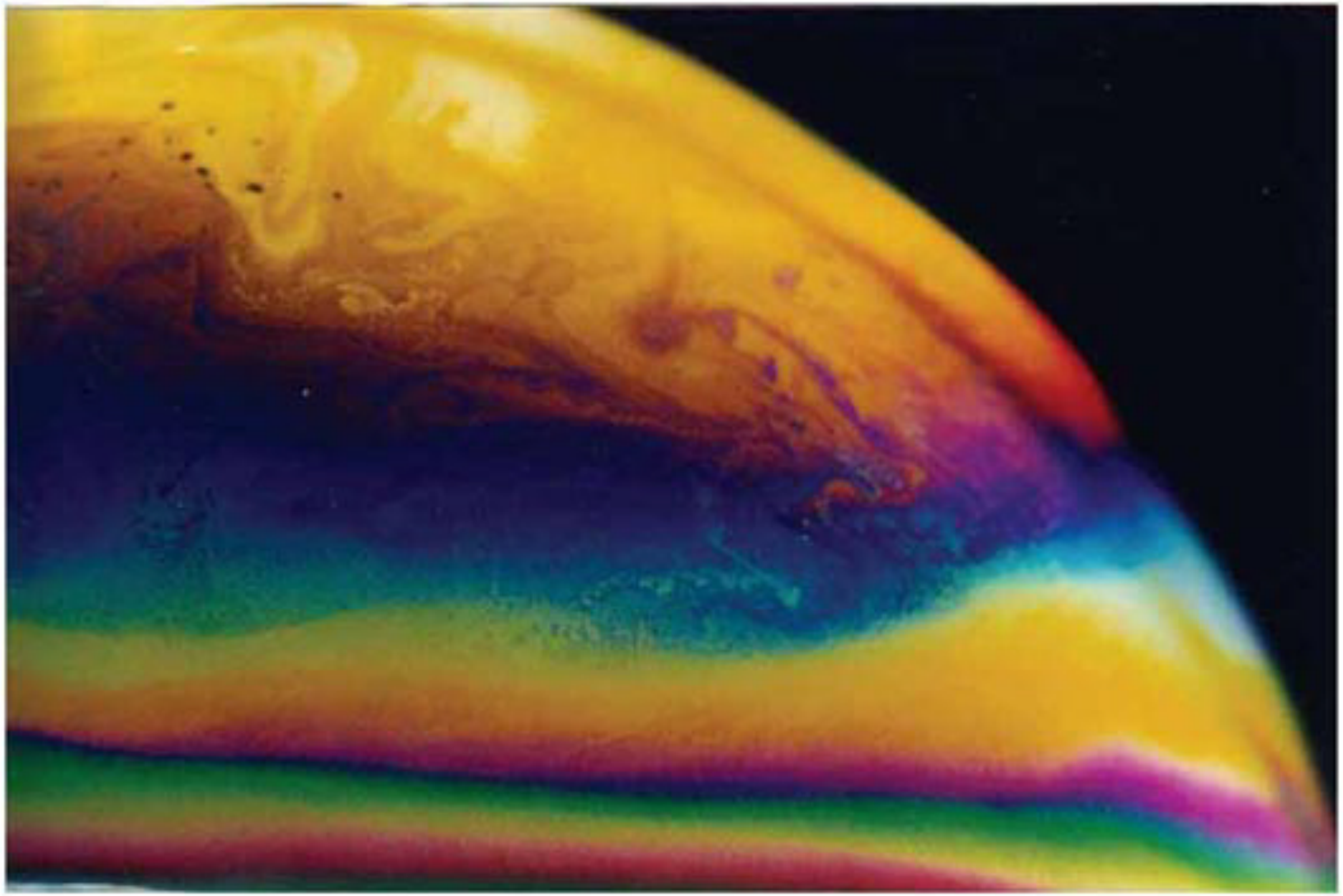
Module 13

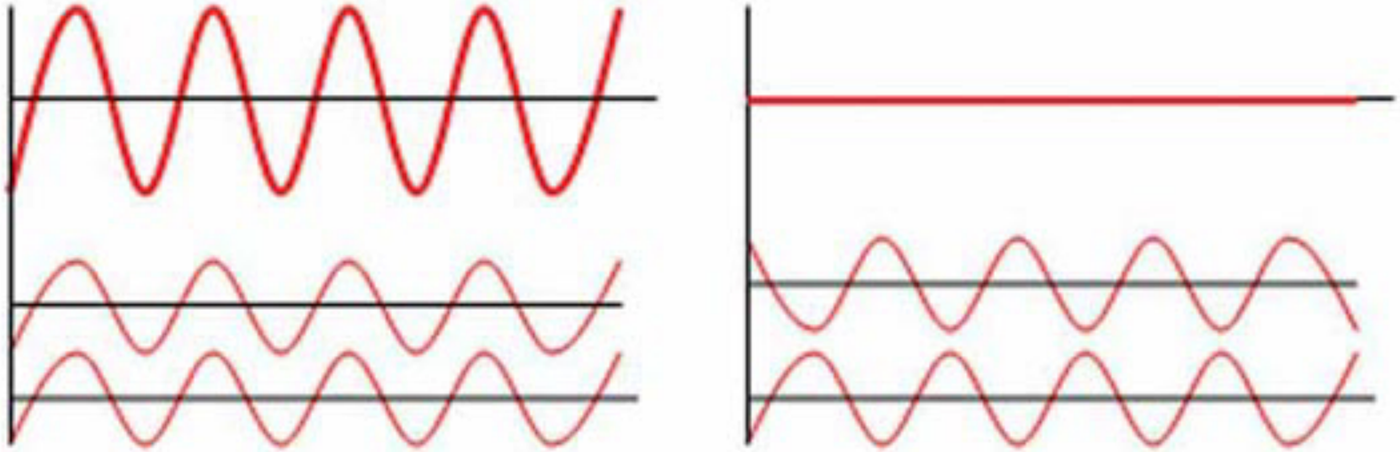
Wave Optics

Session Slides with Notes

Wave
optics



Interference

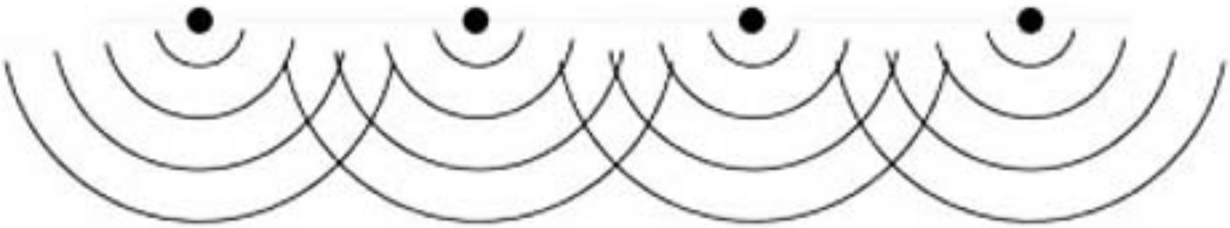


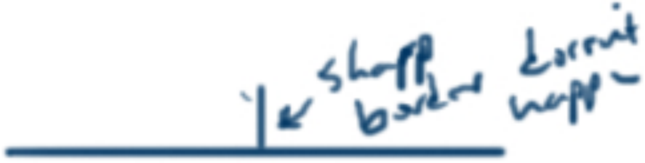
Constructive Destructive

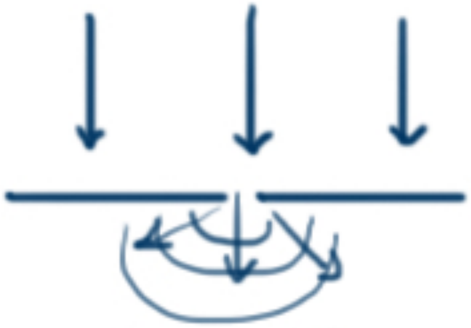
Huygens Principle

Why the ray approach isn't sufficient

treat the wave front as a multitude of independent sources of wavelets

