CPP1113
PRINCIPLES OF PHYSICS

Foundation in Information Technology

ONLINE NOTES

Chapter 6
Properties of Light

6.1 REFLECTION OF LIGHT

1. The first property of light we consider is reflection from a surface, such as that of a mirror.

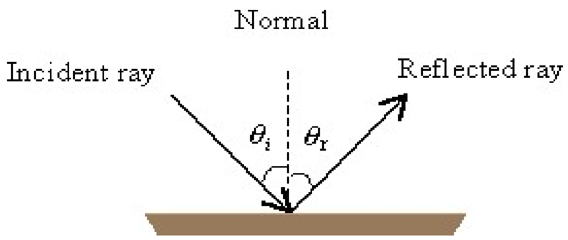


Diagram 6.1

2. **The law of reflection** states that the angle of incidence equals the angle of reflection, for flat surfaces.

3. The incident ray, the normal, and the reflected ray are always in the same plane as shown in Diagram 6.1.

Note: All angles are measured from the normal (line perpendicular) to the reflecting surface.

6.2 WAVEFRONT AND RAYS

1. A wave front is the line (in two dimensions) or surface (in three dimensions) defined by adjacent portions of a wave that is in phase.
2. For example, a point light source emits spherical wave fronts because the points having the same phase angle are on the surface of a sphere.
3. For a parallel beam of light, the wave front is a plane wave front (in three dimensions).
4. The distance between adjacent wave fronts is the wavelength.
5. A ray is a line drawn perpendicular to a series of wave fronts and pointing in the direction of propagation.
6. For a spherical wave, the rays are radically outward, and for a plane wave, they are parallel to each other.
7. The use of wave fronts and rays in describing optical phenomena such as reflection and refraction is called geometrical optics.

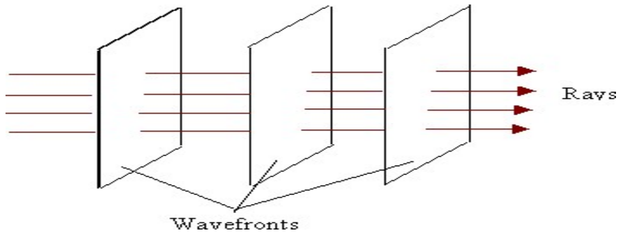


Diagram 6.2

6.3 REFRACTION OF LIGHT.

Index of Refraction

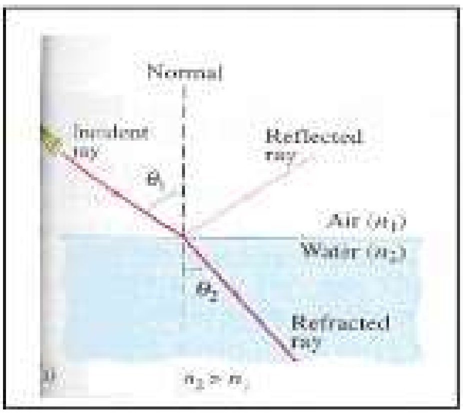
1. The ratio of the speed of light in vacuum to the speed *v* in a given material

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \frac{c}{v}$$

2. Since light travels more slowly in matter than in vacuum, n is never less than 1.
3. As light travels from one medium to another, its frequency does not change but its wavelength does.

Snell's Law

1. Refraction refers to the change in direction of a wave at a boundary where it passes from one medium into another as a result of different wave speeds in different media.
2. If light travels from one medium into a second where its speed is less, the ray bends toward the normal (example: ray traveling from air to water as shown in Diagram 6.3 (a)).
3. If light travels from one medium into a second where its speed is greater, the ray bends away from the normal (example: ray traveling from water to air as shown in Diagram 6.3 (b)).


