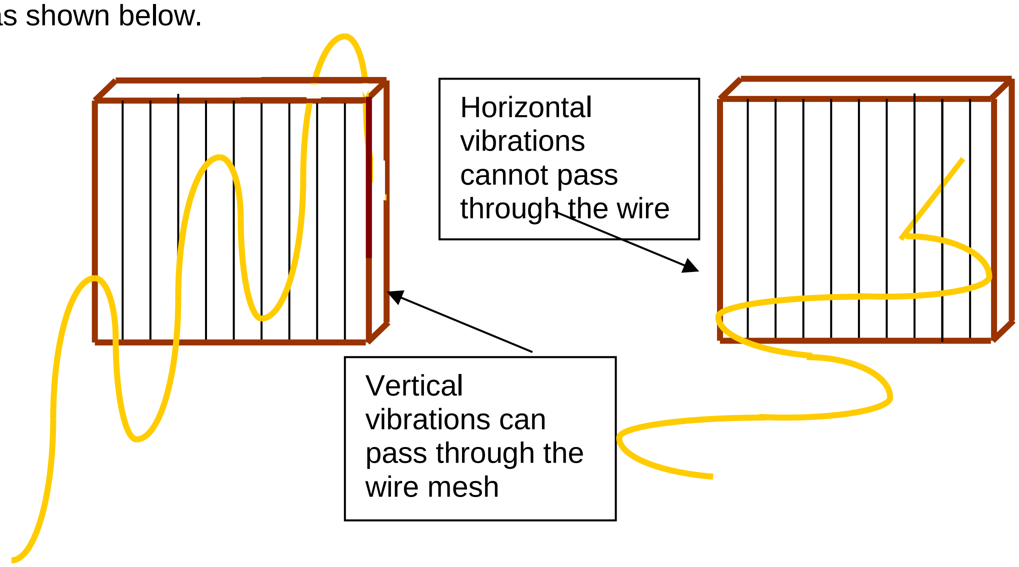


The direction of oscillation of the electric field is called the polarization of the light. In a beam of light from most sources the light is unpolarised, which means that the electric fields of the light are oscillating in many different directions. Consider the diagram on the right. The light is travelling into the page. It is possible for the electric fields (blue arrows) and the magnetic fields (red arrows) to be oscillating in any direction, including the three shown. In unpolarised light, all of these directions are present at the same time.



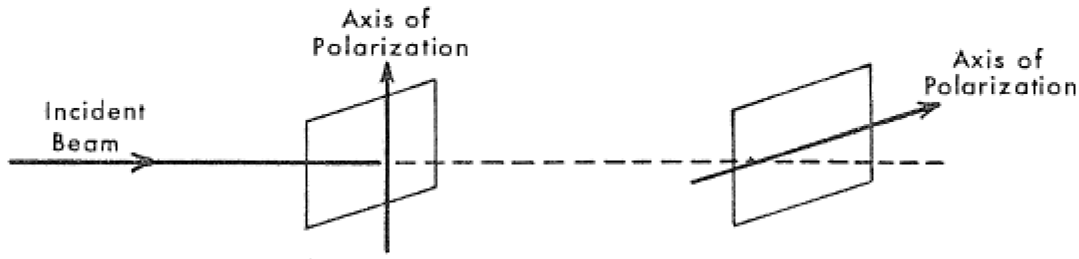
Polarising Light

Consider a string that is passing through a wire grid. Wave passes are sent along the string in two directions as shown below.



In a similar way, optical devices called polarisers only allow light with a specific polarisation to pass through them. The plane of polarisation is defined as the plane of the electric field.

The axes of polarization of two perfect polarizers are perpendicular to each other, as shown in the diagram.



Example 4.66: 1977 Question 74 (1 mark)

Which of the following statements correctly describes the effect of the polarizers on the beam?

A. The transmitted light will be unpolarized.

B. The light transmitted by the first polarizer will be stopped by the second.

C. The light transmitted by the first polarizer will also be transmitted by the second.

D. Light transmitted through the first polarizer will be de-polarized by the second one.

A television channel broadcasts waves with a horizontal plane of polarisation.

Example 4.67: SA 2012 Question 13a (1 mark)

State the orientation of the oscillating magnetic field in such waves.

Source: Photograph by Nedim Ardoğa, http://en.wikipedia.org/wiki/File

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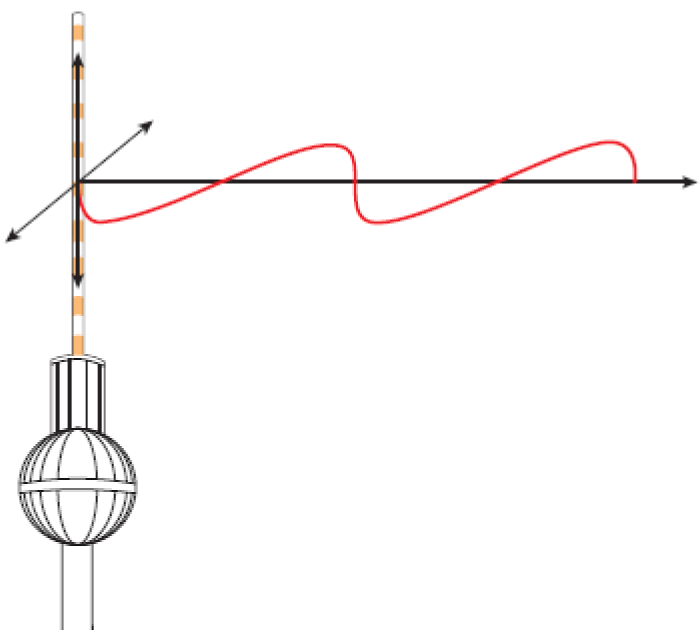
The photograph below shows a television antenna being positioned so that it receives horizontally polarised electromagnetic waves:

Source: www.jimsantennas.com.au

Example 4.68: SA 2014 Question 13a (1 mark)

State the direction of the oscillating electric fields in horizontally polarised electromagnetic waves.

The diagram below shows a transmitting antenna that is aligned vertically on a tower.
The horizontal component of the polarised electromagnetic wave emitted by the antenna is shown in red.



Example 4.69: SA 2016 Question 10a (1 mark)

On the diagram above, draw the vertical component of the polarised electromagnetic wave.

Example 4.70: SA 2016 Question 10b (1 mark)

State the plane of polarisation of the electromagnetic wave.

Light as a wave

- **investigate and analyse theoretically and practically the behaviour of waves including:**

  – refraction using Snell's Law: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ and $n_1 v_1 = n_2 v_2$

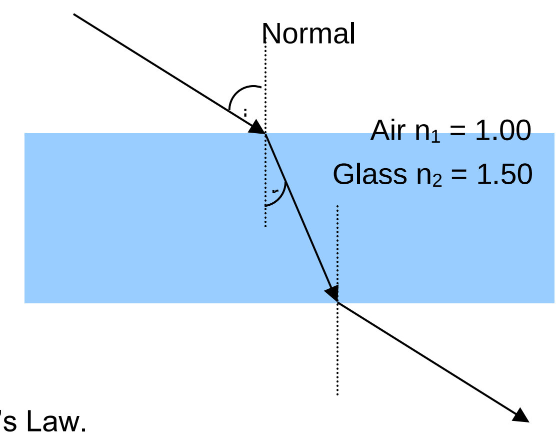
  – total internal reflection and critical angle including applications:

  $n_1 \sin(\theta_c) = n_2 \sin(90°)$

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
6, 7	5	5, 7	7, 9	5, 8	8, 10	5	4, 5, 10	1	7	4, 5

Refraction of Light

A ray of light travels along a straight path within the same medium, e.g. air, water or glass.
However, when a ray of light enters one medium from another, the ray often changes direction at the point of incidence.



Refraction is the bending of the light path as it passes from one transparent material to another.
The amount of refraction can be determined using Snell's Law.

$$n_1 \sin i = n_2 \sin r$$

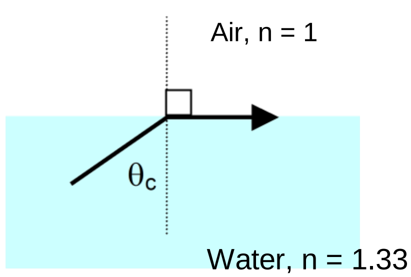
or $$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$$

Where v_1 = speed of light in medium 1,

v_2 = speed of light in medium 2,
n_1 = absolute refractive index of medium 1
n_2 = absolute refractive index of medium 2

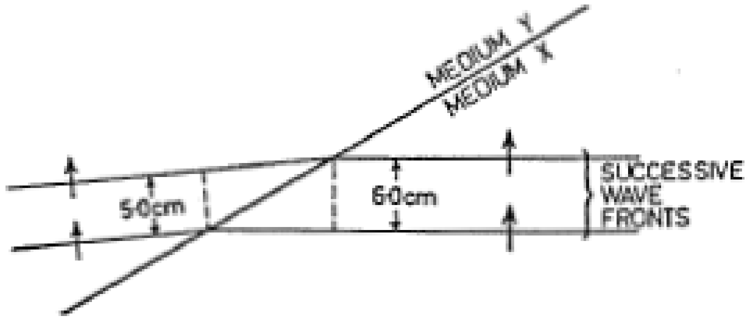
The Critical Angle

The critical angle is the angle at which the refracted way will skim across the surface of the material (the orange ray above). For angles of incidence greater than this critical angle, the ray will be totally internally reflected. The critical angle can be calculated using *Snell's Law*.



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$1.33 \sin\theta_c = 1 \sin 90$$
$$\sin\theta_c = \frac{1}{1.33}$$
$$\theta_c = 48.8$$

Waves are travelling across a boundary between two media.



Example 4.71: 1968 Question 77 (1 mark)

What is the value of the "refractive index" for waves travelling from X to Y?

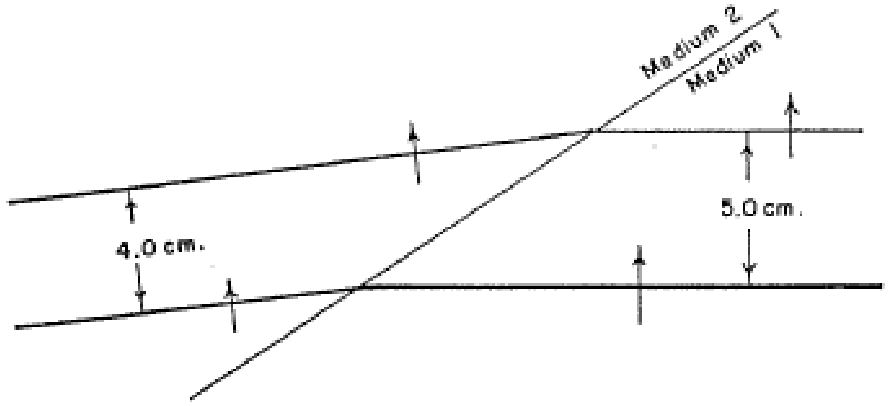
Example 4.72: 1968 Question 78 (1 mark)

What is the value of the ratio $\frac{\text{frequency of waves in medium X}}{\text{frequency of waves in medium Y}}$?