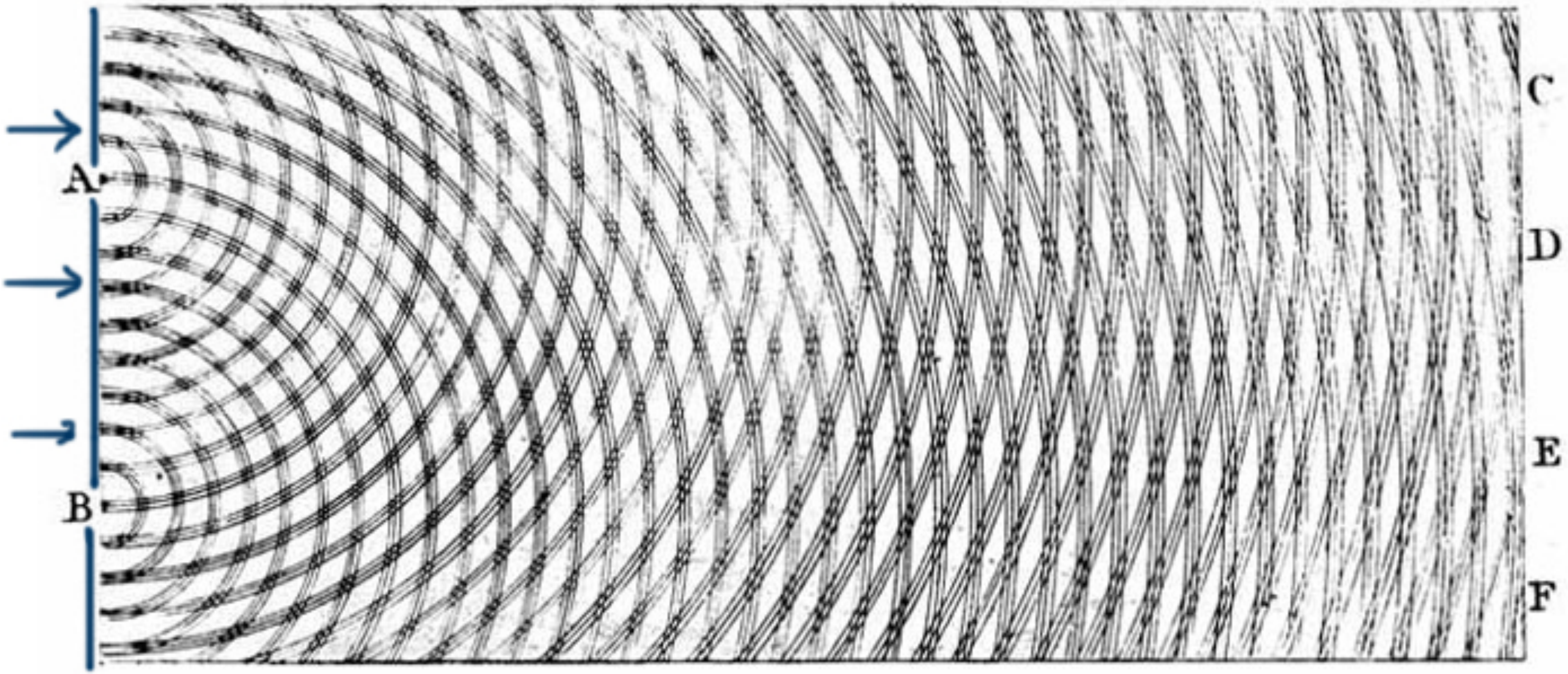


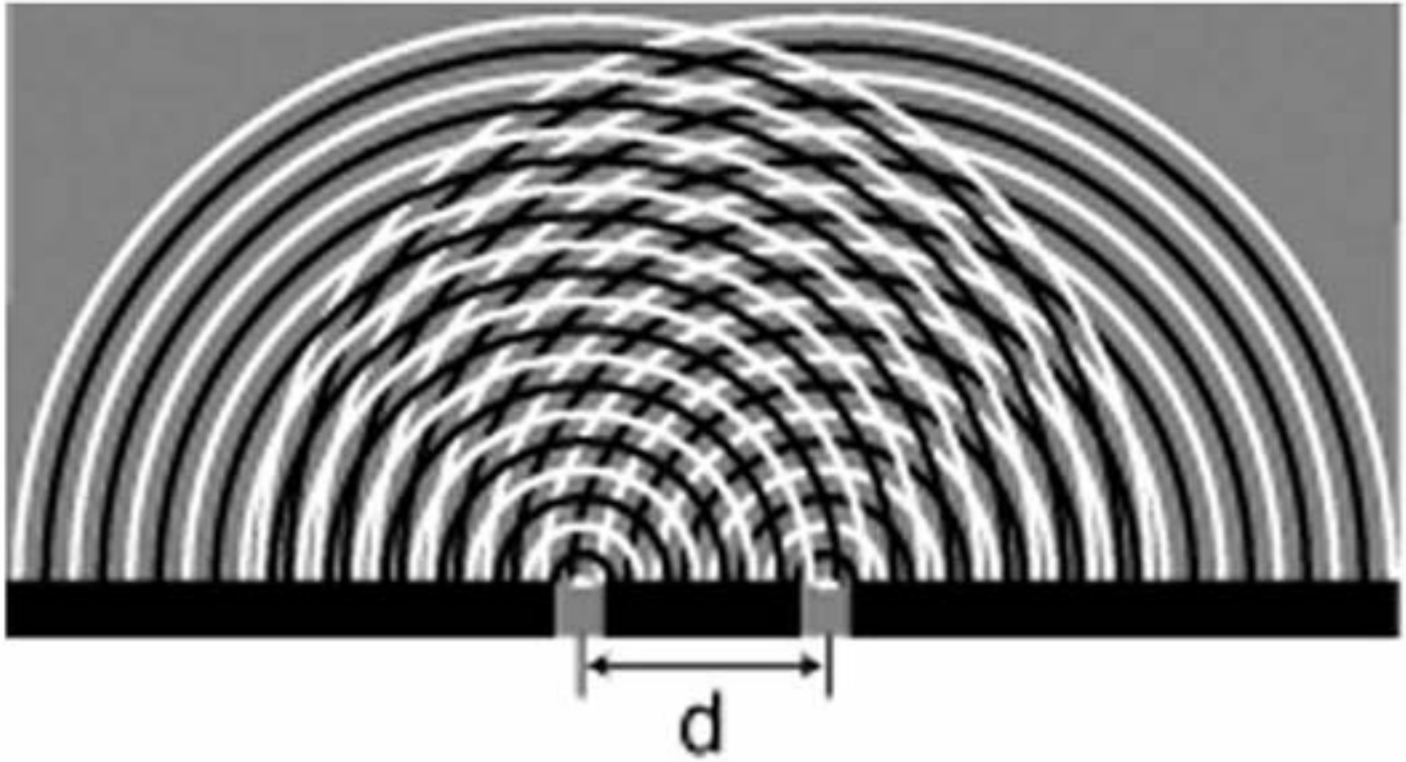




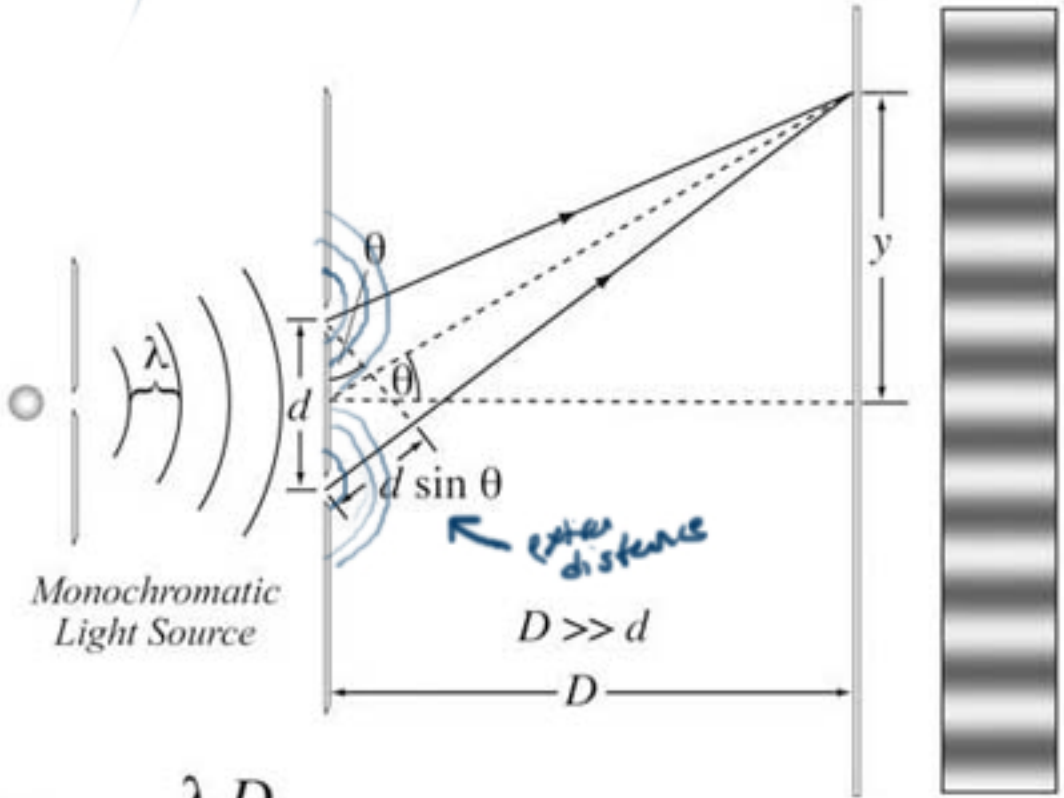
diffraction

the light bends around the corners - **diffraction**


A
B
C
D
E
F


d

Young's Double Slit Interference



$$d \sin \theta = m\lambda$$

$(m = 0, \pm 1, \pm 2, \ldots)$

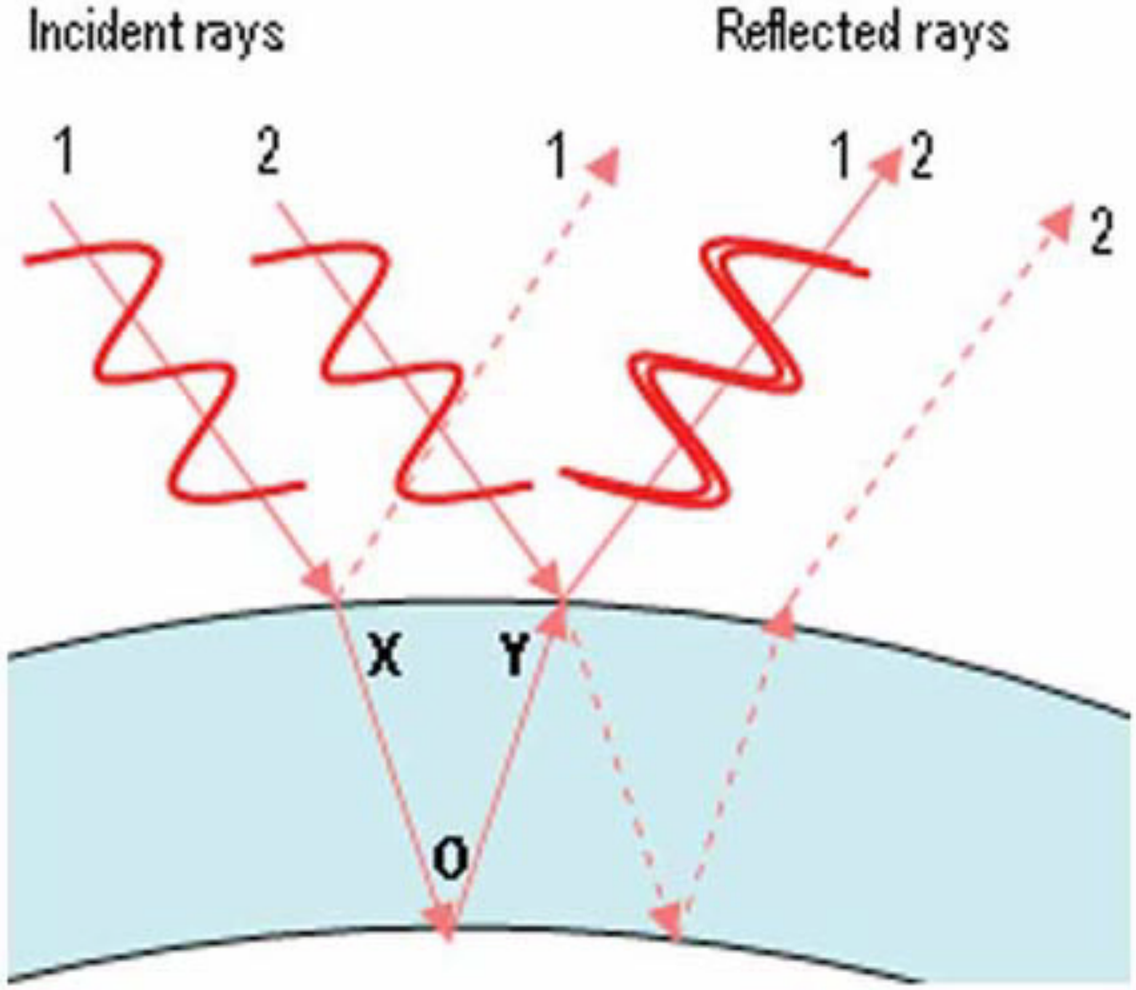
