Unit-10　Interference and Diffraction

Objective：

In this experiment, we used single-slit, double-slit, circular hole and grating to measure the wavelength of laser.

Apparatus：

Optical track, diode laser, light sensor, rotating sensor, digital device, analogy device, single-slit, double-slit, grating, grating base, section paper ,ruler

Principle：

A. Huygens' principle

In 1678, Huygens proposed that every point which a luminous disturbance reaches becomes a source of a spherical wave; the sum of these secondary waves determines the form of the wave at any subsequent time.

As shown in figure 1. He assumed that the secondary waves travelled only in the "forward" direction and it is not explained in the theory why this is the case.

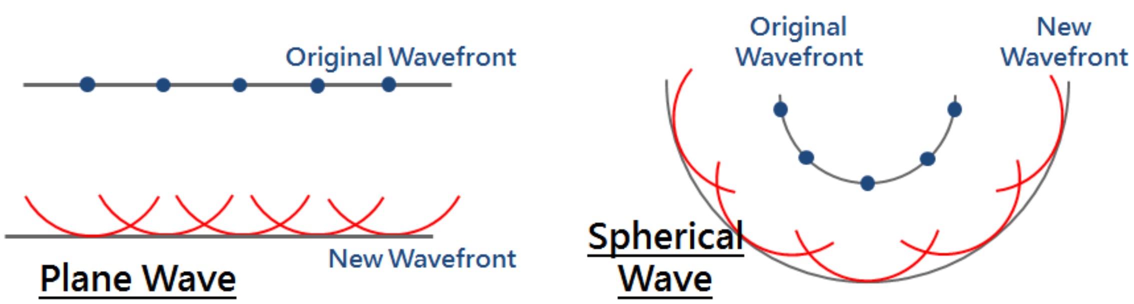

Figure 1. Plane wave and spherical wave

B. Double-slit interference

Young's double-slit experiment was one of the famous optics experiments in 19 century. Interference fringes can be seen on the screen far away when light source passes through a double-slit. The experiment established the theory of "wave optics". It also gave the principle of qualitative observation of "Wave Mechanics".

The phenomena of interference and diffraction are two remarkable features of the wave nature of light. A schematic diagram of the apparatus is shown in figure 2. Coherent plane waves arrive at opaque barrier which contains two parallel slits A and B. These two slits serve as a pair of coherent light source. The light from A and B produces on far away viewing screen a visible pattern of bright and dark parallel bans called fringes. This phenomena is so-called interference and it is a powerful evident of wave nature of light. This is the famous Young's experiment performed in 1801.

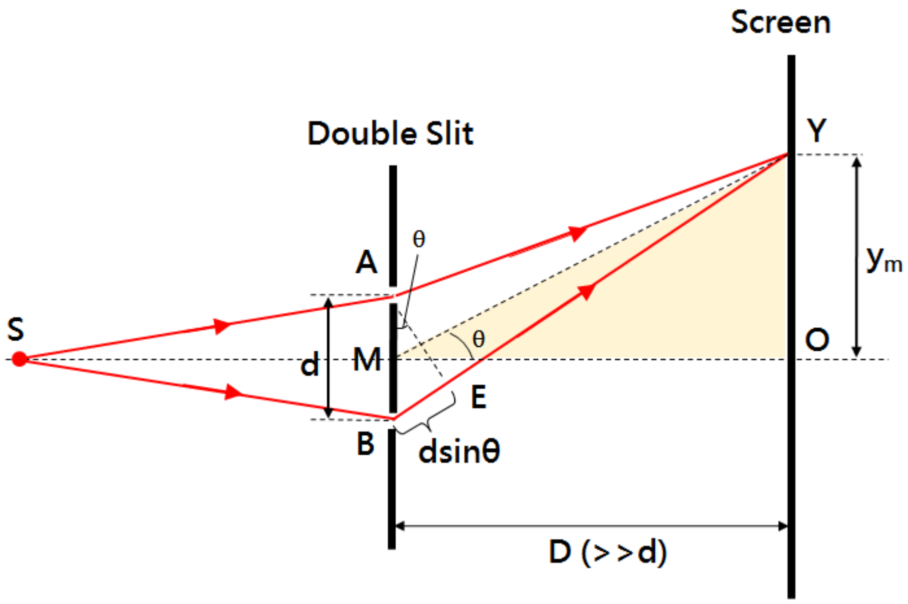

Figure 2. Double-slit interference

As indicated on figure 2 the distance from an arbitrary point Y on viewing screen to two slits A and B are $\overline{AY}$ and $\overline{BY}$ respectively. The optical path difference is $\overline{BE} = \overline{BY} - \overline{AY}$.

