Class 5, Sections 22.1-22.4 Preclass Notes

physics

FOR SCIENTISTS AND ENGINEERS

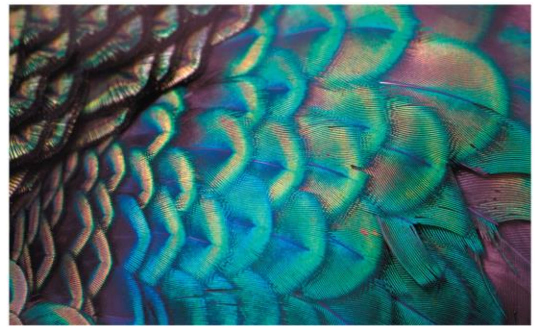
a strategic approach

THIRD EDITION

randall d. knight

ALWAYS LEARNING PEARSON

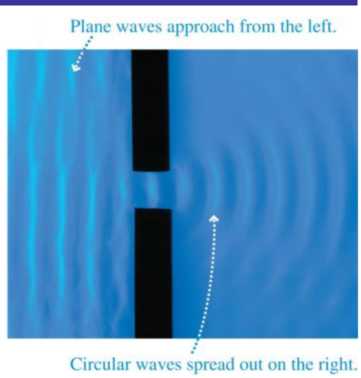
Chapter 22 Wave Optics



Chapter Goal: To understand and apply the wave model of light.

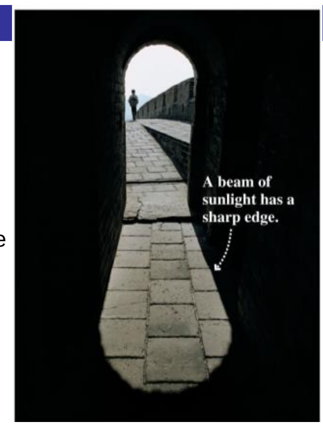
Diffraction of Water Waves

- A water wave, after passing through an opening, *spreads out* to fill the space behind the opening.
- This well-known spreading of waves is called **diffraction**.



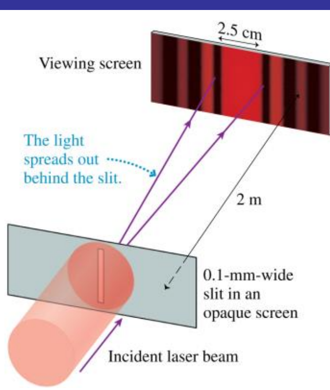
Models of Light

- Unlike a water wave, when light passes through a a large opening, it makes a sharp-edged shadow.
- This lack of noticeable diffraction means that if light is a wave, the wavelength must be very small.



Diffraction of Light

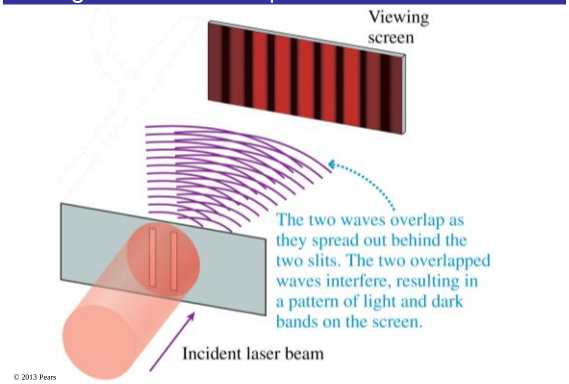
- When red light passes through an opening that is only 0.1 mm wide, it does spread out.
- Diffraction of light is observable *if* the hole is sufficiently small.

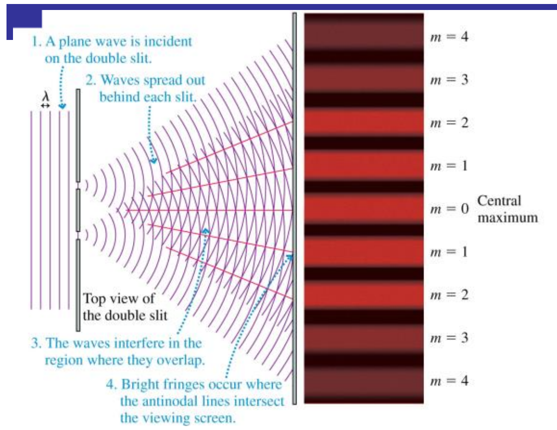


Models of Light

- **The wave model:** Under many circumstances, light exhibits the same behavior as sound or water waves. The study of light as a wave is called *wave optics***.**
- **The ray model:** The properties of prisms, mirrors, and lenses are best understood in terms of *light rays*. The ray model is the basis of *ray optics*.
- **The photon model:** In the quantum world, light behaves like neither a wave nor a particle. Instead, light consists of *photons* that have both wave-like and particle-like properties. This is the *quantum theory* of light.