Constructive interference occurs at positions on the screen where the path difference from the two slits is an integral number of wavelengths.

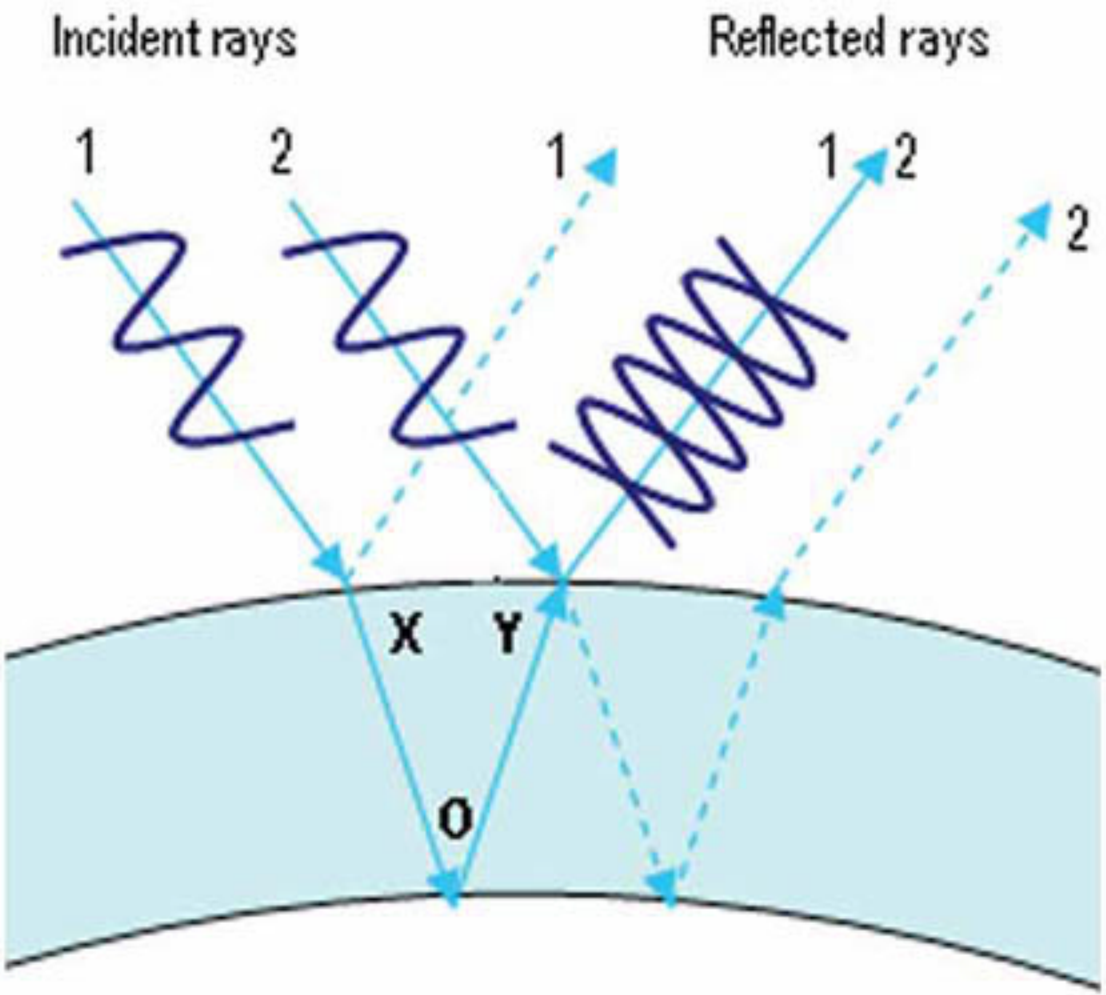
$$y_{br} = \frac{\lambda D}{d} m$$

$(m = 0, \pm 1, \pm 2, \ldots)$

If θ is small, then sin θ ~ y/D, *and this formula can be applied. Notice that narrowing slit separation, d, causes the fringes to spread out. (A larger angle is required for the same path difference.)*

