Physics 4C
Chapter 35: Interference

"For every minute you are angry, you lose 60 seconds of happiness." – Ralph Waldo Emerson

"Consider how much more often you suffer from your anger and grief than from those very things for which you are angry and grieved." – Marcus Aurelius

"Forgive all who have offended you, not for them, but for yourself." – Harriet Uts Nelson

"Holding on to anger is like grasping a hot coal with the intent of throwing it at someone else; you are the one who gets burned." – Buddha

Reading: pages 958 – 981

Outline:

⇒ interference
    constructive and destructive interference
    interference because of difference in path length
    interference because of indexes of refraction
⇒ interference from thin films
    reflection phase shifts
    thin-film interference
⇒ Michelson's interferometer (read on your own)
⇒ Huygen's principle
⇒ diffraction
⇒ Young's interference experiment
    two-slit interference
    location of maxima and minima
⇒ coherence
⇒ intensity in double-slit experiment

Problem Solving Techniques

You should know the relationship between the wave speed in a material medium and the wave speed in vacuum. You should also know that when a wave enters a medium, the frequency does not change but the wave speed and wavelength do.

You should know how to calculate the phase difference of two waves. If wave 1 travels a distance r_1 in a medium with refractive index n_1 and wave 2 travels a distance r_2 in a medium with refractive index n_2, the difference in phase is $\phi = (2\pi/\lambda)(n_2r_2 - n_1r_2)$.

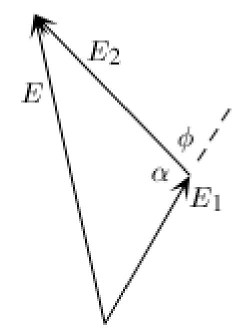
You should understand the conditions for the formation of bright and dark fringes by a double-slit arrangement. Find an expression for the phase difference between the waves from the two slits and set it equal to $2\pi m$ for a bright fringe and $2\pi(m + ½)$ for a dark fringe. In many cases, the phase difference is due to the difference in distance traveled by the waves. This is $d\sin\theta$, where d is the slit separation. If a medium with thickness L and refraction index n is placed in front of a slit, you must add $2\pi(n - 1)L/\lambda$ to the phase of the wave through that slit.

You should also be able to calculate the intensity at points on the interference pattern, relative to the intensity at the center of the central maximum. If the waves have equal amplitudes at the screen, then $I = I_m\cos^2(\phi/2)$. Learn to use phasor diagrams to sum two or more waves. See the Mathematical Skills section below.

Some problems deal with the interference of waves reflected from the front and back surfaces of a thin film. The difference in phase comes from the difference in distances traveled and, in some cases, from the change in phase by π on reflection from a medium with a higher index of refraction. Don't forget to think about both of these sources of phase difference. Also, don't forget to use the wavelength of the wave in the film, not the wavelength in vacuum, to compute the phase difference.

Some problems deal with the Michelson interferometer. Again you calculate the phase difference for the two waves and set it equal to 2πm for a bright fringe and 2π(m + ½) for a dark fringe. The phase difference may be due to the different distances traveled by the waves and due to materials with different indices of refraction in the two arms of the interferometer.

Mathematical Skills



A few problems deal with the addition of two waves with different amplitudes. Suppose one wave is given by $E_1\sin(\omega t)$ and the second by $E_2\sin(\omega t + \phi)$. The phasor diagram is shown to the right. According to the law of cosines, $E^2 = E_1^2 + E_2^2 - 2E_1E_2\cos\alpha$. Since $\alpha = 180° - \phi$ and $\cos(180° - \phi) = -\cos\phi$, this can be written

$$E^2 = E_1^2 + E_2^2 + 2E_1E_2\cos\phi.$$

Use this equation to calculate the amplitude of the resultant.

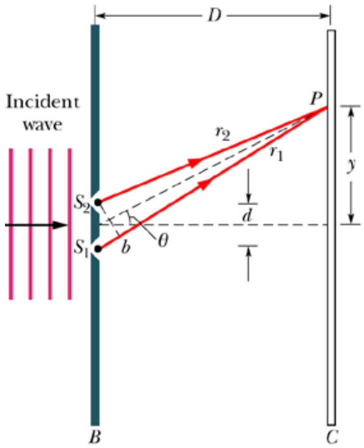
If the waves are in phase, then $\phi = 0$, $\cos\phi = 1$, and $E^2 = E_1^2 + E_2^2 + 2E_1E_2 = (E_1 + E_2)^2$. If the waves are 180 ° out of phase, then $\cos\phi = -1$ and $E^2 = E_1^2 + E_2^2 - 2E_1E_2 = (E_1 - E_2)^2$. These results should agree with what you expect.