Example 4.73: 1968 Question 79 (1 mark)

What is the value of the ratio $\frac{\text{speed of waves in medium X}}{\text{speed of waves in medium Y}}$?

The figure shows successive wave-fronts of a wave crossing the boundary between two media.



Example 4.74: 1974 Question 48 (1 mark)

What is the refractive index for waves travelling from medium 1 to medium 2?

Example 4.75: 1974 Question 49 (1 mark)

What is the value of the ratio: $\dfrac{\text{frequency of waves in medium 1}}{\text{frequency of waves in medium 2}}$?

Example 4.76: 1974 Question 50 (1 mark)

What is the value of the ratio: $\dfrac{\text{speed of waves in medium 1}}{\text{speed of waves in medium 2}}$?

Example 4.77: 1974 Question 51 (1 mark)

For the same pair of media, is total internal reflection possible for some angles of incidence?

A. Yes, only for waves travelling from Medium 1 towards Medium 2.

B. Yes, only for waves travelling from Medium 2 towards Medium 1.

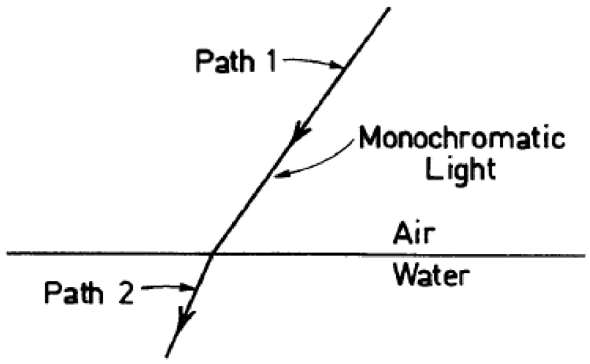
C. Yes, for waves travelling in either direction.

D. No, total internal reflection is not possible.

Example 4.78: 1971 Question 60 (1 mark)

The figures below show light rays in various media.
Considering paths 1 and 2 in each figure, decide whether:
(i) the frequency (f) of the light is the same or different.
(ii) the wavelength (λ) of the light is the same or different.
(iii) the speed (v) of the light is the same or different.

In the appropriate spaces indicate **S** for same and **D** for different.

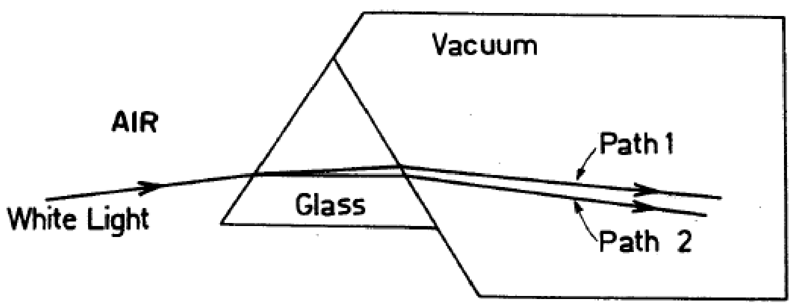


(i)

(ii)

(iii)

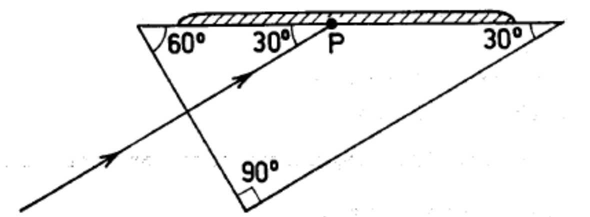
Example 4.79: 1971 Question 61 (1 mark)
Repeat this analysis of question 60 for the figure below.



(i)

(ii)

(iii)



Example 4.80: 1972 Question 46 (1 mark)

Light is incident normally on the smallest face of a $30^0 – 60^0 – 90^0$ prism and strikes the largest face at P. A drop of liquid is placed along the largest face as shown. The refractive index of the prism material is 1.48.
For which *one or more* of the following values of refractive index of the liquid is the light totally internally reflected at P?

A. 1.15.

B. 1.20.

C. 1.25.

D. 1.30.

E. 1.35.

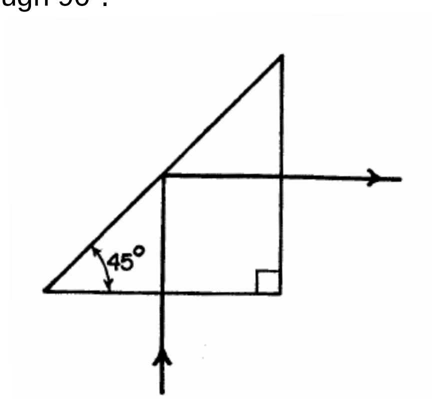
F. 1.40.

G. 1.45.

H. 1.50.

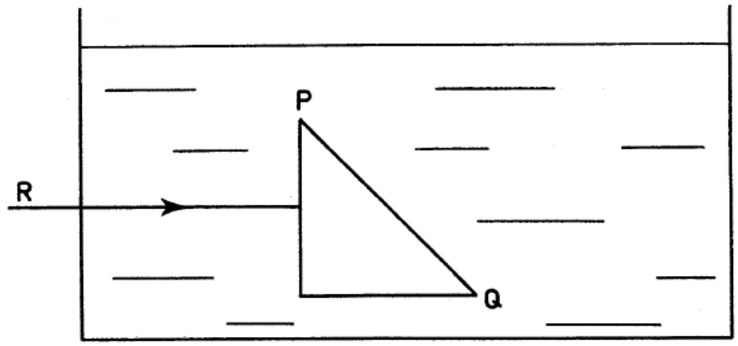
(*One or more answers*)

The prism shown is made out of transparent plastic material. It is to be used in an optical instrument to deviate all of the incident light through 90^0.



Example 4.81: 1975 Question 44 (1 mark)

What is the minimum value of the refractive index of plastic suitable for this purpose?



A 45^0 glass prism (refractive index 1.50) is immersed in water (refractive index 1.33).

Example 4.82: 1976 Question 46 (1 mark)

What is the critical angle for light travelling from glass to water?

Example 4.83: 1976 Question 47 (1 mark)

Will the ray R be totally internally reflected at the PQ interface?

A. Yes, because the angle of incidence is greater than the critical angle.

B. Yes, because the angle of incidence is less than the critical angle.

C. No, because the angle of incidence is greater than the critical angle.

D. No, because the angle of incidence is less than the critical angle.

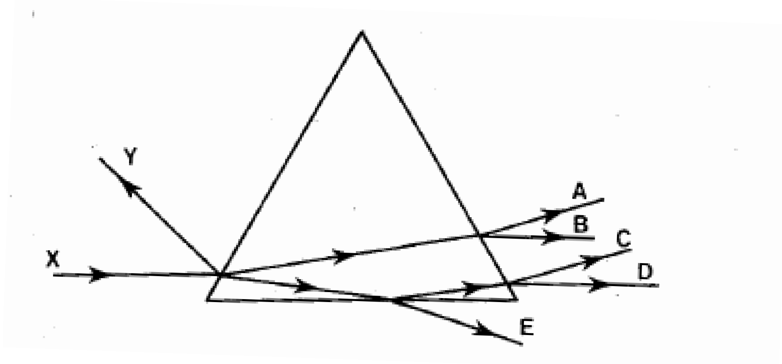
E. No, because light cannot be totally internally reflected when passing from a higher to a lower refractive index medium.

Example 4.84: 1976 Question 48 (1 mark)

What is the value of the ratio: $\dfrac{\text{Speed of light in water}}{\text{Speed of light in glass}}$?

Example 4.85: 1979 Question 35 (1 mark)

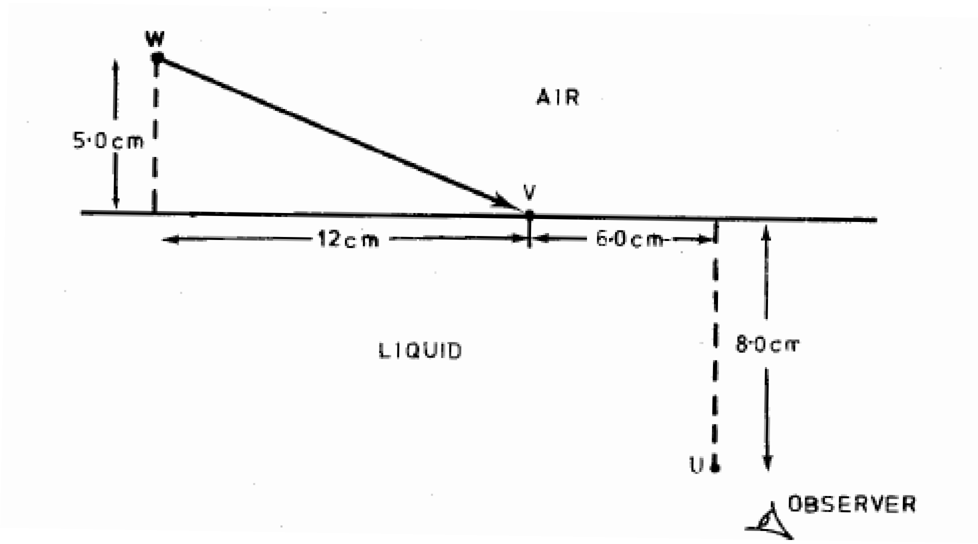
A ray of monochromatic light, X, travelling in air, is incident on a glass prism of refractive index 1.5.



Some of the light travels along path Y. Along which other path or paths (A, B, C, D, E) will light emerge?

(One or more answers)

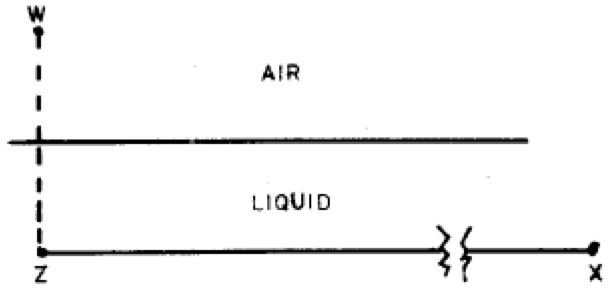
Three objects U, V and W appear to the observer to lie in a straight line. The observer and the object U are in a liquid; V is at the surface of the liquid; W is in air.



Example 4.86: 1979 Question 33 (1 mark)

What is the index of refraction of the liquid relative to the air?

With W in the same position, the observer moves along the line ZX, starting at Z.



