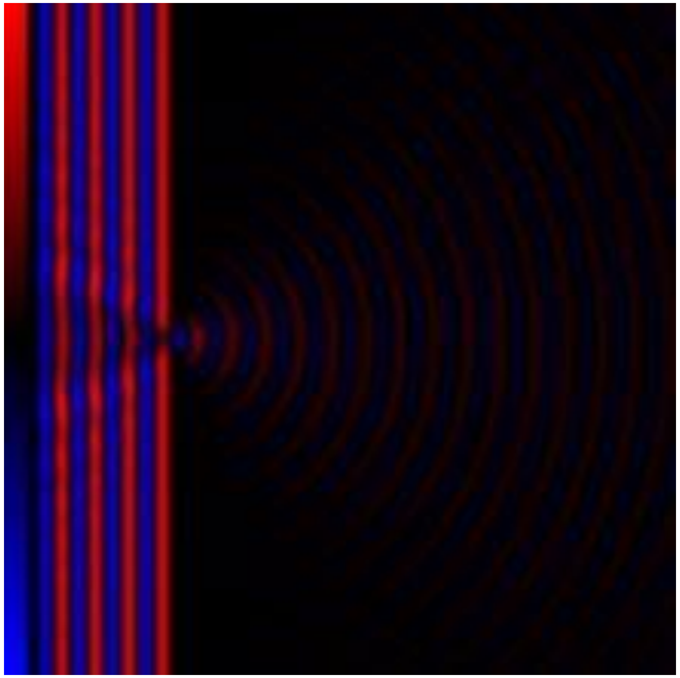


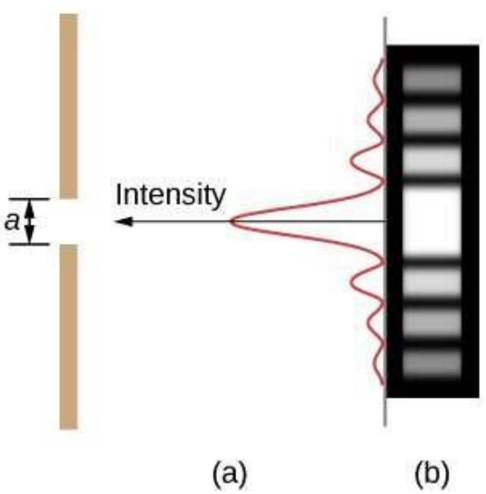
Diffraction: Lecture 1

Diffraction: Outline

1. What is diffraction
2. Technological importance of Diffraction
3. Single Slit Diffraction
4. Multiple slit diffraction: Diffraction Grating
5. Problem solving

What is Diffraction?

1. Diffraction is not just "bending of light". This definition considers light just as a ray. But light is a wave and propagates in the form of wavefront
2. Consider following diagram. Here a single slit is an obstacle. When light passes through it a well defined pattern having dark and bright fringes is produced. The presence of maxima and minima clearly indicates that some wave phenomenon…interference must be involved
3. According to Fresnel: ***when a wavefront of light is obstructed by an obstacle…like a slit…each point in the slit becomes a source of secondary wavelet. All such secondary wavelets spread light waves in all directions. When these diffracted waves interfere a pattern of maxima and minima is generated***



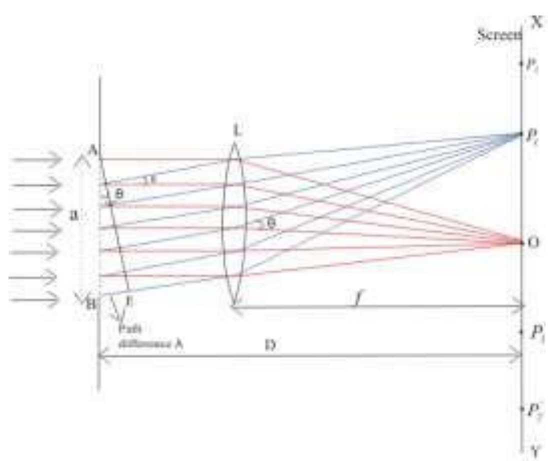
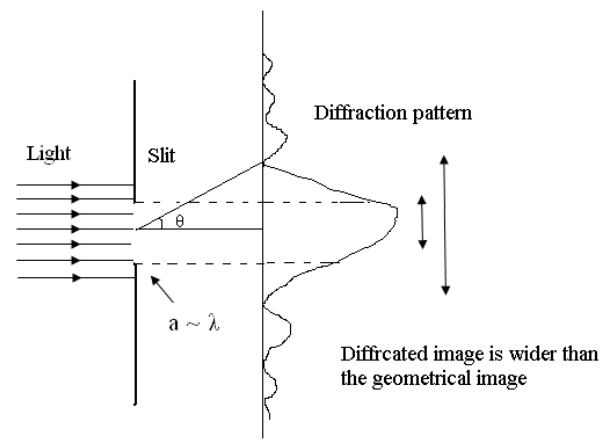
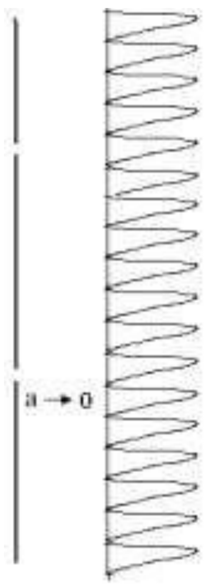


