PHYS 242 BLOCK 13 NOTES

Sections 34.7, 34.8, 35.1 to 35.5

A **magnifier** is a converging lens used with a real object placed at or inside its first focal point. Then the magnifier gives a virtual, erect, enlarged image that has an **angular magnification** M. Note that the angular magnification M is *not* the same thing as the lateral magnification m discussed in Block 12.

Let 25 cm be the nearest distance at which an ordinary eye can focus. As in Fig. 34.51, first place the real object 25 cm from the eye to find θ. Then place the object in the focal plane of the converging lens (so $s = f$). Finally, look through the lens to find θ'. For small angles, $\boxed{M \equiv \frac{\theta'}{\theta} = \frac{25 \text{ cm}}{f}}$. We see that M has no unit.

θ is the angle subtended at the eye by the object (25 cm from the eye) when the magnifier is *not* present.

θ' is the angle subtended at the eye by the image seen through the magnifier (when the object has $s = f$.).

f is the positive focal length (in cm) of the converging lens.

In a **microscope**, the real image from the first lens acts as a real object for the second lens, giving a large net angular magnification of *nearby* objects. (See Fig. 34.52b.)

In a refracting **telescope**, the same process occurs, except for *distant* objects. (see Fig. 34.53.)

Physical Optics

Monochromatic light is light of a single frequency f (and a single vacuum wavelength λ_0)—an ideal approached by laser light.

Coherence means having a definite constant phase relation.

First consider two coherent sources emitting monochromatic waves in phase that have the same f (and thus the same λ). Maximum **constructive interference** occurs when the waves arrive at a point in phase. Since each wave is like the others preceding and following it, the waves can be said to arrive "in phase" when their phase difference ϕ equals $\pm 2\pi$, $\pm 4\pi$, … as well as zero, that is, when $\phi = m(2\pi)$ with $m = 0, \pm 1, \pm 2, \pm 3, \ldots$. Also maximum **destructive interference** occurs when the waves arrive $\pm\pi$, $\pm 3\pi$, $\pm 5\pi$, … out of phase.

If the waves from sources 1 and 2 travel path lengths of r_1 and r_2 from those sources to the point where they interfere, $r_2 - r_1$ is their *path difference*. A little thought should tell you that the ratio of the path difference to the wavelength λ (both in the same unit) equals the ratio of the phase difference ϕ to 2π rad. For example, a path difference of 2.5 wavelengths (2.5λ) gives a phase difference of 2.5 times 2π rad. (This phase difference ϕ is due solely to the path difference $r_2 - r_1$.)

Solving $\frac{r_2 - r_1}{\lambda} = \frac{\phi}{2\pi}$ gives $\boxed{\phi = \frac{2\pi}{\lambda}(r_2 - r_1)}$.

Since the "2π" in the boxed equation above is 2π rad, ϕ is in rad.

Note: you can replace the 2π rad with 360˚ if you want—or are given—the phase difference ϕ in degrees.

Suppose our sources are two (or more) narrow rectangular slits (see Fig. 35.5), that the center-to-center distance between adjacent slits is d, and that the distance from the slits to a screen is much greater than either λ or d. Corrected Fig. 35.5c shows the path difference $r_2 - r_1$ equals $d \sin \theta$ for adjacent slits.

Substituting $r_2 - r_1 = d \sin \theta$ and $\phi = m(2\pi)$ in the preceding boxed equation for the phase difference ϕ gives $\boxed{d \sin \theta = m\lambda \ (m = 0, \pm1, \pm2, \pm3, \ldots)}$ as the relation for *constructive interference* for two (or more) rectangular slits. This constructive interference will give the bright fringes of light illustrated in Fig. 35.5a and shown in Fig. 35.6.

The "m" in this equation is *not* the lateral magnification and *not* the mass, but is an integer.

As usual, θ is the angle the rays make with the normal.

Note that m and θ *must* have the same sign (because d and λ are positive).

Example 35.2 applies this equation to radio waves.

Now we consider interference effects arising from light reflected from the two sides of a thin insulating transparent film of thickness t surrounded by dielectrics. For simplicity, we consider only normal (perpendicular) incidence. (However, we'll draw the rays at an angle with the normal for clarity.) Maxwell's equations give Eq. (35.16), where the E's are *components*, not amplitudes. This equation tells us the light undergoes:

a zero phase shift upon reflection off a *lower* index of refraction medium ($n_b < n_a$), but

a π rad phase shift upon reflection off a *higher* index of refraction medium ($n_b > n_a$).

This equation also tells us that *no* light is reflected if there is *no* change in index of refraction ($n_b = n_a$).

There is also a phase difference between the two reflected rays caused by their path difference $2t$. Thus we have $\boxed{2t = m\lambda}$ with $m = 1, 2, 3, \ldots$ or $\boxed{2t = (m + \frac{1}{2})\lambda}$ with $m = 0, 1, 2, 3, \ldots$. In either case, $\boxed{\lambda = \frac{\lambda_0}{n}}$.

λ is the wavelength *in the film*, n is the index of refraction *of the film*, and t is the thickness *of the film*.

λ_0 is the wavelength *in vacuum*.

For a given value of λ or λ_0, the smallest allowed value of m gives the smallest thickness t.

By conservation of energy, a reflection *maximum* gives a transmission *minimum* and a reflection *minimum* gives a transmission *maximum*.

Which boxed "$2t = \ldots$" equation above should we use? First we determine the phase shifts upon reflection off one side of the film and also off the other side of the film. (Those phase shifts can be both zero, both π rad, or one zero and the other π rad.) Then use logic or see the SUMMARY below (also found on your Objectives sheet).

SUMMARY—THIN INSULATING FILMS, NORMAL INCIDENCE

Number of phase shifts of π rad upon reflection	zero or two	one
Reflection maximum and transmission minimum	$2t = m\lambda$	$2t = (m + \frac{1}{2})\lambda$
Reflection minimum and transmission maximum	$2t = (m + \frac{1}{2})\lambda$	$2t = m\lambda$

Figure 35.19 represents a **Michelson interferometer**. If you move the movable mirror a distance y, the path difference changes by $2y$ (y out plus y back). Changing the path difference changes the interference pattern with m bright fringes (or m dark fringes) moving past a point in that pattern when $\boxed{2y = m\lambda}$.