General- Physics-2 Q4 Week-6

Fundamental Physics II (University of the Philippines System)

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DEPARTMENT OF EDUCATION
SCHOOLS DIVISION OF NEGROS ORIENTAL
REGION VII
Kagawasan Ave., Daro, Dumaguete City, Negros Oriental

WAVE PROPERTIES OF LIGHT

for GENERAL PHYSICS 2/ Grade 12/ Quarter 4/ Week 6

SELF-LEARNING KIT

NegOr_Q4_GenPhysics2_SLKWeek6_v2

FOREWORD

This Self-Learning Kit discusses the wave properties of light. You already learned how light behaves as it interacts with certain materials. Light can undergo reflection, refraction, or dispersion depending on the material where it will be incident on. As a result of its wave nature, light has other interesting behaviors that you should be familiar with. These are interference and diffraction.

This kit focuses on the geometry of the two slit experiment set up, the properties of light, and its relationship to the properties of interference pattern. This also presents the relationship of the geometry of the diffraction experiment set up and properties of light to the diffraction pattern.

OBJECTIVES

At the end of this Self-Learning Kit, you should be able to:
K: explain the phenomena of interference;
: define constructive interference for a double slit and destructive interference for a double slit;
S: Relate the geometry of the two−slit experiment set up and properties of light to the properties of interference pattern;
: discuss the geometry of the diffraction experiment set up;
: relate the geometry of the diffraction experiment set up and properties of light to the properties of diffraction pattern; and
A: recognize the importance of these concepts to real-life setting.

LEARNING COMPETENCIES

Determine the conditions (superposition, path and phase difference, polarization, amplitude) for interference to occur emphasizing the properties of a laser as a monochromatic and coherent light source **(STEM_GP12OPT-IVf-32).**

Relate the geometry of the two−slit experiment set up (slit separation, and screen−to−slit distance) and properties of light (wavelength) to the properties of interference pattern (width, location, and intensity) **(STEM_GP12OPT-IVf-33).**

Relate the geometry of the diffraction experiment setup (slit size, and screen-to-slit distance) and properties of light (wavelength) to the properties of the diffraction pattern (width, location, and intensity of the fringes) **(STEM_GP12OPT-IVf-35).**

I. WHAT HAPPENED

Hello learners! Before you start learning new concepts in this self-learning kit, let us have an activity first to check what you already knew about Double Slit Experiment.

PRE-TEST:

FINDING MY PERFECT MATCH!

Directions: Match the word/phrase under Column A with its corresponding description under column B. Choose only the letter of your choice and write it down in your notebook/Answer Sheet. (1point each item)

Column A	**Column B**
_____1. Interference Pattern	a. superposition of light from two slits
_____2. Thomas Young	b. bright fringes
_____3. Double−slit Experiment	c. Proponent of Double−slit experiment
_____4. Constructive Interference	d. dark fringes
_____5. Destructive Interference	e. consisting of a single wavelength
_____6. Monochromatic Light	f. proposed the theory of light
	g. It demonstrates the constructive and destructive interference of light

II. WHAT I NEED TO KNOW
DISCUSSION

INTERFERENCE OF LIGHT

Thomas Young was a physicist at the beginning of the 19th century who showed interference demonstrating that light is a wave phenomenon and who also postulated that waves of various lengths were made of different colors of light.

Wave interference is the phenomenon that occurs when two waves meet while traveling along the same medium to form a resultant wave of greater, lower or the same amplitude.

Source:https://www.uh.edu/engines/3024PSM_V05_D270_Thomas_Young.png

Figure 1: Thomas Young

Interference usually refers to the interaction of waves which have constant phase difference and same or nearly same frequency.

Interference effects can be observed with all types of waves, for example, radio waves, light waves, sound waves, surface water waves or matter waves.

Two Types of Wave Interference

When two waves meet while traveling along the same medium, either the amplitudes of both waves are added or the amplitudes of both waves are subtracted. Based on this, the wave interference is of two types: ***constructive interference*** and ***destructive interference***.

