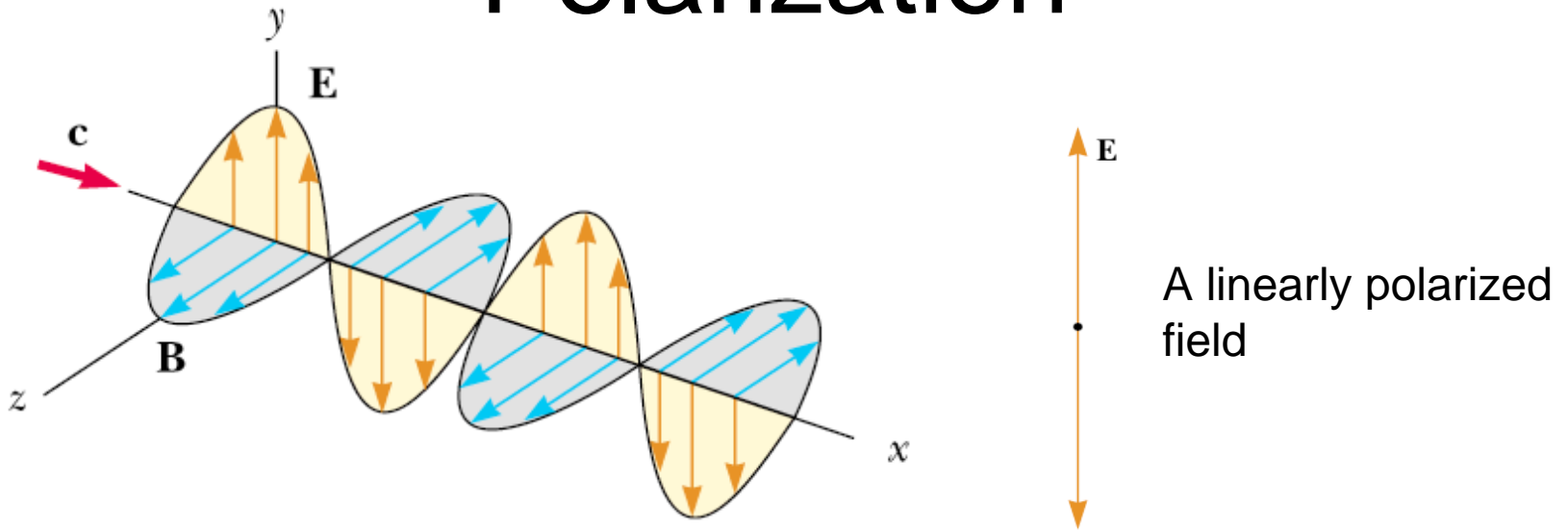


Optics (cont.)

Polarization

- Initially, we said that light is a wave with an amplitude, wavelength and frequency.
- We also said that it is an electromagnetic wave, with an electric and a magnetic field.
- These fields are **vector** quantities, which means they have a direction as well as an amplitude.
- The direction of the electric field associated with the EM wave is called its **polarization**.

Polarization

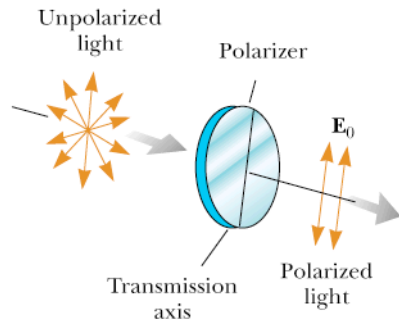


- Light can be;
 - linearly polarized (horizontal or vertical)
 - circularly polarized (clockwise or counter cw)
 - unpolarized (random polarization)

