الجامعة المستنصرية – كلية العلوم

قسم الفيزياء

Mustansiriyah Univ. – College of Science

Physics Department

Optics 2

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Lecture (2)

Interference

Edited by:

Prof. Dr. Mahasin F. Hadi Al-Kadhemy

Physical Terms (English)	**المصطلحات الفيزيائية (العربي)**	**Physical Terms (English)**	**المصطلحات الفيزيائية (العربي)**
Wave front	جبهة الموجة	splitting	انقسام
slit	شق	narrow	ضيق
Amplitude splitting	انقسام السعة	reflected	قوة
transmitted	طول موجي	beam	ازاحة
wedge	حافة	Newton's ring	حلقات نيوتن
Michelson's interferometer	مقياس تداخل مايكلسون	illumination	ضيائية
spherical waves	موجات كروية	Cylindrical wavefronts	جبهات موجة اسطوانية
equidistant	متساوية المسافة	secondary	ثانوية
order of fringe	رتبة الهدبة	separation	الفاصلة
fringe width	عرض الهدة	directly proportional	تناسب طردي
independent	غير معتمد	inversely proportional	تناسب عكسي
less closer	أقل تقارب	wider	أعرض

1- Techniques of Obtaining Interference

The techniques used for creating coherent sources of light can be divided into the following two broad classes.

A- Wave front splitting: one of the methods consists **in dividing a light wave front, emerging from a narrow slit, by passing it through two slits closely spaced side by side**. **The two parts of the same wave front travel through different path and reunite on a screen to produce fringe pattern**. This is known as i**nterference due to division of wave front**. This method is useful only with **narrow sources**. **Young's double slit, Fresnel's double mirror, Fresnel's biprism, Lloyd's mirror**, etc employ this technique.

B- Amplitude splitting: Alternately, the amplitude (intensity) of a light wave is **divided into two parts**, namely **reflected** and **transmitted components**, **by partial reflection at a surface**. The **two part travel through different path and reunite to produce interference fringes**. This is known as **interference due to division of amplitude**. Optical elements such as **beam splitters, mirror** are used for achieving amplitude division. **Interference in thin films (wedge, Newton's ring etc), Michelson's interferometer** etc. interferometers utilize this method. This method requires extended source.

2- Young's Double-Slit Experiment-Wave front Division

- In 1665, **Grimaldi** attempted to produce interference between two beams of light. He directed sunlight into a dark room through two pinholes in a screen, with an expectation that bright and dark bands would be observed in the area where the beams overlap on each other. He observed **uniform illumination** instead.

- In 1801, **Thomas Young** gave the first demonstration of the interference of light waves. Young admitted the **sunlight through a single pinhole** and then directed the **emerging light onto two pinholes**. Finally the light was received on a screen.
- The **spherical waves** emerging from the pinholes **interfered with each other and a few colored fringes** were observed on the screen. The amount of light that emerged from the pinhole was **very small and the fringes were faint and difficult to observe**. The pinholes were later replaced with **narrow slits** that let through much more light. The **sunlight** was replaced by **monochromatic light**. Young's experiment is known as **double-slit experiment**.
- In Figure (1), the primary light source is a **monochromatic source**; it is generally a **sodium lamp**, which emits **yellow light** of wavelength at around **5893** °**A**.

Q// Why sodium lamp is not suitable for causing interference?

Because emissions that emitted from different parts of any ordinary source are not coherent.

- Therefore, the **monochromatic light** is allowed to pass through a **narrow slit** at **S**. The light coming out of the slit originated from only a small region of the light source and hence behaves more nearly like an ideal light source.
- **Cylindrical wavefronts** are produced from the slit S_0, the primary light source, which fall on the two narrow closely spaced slits, S_1, and S_2 as shown in Figure (1). The slits at S_1, and S_2 are **very narrow**. The cylindrical waves emerging from the slits overlap. **If the slits are equidistant from S_0, the phase of the wave at S_1, will be the same as the phase of the wave at S_2** . Further, waves leaving S_1, and S_2 are therefore always in phase. Hence, **sources S_1, and S_2** act as **secondary**

coherent sources. The waves leaving from S_1, and S_2 interfere and **produce alternate bright and dark bands** on the screen at T.