Normal
Incident ray
Reflected ray
θ_1
Air (n_1)
Water (n_2)
θ_2
Refracted ray
$n_2 > n_1$

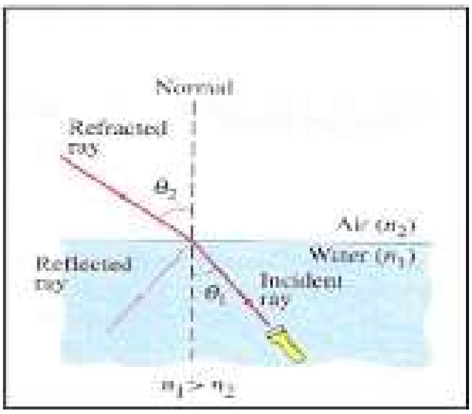

Normal
Refracted ray
θ_2
Air (n_2)
Water (n_1)
Reflected ray
θ_1
Incident ray
$n_1 > n_2$

Diagram 6.3(a) **Diagram 6.3(b)**

4. The angle of refraction, θ_2, depends on the properties of the two media and on the angle of incidence through the relationship (known as **Snell's law**)

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$$

Where, θ_1 is the angle of incidence and θ_2 is the angle of refraction

Critical Angle

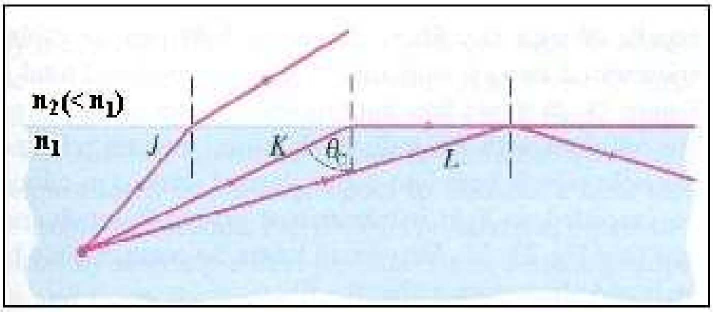


Diagram 6.4

1. When light passes from one material into a second material (where n is less), for example from water into air, the light bends away from the normal, as for ray J in Diagram 6.4.

2. At a particular incident angle (known as critical angle θ_c)
   - the angle of refraction will be 90°
   - the refracted ray would skim the surface (ray K in Diagram 6.3)

$$\sin\theta_c = \frac{n_2}{n_1}\sin 90^0 = \frac{n_2}{n_1}$$

Total Internal Reflection

1. An interesting effect called total internal reflection can occur when light attempts to move from a medium having a given index of refraction to one having a lower index of refraction

2. When an incident angle is greater than θ_c, there is no refracted ray at all, and *all of the light is reflected* (as for ray L in Figure 6.4).

$$\sin\theta_c = \frac{n_2}{n_1} \qquad \text{(for } n_1 > n_2\text{)}$$

3. In this equation n_1 is always greater than n_2. That is,

"Total internal reflection can occur only when light strikes a boundary where the medium beyond has a lower index of refraction."

6.4 Fiber optics

1. An interesting application of total internal reflection is the use of glass or transparent plastic rods to „pipe" light from one place to another.
2. As indicated in the Diagram 6.5 below, light is confined to traveling within the rods even around gentle curves, as result of successive internal reflection.
3. Such a "light pipe" is flexible if thin fibers are used rather than thick rods.
4. If a bundle of parallel fibers is used to construct an optical transmission line, images can be transferred from one point to another.

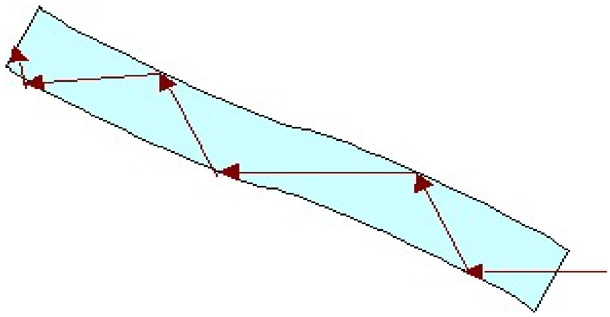


Diagram 6.5

5. This technique is known as fiber optics. Light, signals or other forms of communication can travel a long distance without losing much intensity.

6.5 Diffraction of light

1. Huygens" principle is a construction for using knowledge of an earlier wave front to determine the position of a new wave front at some instant.
2. Huygens" principle states that all points on a given wave front are taken as point sources for the production of spherical secondary waves, called wavelets, which propagate outward with speeds characteristic of waves in that medium.
3. After some time has elapsed, the new position of the wave front is the surface tangent to the wavelets.