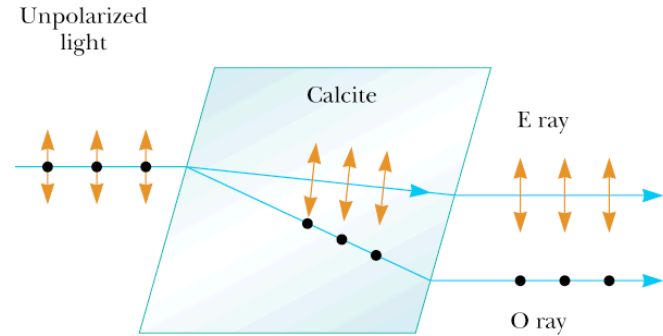
Polarization

- Laser light is generally polarized.
- Sunlight and light from light bulbs are unpolarized.
- They can be turned in to polarized light by a polarizer.
- A polarizer can work by;
 - selective absorption (polaroid films, sunglasses)
 - selective scattering (blue skies, red sunsets)
 - reflection (Brewster's angle, ellipsometry)
 - double refraction (calcite crystals)

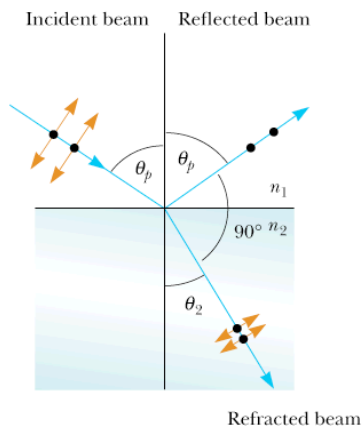
Polarizers



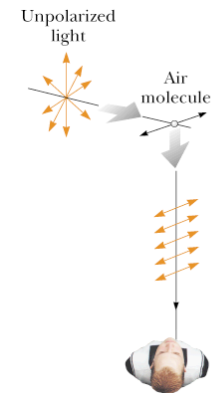
Selective Absorption



Double Refraction



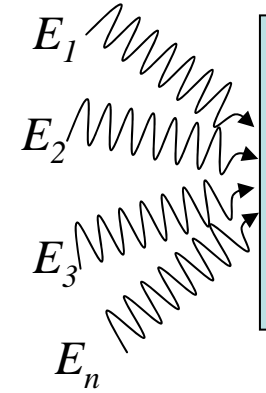
Reflection



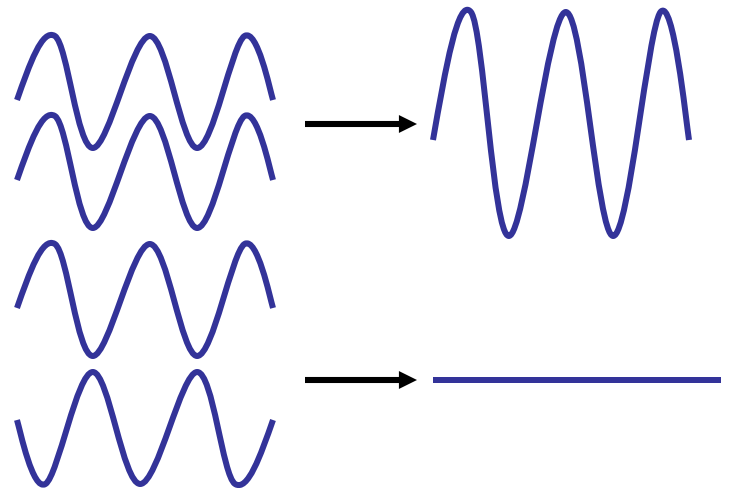
Scattering

Light as a Wave

- Remember that light is really an electromagnetic wave.
- The total intensity of light that we detect is really proportional to the time average of the square of the sum of all the electric fields that are incident.
- The electric and magnetic fields that make up the wave have peaks and valleys.
- If one can arrange for all the waves to arrive synchronously with matching peaks or valleys, the resulting intensity will be high.
- If however, the waves are exactly out of sync (for each wave with a valley, there is one with a peak) then the total field and the intensity will be zero.