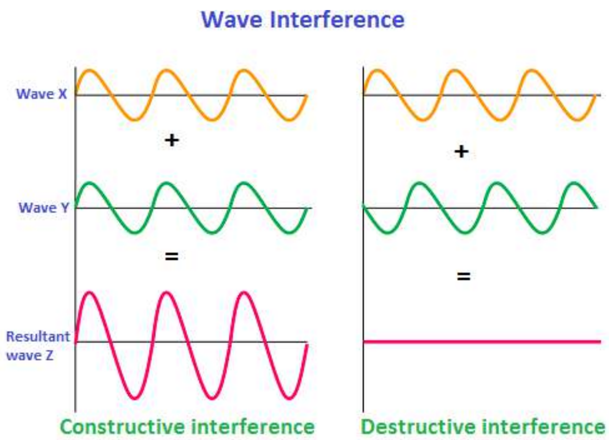

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Figure 2. Two types of Wave Interference

YOUNG'S DOUBLE-SLIT EXPERIMENT

When monochromatic light passing through two narrow slits illuminates a distant screen, a characteristic pattern of **bright** and **dark** fringes is observed. This **interference pattern** is caused by the superposition of overlapping light waves originating from the **two slits.**

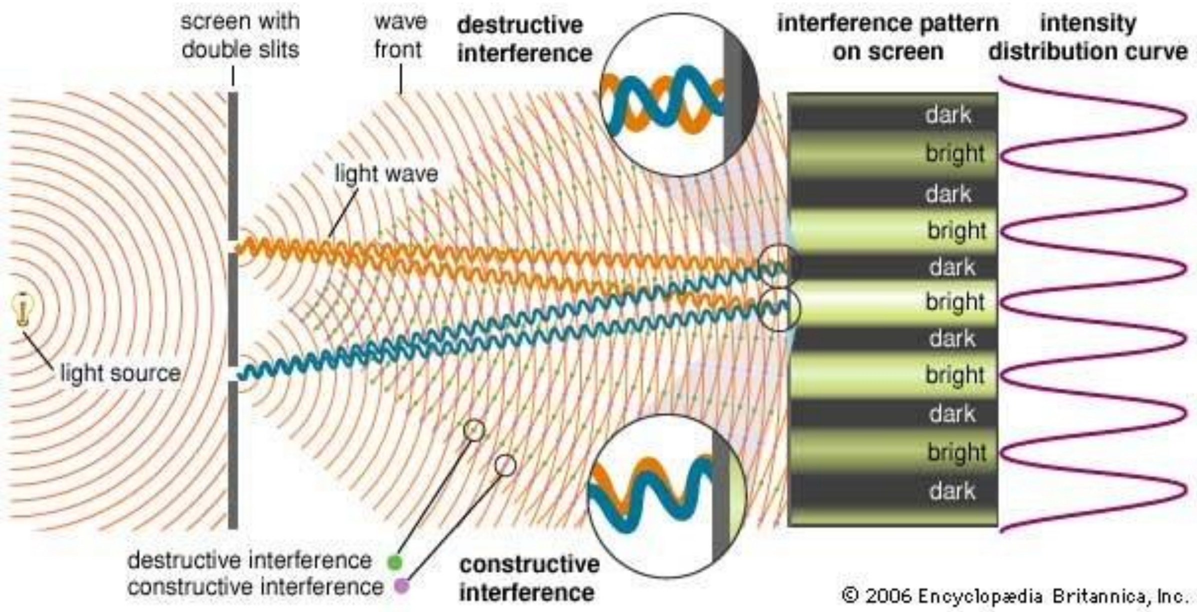

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Figure 3. Double-slit Experiment of Thomas Young

Regions of ***constructive interference***, corresponding to bright fringes, are produced when the path difference from the two slits to the fringe is an integral number of wavelengths of the light. ***Destructive interference*** and dark fringes are produced when the path difference is a half-integral number of wavelengths.

To understand the double slit interference pattern, we consider how two waves travel from the slits to the screen, as illustrated in Figure 4. Each slit has a different distance from a given point on the screen. Thus, different numbers of wavelengths fit into each path. Waves start out from the slits in phase (crest to crest), but they may end up out of phase (crest to trough) at the screen if the paths differ in length by half a wavelength, interfering destructively as shown in Figure 4a.