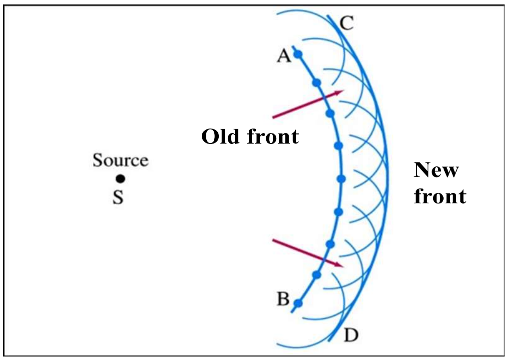


Diagram 6.6(a)

4. Huygens‟ principle is particularly useful when waves impinge on an obstacle and the wave fronts are partially interrupted.
5. Huygens‟ principle predicts that waves bend in behind an obstacle as shown in Diagram 6.6(a)(This is just what water waves do) The bending of waves behind obstacles into the "shadow region" is known as **diffraction**.
6. Since diffraction occurs for waves, but not for particles, it can serve as one means for distinguishing the nature of light.
7. Huygens‟ principle is consistent with diffraction;
   - If the wave meets a barrier in which there is a circular opening whose diameter is large relative to the wavelength as in figure 6.6 (b), the wave emerging from the opening continues to move in a straight line. Hence, the ray approximation continues to valid.
   - If, however, the diameter of the opening is of the order of the wavelength as in figure 6.6 (c), the waves spread out from opening in all directions.
   - Finally, if the opening is small relative to the wavelength, the opening can be approximated as a point source of waves. (Figure 6.6 (d))

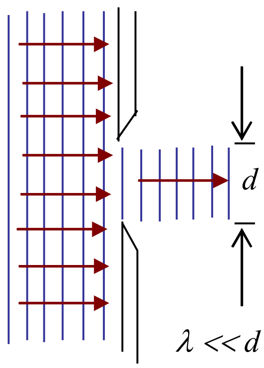


Figure 6.6(b)

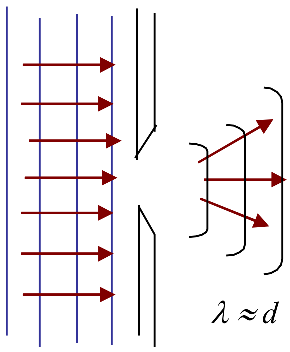


Figure 6.6(c)

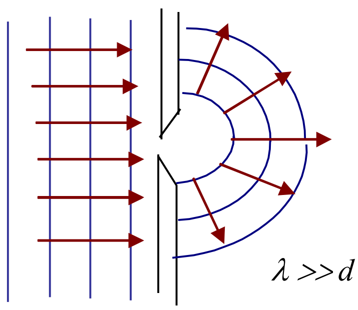


Figure 6.6(d)

6.6. SINGLE SLIT DIFFRACTION

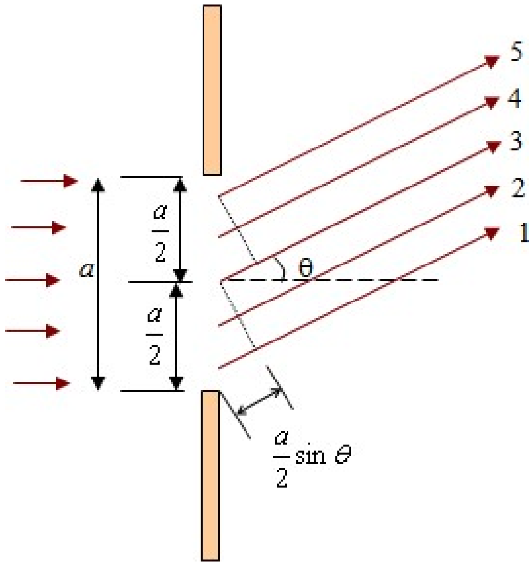


Diagram 6.7(a)

1. According to Huygen‟s principle, each portion of the slit acts as a source of waves. Hence, light from one portion of the slit can interfere with light from another portion, and the resultant intensity on the screen depends on the direction θ.
2. To analyze the diffraction pattern, it is convenient to divide the slit in two halves, as Diagram 6.7 (a).
3. All the waves that originate from the slit are in the phase.
4. Consider waves 1 and 3, which originate from a segment just above the bottom and just above the center of the slit, respectively.
5. Wave 1 travels farther than wave 3 by an amount equal to the path difference (a/2)sin θ, where a is the width of the slit. Similarly, the path difference between wave 2 and 4 is also (a/2) sin θ.
6. If this path difference is exactly one-half wavelength (corresponding to a phase difference of 180°), the two waves cancel each other and destructive interference results.
7. Therefore, waves from the upper half of the slit interfere destructively with waves from the lower half of the slit when
   $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$ or when $\sin\theta = \frac{\lambda}{a}$