Example 4.87: 1979 Question 34 (1 mark)

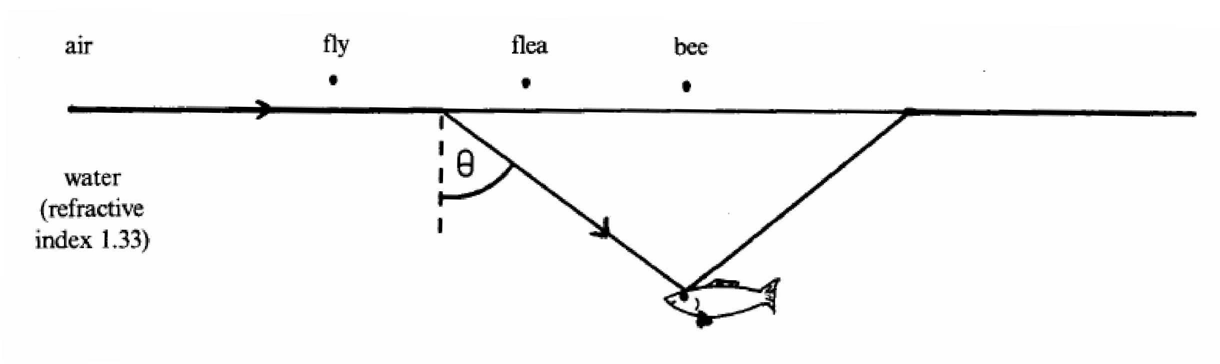
Which of the following is correct?

A. Light from W reaches the observer at all points along the line ZX.

B. Light from W reaches the observer initially, but after he has travelled a certain distance, no light from W reaches the observer due to total internal reflection.

C. Light from W cannot reach the observer until he has travelled some distance from Z.

D. Insufficient information is provided to decide between A, B and C.



Example 4.88: 1981 Question 44 (1 mark)

For a ray of light just grazing the surface of a still pond. what is the value of the angle θ shown in the figure?

Example 4.89: 1981 Question 45 (1 mark)

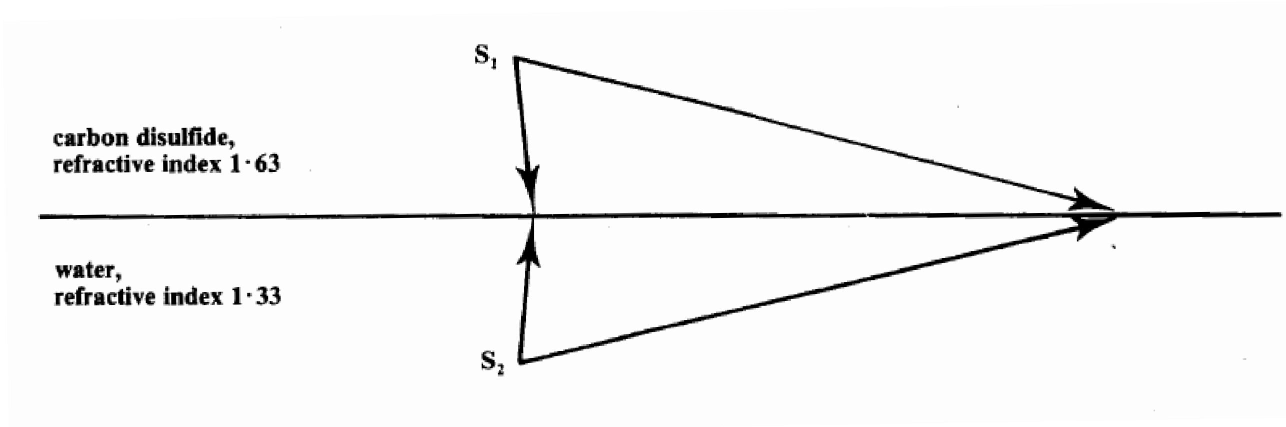
A fish in the pond looks upwards. Three insects are hovering above the water, which of them could the fish see?

A. the bee, but not the flea or the fly

B. the bee and the flea, but not the fly

C. the fly, but not the flea or the bee

D. all three insects



Wide beams of light from S_1 and S_2, are incident on a carbon disulfide/water boundary.

Example 4.90: 1982 Question 46 (1 mark)

Total internal reflection will occur for

A. some of the light from S_1, and some of the light from S_2.

B. none of the light from S_1, and some of the light from S_2.

C. some of the light from S_1, but none of the light from S_2.

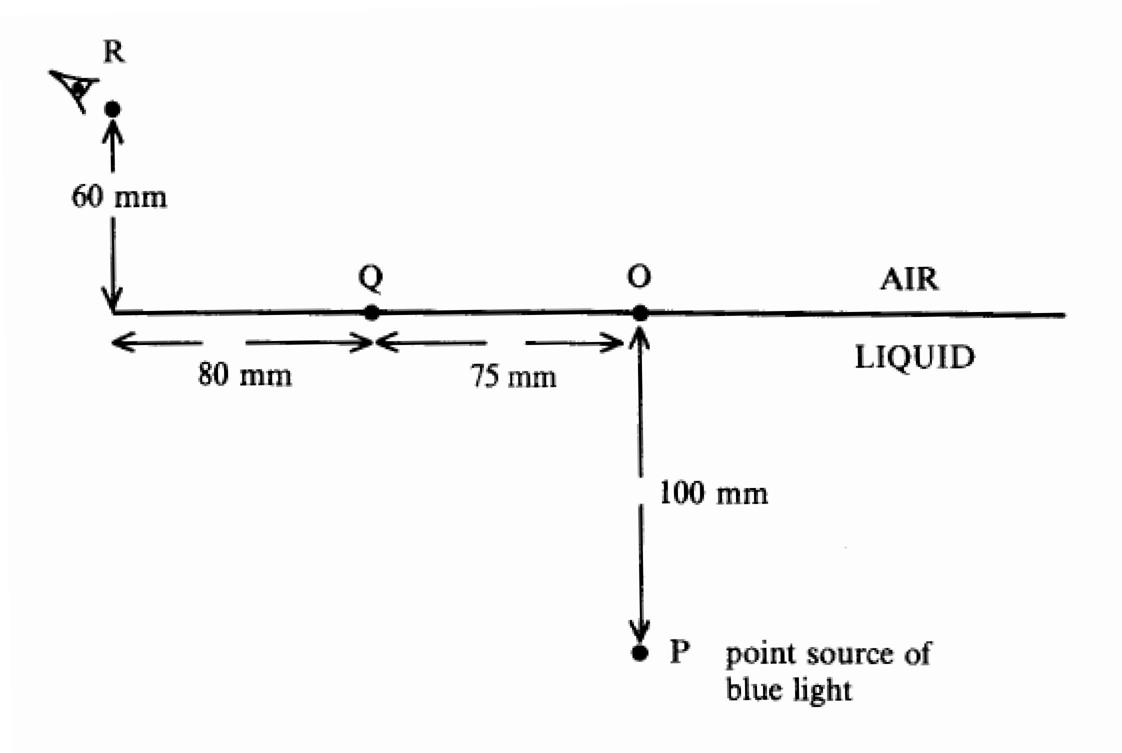
D. all of the light from S_1, and some of the light from S_2.

E. all of the light from S_1, but none of the light from S_2.

Example 4.91: 1982 Question 47 (1 mark)

What is the critical angle for the carbon disulfide/water boundary?

A point source of blue light, P, is fixed 100 mm below the surface of a transparent liquid. The point O is vertically above P. An observer at R observes points PQR to be in a straight line.



Example 4.92: 1983 Question 43 (1 mark)

What is the refractive index of the liquid for blue light?

Example 4.93: 1983 Question 44 (1 mark)

Which one or more of the following statements about the blue light is correct?

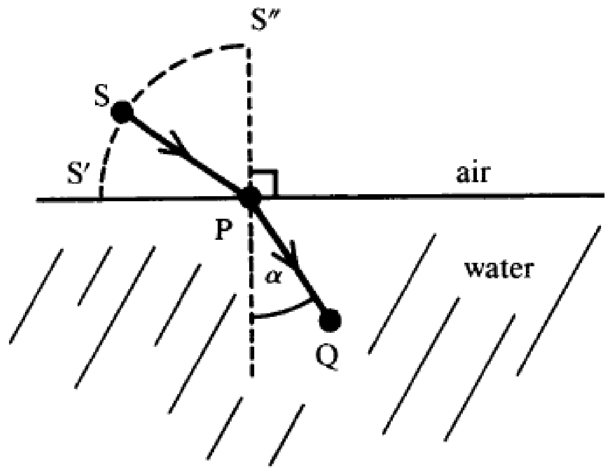
A. No light is transmitted to the air between O and Q.

B. No light is transmitted to the air beyond some point to the left of Q.

C. No light is reflected back into the liquid between O and Q.

D. Some light is reflected back into the liquid for all distances from O.

A narrow beam of green light of wavelength 5.4×10^{-7} m passes from air into a swimming pool in the direction SP, as shown in the diagram. The refractive index of the water for the green light is 1.33. The source can be positioned anywhere along the arc S'S".



As the source, S, is moved along the arc S'S" the angle α in the diagram at which the light from S enters the water changes.

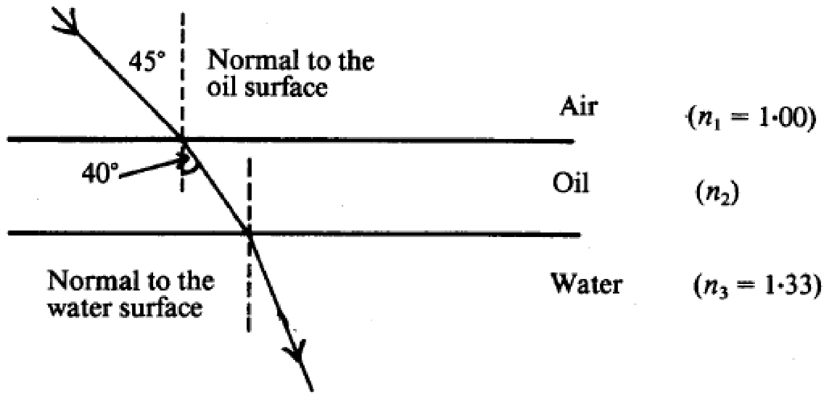
Example 4.94: 1984 Question 34 (1 mark)

What is the maximum value for the angle α at which light from S enters the water?

Example 4.95: 1984 Question 35 (1 mark)

What is the wavelength of the light in water?

A ray of monochromatic yellow light passes from air into a layer of oil floating on the water surface as shown in the diagram. The light then emerges from the oil into the water below. The refractive indices for the yellow light are shown on the diagram.



Example 4.96: 1986 Question 33 (1 mark)

Calculate the value of n_2, the absolute index of refraction for the oil.

