

## Chapter 27

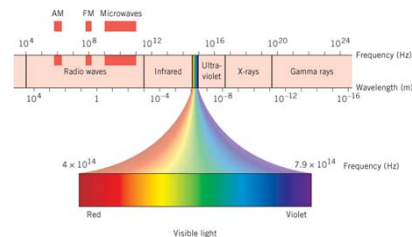
### Interference and the Wave Nature of Light



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This chapter we will concentrate on the **wave properties** of light. The wavelength of visible light is 750 nm to 380 nm.



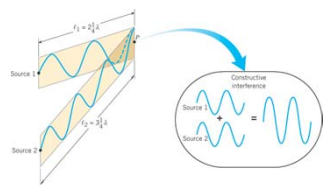
All waves obey the superposition theorem.

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#### 27.1 The Principle of Linear Superposition

When two or more light waves pass through a given point, their electric fields combine according to the **principle of superposition**.



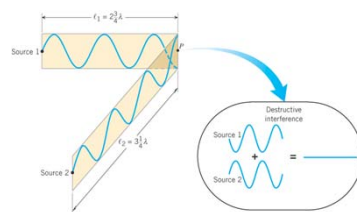
The waves emitted by two different sources start out **in phase**, if the paths difference is  $m\lambda$ , the two waves will arrive at point P in phase, leading to **constructive interference**.

$$\ell_2 - \ell_1 = m\lambda \quad m = 0, 1, 2, 3, \dots$$

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#### 27.1 The Principle of Linear Superposition



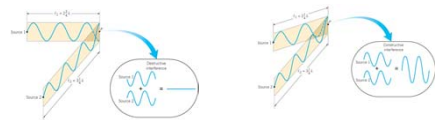
The waves emitted by the sources start out in phase, if the paths difference is  $(m+1/2)\lambda$ , then the two waves will arrive at point P out of phase, leading to **destructive interference**.

$$\ell_2 - \ell_1 = (m + \frac{1}{2})\lambda \quad m = 0, 1, 2, 3, \dots$$

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#### 27.1 The Principle of Linear Superposition



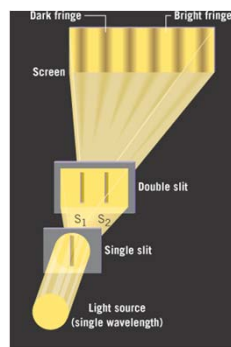
If constructive or destructive interference is to continue occurring at a point, the sources of the waves must be **coherent sources**.

Two sources are coherent if the waves they emit maintain a constant phase relation.

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#### 27.2 Young's Double Slit Experiment



In 1801, Thomas Young (1773-1829) performed a historical experiment that demonstrated the wave nature of light by showing that light wave can interfere with each other.

In Young's experiment, two slits acts as coherent sources of light.

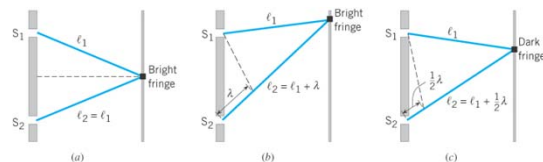
Light waves from these slits interfere constructively and destructively on the screen depending on the paths difference of the waves from these two slits.

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### 27.2 Young's Double Slit Experiment

To understand the origin of the bright and dark fringes, let's examine the figure below (a top view of the double slits and the screen). (a) The waves coming from the two slits interfere constructively when the paths difference is equal to zero, bright fringe formed. (b) At another point on the screen where the paths difference is equal to  $\lambda$ , bright fringe formed. (c) At a position between these two fringes, when the paths difference is  $\frac{1}{2}\lambda$ , the waves interfere destructively, dark fringe formed.