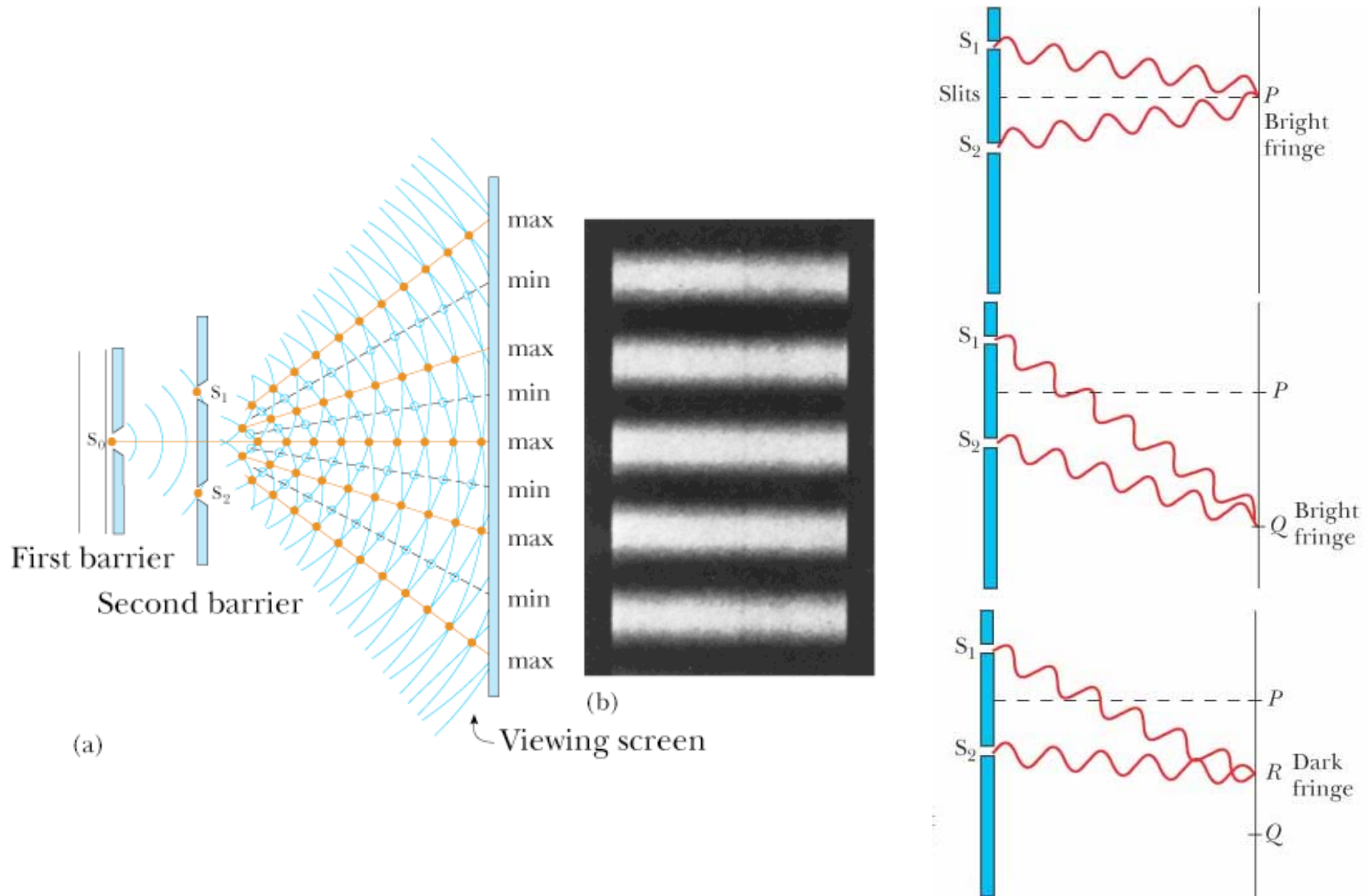
$$I_T \propto (E_1 + E_2 + E_3 + \dots + E_n)^2$$



