Week 11

Physics 1409/1430 – Physics 2

Hello and Welcome to the weekly resources for PHY 1409/1430 – Physics 2!

This week is Week 11 of classes, and typically in this week of the semester, your professors are covering these topics below. If you do not see the topics your particular section of class is learning this week, please take a look at other weekly resources listed on our website for additional topics throughout the semester.

We also invite you to take a look at the group tutoring chart on our website to see if this course has a group tutoring session offered this semester.

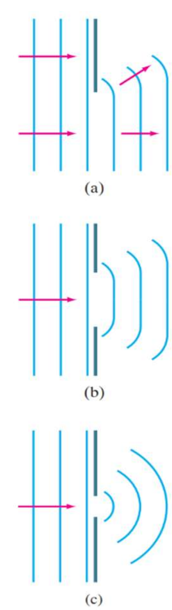
If you have any questions about these study guides, group tutoring sessions, private 30-minute tutoring appointments, the Baylor Tutoring YouTube channel or any tutoring services we offer, please visit our website www.baylor.edu/tutoring or call our drop in center during open business hours, M-Th 9am-8pm on class days, at 254-710-4135.

Important Information

Important Conventions

Keywords: Diffraction, Interference, Diffraction Gratings, Polarization

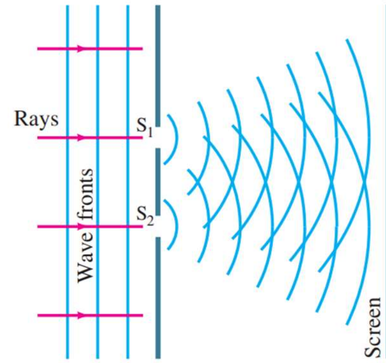
Wave Nature of Light:



Light is pretty weird. Light acts as a wave and like rays. Last week you looked at how light acts as rays and bends or reflects. Now we will discuss its wave nature. Light is an electromagnetic wave, and it is composed of the electric and magnetic field. The two fields interact with one another to transport energy. Since light is a wave, we must also learn to imagine it as one, which involves using Huygen's Principle for waves.

Essentially, what Huygens proposes is that each wave is composed of infinite points which all travel together, we consider all of these points as part of the wave, and these points radiate outward and can interact with points on another wave. Even if there is curved nature of each wave, they are still part of the same wave.

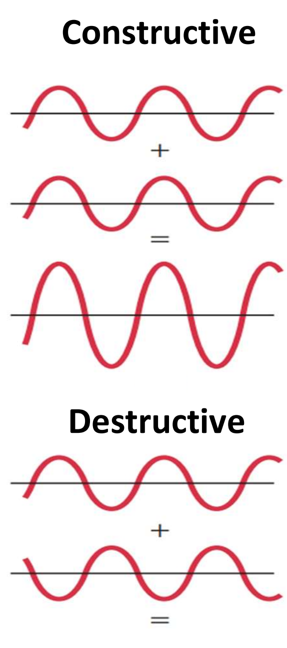
This principle helps us visualize how light travels and the effect obstacles have on it. When the wave hits an obstacle, the part of the wave behind the obstacle bends. This bending of the wave is what is called diffraction. Using Huygens Principle, we can see the effect of diffraction of waves in the figure to the right.



Now let's use this new knowledge to see the behavior of the wave nature of light as it passes through another medium. Earlier, with Snell's law, you learned that when light goes into another medium, it changes its velocity. Due to this, we saw the path of light bends towards or away from the normal. But light is also a wave, so the change in the velocity of light affects its wave nature as well. One component of light as a wave that remains constants is the frequency of the wave. Hence, when light passes into a new medium and refracts, it changes the wavelength of light. The wavelength of light in the new medium can be calculated using:

$$\lambda_n = \frac{\lambda}{n}$$

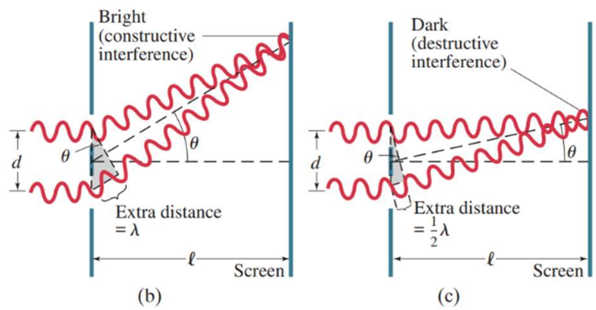
Interference:



Using Huygens principle and diffraction, the wave nature of light was determined by Thomas Young in the famous double slit experiment. In this experiment, a source of light is placed behind a large board with two slits. A screen is placed on the other side of the boards. If light behaved only like a ray, there would only be two lines on the screens. But, when light passed through the two slits, it produced a pattern of lines decreasing in intensity on the screen. This pattern is called the interference pattern. This pattern can only be produced if light travels as a wave! To understand the bands of light produced, remember physics 1, where you learned about waves for the first time. You learned that when two waves are "in phase", which means their peaks and troughs are produced at the same intervals, those waves add up together, which we called a constructive interference. If the waves were "out of phase", which means the peak of one wave and trough of the other wave were at the same position, they eliminated one another, which we called a destructive interference. These phenomena produced the patterns. When light passes through the slits, the waves diffract in both slits and the two resulting waves produce constructive interferences where the light bands are present and no bands where the destructive interference occurs. This pattern is affected by the wavelength of light and the distance between the two slits. These bands form at intervals of angles from the position of the two slits. We use the following equations to determine the angles for the constructive interference and destructive interference bands:

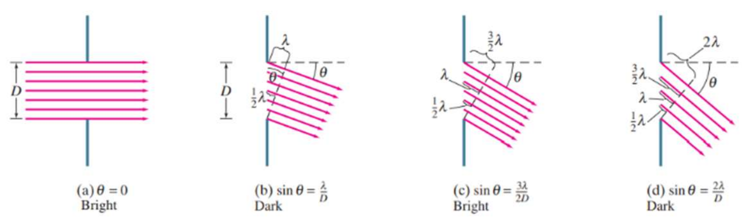
$$d \sin\theta = m\lambda, \qquad m = 0, 1, 2, \cdots. \qquad \begin{bmatrix}\text{constructive} \\ \text{interference} \\ \text{(bright)}\end{bmatrix}$$

$$d \sin\theta = \left(m + \tfrac{1}{2}\right)\lambda, \qquad m = 0, 1, 2, \cdots. \qquad \begin{bmatrix}\text{destructive} \\ \text{interference} \\ \text{(dark)}\end{bmatrix}$$

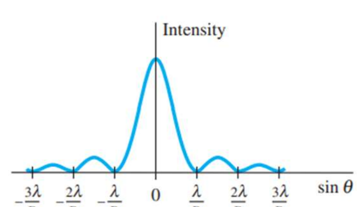


The m refers to the order of the band. The first order is m = 1. The center bands, which has the highest constructive interference is called the central fringe, at m =0.

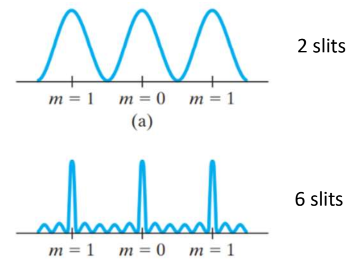
This experiment provided the start for the wave theory of light. It inspired further study of diffraction. What happens when we now use only 1 slit? For this regime, monochromatic light is used, which means light with rays travelling in the same path parallel to one another, so when the rays hit the slit, they diffract and produce the bands. The pattern yet again emerges in a similar pattern, where the width of the slit determines the angle, each band makes. The center band is always the one with the highest intensity. Based on the observations, the following equation was derived to determine the position of the minima (black band).



$$D \sin\theta = m\lambda, \qquad m = \pm 1, \pm 2, \pm 3, \cdots,$$



Finally, we have diffraction gratings. Here, we have multiple, equally spaced slits. Following the same behavior, they produce maxima at predictable angles. What is special is that they have the same intensity. Another property it has is that if you increase the number of slits, the peaks of the maxima get narrower.