8. If we divide the slit into four parts rather than two and use similar reasoning, we find that the screen is also dark when $\sin\theta = \frac{2\lambda}{a}$
9. likewise, we can divide the slits into six parts and show that darkness occurs on the screen when $\sin\theta = \frac{3\lambda}{a}$
10. Therefore, the general condition for **destructive interference** is $\sin\theta = m\frac{\lambda}{a}$ (m = ±1, ±2, ±3, ….)

11. In Diagram 6.7 (b) shows that a broad central bright fringe is observed, flanked by much weaker, bright fringes alternating with dark fringes.

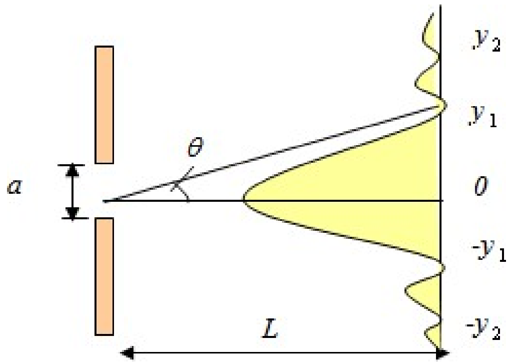


Diagram 6.7(b)

6.7 Interference of Light

1. Treat light as waves.
2. Fundamentally, all interference associated with light waves arises when the electromagnetic fields that constitute the individual waves combine.

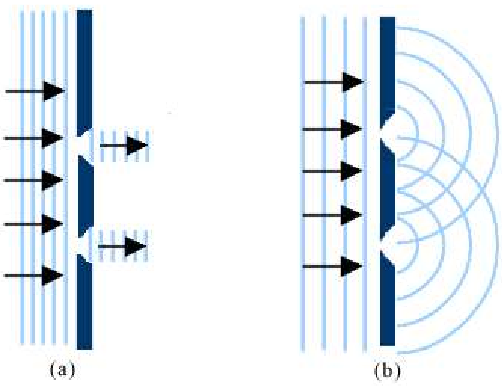


Diagram 6.8

3. To observe sustained interference in light waves, the following conditions must be met:
- ❖ The sources must be coherent; that is, they must maintain a constant phase with respect to each other.
- ❖ The sources must be monochromatic, that is, of a single wavelength.
- ❖ The superposition principle must apply.

4. If light waves did not spread out after passing through the slits, no interference would occur. (Diagram 6.8(a))
5. The light waves from the two slits overlap as they spread out, filing the expected shadowed regions with light and producing interference fringes. (Diagram 6.8(b))
6. Constructive interference is produced when the waves are in phase (the crest of one wave arrives at the same time as a crest of the other wave.
7. Hence the amplitudes of the two waves add to form a larger amplitude as shown in Diagram 6.9(a)
8. Destructive interference is produced when the waves are out of phase (the crest of one wave arrives at the same time as the troughs of the other wave.
9. Hence the amplitudes of the two waves add to produce zero amplitude as shown in Figure 6.9(b)

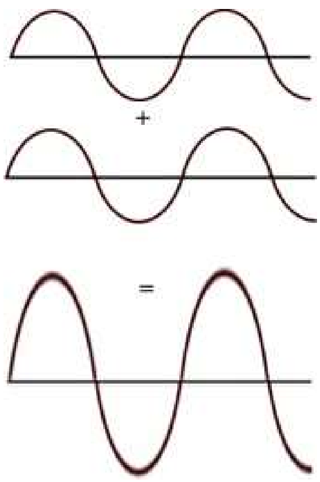


Diagram 6.9(a)