If $E_1 = E_2$, then the general expression reduces to $E^2 = 2E_1^2(1 + \cos\phi)$. Now $\cos\phi = \cos(\phi/2 + \phi/2) = \cos^2(\phi/2) - \sin^2(\phi/2) = 2\cos^2(\phi/2) - 1$, where $\cos^2(\phi/2) + \sin^2(\phi/2) = 1$ was used. Thus, $E^2 = 4E_1^2\cos^2(\phi/2)$ and $E = 2E_1\cos(\phi/2)$, in agreement with the result given in the text.

Questions and Example Problems from Chapter 35

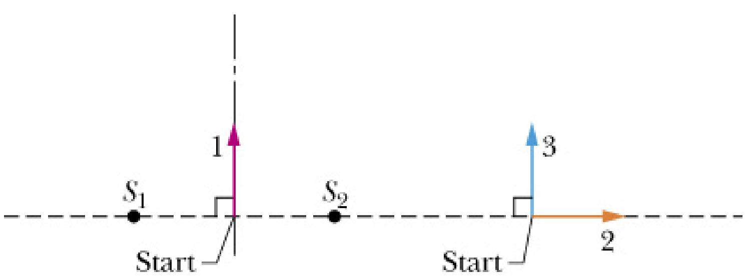
Question 1

Is there an interference maximum, a minimum, an intermediate state closer to a maximum, or an intermediate state closer to a minimum at point P in the figure below if the path length difference of the two rays is (a) 2.2λ, (b) 3.5λ, (c) 1.8λ, and (d) 1.0λ? For each situation, give the value of m associated with the maximum or minimum involved.



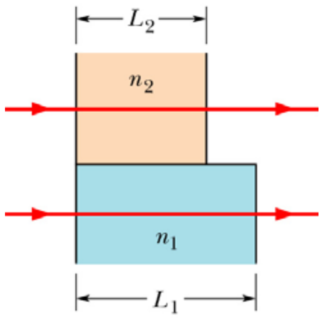
Question 2

The figure shows two sources S_1 and S_2 that emit radio waves of wavelength λ in all directions. The sources are exactly in phase and are separated by a distance equal to 1.5λ. The vertical broken line is the perpendicular bisector of the distance between the sources. (a) If we start at the indicated start point and travel along path 1, does the interference produce a maximum all along the path, a minimum all along the path, or alternating maxima and minima? Repeat for (b) path 2 and (c) path 3. *Explain your reasoning.*



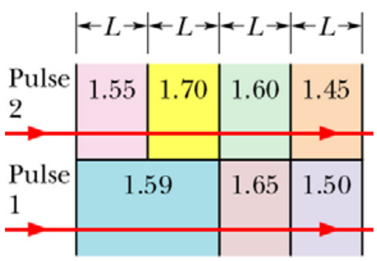
Problem 1

Two waves of light in air, of wavelength 600.0 nm, are initially in phase. They then travel through plastic layers as shown in the figure below, with $L_1 = 4.00$ µm, $L_2 = 3.50$ µm, $n_1 = 1.40$, and $n_2 = 1.60$. (a) In wavelengths, what is their phase difference after they both have emerged from the layers? (b) If the waves later arrive at some common point, what type of interference do they undergo?



Problem 2

In the figure below, two pulses of light are sent through layers of plastic with the indexes of refraction indicated and with thicknesses of either L or 2L as shown. (a) Which pulse travels through the plastic in less time? (b) In terms of L/c, what is the difference in the traversal times of the pulses?



Problem 3
In a double-slit experiment interference experiment, the slit separation is 2.00 μm, the light wavelength is 500 nm, and the separation between the slits and the screen is 4.00 m. (a) What is the angle between the center and the third bright fringe? (b) If we decrease the frequency of light by 10.0% of its initial value, how far along the screen and in what direction does the bright fringe shift?

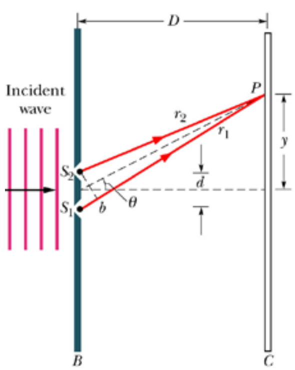
Problem 4
Suppose that Young's experiment is performed with blue-green light of wavelength 500 nm. The slits are 1.20 mm apart, and the viewing screen is 5.40 m from the slits. How far apart are the bright fringes?