Interference

- If the waves are emitted from a single source, we can adjust the synchronicity of the waves by adjusting their arrival times.
- If one wave arrives half a period of oscillation after the other, then it will be completely out of sync with the earlier one and they will cancel each other out – **destructive interference**.
- The same is true for any wave that arrives 1.5 periods later and 2.5 periods later, etc.
- If one wave arrives exactly a period later then it will be again completely in sync with the earlier one and they will add to each other – **constructive interference**.
- Same is true for all waves arriving 2 periods, 3 periods, etc. later.

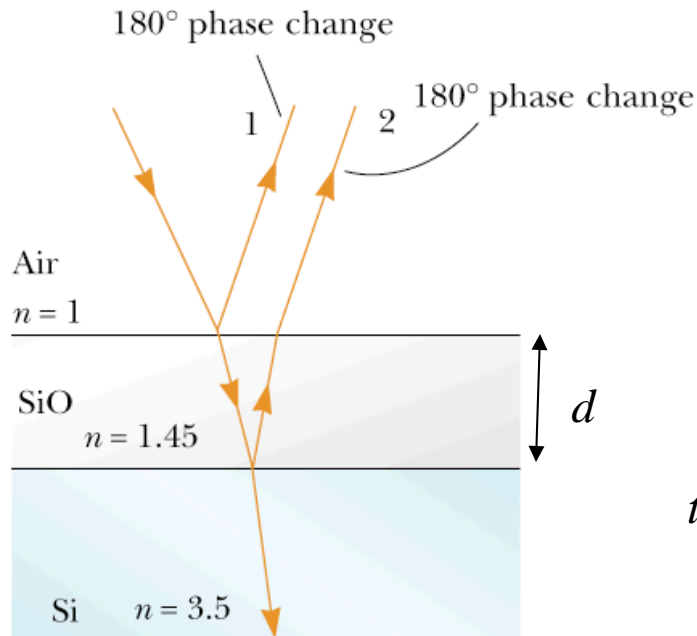
Young's Double-Slit Experiment



Thin Film Interference

- Consider a thin film that is at least partially transparent to light.
- If light is incident from the top, some of the light will be reflected and some will be transmitted in to the film.
- Similarly, as the transmitted light tries to exit the film at the bottom, there will be reflection and transmission.
- The waves that were reflected from the top of the film and the bottom of the film will interfere with each other.
- If the delay introduced by the thickness of the film matches an integer multiple of the period of light, there will be constructive interference.
- If it is half a period of delay, there will be destructive interference.
- One additional wrinkle is that waves that reflect off of a higher index medium will undergo a 180° phase change so that a delay of one period results in destructive interference and a delay of half a period results in constructive interference.

Thin Film Example – Anti-Reflective Coating



If the extra time the 2nd wave spends in the SiO layer is an integer multiple of the period, then there will be constructive interference, otherwise destructive interference.

$$t = \frac{2d}{c/n_{SiO}} = \frac{2dn_{SiO}}{c}$$

Extra time spent in SiO

$$t = T = \frac{\lambda}{c} = \frac{2dn_{SiO}}{c} \rightarrow \lambda = 2dn_{SiO}$$