Thin layer interference





Incident rays
Reflected rays
1
2
1
1
2
2
X
Y
O

Thin Film Interference

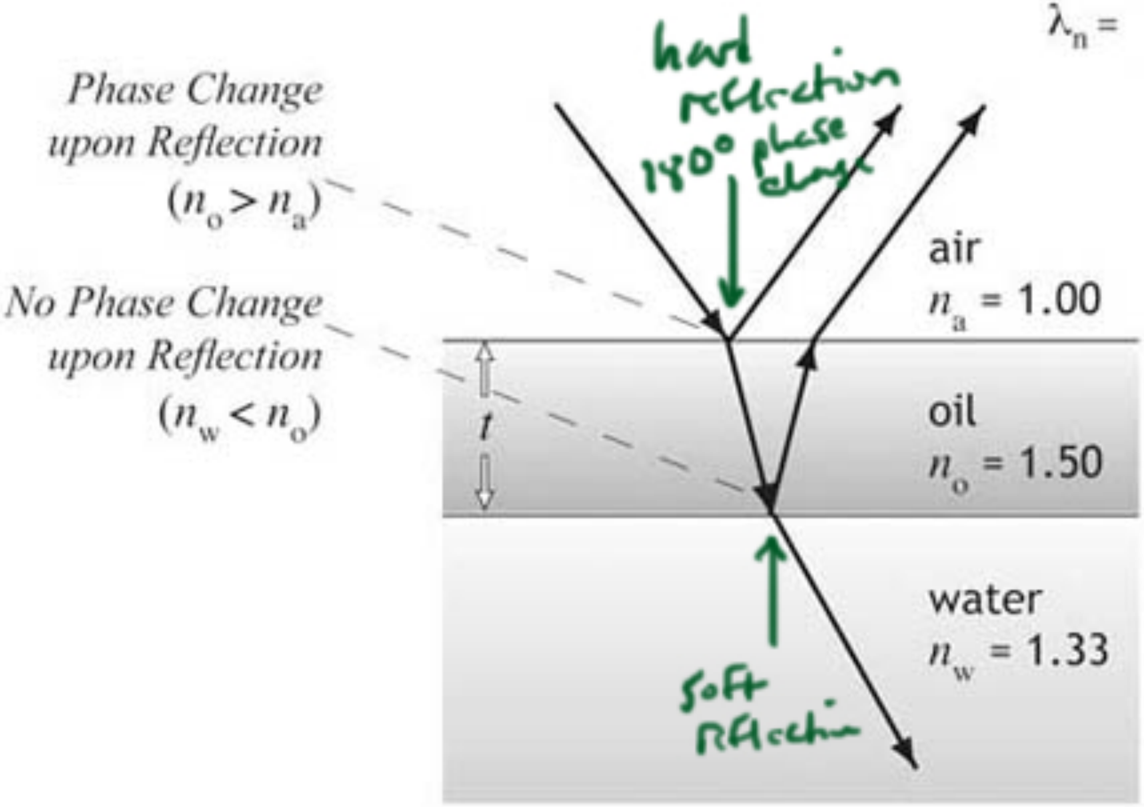
Condition of ConstructiveInterference
(with one reflection having a phase change)

$$2t = (m + \tfrac{1}{2})\lambda_n$$

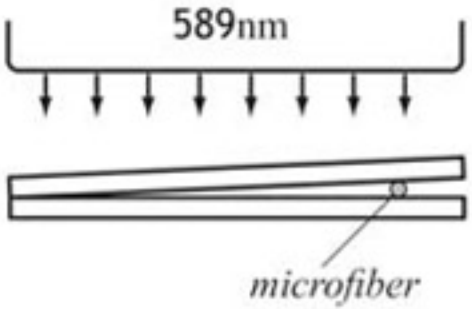
$(m = 0, 1, 2, \ldots)$

because 1 reflection was hard

t = thin film thickness
λ_n = wavelength of light within film medium



An engineer confirmed the thickness of a synthetic microfiber to be approximately 3 microns by placing the filament between two glass slides and illuminating it with a sodium light (λ = 589nm). Which view of the two slides from above shows the pattern of light and dark fringes observed?



a.

b.

c.

d.

$3\mu = 3\times10^{-6}$ m

$\lambda \approx 6\times10^{-7}$ m

near microfiber

$2t \sim 10\lambda$

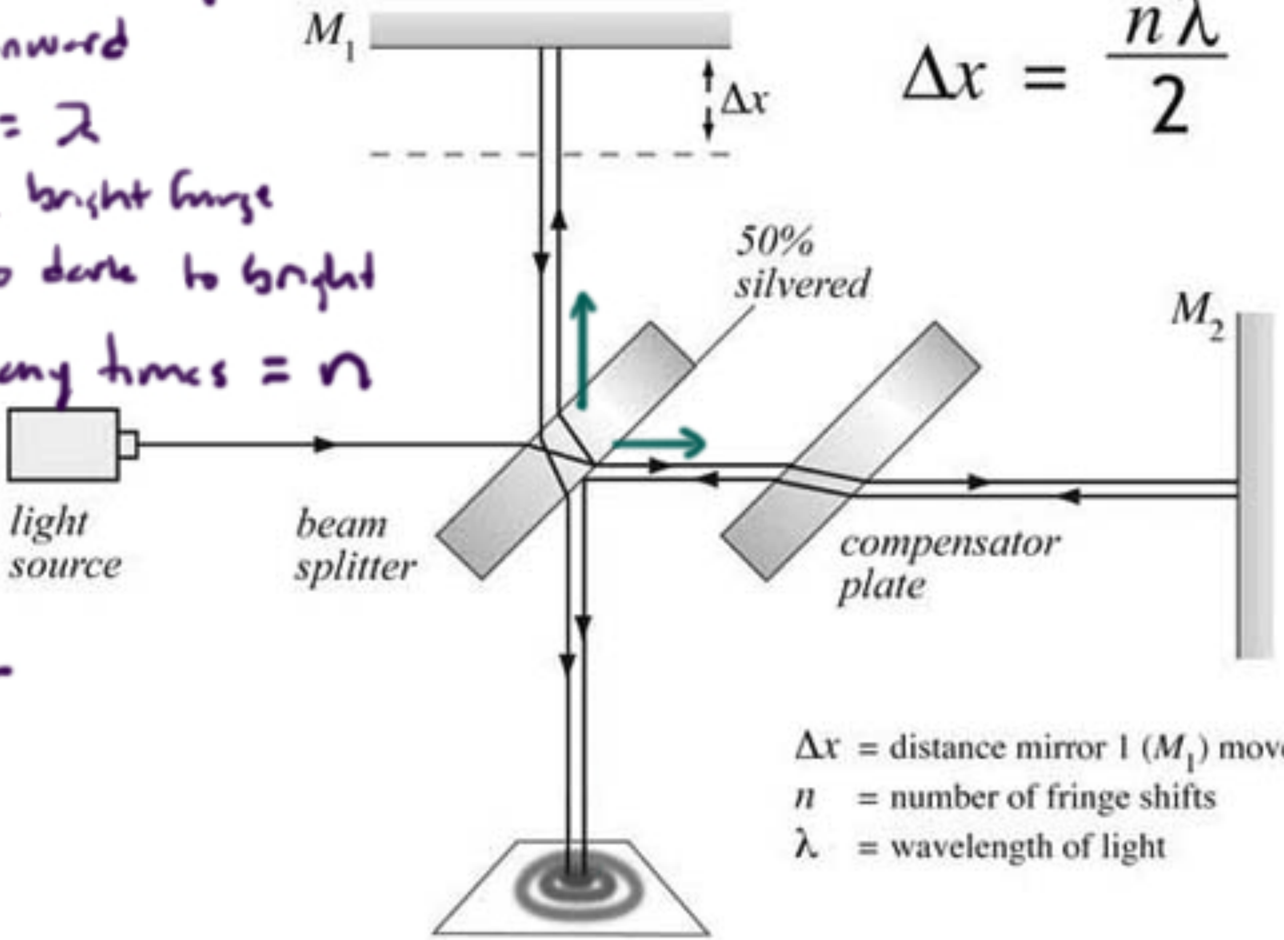
The Michelson Interferometer

to measure very small distances

Imagine we start
central fringe is bright.
Move M_1 inward
when $2\Delta x = \lambda$
will see the bright fringe
go bright to dark to bright
Count how many times = n