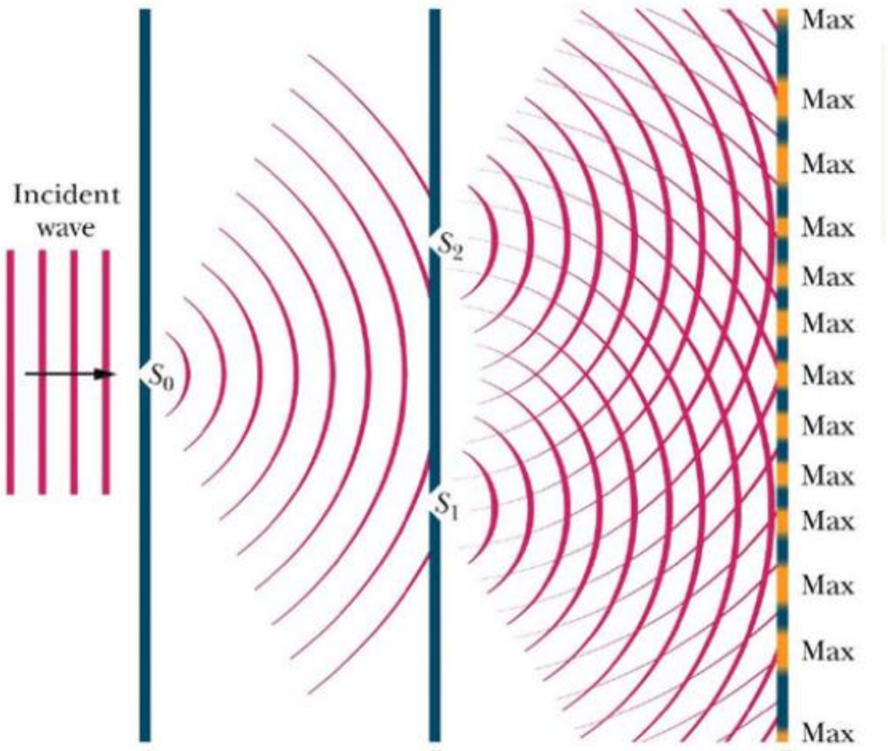

Figure (1) Young's Double-Slit Experiment

In Huygens's construction, the principle states that **every point of a wave front may be considered as the source of small secondary wavelets**. As shown in Figure (2).

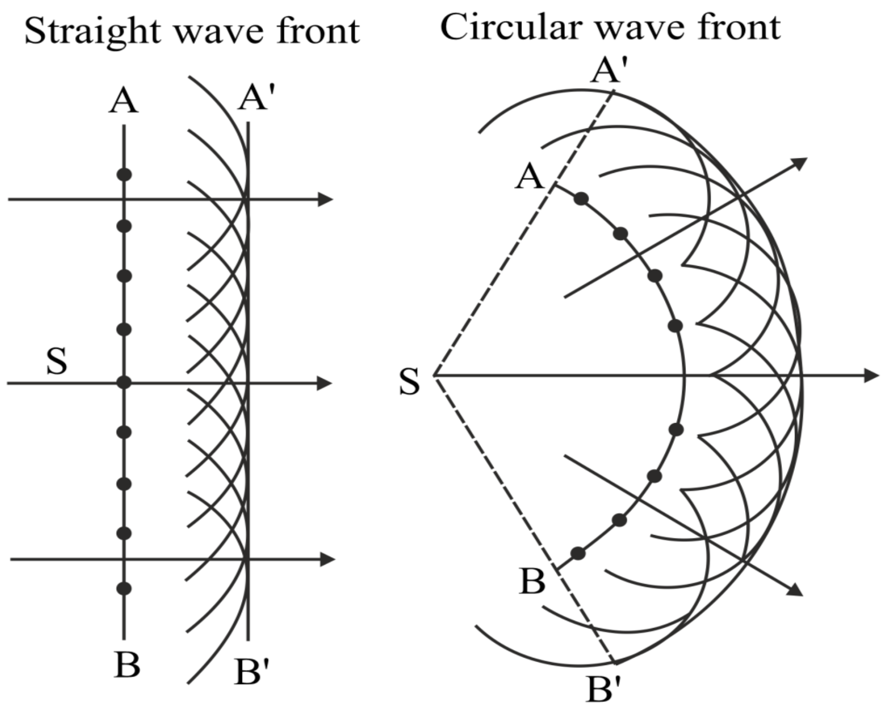

Figure (2) Formation of the secondary wave front according to Huygens 'Principle

2-1 Optical Path Difference between the Waves at P

1- Let **P** be an arbitrary **point** on **screen T**, which is at a **distance D** from the **double slits,** Figure (3).

2- Let **θ** be the **angle** between **MP** and the **horizontal line MO**.