Example 4.97: 1986 Question 34 (1 mark)

Calculate the value of the ratio: $\frac{\text{speed of the yellow light in water}}{\text{speed of the yellow light in air}}$

Example 4.98: 1986 Question 35 (1 mark)

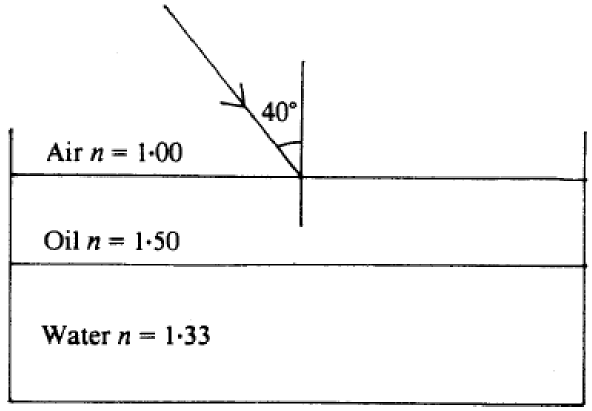
What is the value of the ratio: $\frac{\text{frequency of the yellow light in water}}{\text{frequency of the yellow light in air}}$

The yellow light has a wavelength of 660 nanometers (nm) in air.

Example 4.99: 1986 Question 36 (1 mark)

Calculate the wavelength of the yellow light in water.

A layer of oil of refractive index n = 1.50 lies on top of water (n = 1.33) as shown below.

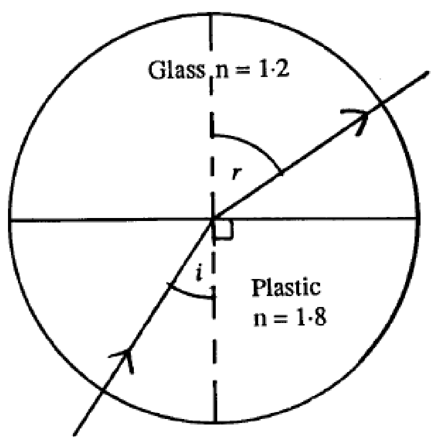


Example 4.100: 1987 Question 44 (1 mark)

A ray of light meets the air-oil interface at an angle of incidence of 40^0. Find the angle to the normal with which the ray emerges into the water.

A student carries out a laboratory experiment to study the refraction of light. She uses two semi-circular slabs of transparent material in perfect contact, one of plastic (refractive index n = 1.8) and the other glass (refractive index n = 1.2).

With the apparatus set up as below, she allows a beam of light to fall on the boundary between the plastic and the glass at angle of incidence, *i*, as shown.



Example 4.101: 1988 Question 31 (1 mark)

With the angle of incidence, *i*, equal to 30^0, what is the angle to the normal, *r*, with which the ray emerges into the glass?

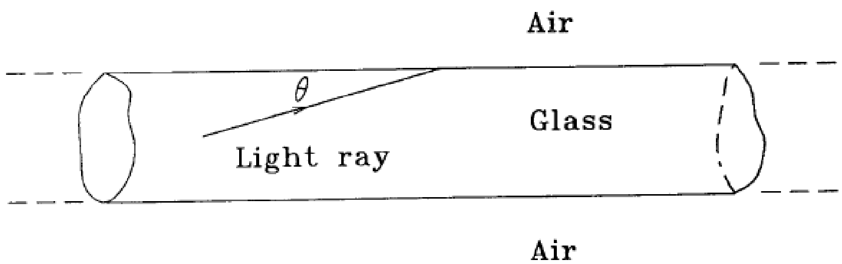
Example 4.102: 1988 Question 32 (1 mark)

What is the maximum angle of incidence, *i*, for which the ray emerges into the glass?

Example 4.103: 1988 Question 33 (1 mark)

What is the value of the ratio $\frac{\text{speed of light in glass}}{\text{speed of light in plastic}}$?

A 'light-pipe' consists of a solid glass cylinder in air as shown in the diagram below.
For a wavelength of 5.890×10^{-7} m the refractive index of the glass is 1.650.



Example 4.104: 1990 Question 34 (1 mark)

What is the maximum angle θ in the diagram for which light of wavelength 5.890×10^{-7} m is totally internally reflected at the glass-air interface?

The light-pipe is now immersed in water.
The refractive index of water for light of wavelength 5.890×10^{-7} m is 1.333.

Example 4.105: 1990 Question 35 (1 mark)

For what maximum angle θ will light of wavelength 5.890×10^{-7} m now be totally internally reflected at the glass-water interface?

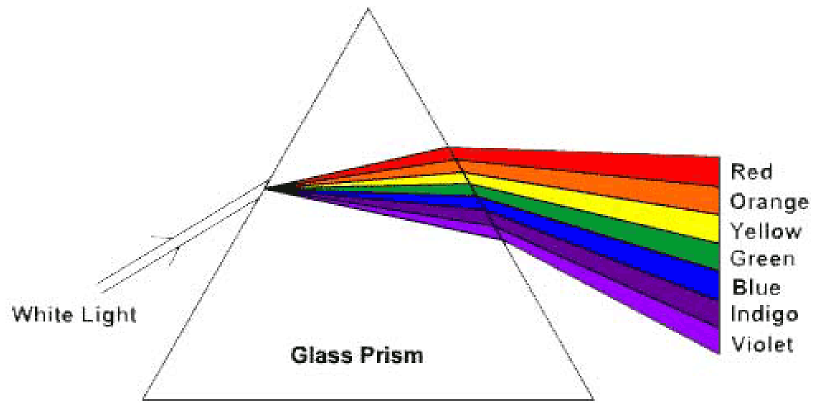
Light as a wave

- **investigate and explain theoretically and practically colour dispersion in prisms and lenses with reference to refraction of the components of white light as they pass from one medium to another**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016

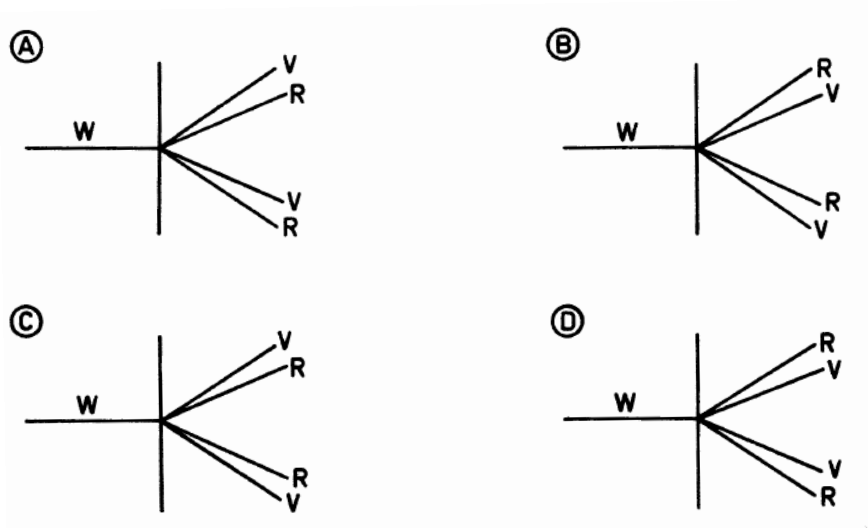
White Light

White light is made up of all of the colours of the visible spectrum. The light can be split into its constituent colours by shining it through a prism. The refractive index of a material depends on the wavelength of light travelling through the material. There is a large difference in speed (depending on wavelength) and therefore a large difference in the angle of refraction. The effect that this has is to separate the colours of white light. This process is known as dispersion.



Example 4.106: 1976 Question 54 (1 mark)

A beam of white light.is incident upon a single slit. Which diagram the first best shows the directions of the first order diffraction pattern for red light and violet light?



Example 4.107: 1976 Question 55 (1 mark)

"Along part of the path, the speed of red light differs from the speed of violet light". This statement is

A. relevant in explaining refraction by a prism, but not diffraction by a single slit.

B. relevant in explaining diffraction by a single slit, but not refraction by a prism.

C. relevant in explaining both refraction by a prism and diffraction by a single slit.

D. incorrect and therefore does not help explain either refraction or diffraction.

Example 4.108: 1980 Question 41 (1 mark)

Glass has a slightly higher refractive index for blue light than for red light.
Compared with red light, blue light has

A. a lower speed in both glass and in a vacuum.

B. a higher speed in glass, but a lower speed in a vacuum.

C. a lower speed in glass, but a higher speed in a vacuum.

D. a higher speed in glass, but the same speed in a vacuum.

E. a lower speed jn glass, but the same speed in a vacuum.

Example 4.109: 1982 Question 40 (1 mark)

The fact that glass has a different refractive index for light of differing colours causes the phenomenon known as

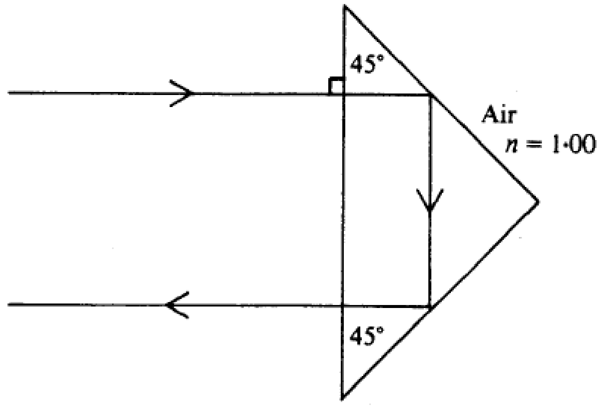
A. diffraction.

B. interference.

C. dispersion.

D. total internal reflection.

Binoculars use a prism to turn a ray of red light through 180^0 by total internal reflection. The diagram below shows the path through the prism of a ray of red light incident normal to the surface.

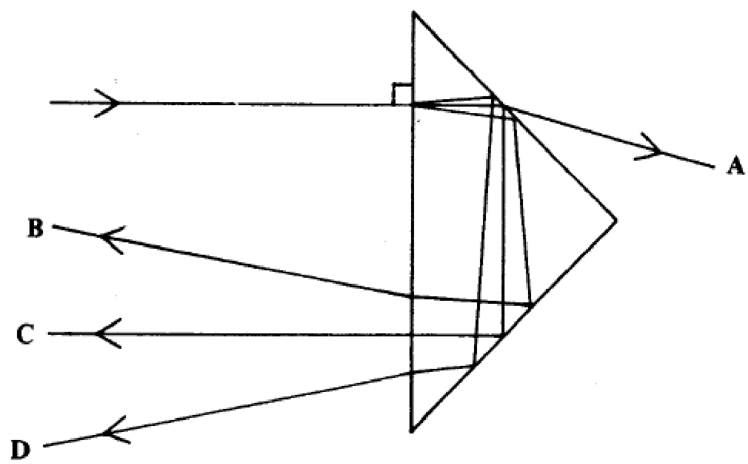


Example 4.110: 1987 Question 35 (1 mark)

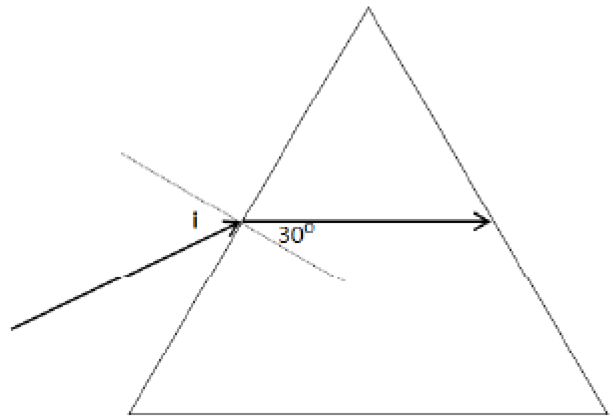
What is the minimum refractive index for the material of the prism?

