6.1 Introduction

- In previous chapter we ignore the width of the slits, i.e. slits were points sources.

- Remember

  ![Diagram of light spreading out through slits]

  if \( \pi d \) or \( 2 \pi d \) incoming light spreads out. This phenomenon is known as "diffraction".

  Other waves (sound, water) also have this property of spreading through slits or sharp edges.

- Diffraction can also be observed at sharp edges (opaque barrier).

  ![Diagram of diffraction at an opaque object]

  A: \( \text{holding your hand at arm's length, you can readily block sunlight from reaching your eyes. why can you not block sound from reaching your ears this way?} \)

  [Note: This question and answer pair is incomplete and may require additional context or clarification from the source text.]

  A: wavelength of light is extremely small in comparison to the dimensions of your hand, so light diffraction is so small and negligible. However, sound waves have wavelengths that are comparable to your hand, and thus, significant diffraction of sound waves occur around your ear.
6.2 Diffraction Patterns from Narrow Slits

Fraunhofer Diffraction Pattern

\[ L \gg \alpha \]

Each portion of the slit acts as a source of light waves.

So, one portion of a slit can interfere with light from another. Resultant light intensity on the screen depends on \( \theta \).

Consider rays 1 and 3 path difference:

\[ S = \frac{a}{2} \sin \theta \]

If \( S \) is exactly half wavelengths (or multiples), then 1 and 3 cancel each other (destructive interference).

\[ \frac{a}{2} \sin \theta = \pm \frac{\lambda}{2} \rightarrow \sin \theta = \pm \frac{\lambda}{a} \]

or

\[ \sin \theta = \pm \frac{2\lambda}{a} \]

\[ \sin \theta_{\text{dark}} = m \frac{\lambda}{a} \]

\[ m = \pm 1, \pm 2, \ldots \]

* If \( L \gg \alpha \) and a converging lens is used \( \Rightarrow \) Fraunhofer diff. pattern is observed

* If \( L \approx \alpha \) and no lens is used \( \Rightarrow \) Fresnel diff. pattern is observed (more difficult to analyze)
\[
\sin \theta_d = \frac{m \lambda}{a} \Rightarrow m = \pm 1 \Rightarrow \sin \theta_d = \mp \frac{600 \times 10^{-9}}{0.3 \times 10^{-3}} = \mp 2 \times 10^{-3}
\]

\[
m = \pm 2 \Rightarrow \sin \theta_d = \mp 2 \times \frac{600 \times 10^{-9}}{0.3 \times 10^{-3}} = \mp 4 \times 10^{-3}
\]

OR

\[
y = m \frac{L \lambda}{a} = m \frac{(2)(600 \times 10^{-9})}{0.3 \times 10^{-3}} = m (4 \times 10^{-3})
\]

\[
m = \pm 1 \Rightarrow y_1 = \mp 4 \times 10^{-3} m = \mp 4 \text{mm}
\]

\[
m = \pm 2 \Rightarrow y_2 = \mp 2 \times 4 \times 10^{-3} m = \mp 8 \text{mm}
\]

Width of the central bright fringe is

\[
\omega = 2 |y_1| = 2 \left| \pm 4 \text{mm} \right| = 8 \text{mm}
\]
6.3 Intensity of a single-slit diffraction patterns

\[ I = I_0 \left[ \frac{\sin \left( \frac{\pi a \sin \theta}{\lambda} \right)}{\frac{\pi a \sin \theta}{\lambda}} \right]^2 \]

Note that "diffraction" occurs when \( \pi a \sin \theta / \lambda = m \pi \) \( \iff m \) is integer \# or \( \sin \theta = \frac{m \pi}{a} = \sin \theta_d \)

**EXAMPLE 2** Find the ratio of \( I_1/I_0 \)

**Solution** from figure 1, \( \lambda \) lies between \( \pi a \) and \( \lambda = 2\pi \)

\[ \therefore \text{we can select } \lambda = \frac{2\pi}{2} \text{ (center position)} \]

\[ \frac{I_1}{I_0} = \left[ \frac{\sin \left( \frac{\pi a}{2} \right)}{\frac{\pi a}{2}} \right]^2 = 0.045 \approx 4.5\% \]

That is first maxima have an intensity of 4.5% that of the central maximum.
6.4 The Diffraction Grating

The diffraction grating consists of a large number of equally spaced parallel slits, and it is useful for analysing light sources.

First-order maximum \( (m=1) \)

Central zeroth-order maximum \( (m=0) \)

First-order maximum \( (m=1) \)

- The pattern on the screen is a combination of interference and diffraction.
- Each slit produces diffraction and diffracted beams interfere to form final pattern.

\[
\begin{align*}
&\frac{2\pi}{\lambda}, \frac{4\pi}{\lambda}, \frac{6\pi}{\lambda}, \ldots \rightarrow \sin \theta \\
&\frac{2\pi}{d}, \frac{4\pi}{d}, \frac{6\pi}{d}, \ldots \\
&\theta \rightarrow \frac{d}{\lambda} \\
&\theta = \frac{d}{\lambda} \sin \theta
\end{align*}
\]
Condition for maxima in the interference pattern at angle \( \theta_{\text{bright}} = \theta_b \):

\[
\dfrac{d \sin \theta_b}{m} = n \\
\text{m = 0, \pm 1, \pm 2, \ldots}
\]

\( d \) is the slit spacing.

**Example 2** A monochromatic light of laser (\( \lambda = 630\text{nm} \)) is incident normally on a diffraction grating containing 6000 grooves (lines) per centimeter. Find the angles at which first and second order maxima are observed.

**Solution**

Slit separation: \( d = \dfrac{1}{6000} \text{ cm} = 1.67 \times 10^{-4} \text{ cm} \).

First order maxima (\( m = 1 \))

\[
\sin \theta_1 = \dfrac{2 \lambda}{d} = \dfrac{630 \times 10^{-9}}{1.67 \times 10^{-4}} = 0.377 \rightarrow \theta_1 \approx 22.2^\circ
\]

Second order maxima (\( m = 2 \))

\[
\sin \theta_2 = \dfrac{2 \lambda}{d} = \dfrac{(2) (630 \times 10^{-9})}{1.67 \times 10^{-4}} = 0.754 \rightarrow \theta_2 \approx 48.9^\circ
\]

Note that for \( m = 3 \)

\[
\sin \theta_3 = 1.131 \quad \text{not observed!}
\]

We can only observe \( 0^{th} \), \( 1^{st} \) and \( 2^{nd} \) order maxima.

- Explain how multicolor are observed in the CD.
- CD has spiral grooved tracks (\( d = 1\mu m \)). Thus surface of the CD acts as a grating (sending different colors different directions).