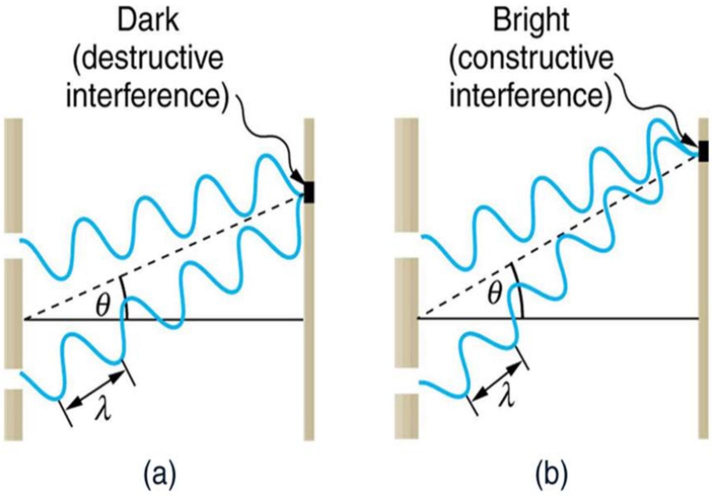

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Figure 4. Waves follow different paths from the slits to a common point on a screen. (a) Destructive interference occurs here, because one path is a half wavelength longer than the other. The waves start in phase but arrive out of phase. (b) Constructive interference occurs here because one path is a whole wavelength longer than the other. The waves start out and arrive in phase.

If the paths differ by a whole wavelength, then the waves arrive in phase (crest to crest) at the screen, interfering constructively as shown in Figure 4b. More generally, if the paths taken by the two waves differ by any half-integral number of wavelengths [$(1/2)\ \lambda$, $(3/2)\ \lambda$, $(5/2)\ \lambda$, etc.], then destructive interference occurs. Similarly, if the paths taken by the two waves differ by any integral number of wavelengths (λ, 2λ, 3λ, etc.), then constructive interference occurs.

Example 1: **Finding a Wavelength from an Interference Pattern**

Suppose you pass light from a He-Ne laser through two slits separated by 0.0100 mm and find that the third bright line on a screen is formed at an angle of 10.95º relative to the incident beam. What is the wavelength of the light?

Strategy:

The third bright line is due to third-order constructive interference, which means that m = 3. We are given d = 0.0100 mm and θ = 10.95º. The wavelength can thus be found using the equation $d \sin \theta = m\lambda$ for constructive interference.

Solution:

The equation is $d \sin \theta = m \lambda$. Solving for the wavelength λ gives

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

Substituting known values yields

$$\lambda = \frac{(0.0100nm)(\sin 10.95°)}{3}$$

$$= 6.33 \times 10^{-4} \text{ nm} = 633 \text{ nm}$$

Discussion:

To three digits, this is the wavelength of light emitted by the common He-Ne laser. Not by coincidence, this red color is similar to that emitted by neon lights. More important, however, is the fact that interference patterns can be used to measure wavelength. Young did this for visible wavelengths. This analytical technique is still widely used to measure electromagnetic spectra. For a given order, the angle for constructive interference increases with λ, so that spectra (measurements of intensity versus wavelength) can be obtained.

***Example 2:* Calculating Highest Order Possible**

Interference patterns do not have an infinite number of lines, since there is a limit to how big *m* can be. What is the highest-order constructive interference possible with the system described in the preceding example?

Strategy and Concept:

The equation $d \sin \theta = m \lambda$ (for $m = 0, 1, -1, 2, -2, \ldots$) describes constructive interference. For fixed values of d and λ, the larger *m* is, the larger $\sin \theta$ is. However, the maximum value that $\sin \theta$ can have is 1, for an angle of 90°. (Larger angles imply that light goes backward and does not reach the screen at all.) Let us find which *m* corresponds to this maximum diffraction angle.

Solution:

Solving the equation $d \sin \theta = m\lambda$ for *m* gives

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

Taking $\sin \theta = 1$ and substituting the values of *d* and λ from the preceding example gives

$$m = \frac{(0.0100\ mm)(1)}{633nm} \approx 15.8$$

Therefore, the largest integer *m* can be is 15, or *m* = 15.