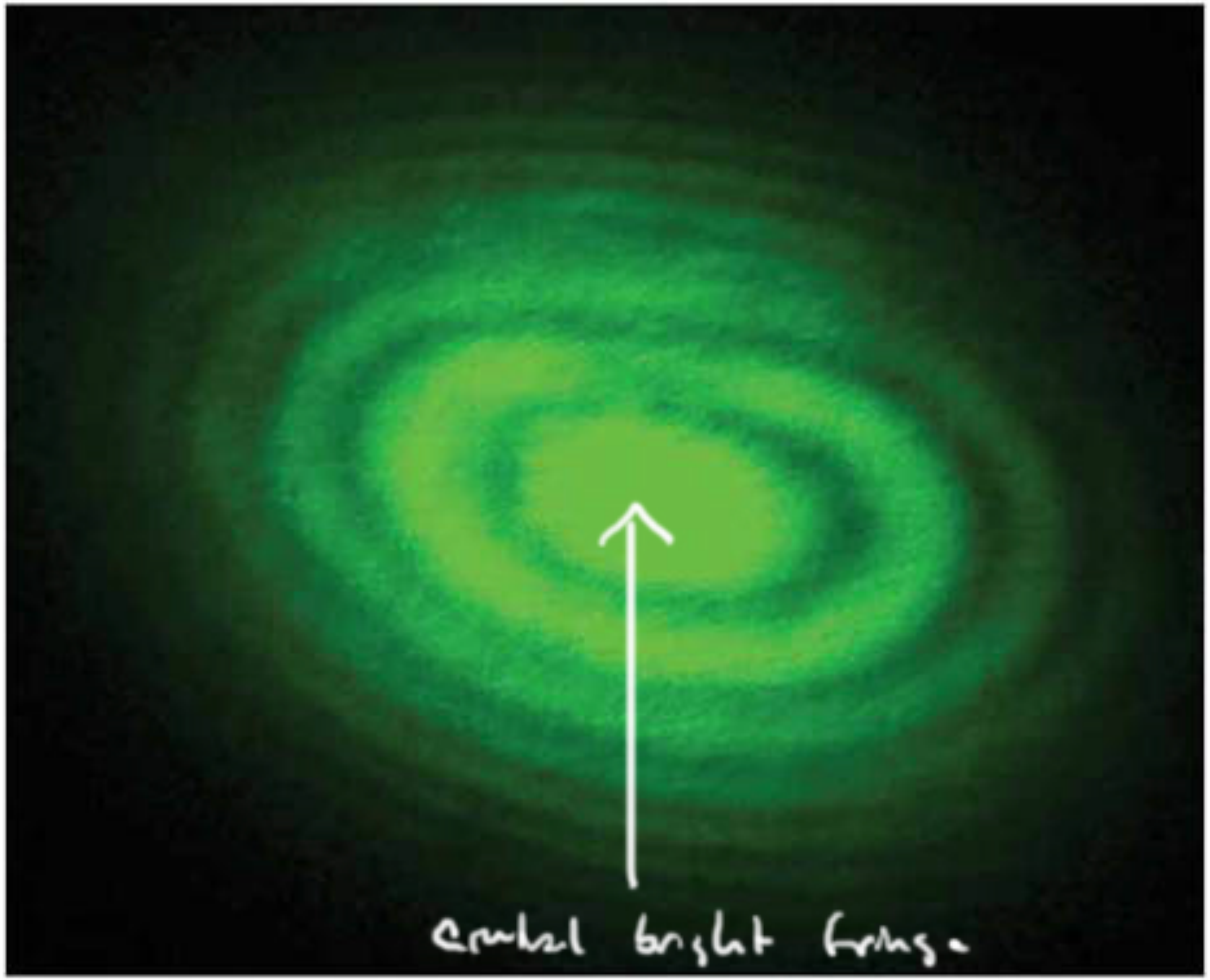
$$2\Delta x = n\lambda$$

$$\Delta x = \frac{n\lambda}{2}$$

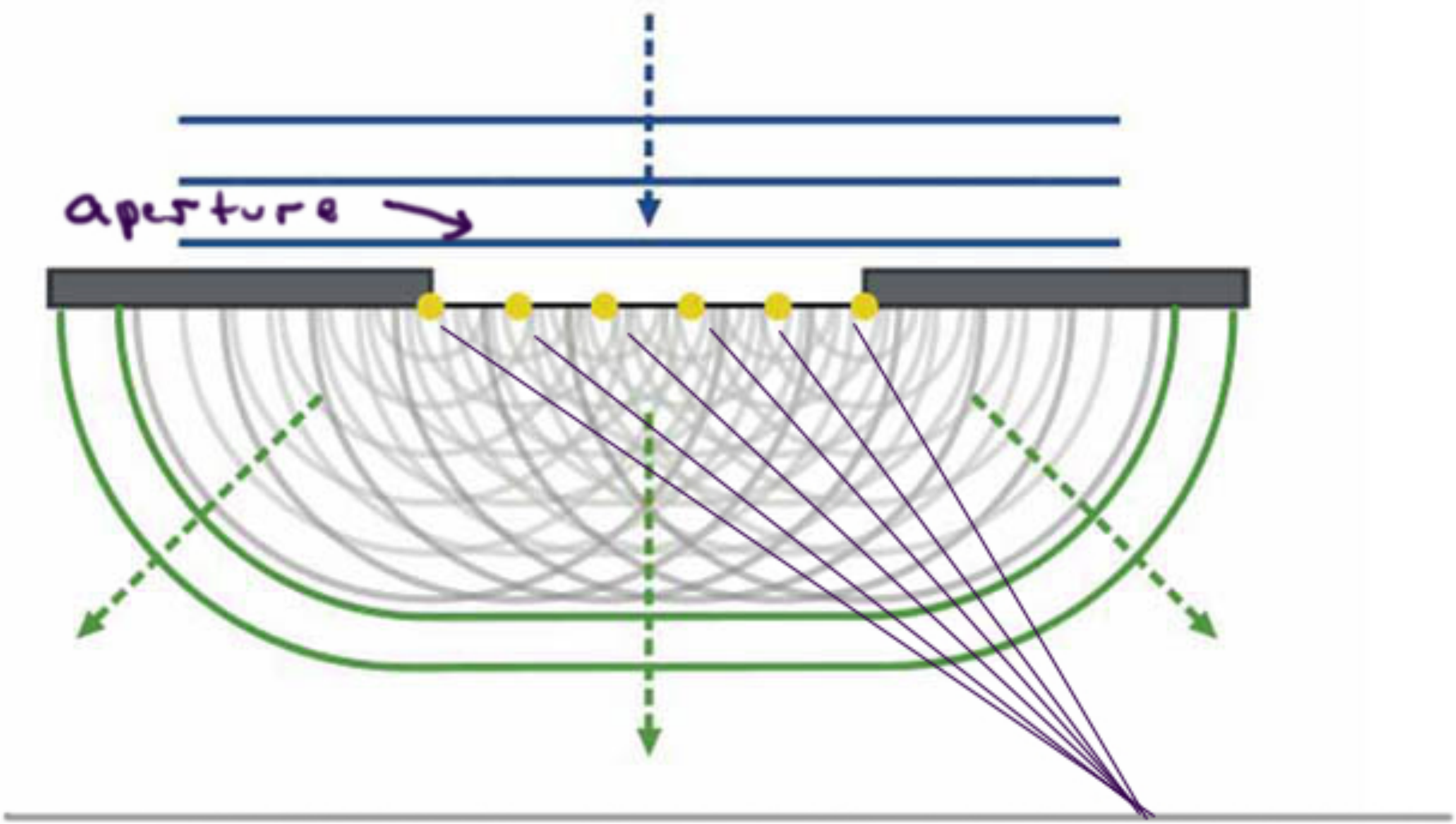


$$\Delta x = \frac{n\lambda}{2}$$

Δx = distance mirror 1 (M_1) moved
n = number of fringe shifts
λ = wavelength of light