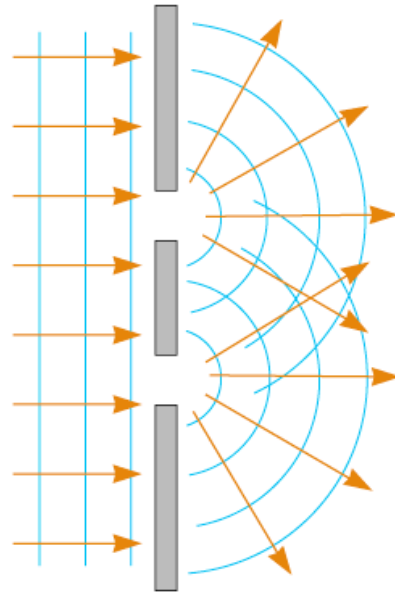
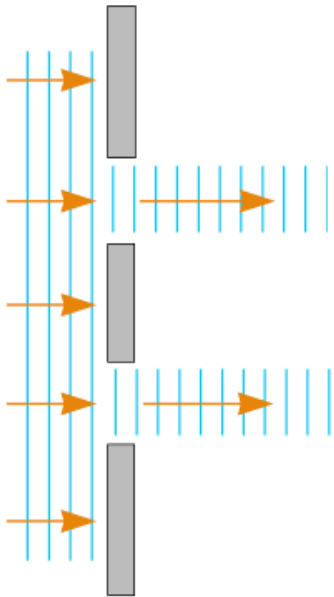
Condition for constructive interference

$$t = \frac{T}{2} = \frac{\lambda}{2c} = \frac{2dn_{SiO}}{c} \rightarrow \lambda = 4dn_{SiO}$$

Condition for destructive interference

If you want a film that does not reflect red light (~620 nm), you would make the film thickness, $d = 107$ nm