Problem 5

Laser light of wavelength 632.8 nm passes through a double-slit arrangement at the front of a lecture room, reflects off a mirror 20.0 m away at the back of the room, and then produces an interference pattern on a screen at the front of the room. The distance between adjacent bright fringes is 10.0 cm. (a) What is the slit separation? (b) What happens to the pattern when the lecturer places a thin cellophane sheet over one slit, thereby increasing by 2.50 the number of wavelengths along the path that includes the cellophane?

Problem 6

In a double slit experiment (see the figure below), λ = 546 nm, d = 0.10 mm, and D = 20 cm. On a viewing screen, what is the distance between the fifth maximum and the seventh minimum from the central maximum?

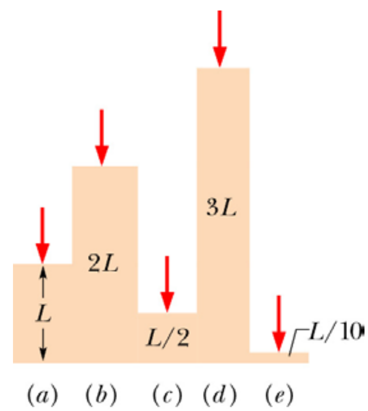


Problem 7

The rhinestones in costume jewelry are glass with index of refraction 1.50. To make them more reflective, they are often coated with a layer of silicon monoxide of index of refraction 2.00. What is the minimum coating thickness needed to ensure that light of wavelength 560 nm and of perpendicular incidence will be reflected from the two surfaces of the coating with fully constructive interference?

Problem 8

In the figure to the right, light of wavelength 600 nm is incident perpendicularly on five sections of a transparent structure suspended in air. The structure has index of refraction 1.50. The thickness of each section is given in terms of L = 4.00 μm. For which sections will the light that is reflected from the top and bottom surfaces of that section undergo fully constructive interference?



Problem 9

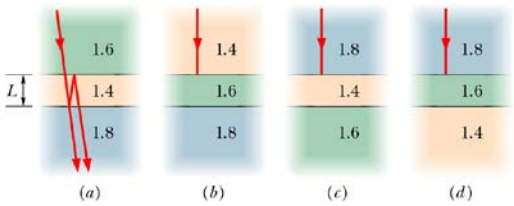
The reflection of perpendicularly incident white light by a soap film in air has an interference maximum at 600 nm and a minimum at 450 nm, with no minimum in between. If n = 1.33 for the film, what is the film thickness, assumed uniform?

Problem 10

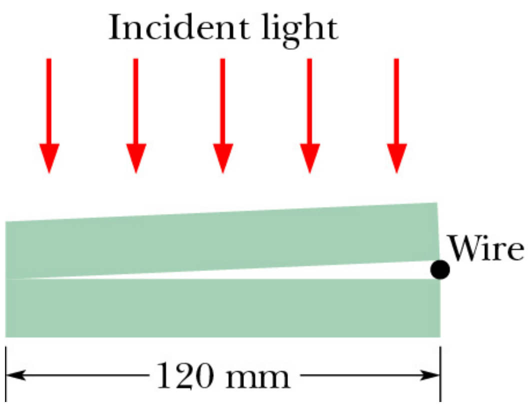
In the figure below, light is incident perpendicularly on four thin layers of thickness L. The indexes of refraction of the thin layers and of the media above and below these layers are given. Let λ represent the wavelength of the light in air, and n_2 represent the index of refraction of the thin layer in each situation. Consider only the transmission of light that undergoes no reflection or two reflections, as in figure a below. For which of the situations does the expression

$$\lambda = \frac{2Ln_2}{m}, \text{ for } m = 1, 2, 3, \ldots,$$

give the wavelengths of the transmitted light that undergoes fully constructive interference?



Problem 11
In the figure below, a broad beam of light of wavelength 683 nm is sent directly downward through the top plate of a pair of glass plates. The plates are 120 mm long, touch at the left end, and are separated by a wire of diameter 0.048 mm at the right end. The air between the plates acts as a thin film. How many bright fringes will be seen by an observer looking down through the top plate?



Problem 12

In the figure below, an airtight chamber 5.0 cm long with glass windows is placed in one arm of a Michelson interferometer. Light of wavelength λ = 500 nm is used. Evacuating the air from the chamber causes a shift of 60 fringes. From these data, find the index of refraction of air at atmospheric pressure.