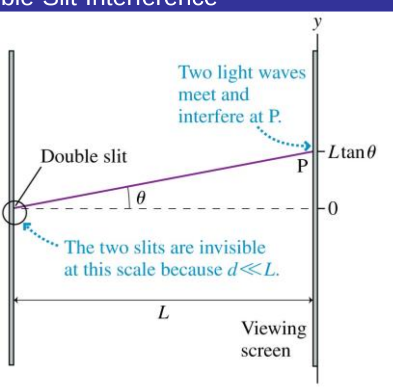
Young's Double-Slit Experiment





Analyzing Double-Slit Interference

- The figure shows the "big picture" of the double-slit experiment.
- The next slide *zooms in* on the area inside the circle.

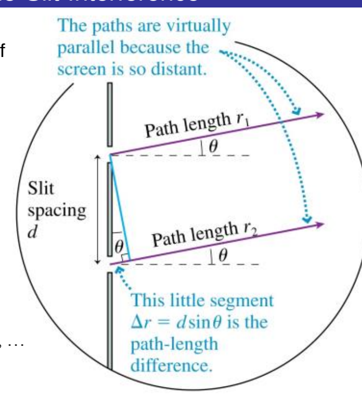


Analyzing Double-Slit Interference

- The figure shows a magnified portion of the double-slit experiment.
- The wave from the lower slit travels an extra distance:

$$\Delta r = d \sin\theta$$

- Bright fringes (constructive interference) will occur at angles θ_m such that $\Delta r = m\lambda$, where $m = 0, 1, 2, 3, \ldots$



Analyzing Double-Slit Interference

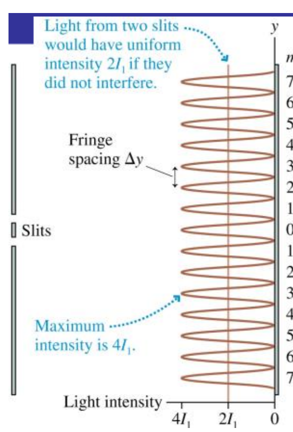
- The mth bright fringe emerging from the double slit is at an angle:

$$\theta_m = m\frac{\lambda}{d} \qquad m = 0, 1, 2, 3, \ldots \qquad \text{(angles of bright fringes)}$$

where θ_m is in radians, and we have used the small-angle approximation.

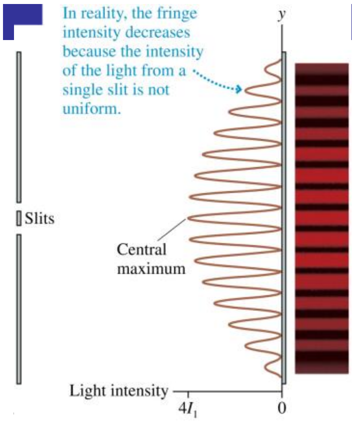
- The y-position on the screen of the mth bright fringe on a screen a distance L away is:

$$y_m = \frac{m\lambda L}{d} \qquad m = 0, 1, 2, 3, \ldots \qquad \text{(positions of bright fringes)}$$



The intensity of the double-slit interference pattern at position y is:

$$I_{double} = 4I_1 \cos^2\left(\frac{\pi d}{\lambda L} y\right)$$



The actual intensity from a double-slit experiment slowly decreases as $|y|$ increases.