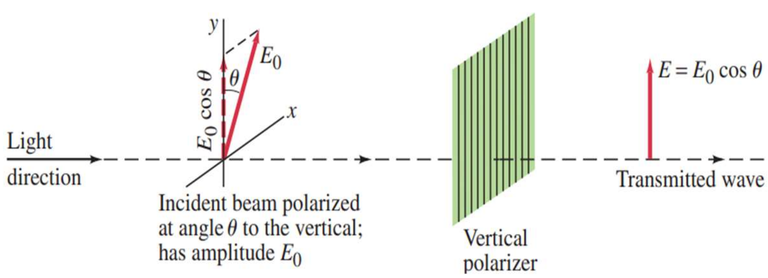


$$\sin\theta = \frac{m\lambda}{d}, \qquad m = 0, 1, 2, \cdots \qquad \begin{bmatrix}\text{diffraction grating} \\ \text{principal maxima}\end{bmatrix}$$

What is going to be essential is keeping track of the type of problem you are looking at. Make sure you know whether it is two slits, one slit or a diffraction grating so that you use the correct equations and conventions. Also make sure you know whether you are looking at the maxima or minima.

Polarization:

Polarization is something we can do to light. We can use the wave property of light to determine the direction in which the wave motion is propagating- meaning the oscillations are occurring in a particular plane. We can choose which plane of oscillation for light we want to use.". Think of this as waves trying to get through a very narrow slit, which is parallel to the y-axis. Because of this interaction, only waves that are oscillating in the y axis can pass though the slit or come out of it. We use sheets with a lot of these narrow slits (called a polaroid sheet) to isolate a particular linearly polarized wave of light. So, when any form of light waves passes



through the sheet, it is polarized. The polarization changes the intensity of the light waves that pass though. The effect of the change depends on the angle that the light wave makes with polarization plane. We calculate the new intensity using the following formula.

$$I = I_0 \cos^2\theta, \qquad \begin{bmatrix}\text{intensity of plane-polarized} \\ \text{wave passed by polarizer}\end{bmatrix}$$

Now, if you cross two polarizers that have polarizing planes perpendicular to one another, they eliminate all of the light and none passes through!

What is important to do when you have a system of polarizers is to keep track of the changes to intensity as it passes through each one. Remember, the order matters!!

CHECK YOUR LEARNING

1. The second order bright fringe of 500 nm light is observed 21° when the light falls on two narrow slits. How far apart are the slits?
2. A grating that has 5000 slits per cm produces a third order fringe at 30° angle. What wavelength of light is being used?
3. If a soap bubble is 80 nm thick, what wavelength is most strongly reflected at the center of the outer surface when illuminated normally by white light? (n=1.33)

THINGS YOU MAY STRUGGLE WITH

1. The Huygens Principle and its application for the law or refraction and for diffraction is a difficult topic to conceptualize. The best imagery to use is imagining how water would flow in the same scenarios. Imagine the waves you make when you tap the water and how it interacts with other things in the water.
2. The bright and dark fringes formed by the light passing through the slits is also difficult to understand because it's not easy to visualize. Remember the constructive and destructive interference, their relationship to the waves interacting with one another. The slit experiment and understanding them are central to this chapter.
3. Polarization is another major topic to be careful with. Here, I would also use the visual of the flow of water through the grates and how it affects how much water gets to pass through.

Thanks for checking out these weekly resources! Don't forget to check out our website for group tutoring times, video tutorials and lots of other resource: www.baylor.edu/tutoring ! Answers to check you learning questions are below!

Answers: 1. 2.79 µm, 2. 3.33 nm, 3) 425.6 nm

All images are from Physics: Principles with Applications (7th Edition) by Douglas C. Giancoli