Discussion:

The number of fringes depends on the wavelength and slits separation. The number of fringes will be very large for large slit separations. However, if the slit separation becomes much greater than the wavelength, the intensity of the interference pattern changes so that the screen has two bright lines cast by the slits, as expected when light behaves like a ray. We also note that the fringes get fainter further away from the center. Consequently, not all 15 fringes may be observable.

Why do we not ordinarily observe wave behavior for light, such as observed in Young's double slit experiment? First, light must interact with something small, such as the closely spaced slits used by Young, to show pronounced wave effects. Furthermore, Young first passed light from a single source (the Sun) through a single slit to make the light somewhat coherent. By *coherent*, we mean waves are in phase or have a definite phase relationship. *Incoherent* means the waves have random phase relationships. Why did Young then pass the light through a double slit? The answer to this question is that two slits provide two coherent light sources that then interfere constructively or destructively. Young used sunlight, where each wavelength forms its own pattern, making the effect more difficult to see. We illustrate the double slit experiment with monochromatic (single λ) light to clarify the effect.

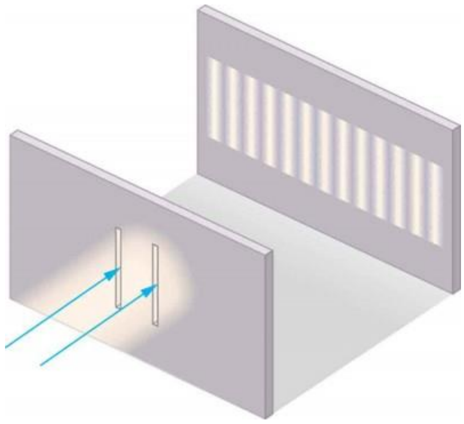

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Figure 5. Young's double slit-experiment. Here pure wavelength light sent through a pair of vertical slits is diffracted into a pattern on the screen of numerous vertical lines spread out horizontally. Without diffraction and interference, the light would simply make two lines on the screen.

Figure 6 shows the pure constructive and destructive interference of two waves having the same wavelength and amplitude.

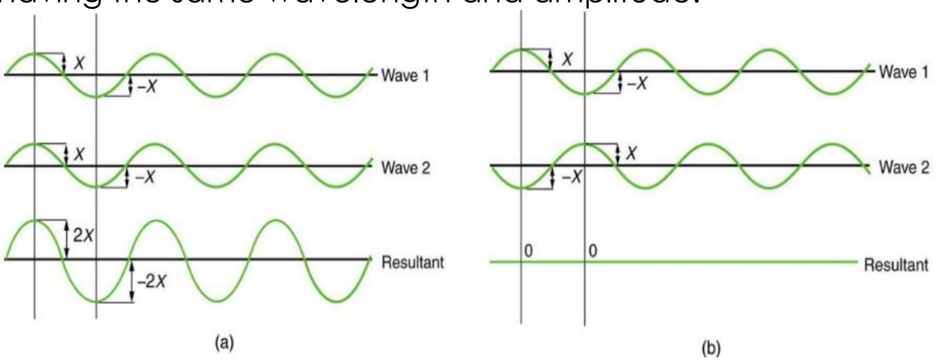

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Figure 6. The amplitudes of waves add. (a) Pure constructive interference is obtained when identical waves are in phase. (b)Pure destructive interference occurs when identical waves are exactly out of phase or shifted by half a wavelength.

When light passes through narrow slits, it is diffracted into semicircular waves, as shown in Figure 7a. Pure constructive interference occurs where the waves are crest to crest or trough to trough. Pure destructive interference occurs where they are crest to trough. The light must fall on a screen and be scattered into our eyes for us to see the pattern. An analogous pattern for water waves is shown in Figure 7b. Note that regions of constructive and destructive interference move out from the slits at well-defined angles to the original beam. These angles depend on wavelength and the distance between the slits.