3- Let **S_1N** be a normal on to the line **S_2P**. The **distances PS_1 and PN are equal**.

4- The waves emitted at the slits, **S_1** and **S_2**, are **initially in phase with each other**. **The difference in the path lengths of these two waves is** S_2N.

5- We assume that the experiment is carried out **in air**. Therefore, the **optical paths are identical with geometrical paths**.

6- The **nature of the interference** of the two waves at **P depends** simply on **how many waves are contained in the length of the path difference S_2N**.

7- If **S_2N contains an integral number of wavelengths**, the two waves **interfere constructively**, producing a **maximum in the intensity** of light on the screen at **P**. If it contains an **odd number** of **half-wavelengths,** then **the waves interfere destructively** and produce a **minimum intensity at P**.

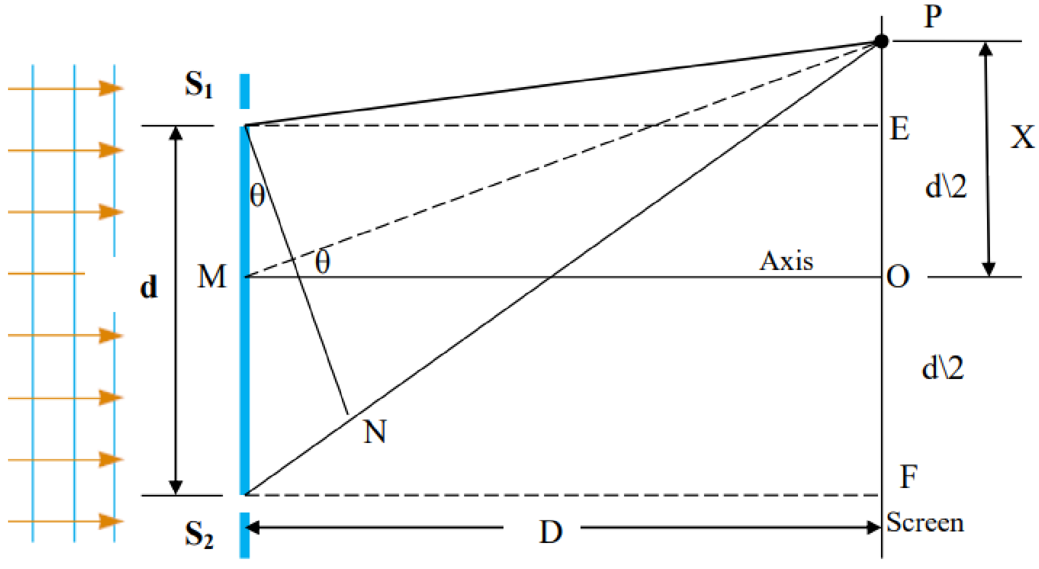

Figure (3) Optical path difference

Let the point P be at a distance **x** from **O** (Figure (3)). Then

$PE = x - \frac{d}{2}$ and $PF = x + \frac{d}{2}$

$(S_2P)^2-(S_1P)^2=[D^2+(PE)^2]-[D^2+(PF)^2]$

$(S_2P)^2-(S_1P)^2=[D^2+(x - \frac{d}{2})^2]-[D^2+(x + \frac{d}{2})^2]$

$$(S_2P)^2 - (S_1P)^2 = \left[D^2 + x^2 - 2x\frac{d}{2} + \frac{d^2}{4}\right] - [D^2 + x^2 + 2x\frac{d}{2} + \frac{d^2}{4}]$$

$$(S_2P)^2 - (S_1P)^2 = 2xd$$

$$(S_2P-S_1P)\ (S_2P+S_1P)=2xd$$

$$(S_2P - S_1P) = \frac{2xd}{(S_2P + S_1P)}$$

We can approximate that $S_2P \cong S_1P = D$

Path difference = $(S_2P - S_1P) = \frac{xd}{D}$ **(1)**

We now find out the conditions for observing bright and dark fringes on the screen.

2-2 Bright Fringes

Bright fringes occur whenever the wave from S_1 and S_2 **interfere constructively**. The first time this occurs is at O, the axial point. There, the waves from S_1 and S_2 travel the **same optical path length** to O and arrive in phase.

The next bright fringe occurs when the wave from S_2 travels one complete wavelength further the wave from S_1. In general constructive interference occurs if S_1P and S_2P differ by **a whole number of wavelengths**.