Example 4.111: 1987 Question 36 (1 mark)

If blue light is used instead of red light, which of the rays **(A - D)** below would be the path of the blue ray?



White light travels from air into a glass prism. The **red component** of this light is refracted into the prism as shown in the diagram.
In the glass used, the refractive index for red light is 1.55.



Example 4.112: TAS 2016 Question 13a (2 marks)

What is the incident angle i?

Example 4.113: TAS 2016 Question 13b (3 marks)

Without calculation, on the above diagram draw labelled lines to show:

(i) The path of the red light as it leaves the prism.

(ii) The path of the **blue component** of the light as it passes through and exits the prism. The refractive index of blue light in the prism is 1.59.

(iii) Explain your answers to (ii).

Properties on mechanical waves

- **investigate and analyse theoretically and practically constructive and destructive interference from two sources with reference to coherent waves and path difference: nλ and $\left(n-\frac{1}{2}\right)\lambda$ respectively**

Light as a wave

- **explain the results of Young's double slit experiment with reference to: – evidence for the wave-like nature of light**

  – constructive and destructive interference of coherent waves in terms of path differences: nλ and $\left(n-\frac{1}{2}\right)$ respectively

  – effect of wavelength, distance of screen and slit separation on interference patterns: $\Delta x = \frac{\lambda L}{d}$

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
7, 8		3, 4, 5	1, 3, 4	1, 4	1, 2, 3, 4	2a, b, c, d	22a, b, c, d	19a, b	17a, b	18a, b

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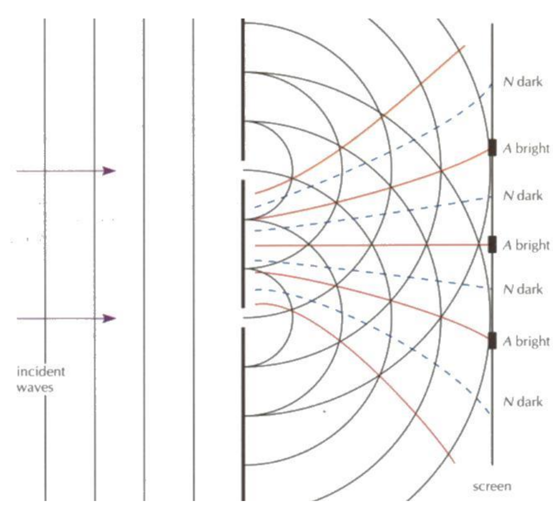
Wave model

In 1690 Huygens proposed the wave theory of light. This model suggests that light is transmitted as a wave between source and observer. The wave does not require a medium for transmission.

- Linear Propagation: The direction of energy transmission is perpendicular to the wave front. Two sets of waves pass through each other, apparently unaffected, as do two beams of light.
- Reflection: Can be explained in terms of waves.
- Refraction: Can be explained in terms of waves. The wave model predicts velocity changes on refraction of light that are, in fact, verified by experiment.
- Inverse Square Law: A spherical wave starting from a point obeys the inverse square law.
- Diffraction; Interference and Polarisation: These effects can all be explained with the wave model.

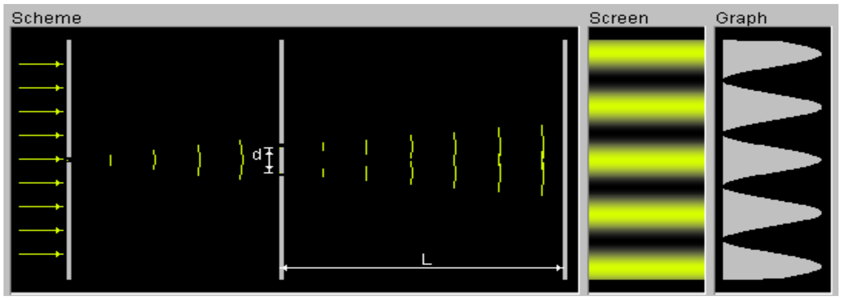
Young's Double Slit Experiment:

This experiment showed that light would produce an interference pattern, because it diffracted when passing through very small slits if the sources were close enough together. Young explained this result, using Huygens' Principle and assuming that each narrow slit acted as a source of secondary waves which spread out behind the slits and interfered with each other to form the bright and dark bands.

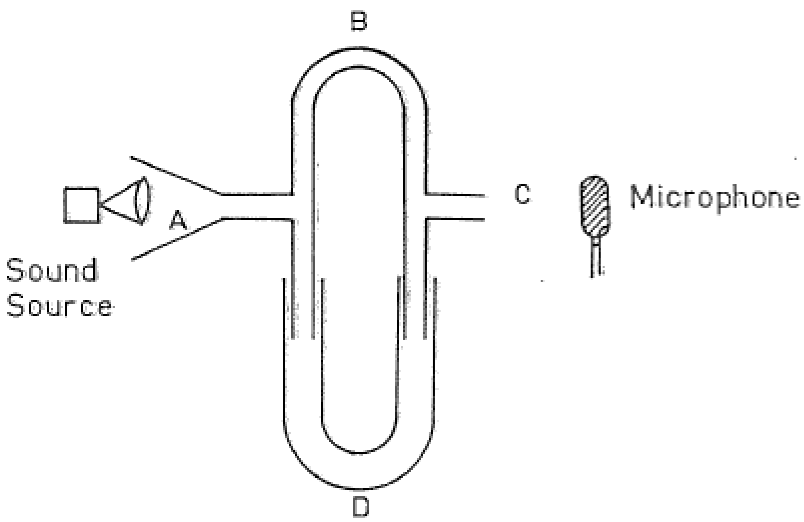


The pattern produced has a pattern of nodes and antinodes just like sound or water. A series of light and dark lines were observed on the screen. Dark lines correspond to cancellation, or nodes, bright lines to antinodes.

Antinodes were where crests met crests and troughs met troughs and constructively interfered with each other to form the bright lines. Nodes were formed where crests met troughs and troughs met crests and the displacements cancelled each other out by deconstructive interference, producing lines of minimum intensity.



The pattern can be described algebraically as $x \approx \frac{n\lambda L}{d}$. Where x is the distance between the central maximum and the local maximum, n is the nodal line, λ is the wavelength, L is the perpendicular distance from the slits to the screen, and 'd' is the distance between the two slits.



The device in the diagram is a sound interferometer. The sound waves enter at *A* and travel to *C* via paths *ABC* and *ADC.* The length of the path *ADC* can be changed by a sliding "U-tube" as shown in the diagram. The source emits a sound of a single frequency. The wavelength in air of this sound is λ.

Example 4.114: 1967 Question 57 (1 mark)

Initially *ABC* and *ADC* are equal. Then *ADC* is increased until the microphone records the first minimum in intensity. The change in pathlength *ADC* is

A. λ

B. λ/2

C. λ/4

D. 2λ

The frequency is fixed at a certain value and the tube is filled with oxygen gas. Successive minima are detected each time the distance *ADC* is increased by 30 cm.

When the experiment is repeated using hydrogen gas the corresponding change in *ADC* is 120 cm.

Example 4.115: 1967 Question 58 (1 mark) (modified)

If the velocity of sound in oxygen is 340 m sec^{-1}, what is the velocity of sound in hydrogen?

A. 85 m sec^{-1}

B. 680 m sec^{-1}

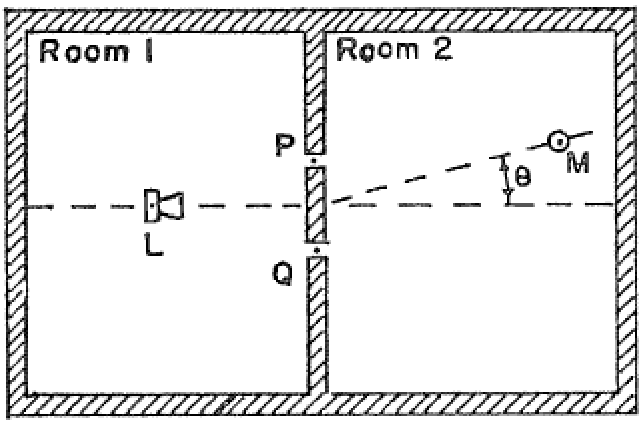
C. 1020 m sec^{-1}

D. 1360 m sec^{-1}

P and Q are two small holes in the wall separating two rooms. A small loudspeaker, L, located in Room 1, emits soundwaves of wavelength λ. M is a microphone which measures the sound intensity in Room 2. All the walls are made of sound absorbing material so that reflected sound is negligible.

In questions 57 and 58 use the following symbols for the distances between the points indicated.

PQ = *x*
LP = *a*
LQ = *b*
PM = *c*
QM = *d*



In the positions shown in the diagram, L is located so that *a* = *b,* and M is located on the first nodal line.

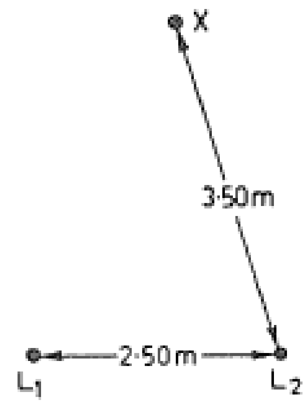
Example 4.116: 1970 Question 57 (1 mark)

Write an expression for λ in terms of symbols given above.

Example 4.117: 1970 Question 58 (1 mark)

The angle *θ* marks the direction of the first nodal line when c and *d* are very much greater than λ. Write an expression for the angle *θ* in terms of λ and symbols given above.

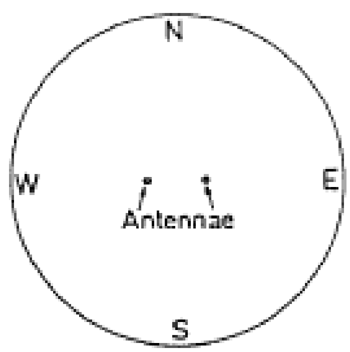
Two small identical loudspeakers, L_1 and L_2, are placed 2.50 m apart. They both emit sound uniformly in all directions.
The wavelength of the sound is 1.00 m. They are in phase.
Point X, a nodal point, is 3.50 m from L_2 and *at least* 3.50 m from L_1.