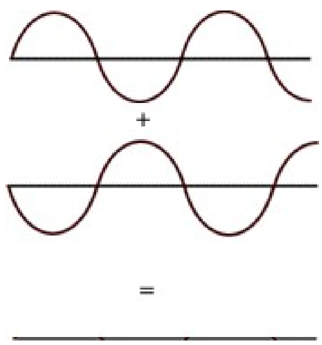


Diagram 6.9(b)

<u>Young's double-slit experiment</u>

1. We can describe Young"s experiment quantitatively with the help of the diagram 6.10.(a)

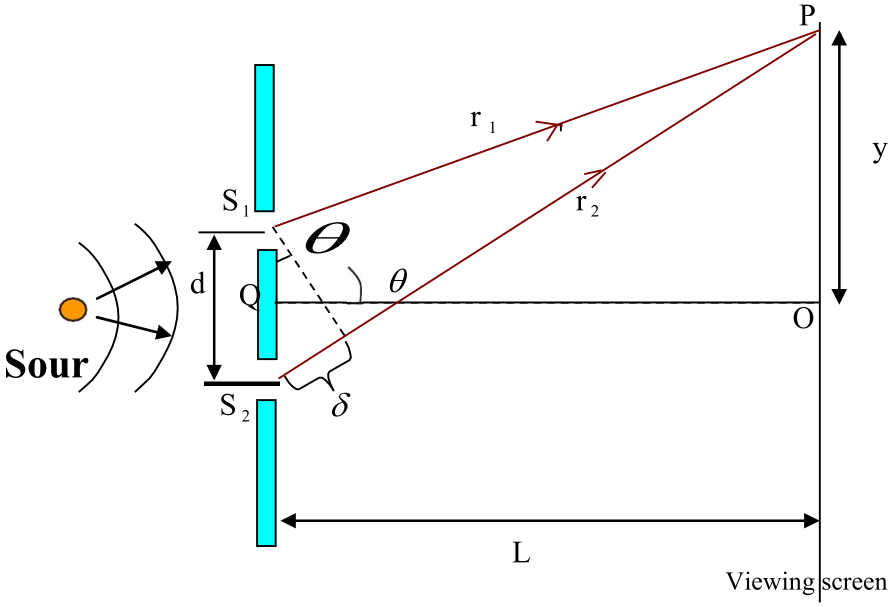


Diagram 6.10(a)

2. The screen is located a perpendicular distance L from the screen containing slits S_1 and S_2,which are separated by a distance d and the source is monochromatic.
3. Under this condition, the waves emerging from S_1 and S_2 have the same frequency and amplitude and are in phase.
4. The light intensity on the screen at any arbitrary point P is the resultant of the light coming from both slits.

5. In order to reach P, a wave from the lower slits travels farther than a wave from the upper slit by a distance equal to $d\, sin\theta$. This distance is called the path difference, δ , where $\delta = r_2 - r_1 = d\ \sin\theta$

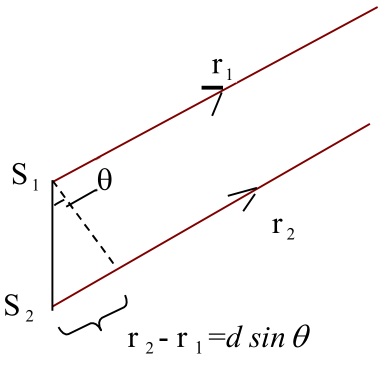


Diagram 6.10(b)

6. This equation assumes that r_1 and r_2 are parallel, which is approximately true because L is much greater than d.
7. The value of this path difference determines whether or not the two waves are in phase when they arrive at P.
8. If the path difference is either zero or some integral multiple of the wavelength, the two waves are in phase at P and constructive interference results.
9. Therefore, the condition for bright fringes, or **constructive interference**, at P is
   $\delta = d\sin\theta = m\lambda$ (m = 0, ±1, ±2, ...)
10. The number m is called the order number of the interference fringe.
11. The central bright at θ = 0 (m = 0) is called the **zeroth-order** maximum.
12. The first maximum on either side, when m = ±1, is called the first-order maximum, and so forth.
13. When the path difference is an odd multiple of λ/2, the two waves arriving at P are out of phase and will give rise to destructive interference.
14. Therefore, the condition for dark fringes, or **destructive interference**, at P is
   $\delta = d\sin\theta = (m + 1/2)\lambda$ (m = 0, ±1, ±2, …….)
15. In addition to our assumption that L >> d, we assume $d \gg \lambda$.
16. Under these conditions, θ is small, and so we can use the approximation sin θ ≈ tan θ.
17. From the triangle OPQ in Diagram 6.5.1(a), we see that
   $\sin\theta \approx \tan\theta = \frac{y}{L}$
18. So the positions of the bright fringes measured from O are given by
   $$y_{bright} = \frac{\lambda L}{d} m$$
19. Similarly,
   $$y_{dark} = \frac{\lambda L}{d}(m + \frac{1}{2})$$

Note: How the wave theory explains the pattern of lines seen in the double-slits experiment.