The Diffraction Grating

- Suppose we were to replace the double slit with an opaque screen that has N closely spaced slits.
- When illuminated from one side, each of these slits becomes the source of a light wave that diffracts, or spreads out, behind the slit.
- Such a multi-slit device is called a **diffraction grating**.
- Bright fringes will occur at angles θ_m, such that:

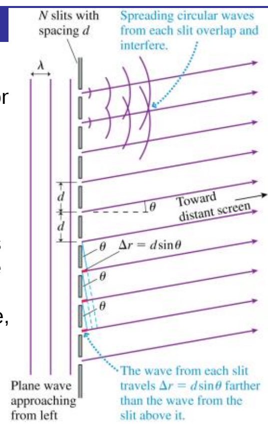
$$d\sin\theta_m = m\lambda \qquad m = 0, 1, 2, 3, \ldots$$

- The y-positions of these fringes will occur at:

$$y_m = L\tan\theta_m \qquad \text{(positions of bright fringes)}$$

The Diffraction Grating

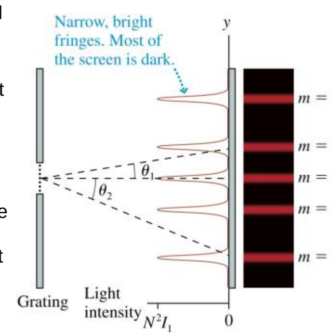
- The figure shows a diffractior grating in which N slits are equally spaced a distance d apart.
- This is a top view of the grating, as we look down on the experiment, and the slits extend above and below the page.
- Only 10 slits are shown here, but a practical grating will have hundreds or even thousands of slits.



The Diffraction Grating

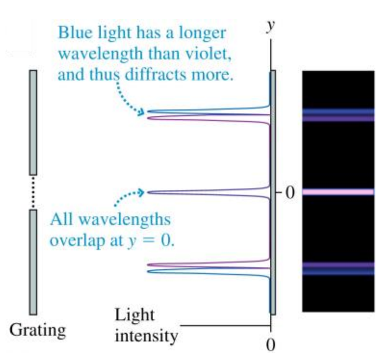
- The integer m is called the **order** of the diffraction.
- The wave amplitude at the points of constructive interference is Na.
- Because intensity depends on the square of the amplitude, the intensities of the bright fringes are:

$$I_{max} = N^2 I_1$$



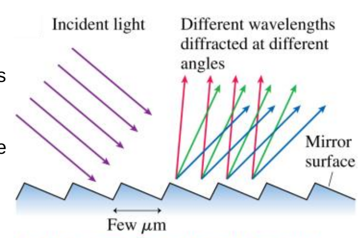
The Diffraction Grating

- Diffraction gratings are used for measuring the wavelengths of light.
- If the incident light consists of two slightly different wavelengths, each wavelength will be diffracted at a slightly different angle.



Reflection Gratings

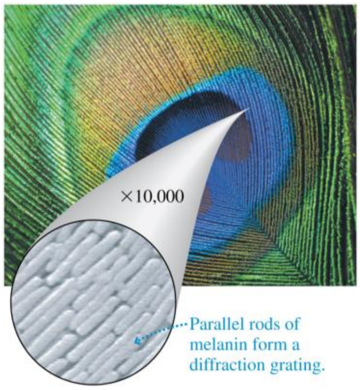
- In practice, most diffraction gratings are manufactured as *reflection gratings.*
- The interference pattern is exactly the same as the interference pattern of light transmitted through N parallel slits.



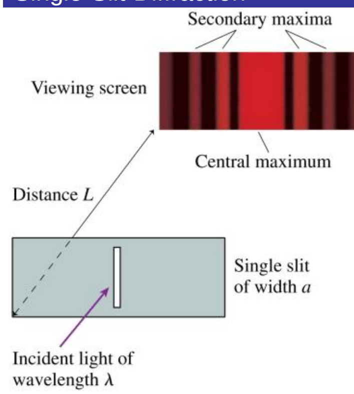
A reflection grating can be made by cutting parallel grooves in a mirror surface. These can be very precise, for scientific use, or mass produced in plastic.

Reflection Gratings

- Naturally occurring reflection gratings are responsible for some forms of color in nature.
- A peacock feather consists of nearly parallel rods of melanin, which act as a reflection grating.

