14 chapter Waves Superposition:

The principle of superposition of waves:

We use the principle of linearity which allows us to add the waves.

Most of the time, we will be dealing with the waves of the same amplitudes and frequencies.

$$A\sin(\left(α\right)+A\sin(\left(β\right)))=2A\cos(\left(\frac{α-β}{2}\right))\sin(\left(\frac{α+β}{2}\right))$$

Diffraction of waves:

Diffraction can be observes as the waves go through the slits.

The result of diffraction is often interference.

Interference:

Interference pattern shows beautiful pictures often splitting white light into the spectrum.

The Young double-slit experiment:

This is the simplest experiment showing the interference as a result of the diffraction, allowing to measure the wavelength.

$$λ= \frac{ax}{D}$$

a = slit separation

x = fringe separation

D = slit-to-screen distance

Diffraction gratings:

Diffraction grating allows measuring the wavelength easier, more accurately and more precisely because there more maxima and they are more visible then in the double-slit experiment.

If you close your eyes enough while looking at a light source then your eyelashes produce diffraction grating and you observe diffraction and interference.

Disc is a reflection diffraction grating.

Self-assessment questions:

1.1.14. On graph paper, draw two ‘triangular’ waves like those shown in Figure 14.4.

(These are easier to work with than sinusoidal waves.)

One should have wavelength 8 cm and amplitude 2 cm; the other wavelength 16 cm and amplitude 3 cm.

Use the principle of superposition of waves to determine the resultant displacement at suitable point along the waves, and draw the complete resultant wave.

2.1.14. A microwave oven (Figure 14.9) uses microwaves of 12.5 cm. The front door of the oven is made of glass with a metal grid inside; the gaps in the grid are few millimeters across.

Explain how this design allows us to see the food inside the oven, while microwaves are not allowed to escape into the kitchen (where they might cook us).

Answer:

The grid spacing is much smaller than

the wavelength of the microwaves, so the

waves do not pass through. However, the

wavelength of light is much smaller, so it can

pass through unaffected.

3.1.14. Explain why the two loudspeakers must produce sounds of precisely the same frequency if we are to hear the effects of interference.

Answer:

Two loudspeakers with slightly different

frequencies might start off in step, but they

would soon go out of step. The interference

at a particular point might be constructive at

first, but would become destructive.

4.1.14. Look at the experiment arrangement shown in Figure 14.17. Suppose that the microwave probe is placed at a point of low intensity in the interference pattern. What do you predict will happen if one of the gaps in the barrier is now blocked?

Answer:

The intensity would increase.

5.1.14. Draw sketches of displacement against time to illustrate the following:

a. two waves having the same amplitude and in phase with one another.

b. two waves having the same amplitude and with a phase difference of 90 degrees.

c. two waves initially in phase but with slightly different wavelengths.

Use your sketches to explain why two coherent sources of waves are needed to observe interference.

6.1.14. Consider points D and E on the screen, where BC = CD = DE. State and explain what you would expect to observe at D and E.

Answer:

D: dark fringe, because rays from slits 1 and

2 differ in path length by one-and-a-half

wavelengths (11/2*λ*).

E: bright fringe, because the path difference

is 2*λ*.

7.1.14. If the student in Worked example 1 moved the screen to a distance of 4.8 m from the slits, what would the fringe separation become?

Answer:

Wavelength of light used, *λ,* and separation of

slits, *a*, remain the same.

This means that *x*1

*D*1

= *x*2

*D*2

. Doubling *D* means *x*

must also double, so separation of fringes

*x*2 = 3.0 mm.

lambda = 6.3 \* 10 ^ (-7)

a = 10 ^ (-3)

D = 4.8

x = lambda \* D / a

MsgBox x

8.1.14.

Use $λ= \frac{ax}{D}$

to explain the following observations:

a. With the slits closer together, the fringes are further apart.

b. Interference fringes for blue light are closer together than for red light.

c. In an experiment to measure the wavelength of light, it is desirable to have the screen as far from the slits as possible.

Answer:

a *x* = *λD*

*a .* Therefore *x* ∝ 1*a*

, so decreasing *a* gives

increased *x*.

b Blue light has shorter wavelength, so *x* is less

(*x* is proportional to *λ*).

c For larger *D*, *x* is greater, so there is a smaller

percentage uncertainty in *x* (*x* is proportional

to *D*).

1.9.14. Yellow sodium light of wavelength 589 nm is used in the Young double-slit experiment. The slit separation is 0.20 mm, and the screen is places 1.20 m from the slits. Calculate the separation of neighboring fringes formed on the screen.