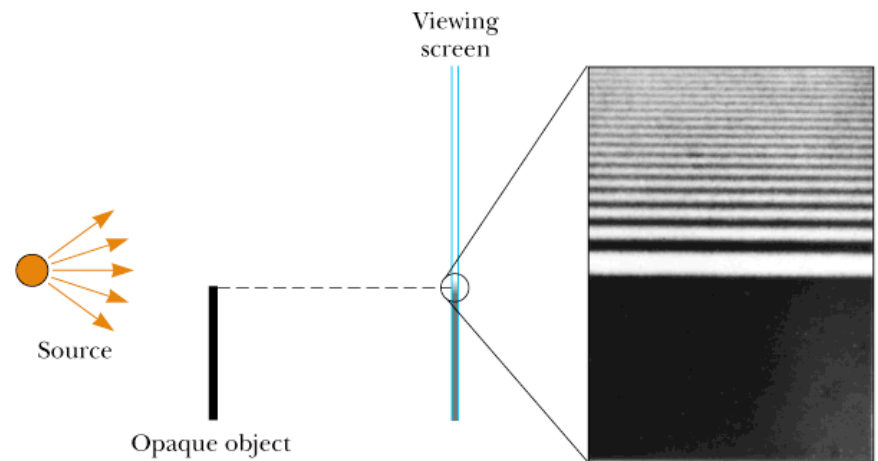
Diffraction



Light rays can bend around corners

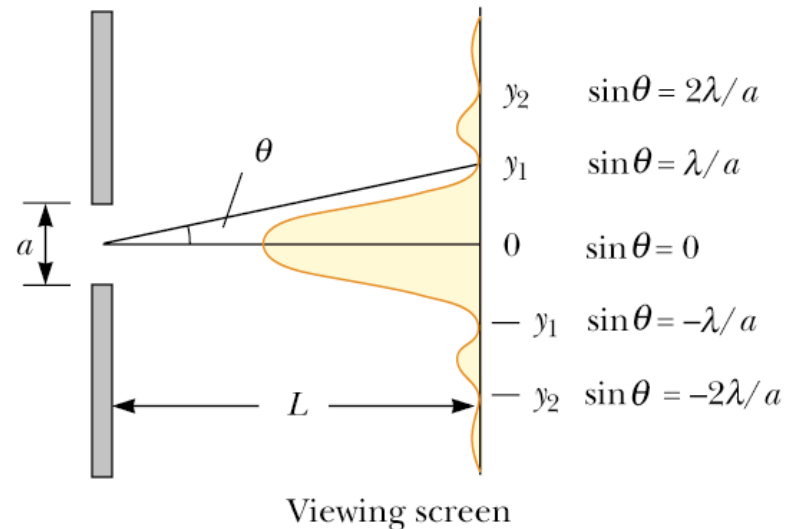


No sharp boundary exists between the dark and bright parts on the screen



Diffraction

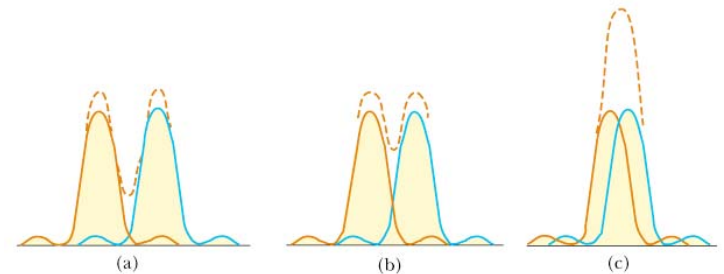
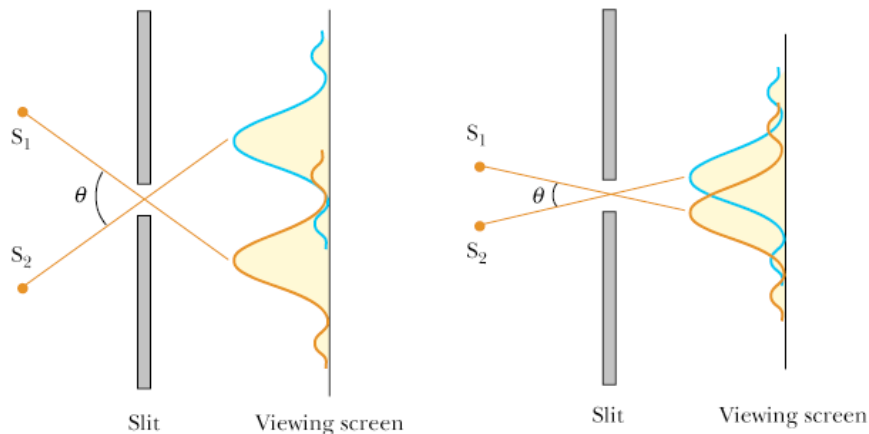
- Diffraction occurs because light waves that go through an opening (or around an obstruction) interfere with themselves.
- This results in a series of constructive and destructive interference bands.
- Most of the light intensity is in the central bright band.
- The width of the band is inversely proportional to the width of the opening and directly proportional to the wavelength of the light.



$$y_1 \approx \frac{L}{a} \lambda$$

Optical Resolution

- When light from two different sources pass through an aperture, their diffraction patterns will overlap.
- If the overlap is severe, the two sources will not be resolved.