If the screen is very far from the slits ($D >> d$), then $\angle AYB$ is minimal, so $\overline{YA}$, $\overline{YM}$ and $\overline{YB}$ are approximately perpendicular to $\overline{AE}$, the optical path difference can be expressed as

$$\overline{BE} \approx d \sin\theta \approx d \tan\theta = d\frac{y_m}{D} \qquad (\theta <<)$$

(a) Constructive interference

If the path difference is either zero or some integer multiple of the wavelength, the constructive interference occurs. The number m is called the order number.

$$d \sin\theta = m\lambda \qquad (m = 0, 1, 2, 3, \ldots\ldots) \qquad (1)$$

The interference fringes on the screen would be symmetric respect to the middle point O. The wavelength of the light could be expressed through the above equation with position of the mth bright fringe y_m measured from O.

$$m\lambda = d \sin\theta \approx d \tan\theta = d\frac{y_m}{D}$$

$$\lambda \approx \frac{dy_m}{mD}$$

(b) Destructive interference

When the path difference is an odd multiple of $\frac{\lambda}{2}$, the destructive interference occurs. The number m is called the order number.

$$d \sin\theta = \left(m - \frac{1}{2}\right)\lambda \qquad (m = 1, 2, 3, \ldots\ldots) \tag{2}$$

And the wavelength of the light could be expressed through the above equation with position of the mth dark fringe y_m measured from O.

$$\left(m - \frac{1}{2}\right)\lambda = d \sin\theta \approx d \tan\theta = d \frac{y_m}{D}$$

$$\lambda \approx \frac{d y_m}{\left(m - \frac{1}{2}\right) D}$$

C. Single-slit diffraction

When plane waves start to spread into a single-slit, according to the Huygens' Principle: each point on the approaching wavefront acts as a source of secondary wavelets. These wavelets would interfere with each other and form interference fringes due to the superposition principle.

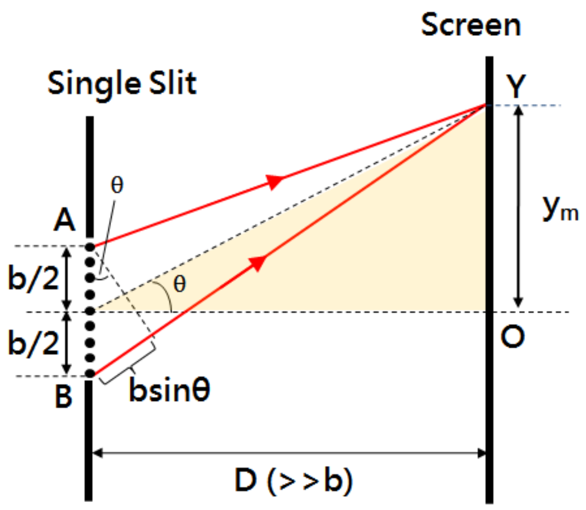

Figure 3. Single-slit interference

As shown in the figure 3, the width of the slit is b, λ is the wavelength of light, and θ is the angle between any arbitrary point Y and the middle point O to the slit.

When destructive interference happened, optical path difference can be expressed as

$$b \sin\theta \approx b \tan\theta = b \frac{y_m}{D} \qquad (\theta <<)$$

(a) Destructive interference

When constructive interference happened, optical path difference can be expressed as

$$b \sin\theta = m\lambda \qquad (m = 1, 2, 3, \ldots\ldots) \tag{3}$$

Where m is integer, the center bright fringe is due to m=0, with twice width as other bright bands. Also, the diffraction fringes must be symmetric related to the point O.