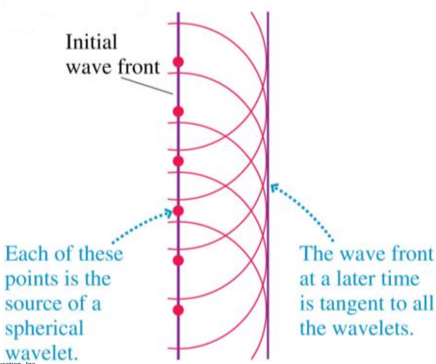


Single-Slit Diffraction

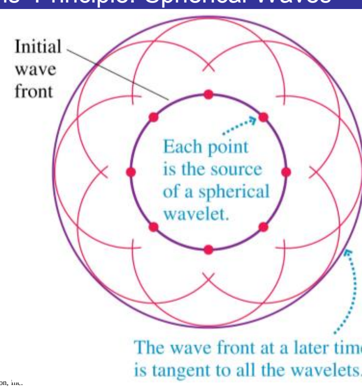


- Diffraction through a tall, narrow slit is known as single-slit diffraction.
- A viewing screen is placed distance L behind the slit of width a, and we will assume that $L >> a$.

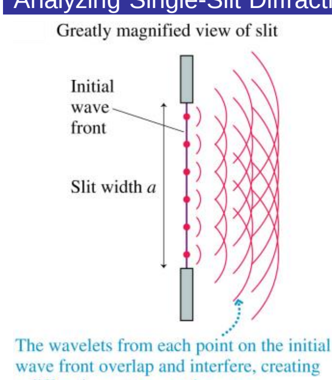
Huygens' Principle: Plane Waves



Huygens' Principle: Spherical Waves

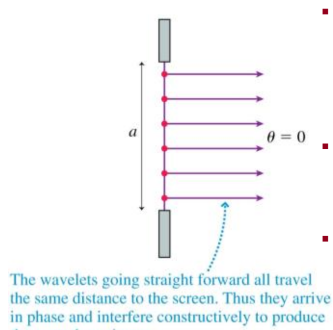


Analyzing Single-Slit Diffraction



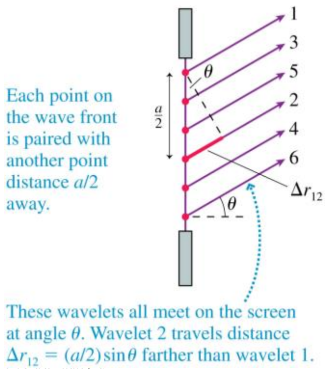
- The figure shows a wave front passing through a narrow slit of width a.
- According to Huygens' principle, each point on the wave front can be thought of as the source of a spherical wavelet.

Analyzing Single-Slit Diffraction



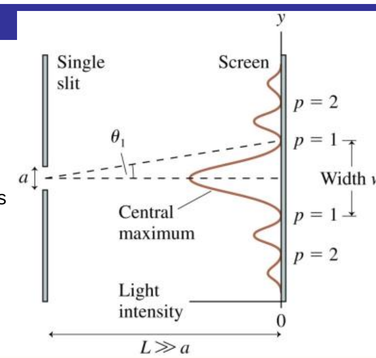
- The figure shows the paths of several wavelets that travel straight ahead to the central point on the screen.
- The screen is *very* far to the right in this magnified view of the slit.
- The paths are very nearly parallel to each other, thus all the wavelets travel the same distance and arrive at the screen *in phase* with each other.

Analyzing Single-Slit Diffraction



- In this figure, wavelets 1 and 2 start from points that are $a/2$ apart.
- Every point on the wave front can be paired with another point distance *a*/2 away.
- If the path-length difference is $\Delta r = \lambda/2$, the wavelets arrive at the screen out of phase and interfere destructively.

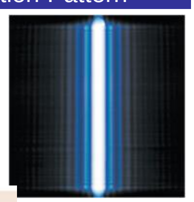
- The light pattern from a single slit consists of a *central maximum* flanked by a series of weaker **secondary maxima** and dark fringes.
- The dark fringes occur at angles:



$$\theta_p = p\frac{\lambda}{a} \qquad p = 1, 2, 3, \ldots \qquad \text{(angles of dark fringes)}$$

The Width of a Single-Slit Diffraction Pattern

- The central maximum of this single-slit diffraction pattern is much brighter than the secondary maximum.
- The width of the central maximum on a screen a distance *L* away is *twice* the spacing between the dark fringes on either side:



$$w = \frac{2\lambda L}{a} \qquad \text{(single slit)}$$

- The farther away from the screen (larger *L*), the wider the pattern of light becomes.
- The narrower the opening (smaller *a*), the wider the pattern of light becomes!