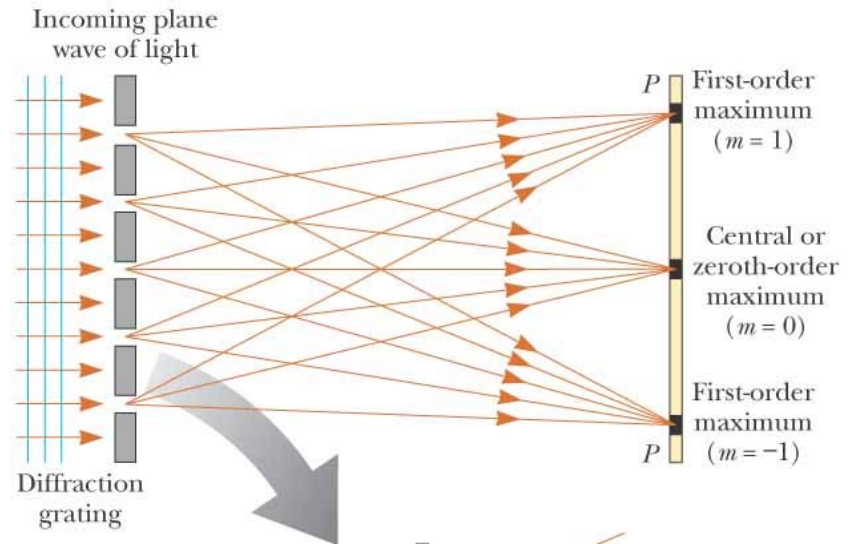


$$\theta_{\min} = 1.22 \frac{\lambda}{D}$$

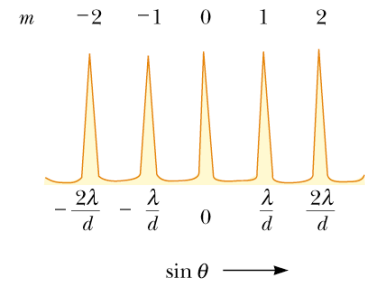
Rayleigh's criterion for optical resolution

Diffraction Gratings

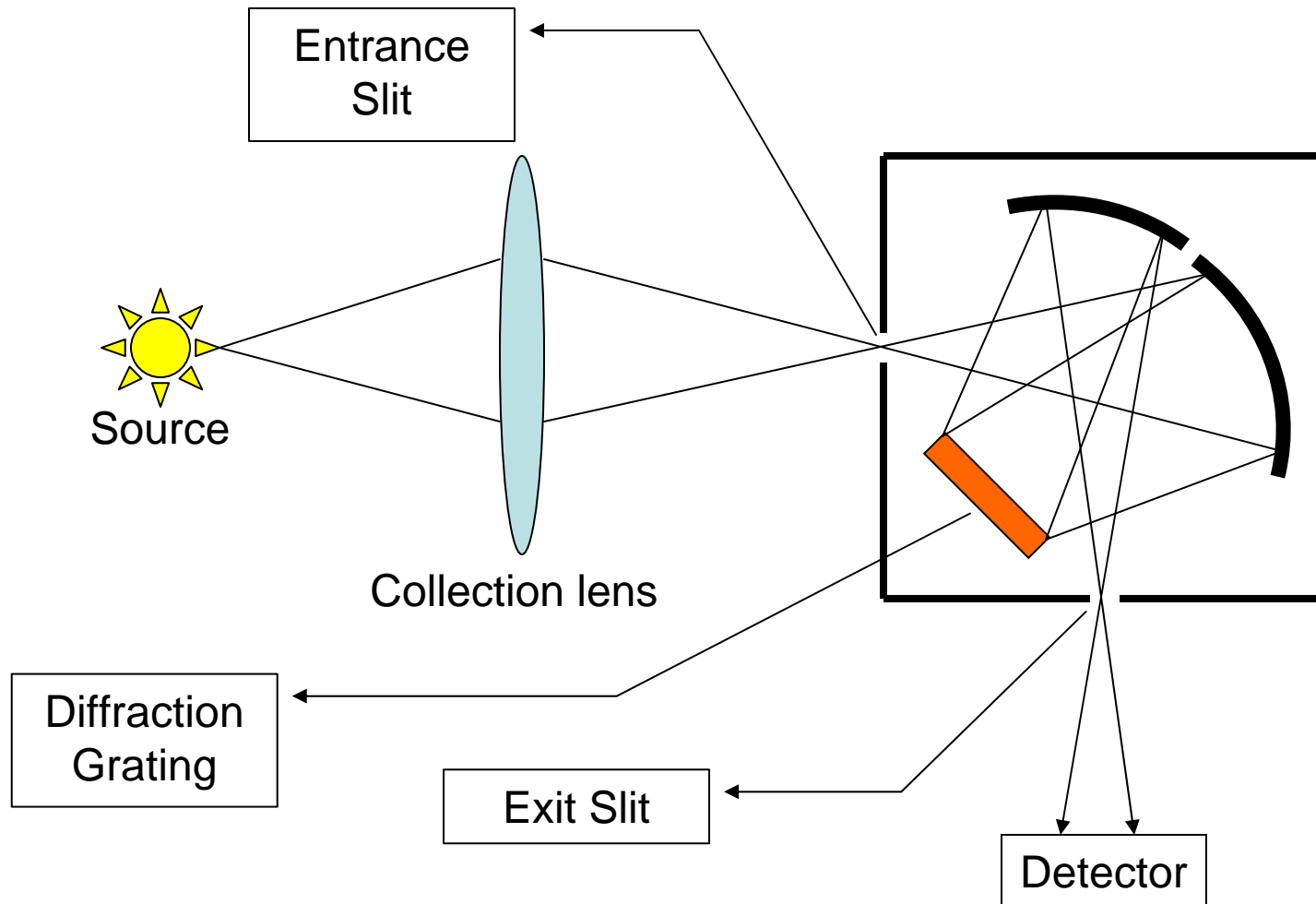
- A series of finely spaced slits creates a multiple slit interference pattern of sharp bright spots.
- The location of the spots depend on the wavelength of light.
- Such a device is used to separate light in to its spectral components.