Answer:

Rearrange *λ* = *ax*

*D* to give

*x* = *λD/a* = 589 × 10–9 × 1.20/0.0002 = 3.5 mm

a = 2 \* 10 ^ (-4)

D = 1.2

lambda = 589 \* 10 ^ (-9)

x = lambda \* D / a

MsgBox x

10.1.14. In a double-slit experiment, filters are placed in front of the white light source to investigate the effect of changing the wavelength of the light. At first a red filter was used instead (λ = 600 nm) and the fringe separation was found to be 2.40 mm. A blue filter was then used instead (λ = 450 nm). Determine the fringe separation with the blue filter.

Answer:

*D* and *a* are fixed. So *λ*1

*x*1

= *λ*2

*x*2

and so

*x*2 = 4.5 × 10–7 × 2.4 × 10–3

6.0 × 10–7 = 1.8 × 10–3 m = 1.8 mm

(or wavelength is 34

of previous value, so

spacing of fringes is 34

of previous value)

lambda1 = 600 \* 10 ^ (-9)

lambda2 = 450 \* 10 ^ (-9)

X1 = 2.4 \* 10 ^ (-3)

X2 = X1 \* lambda2 / lambda1

MsgBox X2

11.1.14. Explain how the second-order maximum arises.

Use the term path difference in your explanation.

Answer:

For the second-order maximum, rays from

adjacent slits have a path difference of 2*λ*, so

they are in phase.

Summary:

The principle of superposition states that when two or more waves meet at a point, the resultant displacement is the algebraic sum of the displacements of the individual waves.

When waves pass through a slit, they may be diffracted so that they spread out into the space beyond.

The diffraction effect is greatest when the wavelength of the waves is similar to the width of the gap.

Interference is the superposition of waves from two coherent sources.

Two sources are coherent when they emit waves that have a constant phase difference. (This can only happen if the waves have the same frequency or wavelength.)

For constructive interference the path distance is a whole number of wavelengths:

path difference = 0, λ, 2λ, 3λ, etc. or

path difference = nλ

For destructive interference the path difference is an odd number of half wavelengths:

path difference = $\frac{1}{2}λ$, $1\frac{1}{2}λ$, $2\frac{1}{2}λ$, etc. or

path difference = $\left(n+\frac{1}{2}\right)λ$

When light passes through a double slit, it is diffracted and an interference pattern of equally spaced light and dark fringes is observed.

This can be used to determine the wavelength of light using the equation:

$$λ= \frac{ax}{D}$$

This equation can be used for all waves, including sound and microwaves.

A diffraction grating diffracts light at its many slits or lines.

The diffracted light interferes in the space beyond the grating.

The equation for a diffraction grating is:

d sin θ = nλ

End-of-chapter questions:

3.2.14. Explain why, in the remote mountainous regions, such as the Hindu Kush, radio signals from terrestrial transmitters can be received, but television reception can only be received from satellite transmissions.

Answer:

Radio waves have a long enough wavelength,

up to 1 km, that they can diffract round the

hills.

TV waves have very short wavelength

(centimetres or millimetres), so cannot

diffract round the hills.

4.2.14. Damita and Jamal are organizing a disco. Damita suggests that feeding the sound from the music center to a second loudspeaker will increase the loudness of the music. Jamal says it won’t work as there will be places where the sound will be very loud, due to constructive interference, and places where it will be much quieter, due to destructive interference. State who is correct and explain your reasoning.

Answer:

Damita is correct; the sound from the

speakers will have many different frequencies

and cannot be coherent.

5.2.14. The constant frequency signal from a signal generator is fed to two loudspeakers placed 1.5 m apart. A girl, who is 8 meters away from the speakers, walks across in a line parallel to the line between the speakers. She finds that there is a distance of 1.2 m between successive spots where the sound is very quiet. Calculate the wavelength of the sound.

Answer:

Using *ax* = *λd*

wavelength *λ* = *ax/d* = 1.5 × 1.2

8.0 = 0.225 m ≈ 0.23 m.

6.2.14. Two signal generators feed signals with slightly different frequencies to two separate loudspeakers.

Suggest why a sound of continuously rising and falling loudness is heard.

Answer:

When the waves are in phase, they add up to

give loud sound.

They gradually go out of phase, and when

they are in antiphase the sound is at its

quietest.

The waves gradually come back into phase

and become loud again.

10.2.14.a. Explain what it meant by the term destructive interference.

10.2.14.b. A student sets up an experiment to investigate the interference pattern formed by microwaves of wavelength 1.5 cm. The apparatus is set up as in Figure 14.17 on page 199. The distance between the centers of the two slits is 12.5 cm. The detector is centrally placed 1.2 m from the metal plates where it detects a maximum. The student moves the detector 450 cm across the bench parallel to the plates. Calculate how many maxima the detector will be moved through.

10.2.14.c. Calculate the frequency of these microwaves.

Answer:

a The superposition of two waves 180° out of

phase

to give (nearly) zero resultant.

b *λ* = *ax/D* leading to *x* = *Dλ/a* = 1.2 × 1.5 × 10–2

12.5 × 10–2