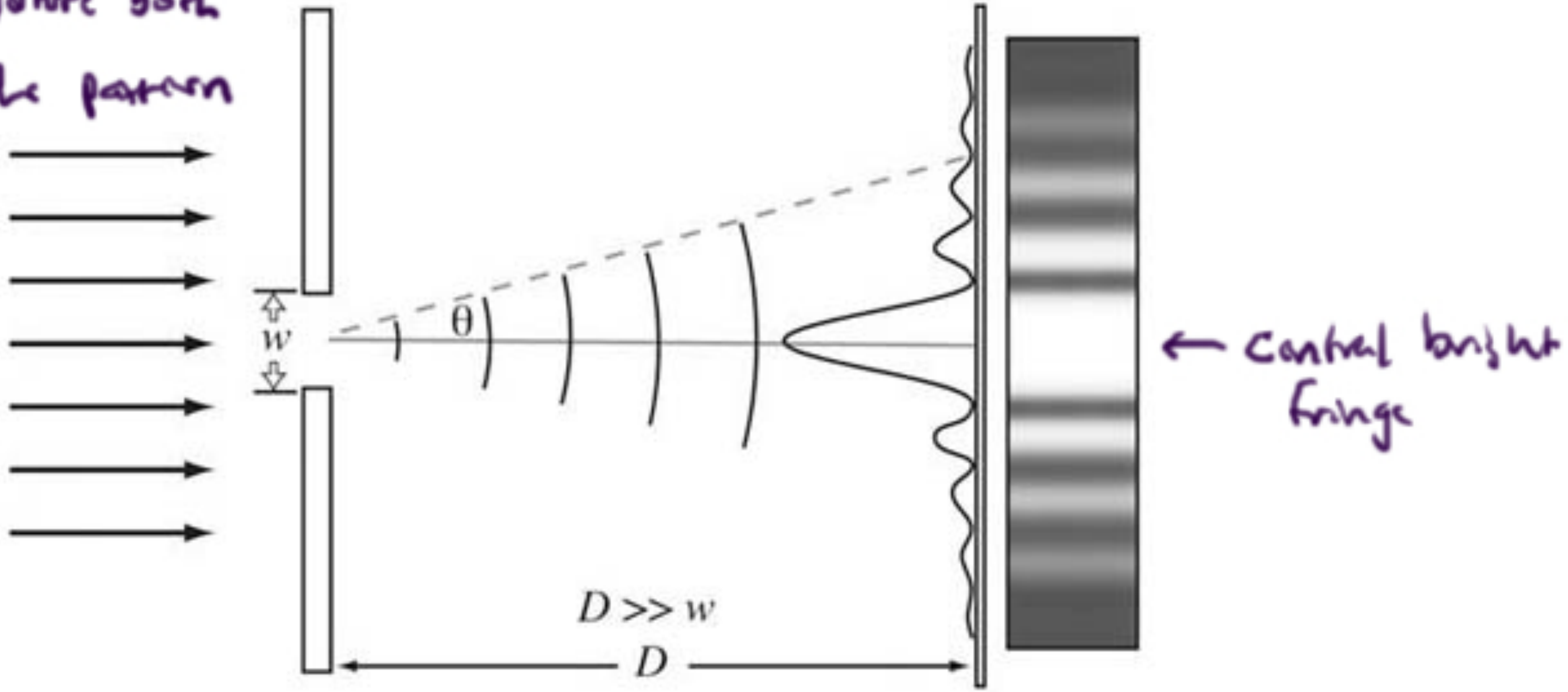

central bright fringe.

Single Slit Diffraction



Single Slit Diffraction

Shorter λ or bigger aperture both compress the pattern

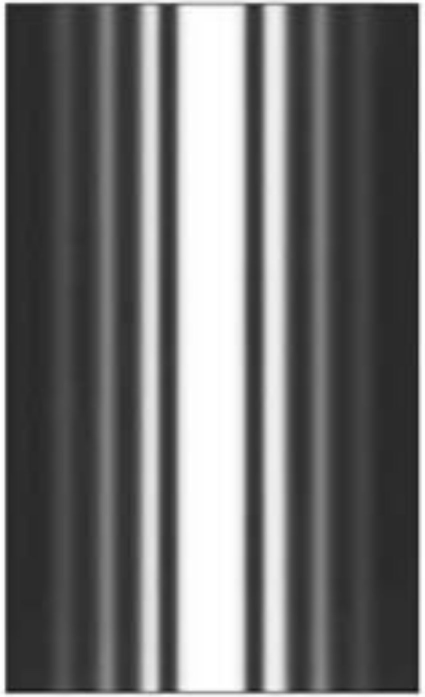


$$\sin\theta = \frac{n\,\lambda}{w}$$

$(n = \pm 1, \pm 2, \ldots)$

angular positions of dark fringes (intensity minima)

Monochromatic light is incident on a screen which is provided with a narrow 200μ wide slit. The light emerging from this slit casts the visible pattern seen at right onto a second screen 1.5m beyond the first slit. The width of the central bright fringe is 10mm. Which of the following actions would *increase* the width of this central fringe?



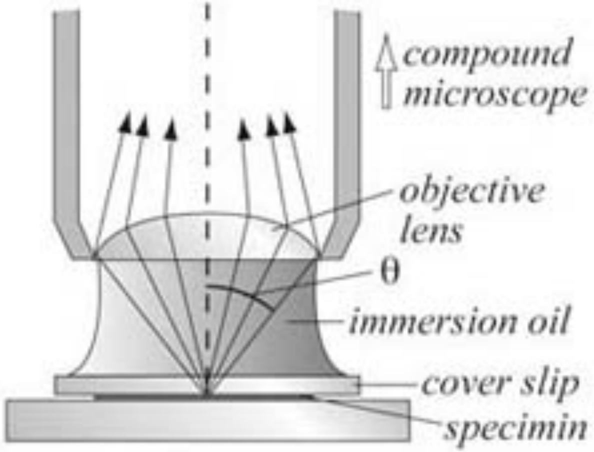
a. Decreasing the wavelength of the light

b. Narrowing the slit to 100μ in width

c. Moving the second screen to 1.0m distance from the first screen

d. Employing an incandescent light source

The resolution of a microscope reflects the ability of the apparatus to form an image in which fine details can be discriminated. A key to resolving power is the *numerical aperture* of the objective lens, $n\sin(\theta)$ (n is the refractive index of the medium between the specimin and lens. The angle θ is shown at right.)



higher n
lower v
same f
shorter λ

Immersion oil with refractive index matched to glass, 1.51, is often used to fill the space between cover slip and objective lens. What is the most important contribution of immersion oil to microscope resolution?

a. eliminating chromatic aberration

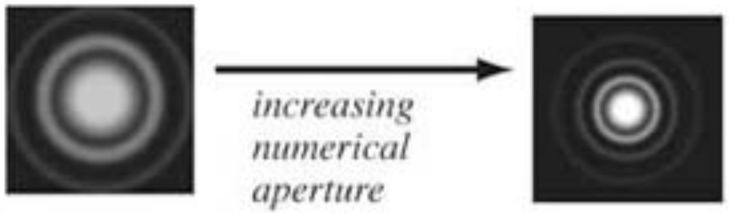
b. preventing variation of cover slip thickness

c. reducing spherical aberration by making the media homogeneous

d. increasing the possible phase difference at an image point of light waves originating from the same object point