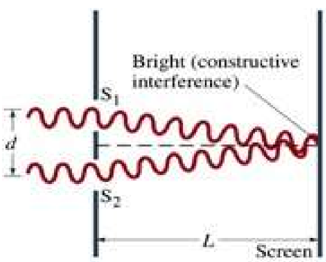


Diagram 6.10 (c)

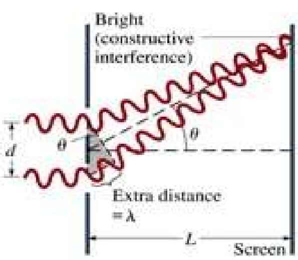


Diagram 6.10(d)

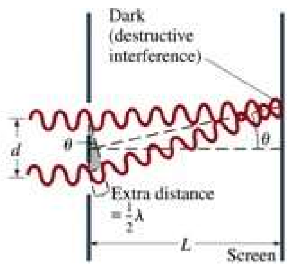


Diagram 6.10 (e)

Diagram 6.10(c): At the center of the screen the waves from each slit have traveled the same distance and are in phase.

Diagram 6.10(d): At this angleθ, the lower wave travels and extra distance of one whole wavelength, and the waves are in phase; note from the shaded triangle that the extra distance equals d sin θ.

Diagram 6.10(e): For this angle θ, the lower wave travels an extra distance equal to one-half wavelength , so the two waves arrive at the screen fully out of phase.

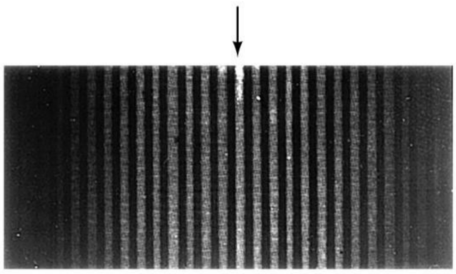


Diagram 6.10(f)

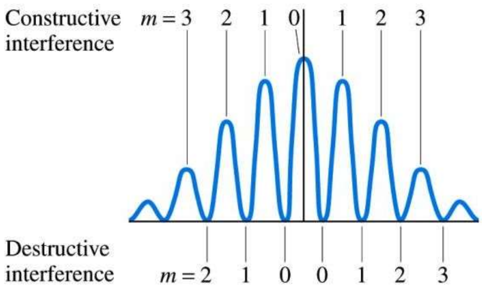


Diagram 6.10 (g)

Diagram 6.10(f): Interference fringes produces by a double slit experiment and detected by photographic film placed on the viewing screen The arrows marks the central fringe.

Diagram 6.10(g): Intensity of light in the interference pattern. Also shown are values of m for constructive and destructive interference.

<u>The Diffraction Grating</u>

1. Diffraction grating consists of a large number of equally spaced parallel slits.
2. Gratings with many lines very close to each other can have very small slit spacing. For example, a grating ruled with 5000 lines/cm has a slit spacing d = (1/5000) cm = 2.00 x 10^{-4} cm.

3. From Diagram 6.11(a), note that the path difference between waves from any two adjacent slits is equal to d sin θ.
4. If this **path difference equals one wavelength or some integral multiple of a wavelength**, waves from all slits are in phase at a point on screen and a bright line is observed.
5. Therefore, the condition for **maxima** in the interference pattern at the angle θ is $d \sin\theta = m\lambda$ (m = 0, 1, 2, 3, ……)