$$d \sin \theta = m \lambda$$

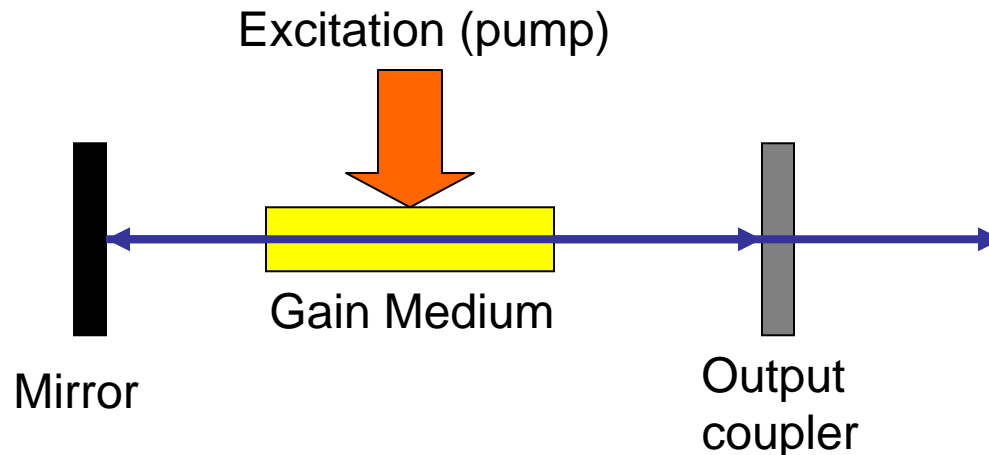


Spectrometers



Lasers

- Consider a gain medium sandwiched between two mirrors.
- The gain medium can absorb external energy and convert it to light.
- The light emitted by the gain medium will be reflected from the mirrors back in to the medium, resulting in more absorption and light generation.
- If the number of excited electrons in the gain medium exceed the number of ground state electrons, the process can become self sustaining (inversion).



Some Details

- The gain medium can be;
 - a crystal (YAG, Ti: Sapphire)
 - a dye (Rhodamine, LDP)
 - a gas (Argon, HeNe, CO₂)
 - a plasma (ArF)
 - a semiconductor (GaAs, GaN)
- The excitation can be;
 - electric current (semiconductor diode lasers)
 - optical (dye lasers)
 - electric discharge (Gas lasers)

Properties of Laser Light

- Laser light is coherent.
 - All the waves emitted by the laser oscillate in phase (unlike incoherent light from the sun or a light bulb).
- Laser light is monochromatic.
 - Since the emitted light is the result of a particular electronic transition, it only has a single wavelength.
- Laser light is directional.
 - The gain medium and the “cavity” formed by the mirrors determine the direction of the emitted light.