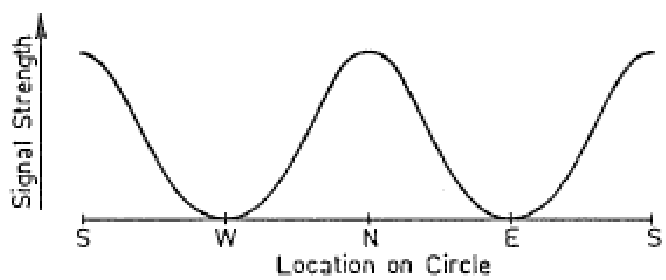
Example 4.118: 1972 Question 59 (1 mark) 57%

What is the smallest distance that X can be from L_1?

A radio station broadcasting on a wavelength of 100 metre is required to arrange that no signal is radiated in the East-West direction. This is achieved by using two antennae oriented as shown below, and feeding each with signals in phase. Interference effects between the two sources, which independently radiate uniformly in all directions, produce a signal strength dependent on direction.

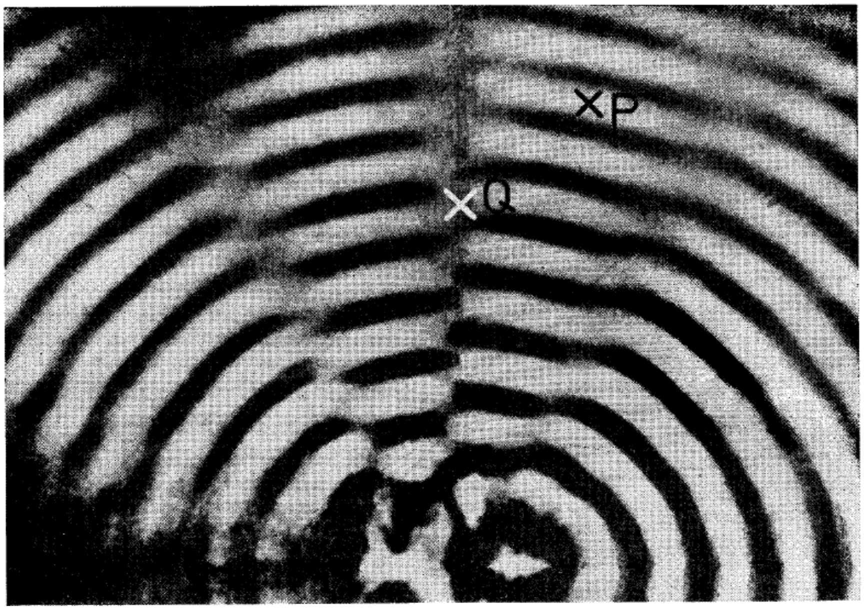


The signal strength is measured around a circle of radius 1 kilometre, and is graphed below as a function of direction, showing that the broadcast conditions are satisfied.



Example 4.119: 1971 Question 57 (1 mark)

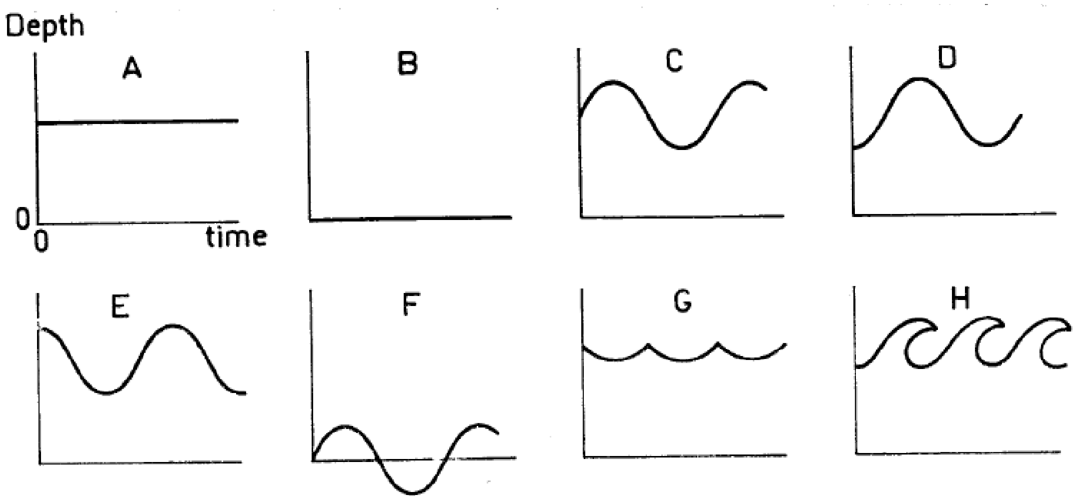
What is the separation of the two antennae?



Two point sources, vibrating with the same frequency, produce an interference pattern in a ripple tank.
A light above the tank produces an image of the pattern on the floor.
At the time t = 0 the image appears as shown in the photograph.

Example 4.120: 1970 Question 53 (1 mark)

Which graph shows the relation between depth of water and time for point P?



Example 4.121: 1970 Question 54 (1 mark)

Which graph shows the relation between depth of water and time for point Q?

Example 4.122: 1970 Question 55 (1 mark)

The period of the waves is *T.* How long after *t* = 0 will the depths of water at P and Q be the same?

Example 4.123: 1970 Question 56 (1 mark)

Which *one or more* of the following changes will increase the number of nodal lines?

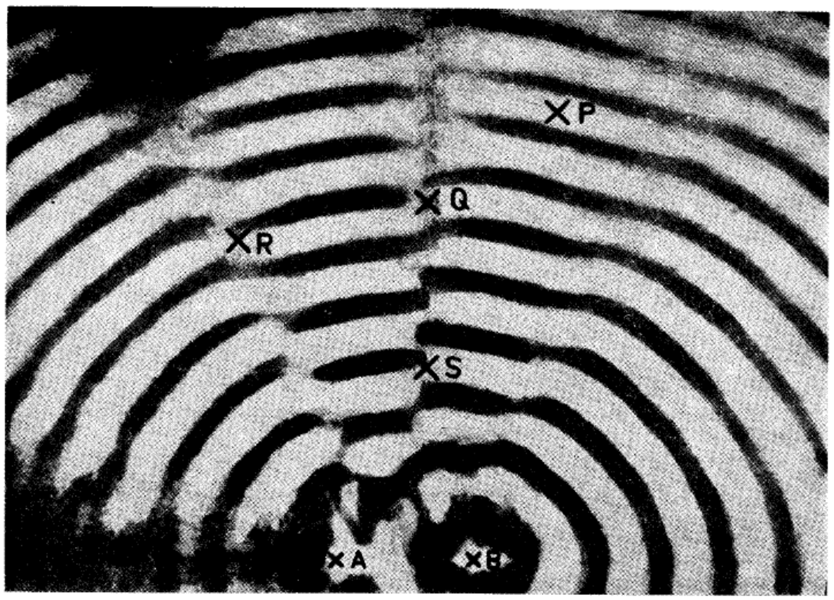
A. double the frequency

B. halve the frequency

C. double the distance between the sources

D. halve the distance between the sources

(One or more answers)



Two point sources, vibrating with the same frequency, produce an interference pattern in a ripple tank. Answer the following questions in numbers of wavelengths.

Example 4.124: 1973 Question 52 (1 mark)

What is the length of QS?

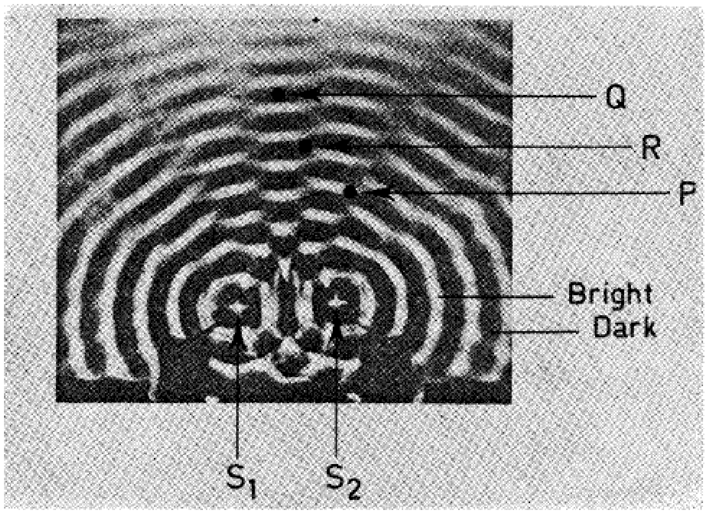
Example 4.125: 1973 Question 53 (1 mark)

What is the length of (BR - AR)?

Example 4.126: 1973 Question 54 (1 mark)

What is the length of (AP - BP)?

Two point sources S. and S, vibrating in phase produce an interference pattern in a ripple tank. A light above the ripple tank projects an image of the pattern on a screen below the tank.



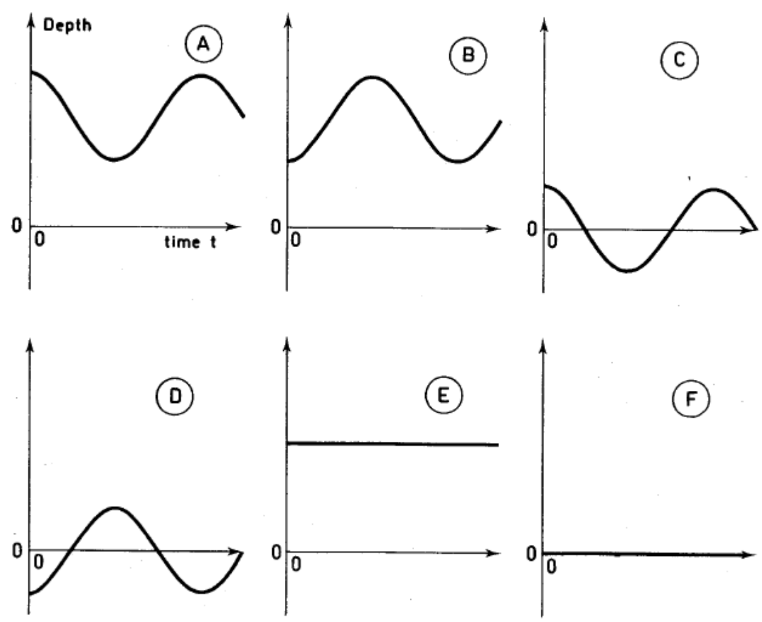
A photograph of the image, taken at time t = 0, is shown above.

Example 4.127: 1979 Question 36 (1 mark)

In terms of the wavelength λ, what is the distance $PS_2 - PS_1$?

