PHYSICS 8B – Notes to help you prepare for Midterm 2

Things you need to know for the second midterm:
- *EM waves* (Maxwell's equations, wave number, wavelength, frequency, Poynting vector, the sinusoidal form of E and B fields of an EM wave, wave intensity and power)
- *Reflection* and *refraction* (Snell's law)
- *Ray tracing* with lens and mirrors (bring straight edges to the exam)
- Know how to **derive** the formulas of *double slit diffraction* and *thin film interference*.
- Formula for *resolvability* for diffraction grating

----- slit:

$$\theta \approx \sin\theta = \frac{\lambda}{a}$$

where θ is the angular separation of the 2 objects (light sources), measured from the central peak to the first minimum on the screen, a is the width of the slit

----- circular aperture:

$$\theta \approx \sin\theta = \frac{1.22\lambda}{D}$$

where D is the aperture diameter.
- Time dilation and length contraction

Thin Films:

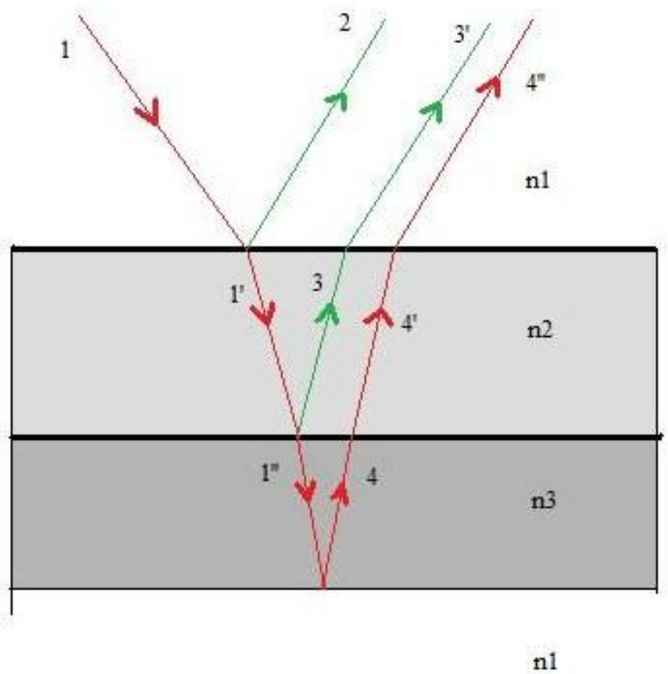
There are two things related to interference patterns:
1. path difference
2. phase difference

The *path difference* for thin film interference is 2d, where d is the thickness of the film.
In the picture I've inserted here, let's say d_1 is the thickness of the light gray film (with refractive index n_2). The photons that form ray 3' have travelled approximately a distance $2d_1$ longer than the photons that form ray 2.

About *phase difference*:
Recall that for EM wave, the electric field (and magnetic field) of the wave has the form:

$$E = E_0 \sin(kx - wt)$$

Where $\phi = wt$ is the phase of the wave.
When a light ray hits a surface, part of it is reflected and part of it is refracted. You don't need to worry about how much is reflected or refracted. A thin film has two surfaces. What you concern about is the relative phase between the reflected ray at the first interface and the ray produced by refraction and reflection at the second interface.



Look at the picture. Rays of the same color have the same phase, and rays of different colors have phases different by 180°. Notice that refracted rays do not change phase.

Let us assume that $n_1 < n_2 < n_3$.

------ Then ray 2 and ray 1 have a 180° phase difference because ray 2 is reflected off a "hard surface". Likewise, ray 3 and ray 1' have a 180° phase difference because ray 3 is also reflected off a hard surface. Thus, ray 2 and ray 3' have the same phase (both differ from ray 1 by 180°).

Also recall that no phase difference means the peaks of the two waves/light rays "match", while a 180° phase difference means the waves are $\frac{1}{2}\lambda$ mismatched.

So in order to have constructive interference, ray 2 and ray 3' must have their path difference equal to an integral number of the wavelength:

$$2d_1 = m\lambda, \qquad (m = 1,2, \dots)$$

To have destructive interference, ray 2 and 3' must have some $\frac{1}{2}\lambda$ difference:

$$2d_1 = \left(m + \frac{1}{2}\right)\lambda \qquad (m = 0,1,2 \dots)$$

[Note: this result is similar to double slit diffraction]

------ Let us now look at ray 3 and 4'. Ray 3 and ray 1' have a 180° phase difference because ray 3 is reflected off a "hard surface". But ray 4 and ray 1'' have the same phase because ray 4 reflects off a "soft surface" ($n_3 > n_1$). So ray 3 and 4 have a 180° phase difference, i.e. they are $\frac{1}{2}\lambda$ mismatched.

So in order to have constructive interference, there has to be another $\frac{1}{2}\lambda$ mismatched from the path difference to compensate for the phase difference. Thus:

$$2d_2 = \left(m + \frac{1}{2}\right)\lambda \qquad (m = 0,1,2 \ldots)$$

And for destructive interference:

$$2d_2 = m\lambda, \qquad (m = 1,2, \ldots)$$

where d_2 is the thickness of the dark gray film (with index n_3)

Summary:

- Ray reflected off a hard surface (incident ray is in lower index material) has a $180°$ phase change.
- Ray reflected off a soft surface (incident ray is in higher index material) has no phase change.
- Refracted ray has no phase change.

One last thing: the wavelength in all of the above equations is the wavelength in the thin film, i.e.:

$$\lambda = \frac{\lambda_{air}}{n}$$

Practice problems:

1. A soap bubble has thickness $0.5\mu m$. Find the longest wavelength possible to obtain maximum and minimum reflection from the film soap.

2. You want to coat your camera lens with a thin film to get rid of background haze created by light of $\lambda = 350nm$. Find the minimum thickness of the thin film, knowing that $n_{coating} = 1.3$, $n_{glass} = 1.5$, $n_{air} = 1$.

3. A point source of EM radiation has average power output of 800W.
(a) Calculate the intensity of EM radiation at a point D meters from the source.
(b) Find the maximum values of electric and magnetic fields at a point 3.5m from the source.

4. Two lenses, $f_1 = 30cm,\ f_2 = -10cm$, are separated by 20cm. The object is 15cm left of the first lens. Find the position and magnification of the final image.