The condition for finding a bright fringe at P is that

$$\Delta = S_2P - S_1P = m\lambda \quad or \quad \delta = S_2P - S_1P = 2m\pi$$

Using equation (1), it means that

$$\frac{xd}{D} = m\lambda \qquad \textbf{(2)}$$

Where **m** is called **the order of fringe.**

Where **m = 0** called **zero- order of fringe** , **m = 1** called **first- order bright fringe** and **m = 2** called **second- order bright fringe**.

2-3 Dark Fringes

The **first dark fringe** occurs when **S_2P-S_1P** is equal **λ\2**. The waves are now **in opposite phase** at P. The **second dark fringe** occurs when **S_2P-S_1P** is equal **3λ\2**. The m^{th} dark fringe occurs when

$$\Delta = S_2P - S_1P = (2m+1)\frac{\lambda}{2} \quad or \quad \delta = S_2P - S_1P = \frac{(2m+1)}{\pi}$$

The condition for finding a dark fringe is

$$\frac{xd}{D} = (2m+1)\frac{\lambda}{2} \qquad \textbf{(3)}$$

Where **m = 0** called **first- order dark fringe**, **m = 1** called **second- order dark fringe.**

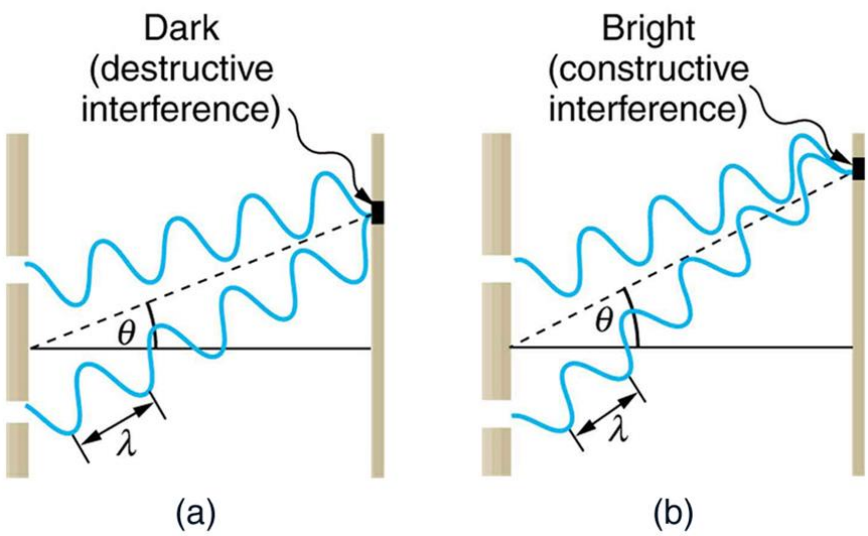

Figure (4) Bright and dark fringes

2-4 Separation between Neighboring Bright Fringe

The **mth order fringe** occurs when

$$x_m = \frac{m\lambda D}{d}$$

And the **(m +1)th order fringe**

$$x_{m+1} = \frac{(m+1)\lambda D}{d}$$

The **fringe separation, β** is given by

$$\beta = x_{m+1} - x_m = \frac{\lambda D}{d} \qquad \textbf{(4)}$$

The same result will be obtained for dark fringes. Thus, **the distance between any two consecutive bright or dark fringes** known as the **fringe width** and **is same everywhere** on the screen. Further, **the width of the bright fringe is equal to the dark fringe**. Therefore, the **alternate bright and dark fringes are parallel**.

From equation (4), we find the following:

1. The **fringe width β** is **independent of the order of the fringe**. It is **directly proportional** to the **wavelength** of light, i.e. **β α λ**. The fringes produced by **red light** are **less closer** compared to those produced by **blue light**.
2. The **width of the fringe** is **directly proportional** to the **distance the of the screen from the two slits,β α D**. The **farther** the screen, the **wider is the fringe separation**.
3. The **width of the fringe** is **inversely proportional** to the **distance between two slits**. The **closer are the slits**, the **width will be the fringes**.

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Example (1): Two coherent sources, whose intensity ratio is 9:4, produce interference fringes. Deduce the ratio of maximum intensity to minimum intensity of the fringe system.