Example 4.128: 1979 Question 37 (1 mark)

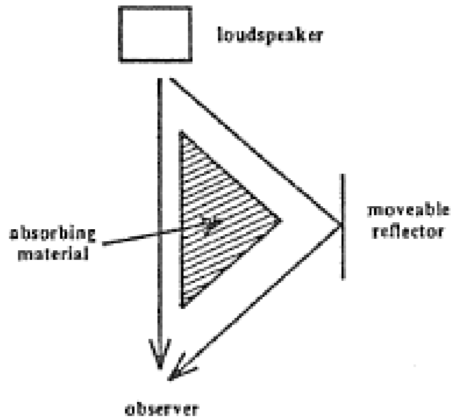
Which of the graphs below shows the variation of depth of water with time at point Q?



Example 4.129: 1979 Question 38 (1 mark)

Which of the above graphs shows the variation of depth of water with time for point R ?

Sound of frequency 660 Hz is emitted by a loudspeaker, and reaches an observer by two different paths. It is found that as the path difference increases from zero, the intensity of the sound passes through a series of maxima and minima.
The first three minima occur for path differences of 0.25, 0.75 and 1.25 m.



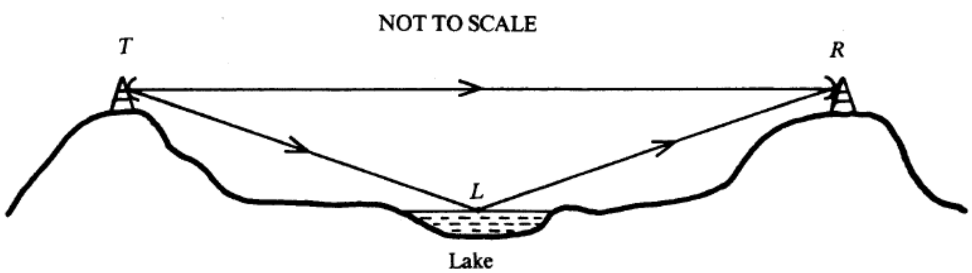
Example 4.130: 1982 Question 33 (1 mark)

What is the speed of the sound?

Microwaves of wavelength 0.30 m form the link between two radio stations on mountain-tops. The speed of light in the particular conditions is 3.0×10^8 m s^{-1}.

Example 4.131: 1987 Question 33 (1 mark)

What is the frequency of the microwaves?



There is a lake in the valley below and some microwaves reflect off the surface (with no phase change). The direct distance between the transmitter and the receiver R is 2210.00 m.

Example 4.132: 1987 Question 34 (1 mark)

Which one of the distances (**A - E**) below for the reflected path TLR would cause destructive interference?

A. 2213.00 m

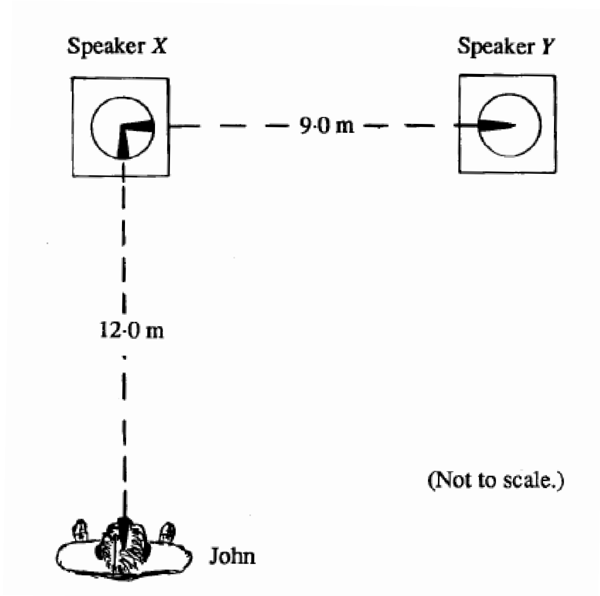
B. 2210.90m

C. 2210.45 m

D. 2210.60 m

E. 2249.70m

The sound system at a concert is sketched in the diagram below. It consists of two loudspeakers X and Y, separated by 9.0 m.
John, is standing 12.0 m directly in front of speaker X. As a test of sound levels a performer plays a sound of wavelength 2.0 m.



Example 4.133: 1988 Question 38 (1 mark)

What is the frequency of the sound?
(The speed of sound in air is 330 m s^{-1} in these conditions).

John complains that the sound is too soft, and it is found that speaker Y has not been connected to its amplifier.
Speaker Y is now connected to its amplifier so as to be in phase with speaker X.

Example 4.134: 1988 Question 39 (1 mark)

Which of the following statements (**A - D**) best explains the volume of the sound that John will now hear?

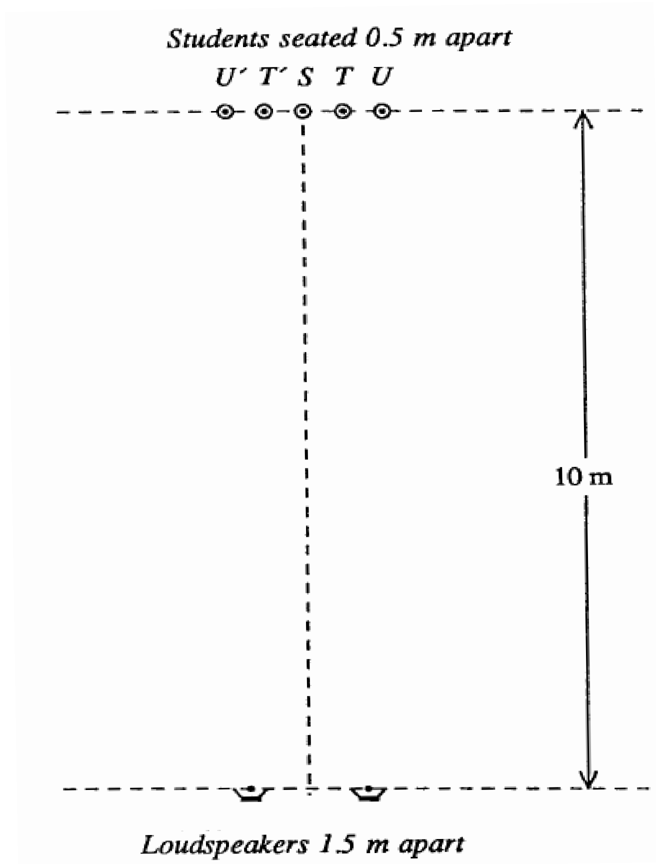
A. The volume will be louder.

B. The volume will be softer.

C. The volume will be unchanged.

D. There is insufficient information given to decide the volume of the sound'

To illustrate interference effects to a class of students, the teacher sets up two loud speakers which emit sound of a single wavelength, in phase. The speakers are 1.5 m apart. At the back of the lecture theatre, 10 m from the speakers, are a number of students seated in a row, 0.5 m apart. The situation is illustrated in the figure at right.



The students are asked to report on the loudness of the sound as they hear it. Student S who is equidistant from the two loud speakers can hear the sound clearly, as can students U and U'. However students T and T' have difficulty hearing the sound since it is very soft.

Example 4.135: 1991 Question 33 (1 mark)

Which of the choices below (**A - E**) gives the best estimate of the maximum wavelength the sound can have?

A. 0.15 m

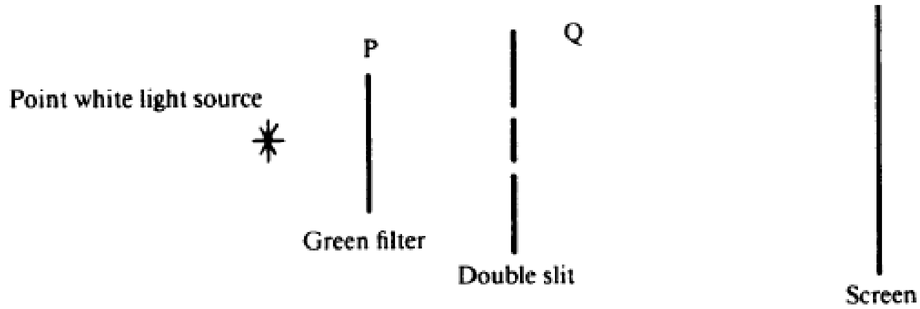
B. 0.5 m

C. 1 m

D. 1.5 m

E. 3 m

The figure below shows a double slit experiment in which an interference pattern is obtained. The apparatus consists of a point source of white light, a green filter, a double slit, and a screen at a large distance from the slits.



Example 4.136: 1984 Question 38 (1 mark)

Which one or more of the following changes would result in an increased spacing between the light and dark bands on the screen?

A. Move the screen closer to the slits.

B. Move the screen further from the slits.

C. Replace the green filter with a red filter.

D. Replace the green filter with a blue filter.

E. Move the point source of light closer to the slits.

(one or more answers)

Example 4.137: 1984 Question 39 (1 mark)

Which one or more of the following statements is correct?

A. Increasing the separation of the slits increases the spacing of the interference fringes.

B. Decreasing the separation of the slits increases the spacing of the interference fringes.

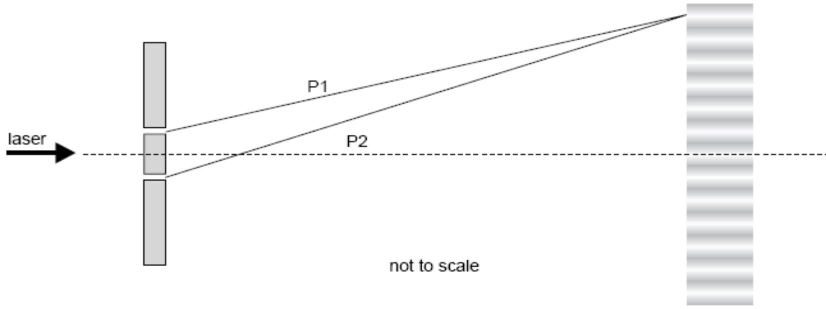
C. Increasing the width of each slit decreases the spacing of the interference fringes.

D. Covering up one of the slits makes no difference to the spacing of the interference fringes.

E. Moving the green filter from the position P to the position Q makes no change to the spacing of the interference fringes.