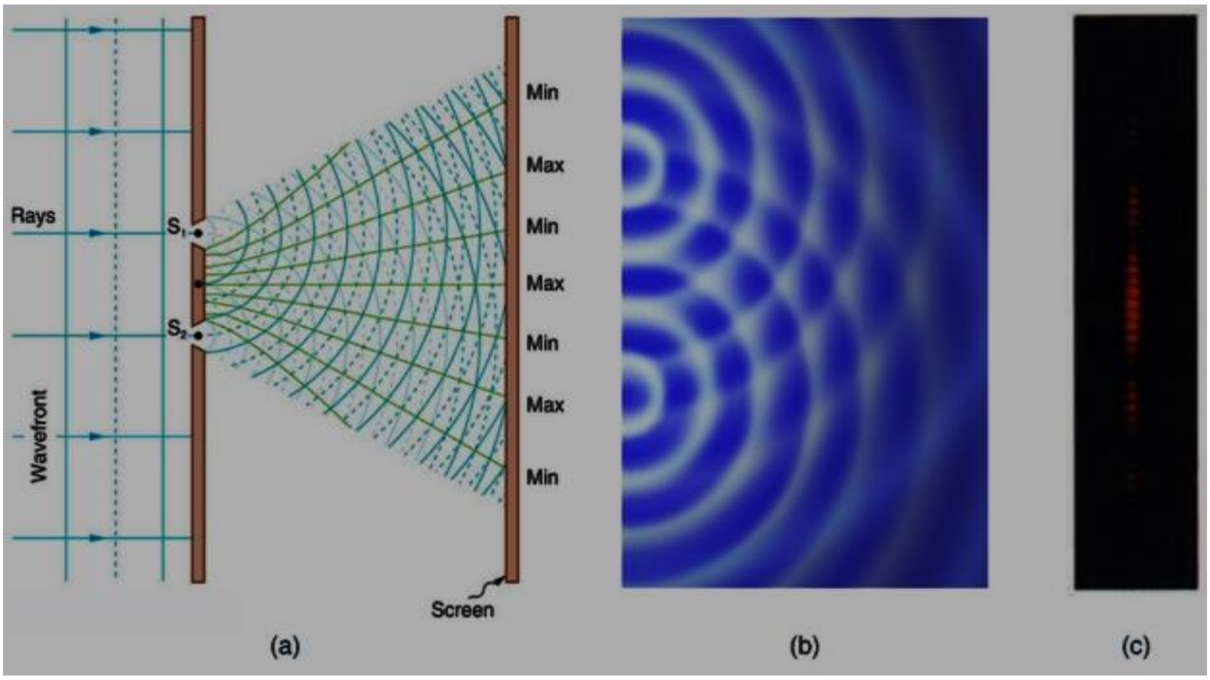

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Figure 7. Double slits produce two coherent sources of waves that interfere. (a) Light spreads out (diffracts) from each slit, because the slits are narrow. These waves overlap and interfere constructively (dark regions). We can only see this if the light falls onto a screen and is scattered into our eyes. (b) Double slit interference pattern of water waves nearly identical to that for light. Wave action is greatest in regions of constructive interference and least in regions of destructive interference. (c) When light that has passes through double slits falls on a screen, we see a pattern such as this. (credit: PASCO)

KEY POINTS

- **Young's double slit experiment** gave definitive proof of the wave character of light.
- An interference pattern is obtained by the superposition of light from two slits.
- There is constructive interference when $d \sin\theta = m\lambda$ (for $m = 0, 1, -1, 2, -2, \ldots$), where d is the distance between the slits, θ is the angle relative to the incident direction, and m is the order of the interference.

- There is destructive interference when $d \sin \theta = m\lambda$ (for $m = 0, 1, -1, 2, -2, \ldots$).
- Diffraction refers to various phenomena that occur when a wave encounters an obstacle. In classical physics, the diffraction phenomenon is described as the apparent bending of waves around small obstacles and the spreading out of waves past small openings.

TWO-SLIT DIFFRACTION PATTERN

The diffraction pattern of two slits of width a that are separated by a distance d is the interference pattern of two-point sources separated by d multiplied by the diffraction pattern of a slit of width a.