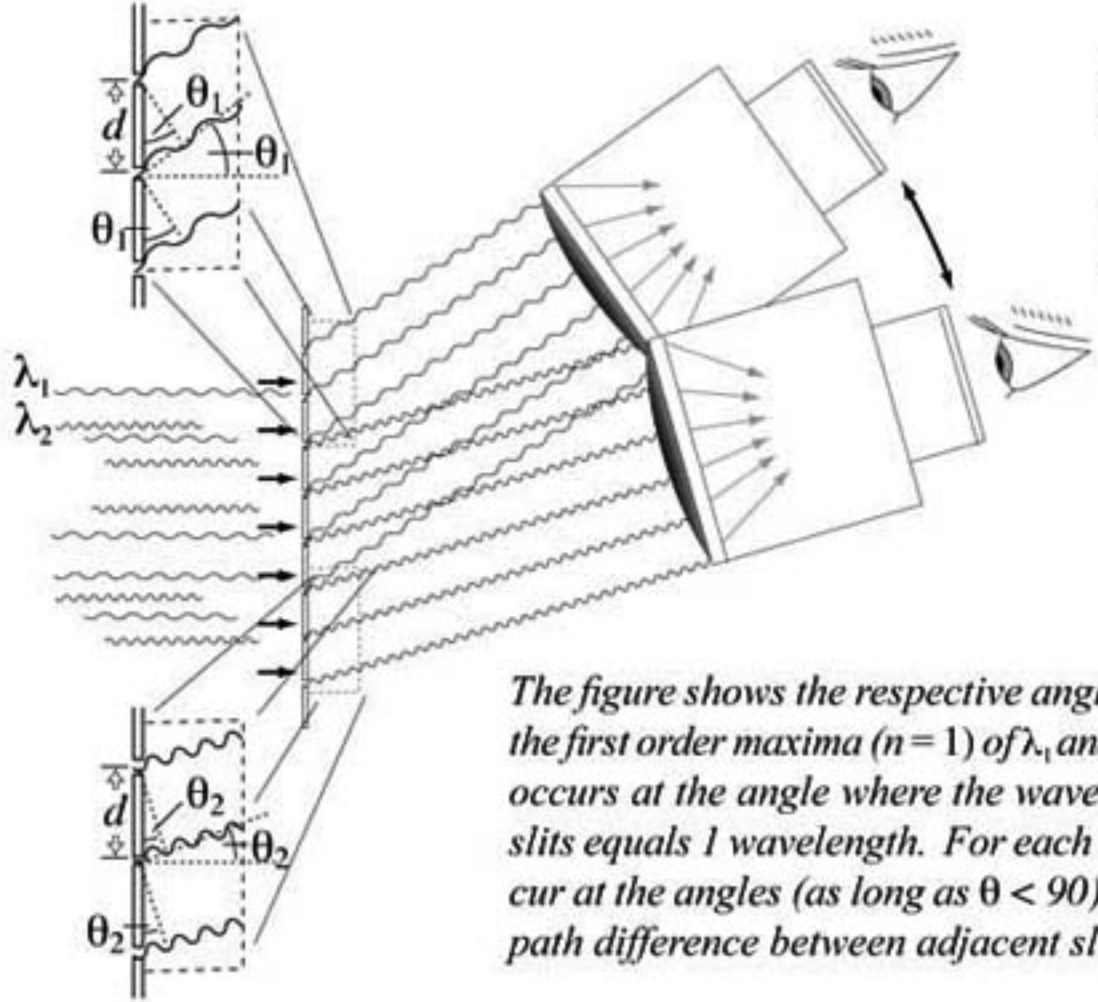
The answer is (d)

Diffraction of light passing through a circular aperture produces an interference pattern similar to single slit diffraction. By *Hugen's principle*, each portion of the aperture acts as a source of waves. For a given image point, the interference of wavelets yields a diffraction pattern known as an *airy disk*. Widening the slit narrows the central maximum in single slit diffraction. Likewise, widening a circular aperture increases the phase difference possible for different light paths, increasing the number of diffraction orders captured, which decreases the size of the central maxima of the airy disk image of a given point source. (With its increased index of refraction, the wavelength of light is shortened in oil vs. air, which has the same effect as widening the aperture, increasing the number of diffraction orders captured.)



When the central maximum of one airy disk falls on the first minimum of another (Rayleigh's criterion), the images are said to be just resolved, so decreasing the size of central maxima increases the ability to resolve two airy disk patterns.

The Diffraction Grating Spectrometer



Condition for Maxima for a Particular Wavelength:

$$d \sin\theta = m\lambda$$

$(m = 0,\ 1,\ 2,\ 3, \ldots)$

just like double slit interference

The figure shows the respective angles of deviation (θ_1 and θ_2) for the first order maxima ($n = 1$) of λ_1 and λ_2. The first order maximum occurs at the angle where the wave path difference for adjacent slits equals 1 wavelength. For each wavelength, maxima also occur at the angles (as long as $\theta < 90$) for $n = 2, 3$ etc. wavelengths path difference between adjacent slits.

The image above shows the zeroth, first and second spectral orders cast on a screen by the beam of a green argon gas-ion laser (λ = 514.5 nm) incident on a diffraction grating. Which pattern results after the entire assembly of laser, grating and screen are immersed in water?

higher n

shorter λ

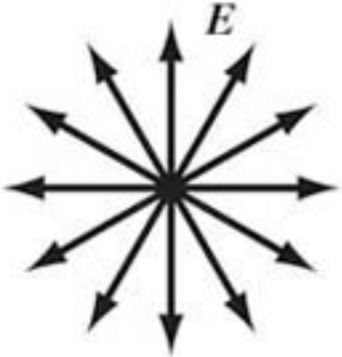
a.

b.

c.

d.

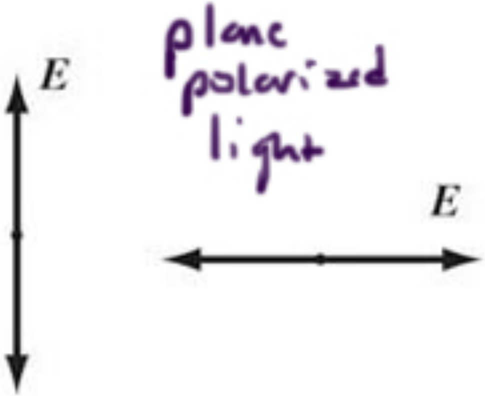
Polarization of Light



Direction of propagation is perpendicular to the page.