The wavelength of the light λ could be expressed through the above equation with the distance y_m from the mth dark fringe to the center bright fringe.

$$m\lambda = b\sin\theta \approx b\tan\theta = b\frac{y_m}{D}$$

$$\lambda \approx \frac{by_m}{mD}$$

(b) Constructive interference

When constructive interference happened, optical path difference can be expressed as

$$b\sin\theta = \left(m - \frac{1}{2}\right)\lambda \qquad (m = 1, 2, 3, \ldots\ldots) \tag{4}$$

Where m is integer, the center bright fringe is due to m=0, with twice width as other bright bands. Also, the diffraction fringes must be symmetric related to the point O.

The wavelength of the light λ could be expressed through the above equation with the distance y_m from the mth dark fringe to the center bright fringe.

$$\left(m - \frac{1}{2}\right)\lambda = b\sin\theta \approx b\tan\theta = b\frac{y_m}{D}$$

$$\lambda \approx \frac{by_m}{\left(m - \frac{1}{2}\right)D}$$

D. Double-slit interference and diffraction

In theoretical discussion, we usually assume the width of slits to be extremely small. But the diffraction of slit itself always happens because of the finite width.

Therefore, the fringes in Young's double-slit experiment [figure 4(c)] are the combination of interference [figure 4(c)] and diffraction [figure 4(c)].

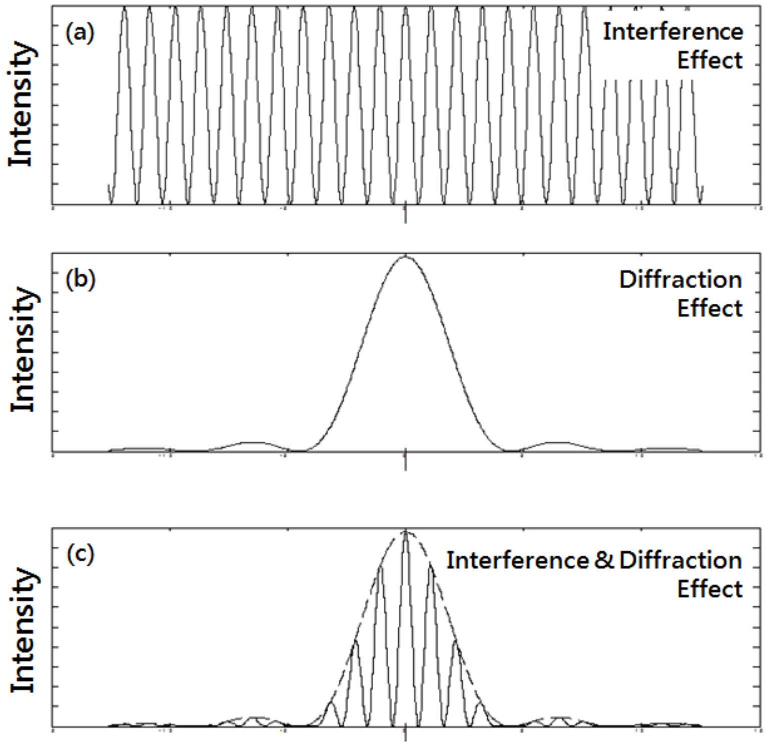

Figure 4. Fringes of double-slit interference

E. Circular hole diffraction

As shown in figure 5. When the light passes through the circular hole, the fringes would be concentric circles. Through theoretically derivation, we find out the distance y_m from the bright or dark fringe to the central light spot satisfies the following equation