(one or more answers)

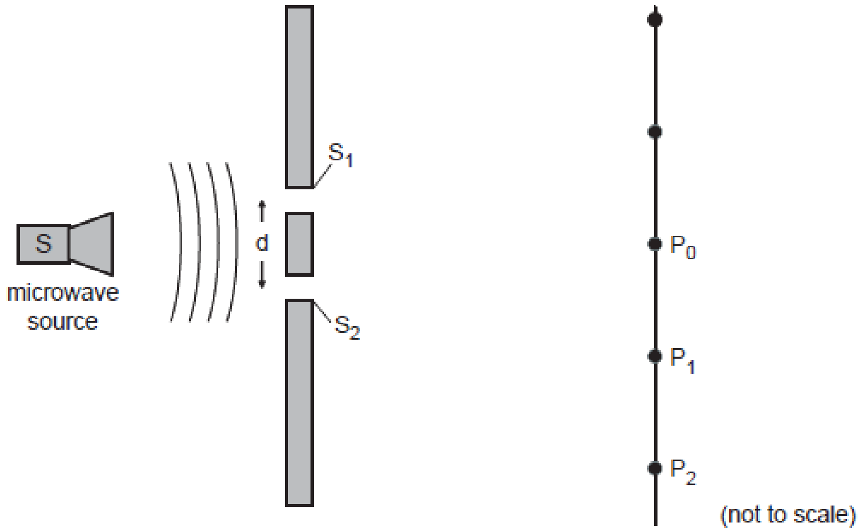
Jac and Jules are observing a demonstration of Young's double slit experiment. Their teacher, Mel, has set up a He-Ne laser of wavelength 632 nm and directed the beam onto a set of two parallel slits. A pattern from these slits has been projected onto a distant wall.



The teacher asks each student to estimate the difference between the length of the lines P1 and P2, which are the lines between the centre of each slit and the 6th bright spot.

Example 4.138: 2004 Pilot Question 10 (3 marks)

Estimate the difference in length between P1 and P2.



Students have set up an experiment similar to that of English physicist Thomas Young. The students' experiment uses microwaves of wavelength λ = 2.8 cm instead of light.
The beam of microwaves passes through two narrow slits shown as S_1 and S_2 below.
The students measure the intensity of the resulting beam at points along the line shown and determine the positions of maximum intensity.
These are shown as filled circles and marked P_0, P_1 . . .

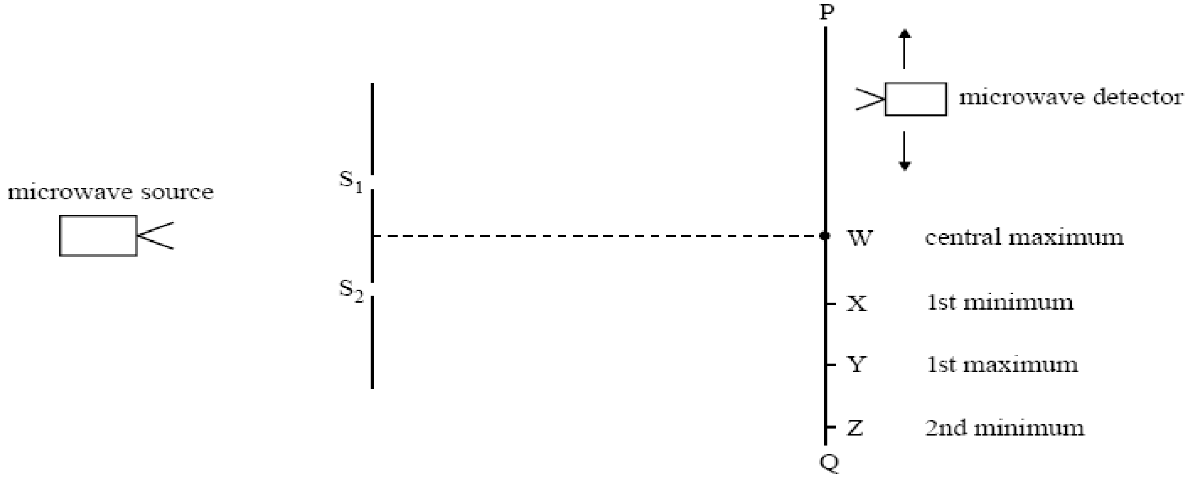
Example 4.139: 2006 Question 7 (2 marks)

What is the difference in length (S_2P_2 . S_1P_2) where P_2 is the second maximum away from the central axis.

Example 4.140: 2006 Question 8 (2 marks)

Explain what Young's observation of bright and dark regions tells us about the nature of light.

A group of students is studying Young's double slit experiment using microwaves (λ = 3.0 cm) instead of light. A microwave detector is moved along the line PQ, and the maxima and minima in microwave intensity are recorded. The experimental apparatus is shown below.



Example 4.141: 2008 Question 3 (2 marks)

What is the path difference $S_1Z – S_2Z$ in cm?

Example 4.142: 2008 Question 4 (2 marks)

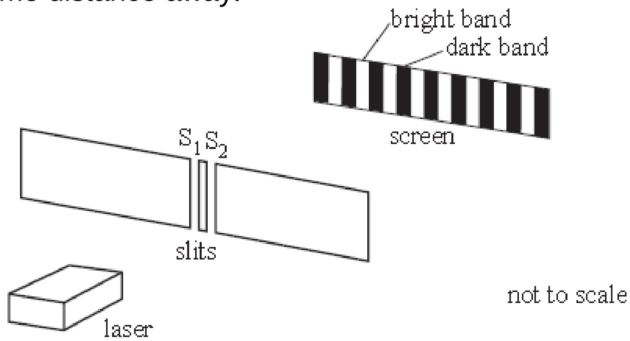
Explain why there is a maximum in microwave intensity detected at point Y.

The students reduce the separation of the slits S_1 and S_2.

Example 4.143: 2008 Question 5 (2 marks)

Explain the effect of this change on the pattern of maxima and minima along the line PQ.

Louise and Thelma set up the apparatus shown below. It consists of a laser providing light of a single wavelength, which passes through two narrow slits and produces a pattern of bright and dark bands on a screen some distance away.



Example 4.144: 2009 Question 3 (3 marks)

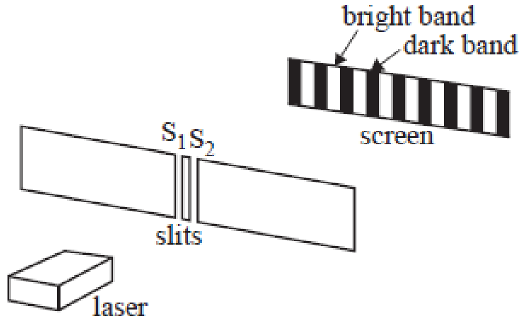
Before doing the experiment, Louise believes that the central band (the one exactly opposite the centre point between the two slits) is a dark band. Thelma believes that this is a bright band. Who is correct? Outline your reasoning clearly.

Example 4.145: 2009 Question 4 (2 marks)

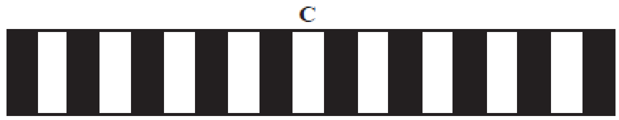
The pattern of bright and dark bands is shown below.

Precision measurement shows that the **path difference** to the middle of dark band **A** (that is, the distance $AS_2 - AS_1$) is greater than the path difference to the middle of dark band **B** by 496 nm. From this information, determine the wavelength of the laser. You may include a diagram.

Two students set up a two-slit interference experiment with a source of laser light, as shown below.



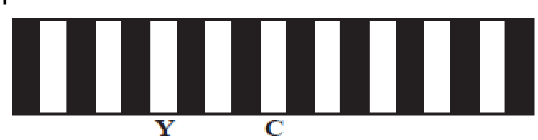
The wavelength of the light from the laser is 612 nm. The figure below shows a sketch of the central section of the interference pattern that they obtain. The central band **C**, which is a bright band, is labelled.



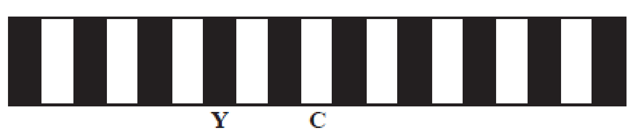
Example 4.146: 2012 Question 2b (2 marks)

Explain why the central band of the pattern at point C is a bright band and not a dark band.

Another laser that produces light of a different wavelength is now used. The pattern is now spaced more closely. The first figure below shows the new pattern and the second figure shows the original pattern.
The second bright band to the left of C in the **new** pattern is at the position labelled **Y**. In the original pattern this was the position of the second **dark** band to the left of C.



New pattern

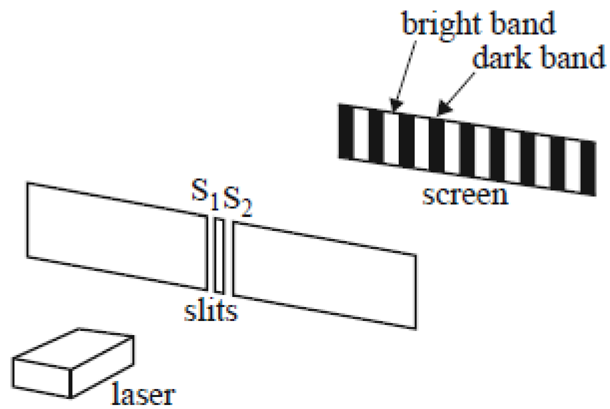


Original pattern

Example 4.147: 2012 Question 2d (2 marks)

Calculate the wavelength of the light produced by this new laser.

The apparatus for a Young's double-slit experiment is shown below.

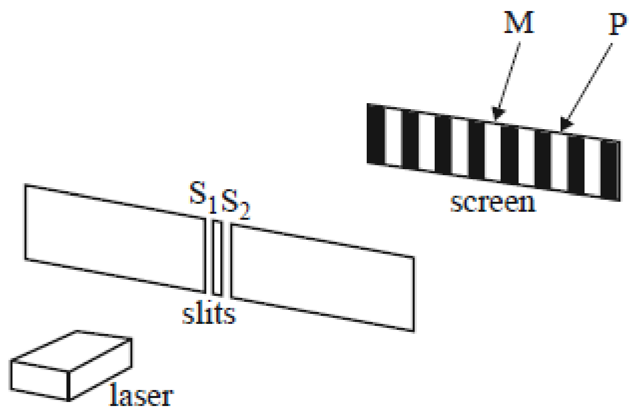


A beam of green light (λ = 550 nm) is incident on the slits.

Example 4.148: 2013 Question 22c (3 marks)

The path difference from the slits to the second bright band from the centre of the interference pattern is 1.4×10^3 nm.
Calculate the path difference (in metres) from the slits to the first dark band from the centre of the pattern.

A group of students carries out a two-slit interference experiment using light with a wavelength of 420 nm. The arrangement of the students' apparatus and the resulting interference pattern are shown below.
The point M on the screen is at the centre of the interference pattern. There is a bright band at point P on the screen. It is the second bright band to the right of M, as shown.



Example 4.149: 2014 Question 19b (3 marks)

The students repeat the experiment using light of a different wavelength. They find that, at the point P on the screen, there is now a **dark** band. It is the second dark band to the right of M. Calculate the wavelength of this light. Show your working.