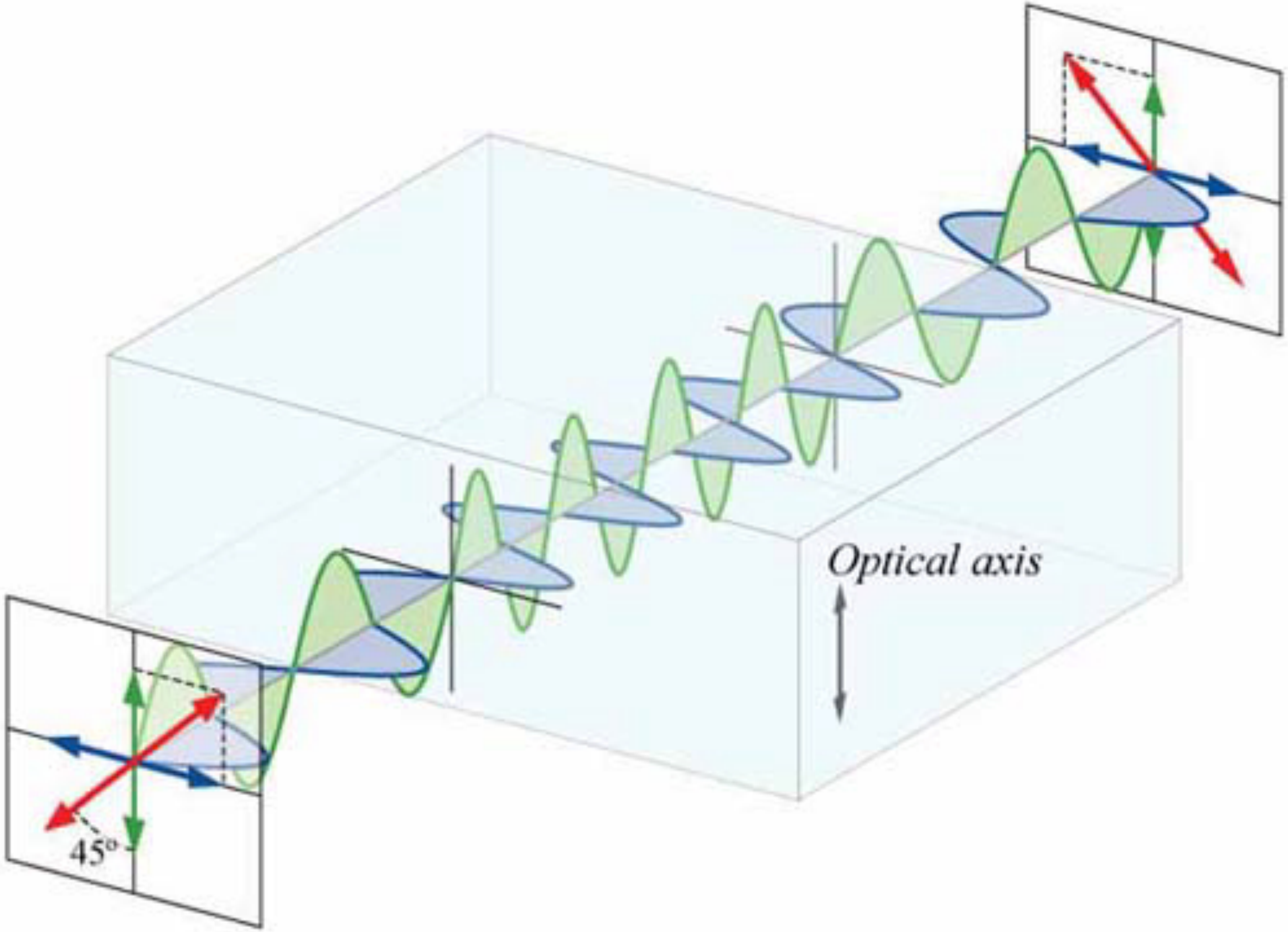
Unpolarized Light

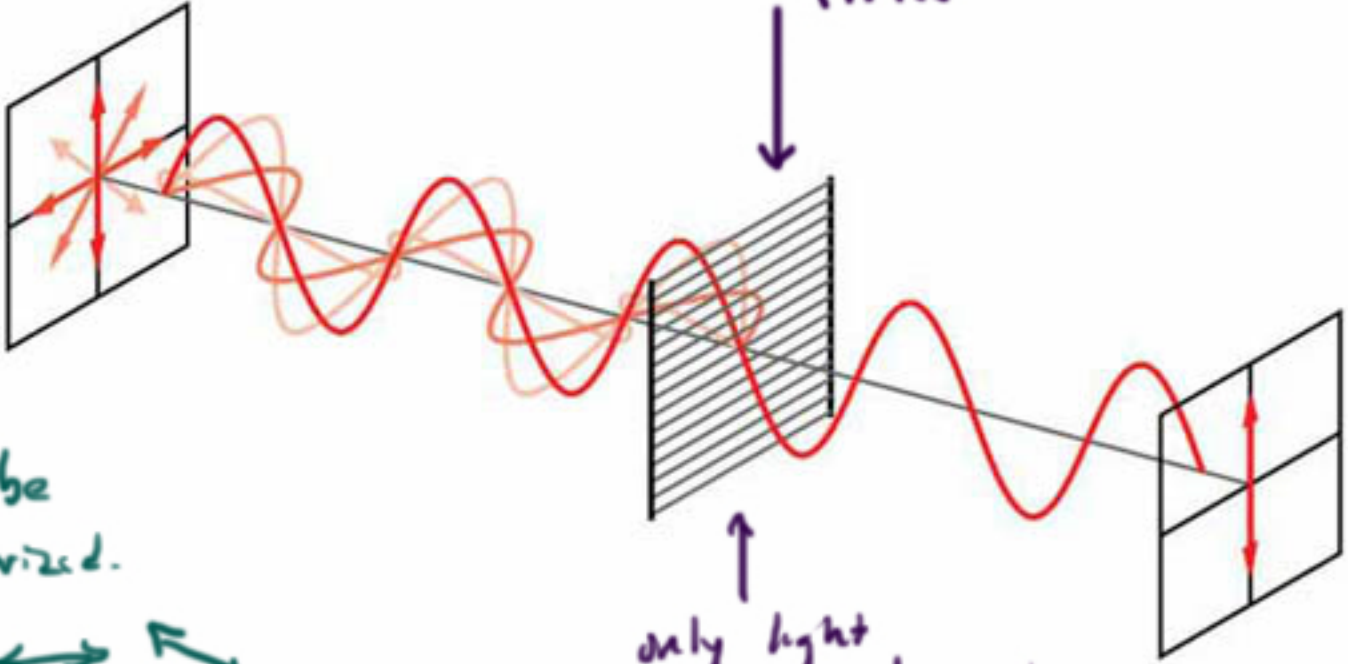
With unpolarized light, all directions of electric field vibrations perpendicular to the direction of wave propagation are possible. Most light sources produce unpolarized light.



Polarized Light

With plane polarized light, the electric field vibrates in a single plane perpendicular to wave propagation. Different means exist to produce polarized light from an unpolarized source including reflection, selective absorption, double refraction and scattering.


Optical axis
45°



- Light can also be circularly polarized.

used in circular dichroism spectroscopy to assay the degree of order in a protein's 2° structure

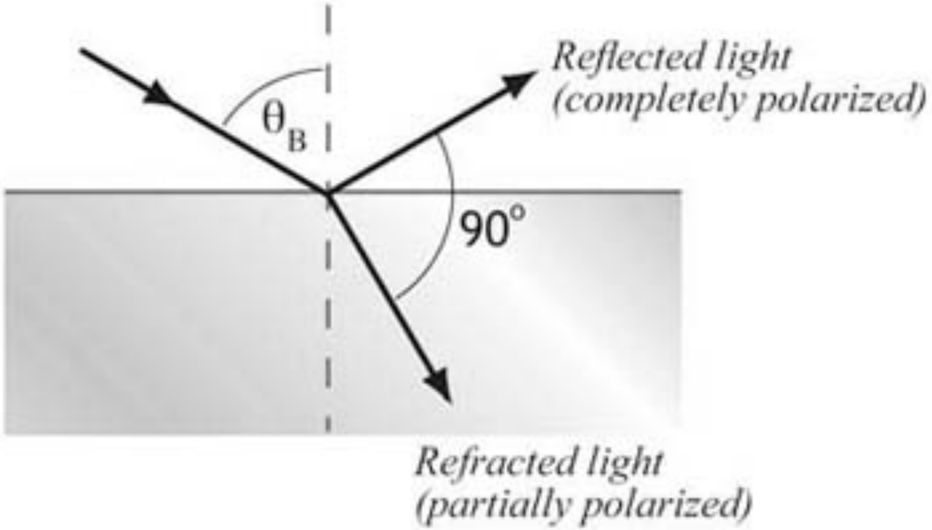
- *Reflection* polarizes light. For intermediate angles of incidence, between 0° and 90°, at least some of the reflected light is polarized because light in which the electric field vibrations parallel to the surface are more strongly reflected.

- *Selective absoprtion* polarize light. A *polaroid film* only allows the components of the electric field vibrations to pass that are parallel to its transmission axis.

- *Double refraction* produces polarized light within *birefringent materials*. In these substances, such as calcite and quartz, the index of refraction is not the same in all directions. Double refraction causes an unpolarized light beam to be split into an *ordinary (O) ray* and an *extraordinary (E) ray*, which are polarized in mutually perpendicular directions.

- *Scattering* produces polarized light. For example, the vibrations of air molecules in the horizontal plane reaches the earth while the vibrations in the vertical plane travel into space.

Brewster's Angle



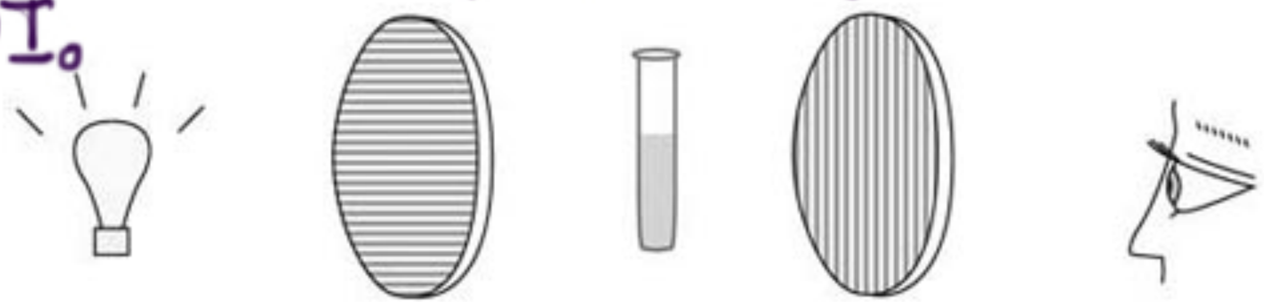
derived from Snell's Law

$$\tan \theta_B = \frac{n_2}{n_1} \quad (\text{if } n_1 \sim 1) \quad \tan \theta_B = n_2$$

supplemental

Brewster's angle, at which the reflected light is completely polarized, depends on the indices of refraction of the two media. (Note that the index of refraction of air is very close to 1, so Brewster's Law can often be simplified to $\tan \theta_B = n_2$*).*

Optically active substances possess the ability to rotate the plane of polarization of plane polarized light. To determine whether a transparent substance was optically active, a biochemist placed it between two crossed polarizers, illuminated the assembly as below, and viewed through the 2nd polarizer. Which of the following indicated optical activity?



a. Angular rotation of the image of the substance

b. Greater brightness where light was passing through the substance

c. A double image of the substance

d. The substance appeared opaque through the 2nd polarizer