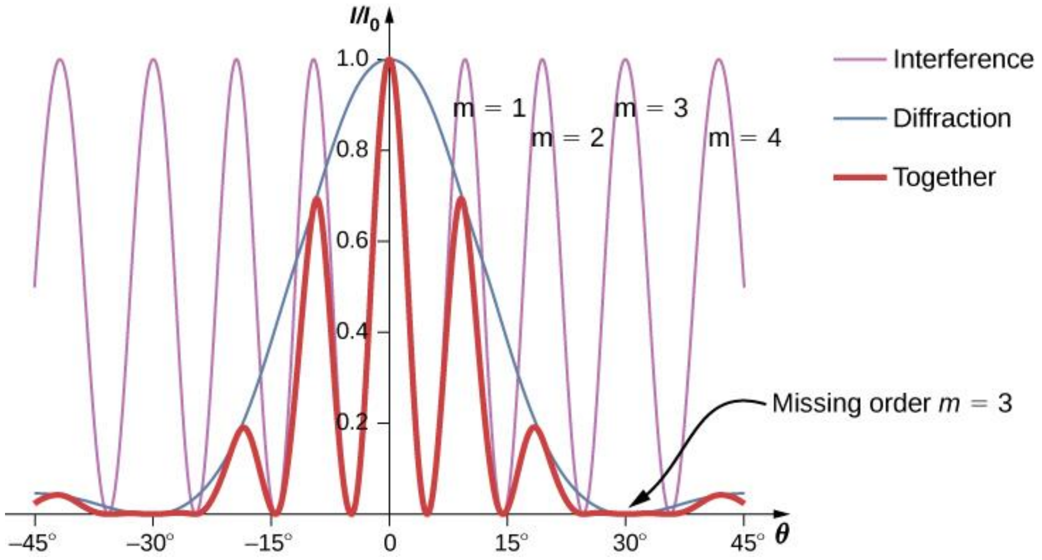

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Figure 8. Diffraction from a double slit. The purple line with peaks of the same height is from the interference of the waves from two slits; the blue line with one big hump in the middle is the diffraction of waves from within one slit; and the thick red line is the product of the two, which is the pattern observed on the screen. The plot shows the expected result for a slit width a=2λa=2λ and slit separation d=6λd=6λ. The maximum of m=±3m=±3 order for the interference is missing because the minimum of the diffraction occurs in the same direction.

Example 3: Intensity of the Fringes

Figure 8 shows that the intensity of the fringe for m = 3 is zero, but what about the other fringes? Calculate the intensity for the fringe at m=1m=1 relative to I_0 , the intensity of the central peak.

Strategy:

Determine the angle for the double-slit interference fringe, using the equation from Interference, then determine the relative intensity in that direction due to diffraction.

Solution:

From the chapter on interference, we know that the bright interference fringes occur at

$$d \sin \theta = m\lambda, \text{ or } \sin\theta = \frac{m\lambda}{d}$$

$$I = I_0\left(\frac{\sin\beta}{\beta}\right)^2, \text{ where } \beta = \frac{\phi}{2} = \frac{\pi \, \mathrm{a} \sin\theta}{\lambda}$$

Substituting from above,

$$\beta = \frac{\pi a \sin\theta}{\lambda} = \frac{\pi a}{\lambda} = \frac{m\lambda}{d} = \frac{m\pi a}{d}$$

For a=2λ, d=6λ, and m=1,

$$\beta = \frac{(1)\pi(2\lambda)}{6\lambda} = \frac{\pi}{3}$$

Then, the intensity is

$$I = I_0\left(\frac{\sin\beta}{\beta}\right)^2 = I_0\left(\frac{\sin\left(\frac{\pi}{3}\right)}{\frac{\pi}{3}}\right)^2 = 0.684\, I_0$$

Significance:

Note that this approach is relatively straightforward and gives a result that is almost exactly the same as the more complicated analysis using phasors to work out the intensity values of the double-slit interference (thin line in Figure 8). The phasor approach accounts for the downward slope in the diffraction intensity (blue line) so that the peak *near* m=1 occurs at a value of θ ever so slightly smaller than we have shown here.

***Example 4:* Two-slit Diffraction**

Suppose that in Young’s experiment, slits of width 0.020 mm are separated by 0.20 mm. If the slits are illuminated by monochromatic light of wavelength 500 nm, how many bright fringes are observed in the central peak of the diffraction pattern?