$$m\lambda = b\sin\theta \approx b\tan\theta = b\frac{y_m}{D}$$

$$\lambda \approx \frac{by_m}{mD}$$

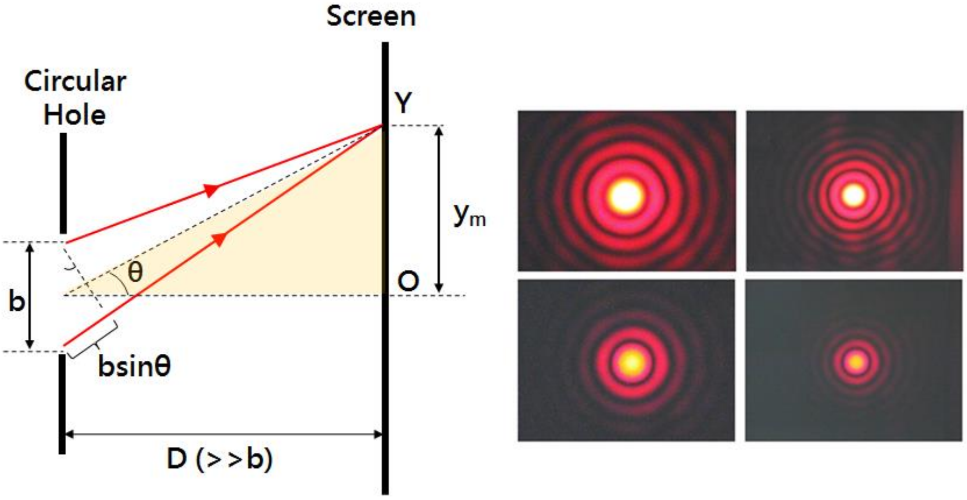

Figure.5 Circular hole diffraction

D is the distance from viewing screen to circular hole, *b* is the diameter of circular hole, and λ is the wavelength of light. Then *m* = 0 is the central bright disk, *m* = 1.220 is the first dark ring, *m* = 1.635 is the second bright ring, *m* = 2.233 is the second dark ring, *m* = 2.679 is the third bright ring, and *m* = 3.238 is the third dark ring.

F. Grating diffraction

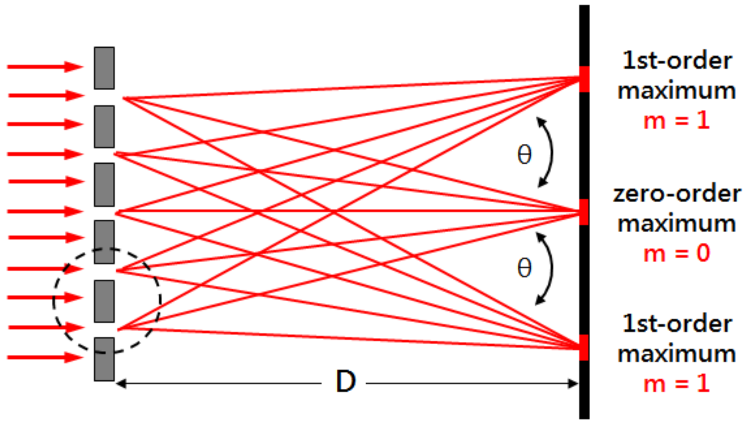

Figure 6. Grating diffraction

As shown in figure 6. On the viewing screen, light fringes will be formed due to interference and diffraction when a coherent plane wave passes through the gratings once the following conditions are satisfied. As shown in figure 7. Optical path difference between the light from adjacent slit can be expressed as $d\sin\theta$, where *d* is the distance between adjacent slit.

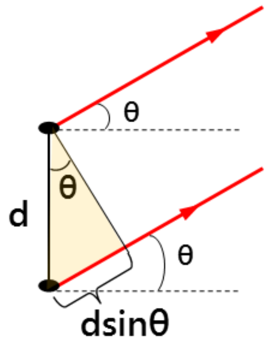

Figure 7. Diagram of optical path difference

If optical path difference is the integer multiple of λ , the waves arriving at point P are in phase and give rise to constructive interference are expressed as

$$d \sin\theta = m\lambda \qquad (m = 0, \pm1, \pm2, \pm3, \ldots\ldots) \tag{5}$$

m = 0, zeroth-order maximum
m = ±1, first-order maximum
m = ±2, second-order maximum

Where D is the distance from viewing screen to grating, and y_m is the distance from the mth bright fringe to central fringe, and then the wavelength of light can be expressed as following equation

$$m\lambda = d \sin\theta \approx d\frac{y_m}{D}$$

$$\lambda \approx \frac{dy_m}{mD}$$

Remarks：

1. Do not look directly at an operating laser; it will cause serious eye injury.
2. Do not touch the mirror of optical element or switch on and off the laser repeatedly.
3. Make sure your laser beam won`t hurt anyone else. If you need move laser, please block the beam or turn it off first in case of any possible hazards.
4. Do not let laser emit out of your table.

