***Reflection and Thin Film Interference***



***Reflection & Phase:*** Light reflecting from a boundary can do so in phase (sort of a free end reflection) or out of phase (a fixed end reflection). The thing that determines whether the reflected wave is in or out of phase is the difference in speed for light in the two media. The wave will undergo a 180° phase change when it is reflected from a medium that has a ***higher*** index of refraction than the one it came through.

There will be no phase change if the wave is reflected from a medium that has a ***lower*** refractive index.

You would get the phase change for light traveling through air and reflecting off glass. Glass has a higher index of refraction than air.

You would not get a phase change for light traveling through glass and being reflected off water, since water has a lower index of refraction than glass.

***This lead us to***:

***Thin Film Interference:*** This occurs when light travels through a very thin layer of transparent material. Thin film interference occurs with oil films, soap bubbles, etc.



Light that is incident on the film has several things happen to it. Some of the light is reflected off the top of the film. These waves have a 180° phase change since the index of refraction for the film is greater than for air. Next, the light that goes into the film is refracted as it travels from air into the film. Some of the light goes into the air on the other side of the film. This light is refracted (back the other way). Finally, some of the light is reflected off the air/film surface. This light does not undergo any phase change.

 We have a lovely drawing showing how all this works. (See drawing to the right.)

The film has a thickness of ***t***.

We let ***n*** be the index of refraction for the film. The index of refraction for air is, of course, 1.

**Ray 1** reflecting off the surface of the film has a 180° phase change.

**Ray 2** reflecting off the opposite film surface has no phase change.

The two rays are out of phase.

The two waves will recombine when you look into the film and the rays enter your eyes. If the path difference is half of the wavelength, or an odd multiple of the wavelength, then the waves will end up in phase and you will see constructive interference – a bright fringe.

The basic kind of problem involves finding the minimum thickness that will cause constructive or destructive interference. This minimum would be when the wave came straight down onto the film. This means that the angle of incidence is zero.

The surface reflected wave undergoes a 180° phase change. The wave that reflects off the bottom surface does not undergo a phase change. In order to get the bottom reflected wave to match up with the first one, the path difference must be different by a half wavelength. The totals distance that the wave travels is twice the thickness of the film, 2 ***t***. This must equal half a wavelength.

Now the wavelength we’re talking about here is the wavelength of the light in the film. This is different than the wavelength in air (or the first medium if it ain’t air). So we have to carefully specify which wavelength we’re talking about.

We’ll call the wavelength in the film ***λf***. This means that the minimum thickness is given by: 

Unfortunately, we’re usually given the wavelength of the light in a vacuum, which is the same as the wavelength in air for our purposes, right? But we aren’t given the wavelength of the light in the film. So what do we do? Oh, poor poor pitiful us, whatever will we do?

Well, we can figure this out, can’t we? We can ***solve*** for the wavelength in the film! We start with the equation for the index of refraction.

 We solve for the speed of light .  This is true for any medium.

So: 

The speed of a wave is given by: 

We can plug this into our equation for *v*.

 The frequency is the same in each medium:

 so the wavelength for the film is: 

So we can plug that into the equation:  

Index of Refraction and Wavelength:



We’ve developed a very useful relationship in solving our little problem: .

In general, we see that: 

Sadly, you won’t be given this equation on the AP Physics Test. So be prepared to figure it out.

* Light with a wavelength of 555 nm is incident on a soap bubble. What is the minimum thickness for thin film interference to take place for this wavelength of light? The index of refraction for the bubble goop is 1.35.

The minimum thickness is 

The path difference has to be half the wavelength of the light in the film and, of course, the path difference is twice the thickness of the film.

But we don’t know what the wavelength of the light is in the film – we can figure it out however.





***Destructive Interference on Thin Film:*** Destructive interference will take place if the path difference is equal to a single wavelength or an integer multiple of the wavelength. To find the minimum thickness, we go through the same deal. The minimum path length is 2 *t*, and it must be an integer multiple.



For the case where m is 1, we get 

* Find minimum film thickness for destructive interference in reflected light if a thin film (n = 1.35) is illuminated by light that has wavelength of 585 nm.

The minimum thickness is 





***Thin Coatings:*** If the thin film rests on a surface that has a different index of refraction than what is on the on the other side, it is a thin coating. Thin coatings are used on glass lenses. Another example of a thin coating would be an oil slick, where a thin layer of oil rests on the water surface.

If the coating has a lower index of refraction than the surface it rests on, light rays will undergo a 180° phase change from the bottom surface of the film as well as the upper surface.

This makes everything opposite to what we saw for a thin film.

If the surface the coating rests on has a smaller index of refraction than the coating, then it is the same as for a thin film and we don’t need to go anywhere else with the thing.

So for your standard thin coating, both reflected waves have the same phase. The interference again will depend on the path difference. You can see that the minimum thickness for ***constructive interference*** will be given by: 

The minimum thickness for ***destructive interference*** is given by: 



* Find the minimum film thickness for constructive interference in reflected light for a coating (*nf* = 1.30 ) on glass (*ng*  = 1.60) is illuminated by light that has wavelength of 555 nm.

 

We know that 



***Non Reflective Coatings:***



Non reflective coatings are used on camera lenses to get rid of unwanted glare and light highlights. To get rid of the flares, we want destructive interference to take place. This gives us the least amount of reflection.

Both rays undergo a 180° phase change.

Net change in phase from reflection is zero.

To get destructive interference:

 

* A camera lens needs coating that will minimize reflection. *nf* = 1.25. Figure wavelength of light at 545 nm. What thickness?

 