Solution:

From the angular position of the first diffraction minimum is

$$\theta \approx \sin\theta = \frac{\lambda}{a} = \frac{5.0\ x\ 10^{-7}m}{2.0\ x10^{-5}m} = 2.5 \text{ x } 10^{-2} rad$$

Using $d \sin\theta = m\lambda$ for $\theta = 2.5\ x\ 10^{-2}$ rad, we find

$$m = \frac{dsin\theta}{\lambda} = \frac{(0.20\ mm)(2.5\ x\ 10^{-2}rad)}{5.0\ x\ 10^{-7}m} = 10,$$

which is the maximum interference order that fits inside the central peak.

We note that m=±10are missing orders as θ matches exactly.

Accordingly, we observe bright fringes for

m=−9,−8,−7,−6,−5,−4,−3,−2,−1,0,+1,+2,+3,+4,+5,+6,+7,+8,and+9m=
−9,−8,−7,−6,−5,−4,−3,−2,−1,0,+1,+2,+3,+4,+5,+6,+7,+8,and+9

for a total of 19 bright fringes.

Now, I think you are ready to face the final stage of this journey. You will refresh your memories by answering the set of activities made for you.

Good Luck! *Don't forget to check your notes at all times as reference.*

Performance Task:

Directions: Read the given facts below. Afterwhich, do what is asked and place your answers short bond paper.

One of the scientists who worked on the interference of light was Thomas Young. In 1801, Young's efforts have been directed to measure the wavelength of light through experimental set-ups. In one of his experiments, he used sunlight that entered his room as the light source. He made a pinhole on his window shutter to control the amount of light, and then used a mirror to direct it. He used a small paper card to break the single beam into two. Because these separated beams come from the same source, they were considered to come from two coherent sources and that these rays would interfere. The interference pattern was then projected onto a screen where measurements could be made to determine the wavelength of light. This experiment is known as the ***double-slit experiment.***

Draw a comic strip to narrate how Young performed his experimentation on the interference of light. Be guided with the rubric that follows:

Comic Strip Rubric:

Category	4	3	2	1
Clarity and Neatness	Comic strip is easy to read and all elements are clearly written and drawn	Comic strip is easy to read and most elements are clearly written and drawn.	Comic strip is somewhat easy to read and some elements are clearly written and drawn.	Comic strip is hard to read and few elements are clearly written and drawn.
Spelling and Grammar	No spelling or grammatical mistakes in a comic strip with at least twenty lines of text.	No spelling or grammatical mistakes in a comic strip with at least fifteen lines of text.	One to three spelling or grammatical errors in the comic strip and at least ten lines of text.	More than four spelling and/or grammatical errors in the comic strip and/or less than ten lines of text.
Required Elements	Comic strip includes all required elements as well as a few additional elements.	Comic strip includes all required elements and one additional element.	Comic strip includes all required elements.	One or more required elements is missing from the comic strip.
Use of Time	Used time wisely and submitted output on time.	Used time wisely most of the time and submits output one day after the deadline.	Used time wisely some of the time and submits output two days after the deadline.	Wasted time in doing the activity and submits output one week after the deadline.

Adapted from https://www.pinterest.ph/pin/583427326707579862/

III. WHAT I HAVE LEARNED
EVALUATION/POST-TEST

Assessment 1: Comprehension check! √

MULTIPLE CHOICE: Choose the letter that corresponds to the correct answer. Write down your answer on your notebook/Answer Sheet. (1 point each item)

1. Interference of light is evidence that:
   a) the speed of light is very large
   b) light is a transverse wave
   c) light is electromagnetic in character
   d) light is a wave phenomenon
2. In a Young's double-slit experiment the center of a bright fringe occurs wherever waves from the slits differ in the distance they travel by a multiple of:
   a) a fourth of a wavelength
   b) a half a wavelength
   c) a wavelength
   d) three-fourths of a wavelength
3. In a Young's double-slit experiment, the slit separation is doubled. To maintain the same fringe spacing on the screen, the screen-to-slit distance D must be changed to:
   a) D/2 b) D 2 c) D 2 d) 2D
4. For destructive interference, the path difference is:
   a) odd number of half wavelength
   b) even number of half wavelength
   c) whole number of wavelengths
   d) even whole number of wavelengths
5. Constructive interference happens when two waves are:
   a) in phase b) out of phase c) zero amplitude
6. Two waves with phase difference 180 degrees have resultant of amplitude
   a) zero b) one
   c) same as the single wave d) doubles the single wave
7. What principle is responsible for light spreading as it passes through a narrow slit?
   a) diffraction b) refraction c) polarization d) interference
8. What principle is responsible for alternating light and dark bands when light passes through two or more narrow slits?
   a) interference b) refraction c) diffraction d) polarization
9. Light of wavelength 575 nm falls on a double slit and the third order bright fridge is seen at an angle of 6.5 degrees. What is the separation between the double slits?
   a) 15 micro−m b) 5.0 micro−m c) 10 micro−m d) 20 micro−m