Solution: Let the intensity of first coherent source I_1 and the second I_2 and the ratio between them $\frac{I_1}{I_2} = \frac{9}{4} \quad \rightarrow \mathbf{I_1} = \frac{9}{4}\mathbf{I_2}$

$$I_{max.} = I_1 + I_2 + 2\sqrt{I_1 I_2}$$

$$I_{max.} = \frac{9}{4}I_2 + I_2 + 2\sqrt{\frac{9}{4}I_2 I_2} = 3.25I_2 + 2\sqrt{2.25I_2^2} = 3.25I_2 + 3I_2$$

$$= 6.25I_2$$

$$I_{min.} = I_1 + I_2 - 2\sqrt{I_1 I_2}$$

$$I_{min.} = 3.25I_2 - 3I_2 = 0.25I_2$$

$$\frac{I_{max.}}{I_{min.}} = \frac{6.25I_2}{0.25I_2} = 25$$

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Example (2): An electromagnetic wave moving through space has electric field given by $= 100\sin[8\pi \times 10^{14}\,(t - \frac{z}{3\times10^8})]$. Calculate the intensity?

Solution: $E = 100\sin[8\pi \times 10^{14}\,(t - \frac{z}{3\times10^8})]$ this wave compared with $\boldsymbol{E = E_o Sin(kz - wt)}$ **so that E_o =100 V/m**

The intensity,

$$I = \frac{1}{2} \in_o CE^2 = \frac{3\times10^8 \times 8.85\times10^{-12}}{2} \times (100)^2 = 13.3\, W/m^2$$

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Example (3): Green light of wavelength 5100˚A from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen 200 cm away is 2 cm, find the slit separation?.

Solution The fringe width $\boldsymbol{\beta = \frac{\lambda D}{d}}$

It is given that D=200 cm, $\lambda=5100\times10^{-8}$ cm and

$10\beta=2$ cm $\rightarrow \beta=0.2$ cm.

The slit separation $d = \frac{\lambda D}{\beta} = \frac{(5100\times10^{-8}\ cm\times200cm)}{0.2cm} = 0.05\ cm$

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Example (4): Two coherent sources are 0.18 mm apart and the fringes are observed on a screen 80 cm away. It is found that with a certain monochromatic source of light, the fourth bright fringe is situated at a distance of 10.8 mm from the central fringe. Calculate the wavelength light?

Solution The distance of nth fringe from the central fringe is $\mathbf{x = \frac{m\lambda D}{d}}$

It is given that D=80 cm, d=0.18mm=0.018 cm, x=10.8 mm=1.08cm and m=4

$$\lambda = \frac{xd}{mD} = \frac{1.08\ cm \times 0.018cm}{4 \times 80\ cm} = 6075 \times 10^{-8}\ cm = 6075\ ^{\circ}A$$

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Example (5): A light source emits light of two wavelengths 4300˚A and 5100˚A. The source is used in a double slit experiment. The distance between the source and screen is 1.5 m and the distance between the slits is 0.025 mm. calculate the separation between the third order bright fringes due to these two wavelengths?

Solution The distance of nth fringe from the central fringe is $\mathbf{x = \frac{m\lambda D}{d}}$

It is given that λ_1=4300˚A =4300×10^{-8}cm, λ_2=5100˚A =5100×10^{-8}cm, m=3, D= 1.5m = 150 cm and d=0.025mm=0.0025 cm.

Now $\boldsymbol{x_1 = \frac{m\lambda_1 D}{d}}$ ***and*** $\boldsymbol{x_2 = \frac{m\lambda_2 D}{d}}$

$$x_2 - x_1 = \frac{nD}{d}(\lambda_2 - \lambda_1) = \frac{3 \times 150cm}{0.0025cm}(5100 - 4300) \times 10^{-8}cm$$

$$= 1.44cm$$

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Example (6): what happens if the monochromatic light used in Young's double slit experiment is replaced by white light?

Solution White light consists of colors between violet and red. The wavelength λ is the shortest for violet light and the longest for red light. At the central fringe, the path difference for all colors is zero. Therefore, at the center of the screen all colors superpose to give a white fringe.

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Questions:

1- State the principle of superposition of light waves?

2- What is meant by interference of light? State the fundamental conditions for the production of interference fringes.

3- What are the conditions necessary for observing interference fringes?

4- Why two independent sources cannot produce observable interference pattern?

5- Why is the condition of coherence necessary to observe interference fringes?

6- State and explain conditions for the interference of light.

7- Discuss the conditions for interference. Describe Young's experiment and derive an expression for (i) intensity at a point on the screen and (ii) fringe width.

8- How can coherent sources be obtained in practice?

9- What are coherent sources? Explain the importance of such sources in interference phenomenon. Two coherent sources form interference fringes. Obtain an expression for the distance between two consecutive bright fringes.

10- What is the reason for bright and dark fringe in Young's double slit experiment?

11- What is the condition for the constructive and destructive interference in Young's experiment?