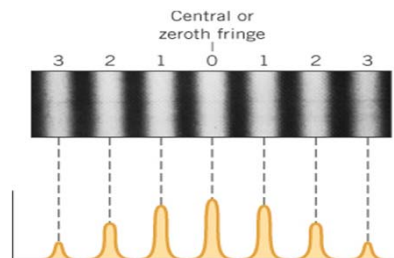


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### 27.2 Young's Double Slit Experiment

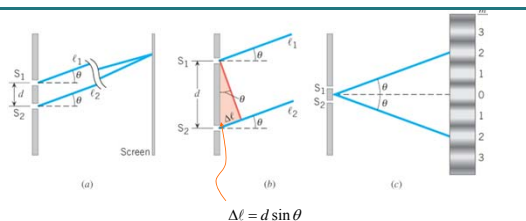
The results of Young's double-slit experiment, showing a photograph of the bright and dark fringes formed on the screen and a plot of the light intensity.



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### 27.2 Young's Double Slit Experiment



**Bright fringes  
of a double-slit**

$$\sin \theta = m \frac{\lambda}{d} \quad m = 0, 1, 2, 3, \dots$$

**Dark fringes  
of a double-slit**

$$\sin \theta = \left(m + \frac{1}{2}\right) \frac{\lambda}{d} \quad m = 0, 1, 2, 3, \dots$$

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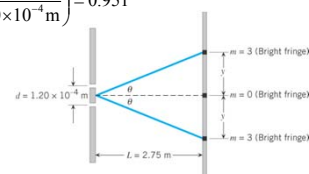
### 27.2 Young's Double Slit Experiment

#### Example 1 Young's Double-Slit Experiment

Red light (664 nm) is used in Young's experiment with slits separated by 0.000120 m. The screen is located a distance 2.75 m from the slits. Find the distance on the screen between the central bright fringe and the third-order bright fringe.

$$\theta = \sin^{-1}\left(m \frac{\lambda}{d}\right) = \sin^{-1}\left(3 \frac{664 \times 10^{-9} \text{ m}}{1.20 \times 10^{-4} \text{ m}}\right) = 0.951^\circ$$

$$\sin \theta = m \frac{\lambda}{d}$$



$$y = L \tan \theta = (2.75 \text{ m}) \tan(0.951^\circ) = 0.0456 \text{ m}$$

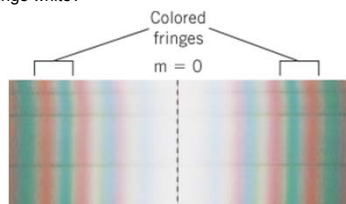
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### 27.2 Young's Double Slit Experiment

#### Conceptual Example 2 White Light and Young's Experiment

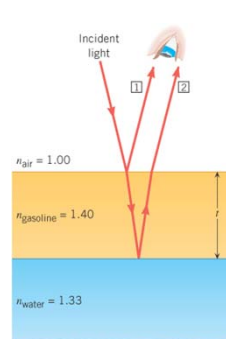
The figure shows a photograph that illustrates the kind of interference fringes that can result when white light is used in Young's experiment. (a) Why does Young's experiment separate white light into its constituent colors? In any group of colored fringes, such as the two singled out, (b) why is red farther out from the central fringe than green is? (c) Why is the central fringe white?



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### 27.3 Thin Film Interference



Because of reflection and refraction, two light waves enter the eye when light shines on a thin film of gasoline floating on a thick layer of water.

Because of the extra distance traveled by ray 2 as compared by ray 1, there can be interference between the two waves.

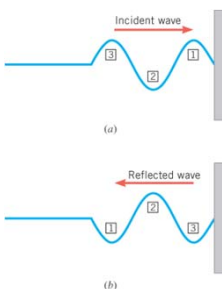
There are two things, we need to know here: (1) The path difference happens inside the film, so it is the  $\lambda_{\text{film}}$  that is important.

$$\lambda_{\text{film}} = \frac{\lambda_{\text{vacuum}}}{n}$$

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## 27.3 Thin Film Interference



Ray 1 has a phase change of  $180^\circ$  when it is reflected. Ray 2 does not have a phase change.

When light travels from medium 1 to medium 2 and is reflected.

If  $n_2 > n_1$ ,  $\Rightarrow$  a phase change of  $\pi$ , or a path change of  $\lambda_{\text{film}}$ .

If  $n_2 < n_1$ ,  $\Rightarrow$  no phase change.