10. Two light sources are said to be coherent if they
    a) are the same frequency, and maintain a constant phase difference
    b) are the same frequency
    c) same amplitude, and maintain a constant phase difference
    d) same frequency and amplitude

Well done! *My dear learners.*
Let's find out how much more you have learned by moving to the next activity.

Assessment 2: Solve it out! Tick-tock!

PROBLEM SOLVING:

Directions: Read each problem very carefully. Solve the problems and show your solutions on your notebook/Answer Sheet.

- Calculate the wavelength of light used in an interference experiment from the following data: Fringe width =0.03 cm. Distance between the slits and eyepiece through which the interference pattern is observed is 1m. Distance between the images of the virtual source when a convex lens of focal length 16 cm is used at a distance of 80 cm from the eyepiece is 0.8 cm.

Congratulations for having reached this part of our exploration!
I am so glad you nailed it!

Source: https://bit.ly/3mBqPtf

REFERENCES

College Physics. Authored by: OpenStax College. Young's Double Slit Experiment. Retrieved on 24 February 2021 from https://courses.lumenlearning.com/physics/chapter/27-3-youngs-double-slit-experiment/

C:\DOCUME~1\goderya\LOCALS~1\Temp\btv32.rtf (tarleton.edu). Retrieved from https://faculty.tarleton.edu/goderya/documents/Teaching/phy105/Phy105-Multiple-Choice-Ch-24-set%201.pdf

Encyclopedia Britannica, Inc. Youngs-double-slit-experiment. Accessed on 24 February 2021 from https://www.britannica.com/science/light/Youngs-double-slit-experiment

Khan Academy. (2021) Interference of Light. Accessed on 24 February 2021 from https://www.khanacademy.org/science/physics/light-waves/interference-of-light-waves/v/youngs-double-slit-part-2

Ling, S., Sanny J. and Moebs, W. (2016 September 29) Double Slit Diffraction. Accessed on 24 February 2021 from https://openstax.org/books/university-physics-volume-3/pages/4-3-double-slit-diffraction

Mustafa, M. (2020) Quizzes Interference and Diffraction. Retrieved on 24 February 2021 from https://quizizz.com/admin/quiz/5e7e3b59d12e00001bcdf26e/interference-diffraction

Pin on Classroom idea (pinterest.ph). Retrieved from https://www.pinterest.ph/pin/583427326707579862/

University Physics Volume 3. Young's double slit Interference. Retrieved on 24 February 2021 from https://opentextbc.ca/universityphysicsv3openstax/chapter/youngs-double-slit-interference/

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SYNOPSIS AND ABOUT THE AUTHORS

This self-learning kit contains interactive approach in explaining the phenomena of interference, defining constructive interference for a double slit and destructive interference for a double slit, relating the geometry of the two–slit experiment set up and properties of light to the properties of interference pattern, discussing the geometry of the diffraction experiment set up and relate the geometry of the diffraction experiment set up and properties of light to the properties of diffraction pattern.

The kit is just less than a week for discussing the connection between the concepts involved. It is made simple, fun, easy and interactive to help facilitate independent learning while learners are at home.

ANSWER KEY

PRE-TEST: FINDING MY PERFECT MATCH!

1. A
2. C
3. F
4. B
5. D
6. E

Assessment 1: Comprehension check! √

1. D
2. C
3. D
4. A
5. A
6. A
7. A
8. A
9. A
10. A

Assessment 2: Solve it out! Tick-tock! ☺

1. λ=6000A°.

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