Optics

Interference

Consequence of Fresnel equations relevant to interference:

When light is reflected by an interface between low and high index of refraction the electric field reflected is inverted (equivalent to a delay of half a wavelength).
On the other hand, when light is reflected by an interface between high and low index of refraction the electric field reflected is in phase (zero delay).

Problem 1.- Blue light of wavelength 480 nanometers is most strongly reflected off a thin film of oil on a glass slide when viewed near normal incidence.
Assuming that the index of refraction of the oil is 1.2 and that of the glass is 1.52, what is the minimum thickness of the oil film (other than zero)?

(A) 150 nm
(B) 200 nm
(C) 300 nm
(D) 400 nm
(E) 480 nm

Solution: The two reflections that cause interference are from the air oil interface and the oil glass interface. In both cases, the electric field reflected is shifted 180º, so to have a strong reflection they are already in phase.
A thickness of zero would give a strong reflection; the next possibility is a thickness such that the extra path covered by the second reflection is one wavelength longer, so:

$$2\times thickness = \lambda_{oil} \rightarrow thickness = \frac{\lambda_{oil}}{2} = \frac{\lambda_{air}}{2n_{oil}} = \frac{480nm}{2\times 1.2} = 200nm \text{ answer } \mathbf{(B)}$$

Problem 2.- A thin anti-scratching coating of index of refraction 1.28 is applied on a lens made of glass (index of refraction 1.52). When illuminated with white light the lens looks red with a wavelength at maximum intensity of 680nm. Calculate the thickness of the coating.
[Assume it is the thinnest coating that would give you that reflection].

Solution: Notice that according to Fresnel's equations the electric field changes sign when reflected both at the air-coating interface and again at the coating-glass interface. This means that the two waves would interfere constructively if the coating had a thickness of zero.
The next possibility is that the coating has a thickness such that the extra path is equal to one wavelength, so:

$$2\times thickness = \lambda_{coating} \rightarrow thickness = \frac{\lambda_{coating}}{2} = \frac{\lambda_{air}}{2n_{coating}} = \frac{680nm}{2\times 1.28} = \mathbf{266\ nm}$$

Problem 3.- To test how flat a slab of glass is you put it in contact with a known flat surface (where the imperfections are much less than one wavelength) and illuminate it with red light of wavelength 633nm.
You notice that there is an air gap and there are four bright fringes between the point of contact of the two surfaces and the thickest part of the gap (which is itself the fourth bright fringe).
Calculate the largest separation between the two surfaces.

Solution: According to Fresnel's equations, the electric field changes sign when reflected at the air-glass interface, but not at the glass-air interface. This means that the two waves would interfere destructively if the gap had a thickness of zero.
The first bright fringe will happen when the gap is such that the extra path covered by one of the waves is $\lambda/2$, the second fringe when it is $3\lambda/2$, the third $5\lambda/2$ and the fourth $7\lambda/2$, so the gap has to be $7\lambda/4 =$ **1.1μm**

Problem 4.- An extremely thin layer of MgF_2 (n=1.38) is deposited on glass (n=1.52) and illuminated with white light. The film first appears dark at 660 nm. What is the next shorter wavelength at which the film will appear dark on reflection?

(A) 132 nm
(B) 165 nm
(C) 220 nm
(D) 330 nm
(E) 495 nm

Solution: Light will be reflected at the air-MgF_2 interface and again at the MgF_2-glass interface. In both instances, the reflected electric field will be inverted, so in principle the two reflections will interfere constructively, however the second reflection covers the thickness of the layer twice.

If that extra distance is half a wavelength, the two reflections will cancel each other and the coating will look dark. The next time it will happen is when the extra distance is 3/2 of the wavelength, so it will happen for 220nm.

Answer: **C**

Problem 5.- Blue light of wavelength 456 nanometers is most strongly reflected off a thin flake of mica on a silicon wafer when viewed near normal incidence.
Assuming that the index of refraction of the mica is 1.52 and that of the silicon is 3.42, what is the minimum thickness of the flake (other than zero)?

Solution:

- The light reflected at the air-mica interface will be reflected with the electric field reversed (a phase shift of 180 degrees) and the same will happen at the mica-silicon interface.
- So the two reflections will be in phase except for the path in and out of the thickness of the flake.

- If the extra distance equals one wavelength the two reflections interfere constructively giving maximum intensity, so it will happen when the thickness is half a wavelength
- Be careful to divide 456 nanometers by 1.52 to get the wavelength inside the mica and then divide by 2 to get the thickness

$$t = \frac{\lambda}{1.52 \times 2} = \mathbf{150\ nm}$$

Problem 6.- Red light from a laser falls on a pair of very narrow slits separated by a small distance, and bright fringes separated by 1.0 millimeter are observed on a distant screen. If the distance between the slits is doubled, what will be the separation of the bright fringes? Explain.

Solution: if the distance between the slits is doubled, the separation of the bright fringes will be **halved.**

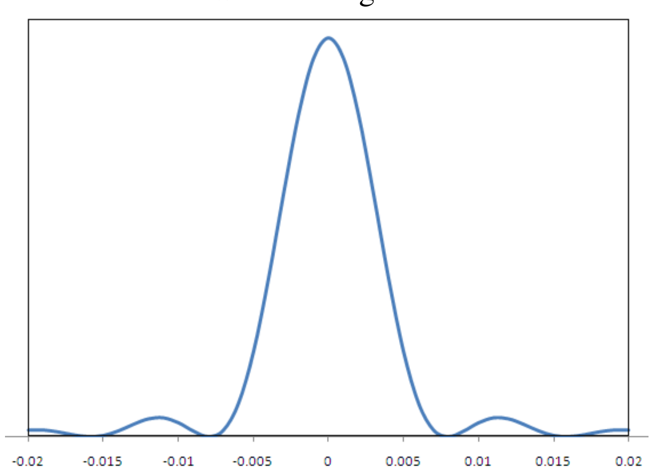
Problem 7.- Use a spreadsheet program to calculate the diffraction pattern produced by a single slit of width 80 microns on a screen 1m away when illuminated by light of wavelength $\lambda = 633\text{nm}$.
[The pattern should be visible in the interval of -2cm to +2cm]

Your simulation will show not only the expected, elementary profile with a center twice as long as the wings, but the value of the electric field squared will also give you an estimation of the actual intensity.

- Calculate the ratio of the maximum intensity to the maximum of one of the first order fringes. Compare this ratio to the published calculated value (you can find this ratio in a textbook or online).

- Observe what happens if you reduce the screen distance (the 1m length). The changes observed will be an indication of the transition from Fresnel (short distance) to Fraunhoffer (long distance) diffraction. Write down your observations.

Solution: The spreadsheet calculates the intensity and phase of the slit, which is divided in small sources of radiation. The results are shown in the figure:



- We observe a ratio between the central peak and the first fringe of about 21, which is the theoretical expectation. This tells us that the simulation is realistic.
- When reducing the screen distance we observe that the fringe peaks become "shoulders" of the main, central peak.

Problem 8.- A uniform thin film of soapy water with index of refraction n = 1.32 is viewed in air via reflected light. The film appears dark for long wavelengths and first appears bright for 570 nm. What is the next shorter wavelength at which the film will appear bright on reflection?

(A) 120 nm
(B) 190 nm
(C) 285 nm
(D) 380 nm
(E) 500 nm