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## 27.3 Thin Film Interference

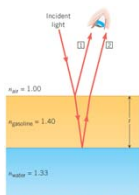
## Example 3 A Colored Thin Film of Gasoline

A thin film of gasoline floats on a puddle of water. Sunlight falls perpendicularly on the film and reflects into your eyes. The film has a yellow hue because destructive interference eliminates the color of blue (469 nm) from the reflected light. The refractive indices of the blue light in gasoline and water are 1.40 and 1.33. Determine the minimum non-zero thickness of the film.

$$2t + \frac{1}{2}\lambda_{\text{film}} = \frac{1}{2}\lambda_{\text{film}} + \frac{3}{2}\lambda_{\text{film}}, \quad \frac{5}{2}\lambda_{\text{film}}$$

$$t = \frac{m\lambda_{\text{film}}}{2}$$

$$t = \frac{m\lambda_{\text{film}}}{2} = \frac{(1)(469 \text{ nm}/1.40)}{2} = 168 \text{ nm}$$



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## 27.3 Thin Film Interference

## Conceptual Example 4 Multicolored Thin Films

Under natural conditions, thin films, like gasoline on water or like the soap bubble in the figure, have a multicolored appearance that often changes while you are watching them. Why are such films multicolored and why do they change with time?



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## 27.3 Thin Film Interference

## Example 5 An air wedge

Green light ( $\lambda=552 \text{ nm}$ ) strikes the glass plates nearly perpendicularly. Determine the number of bright fringes that occur between the place where the plates touch and the edge of the sheet of paper. ( $t=4.1 \times 10^{-5} \text{ m}$ ).

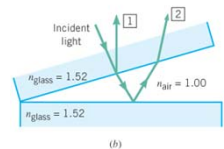
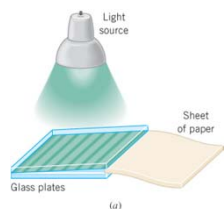
$$\text{Path difference} = 2t + \frac{1}{2}\lambda = m\lambda$$

$$\text{Where } m = 1, 2, 3, \dots$$

$$\Rightarrow 2t = (m - \frac{1}{2})\lambda, \quad m = 1, 2, 3, \dots$$

$$\Rightarrow 2t = (m + \frac{1}{2})\lambda, \quad m = 0, 1, 2, \dots$$

$$\Rightarrow m = (2t/\lambda) - \frac{1}{2} = 148$$

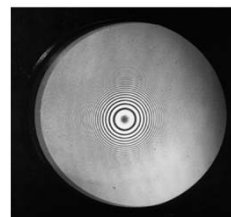
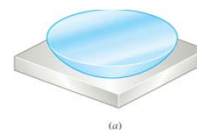


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## 27.3 Thin Film Interference

Another type of air wedge that can be used to determine whether the surface of a lens is spherical or not. The circular fringes in the lower figure on the right are called "Newton's rings".



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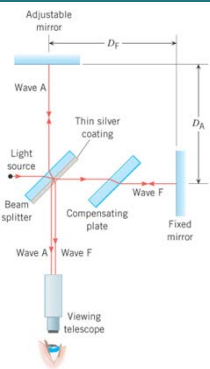
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### 27.4 The Michelson Interferometer

An interferometer is an optical instrument that can be used to measure the wavelength of light by utilizing interference between two light sources. The drawing on the right is the famous Michelson interferometer, named after Albert A. Michelson (1852-1931).

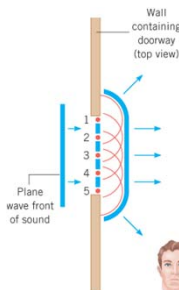


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### 27.5 Diffraction



**Diffraction is the bending of waves around obstacles or the edges of an opening.**

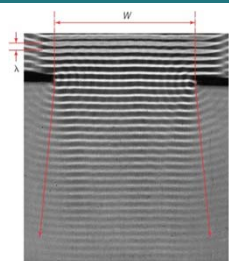
#### Huygens' principle

**Every point on a wave front acts as a source of tiny wavelets that move forward with the same speed as the wave; the wave front at a latter instant is the surface that is tangent to the wavelets.**

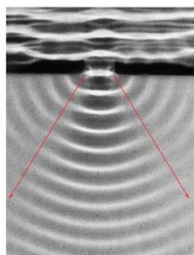
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### 27.5 Diffraction



(a) Smaller value for  $\lambda/W$ , less diffraction.