Procedure：

- **Preparation**

1. Setup the apparatus as shown in Figure 8.

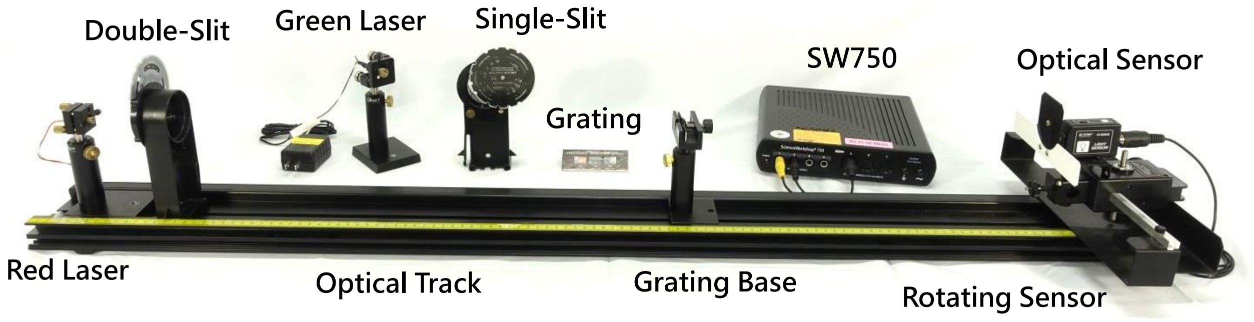

Figure 8. Experiment set-up

A. Double-slit interference

1. Put diode laser and double slit on the optical track. The distance from viewing screen to slit should be greater than 80.00 cm.
2. Record the separation of double slit (d = 0.500 mm). Turn on the red laser and then adjust the laser and the double-slit set to get a series of clear and symmetric fringes.
3. Measure the intensity of fringes by optical sensor on the track; pull or push the track slowly in order to make all fringes pass through optical sensor.
4. Plot the figure of 『Intensity-Position』 to analyze the position of each light spot y_m by using software.
5. Take y_m and the width of double slit d into equation to calculate the wavelength of laser.
6. Change to another double slit (d = 0.250 mm) and repeat the above steps.

B. Single-slit diffraction

1. Put diode laser and single slit on the optical track. The distance from viewing screen to slit should be greater than 80.00 cm.
2. Record the width of single slit (b = 0.160 mm). Turn on the red laser and then adjust the laser and the double-slit set to get a series of clear and symmetric fringes.
3. Measure the intensity of fringes by optical sensor on the track; pull or push the track slowly in order to make all fringes pass through sensor.
4. Plot the figure of 『Intensity-Position』 to analyze the position of each light spot y_m by using software.
5. Take y_m and the separation of single slit b into equation to calculate the wavelength of laser.
6. Calculate the width of center and first bright band.
7. Change to another single slit (b = 0.080 mm) and repeat the above steps.

C. Circular hole diffraction

1. Put diode laser and single slit (with circular hole) on the optical track. The distance from viewing screen to slit should be greater than 80.0 cm.
2. Record the diameter of round hole (b = 0.400 mm). Turn on the diode laser and then adjust the laser and the round-hole set to get a series of clear and symmetric fringes.
3. Measure the intensity of fringes by optical sensor on the track; pull or push the track slowly in order to make all fringes pass through sensor.
4. Plot the figure of 『Intensity-Position』 to analyze the distance from the first dark fringe to the central fringe y_m by using software.
5. Take y_m and the diameter of the round hole into equation to calculate the wavelength of laser.
6. Change to another round-hole (b = 0.200 mm), and repeat the above steps.

D. Grating diffraction

1. Put diode laser and grating with holder on the optical track.
2. Record the separation of grating d = 0.01 mm (100 lines/mm).
3. Turn on the red laser and adjust the grating set to get a series of clear and symmetric fringes on the section paper.
4. Plot the figure of Intensity-Position to analyze the position of each light spot y_m.
5. Take y_m and the separation of grating d into equation to calculate the wavelength of laser.
6. Change to another grating $d = 3.3\times10^{-3}$ mm (300 lines/mm) and repeat the above steps.

Questions：

1. What happened to the interference or diffraction fringes if the slit is tilted with a small angle? Please explain.
2. If we change the wavelength of light source, what will happen? Please explain.
3. How does Young’s demonstration that light and matter can display characteristics of both classically defined waves and particles? Please explain.