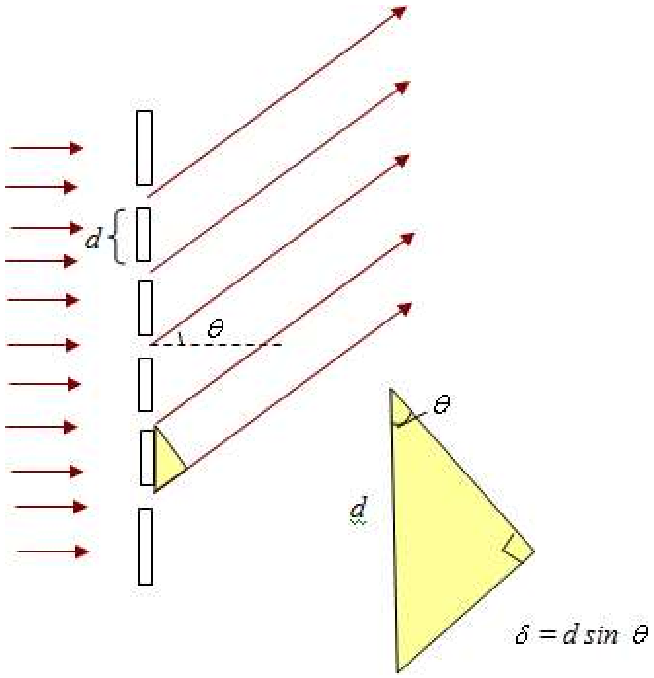


Diagram 6.11(a)

6. Suppose the light striking a diffraction grating is not monochromatic, but rather consists of two or more distinct wavelengths.
7. Then for all orders other than m = 0 , each wavelength will produce maximum at a different angle (diagram 6.11b (a)) , just as for a double slit.
8. If white light strikes a grating, the central (m = 0) maximum will be a sharp white peak.
9. But for all other orders, there will be a distinct spectrum of colors spread out over a certain angular width, (diagram 6.11 (b)).
10. Because a diffraction grating spreads out light into its component wavelengths, the resulting pattern is called a **spectrum.**

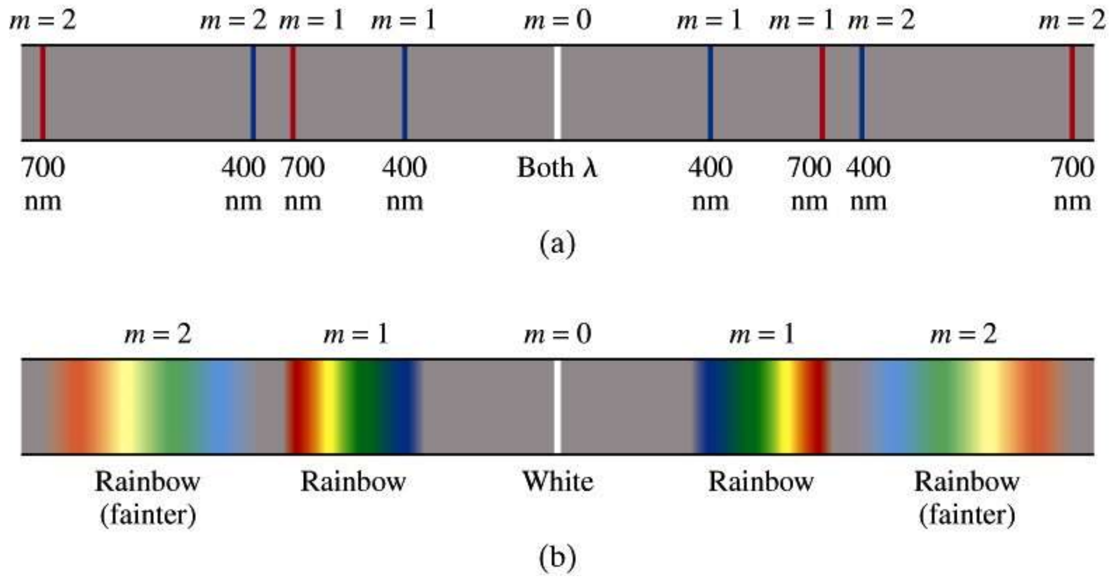


Diagram 6.11(a) & Figure 6.11 (b)

Note: Spectrum produced by a grating:

a.) Two wavelengths, 400 nm and 700 nm ;

b.) White light. The second order will normally be dimmer than the first order. (Higher orders are not shown) If the grating spacing is small enough, the second and higher orders will be missing.

End of Chapter 6