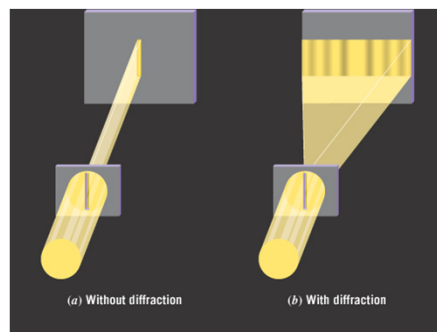
(b) Larger value for  $\lambda/W$ , more diffraction.

**The extent of the diffraction increases as the ratio of the wavelength to the width of the opening increases.**

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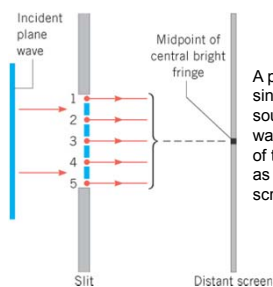
### 27.5 Diffraction



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### 27.5 Diffraction

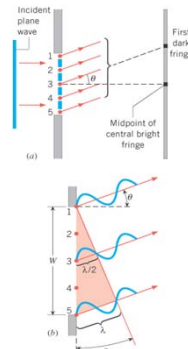


A plane wave front is incident on a single slit. This top view shows five sources of Huygens' wavelets. The wavelets travel toward the midpoint of the central bright fringe on the screen, as the red rays indicate. The screen is very far from the slit.

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### 27.5 Diffraction



These drawings show how destructive interference leads to the first dark fringe on either side of the central bright fringe. For clarity, only one of the dark fringes is shown. The screen is very far from the slit.

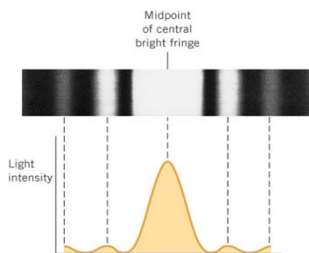
The angle  $\theta$  gives the position of the dark fringe relative to the line between the center of the slit and the midpoint of the central bright fringe, when the light from the upper half of the slit is completely cancel out with the light from the bottom half of the slit.

$$\frac{w}{2} \cdot \sin \theta = \frac{\lambda}{2}, \Rightarrow \sin \theta = \frac{\lambda}{w}$$

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## 27.5 Diffraction



$$\sin \theta = m \frac{\lambda}{W} \quad m = 1, 2, 3, \dots$$

**Dark fringes for single slit diffraction**

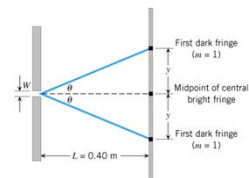
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## 27.5 Diffraction

**Example 6** Single-slit diffraction

Light passes through a slit and shines on a flat screen that is located at  $L = 0.40$  m away. The wavelength of the light in a vacuum is  $\lambda = 410$  nm. The distance between the midpoint of the central bright fringes, and the first dark fringe is  $y$ . Determine the width  $2y$  of the central bright fringes when the width of the slit is  $w = 5.0 \times 10^{-6}$  m.



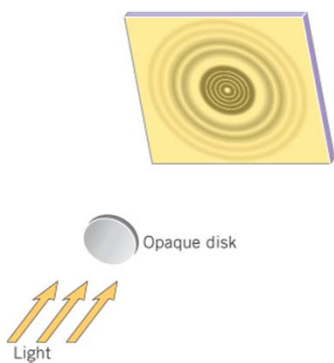
$$\theta = \sin^{-1}\left(\frac{\lambda}{w}\right) = \sin^{-1}\left(\frac{410\text{nm}}{5.0\mu\text{m}}\right) = 4.7^\circ$$

$$2y = 2L \tan \theta = 2(0.4) \tan 4.7^\circ = 0.066\text{m}$$

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## 27.5 Diffraction



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