Figure 1. Fraunhofer diffraction of a plane wave at single slit

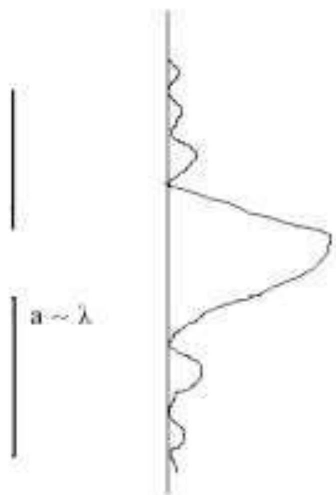


Is Diffraction just like Interference?

- Yes; to some extent. Both these phenomena are based on principle of superposition. But they differ
- Consider Young's double slit experiment. There are two point like slits. Both the slits are extremely narrow. Each slit can become a source of only one…or practically very less number of …secondary sources. Thus two point like slits generate only two secondary sources. They interfere and produce interference pattern
- In diffraction, there is only one slit but it is not a point like slit. It is as wide as the wavelength of light ($\approx 0.55\ \mu m$). Thus there are many points in the slit and hence many secondary wavelets. They interfere and produce a diffractionpattern
- Thus interference deals with superposition of limited number (ideally 2) of secondary wavelets. In diffraction, the number of superimposing secondary wavelets is large



Idealized interference



Idealized diffraction

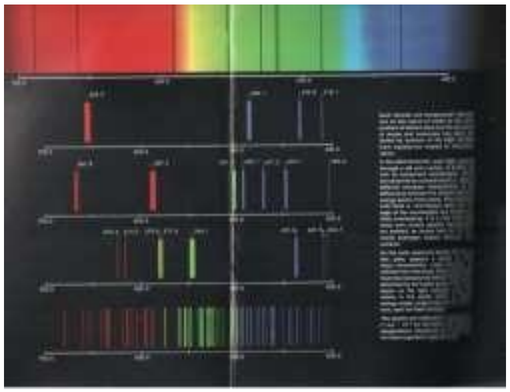
In interference, all fringes have equal brightness and equal widths

In diffraction the principle maxima is wide and bright, while secondary maxima are quite faint and narrow

Does Diffraction has Technological Applications?

- Yes
  - Diffraction grating, a super-prism is the topmost application of Diffraction!. Diffraction grating is a dispersive device which can separate the colors of the light and form the spectrum of a source. This is very much essential in Spectroscopy
  - Resolving power of any optical instrument can be improved by controlling diffraction (telescope microscope, binoculars, cameras and even eye)
  - X ray diffraction is the basis of X ray crystallography and X ray spectroscopy

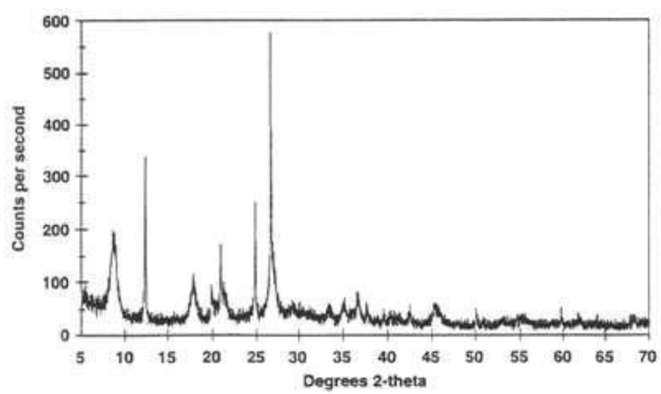
Applications of Diffraction

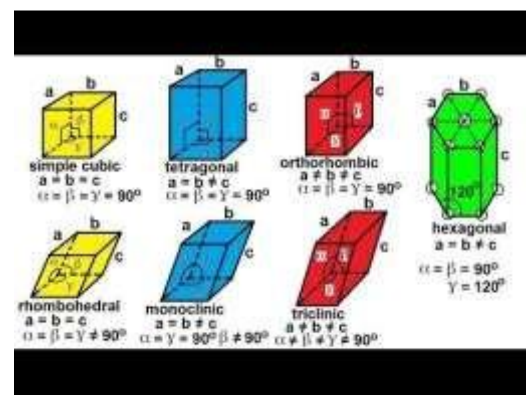


Creating the spectrum of a source by using diffraction grating

The eye of a needle threaded with red cotton. Electron Microscope has incredible resolving power

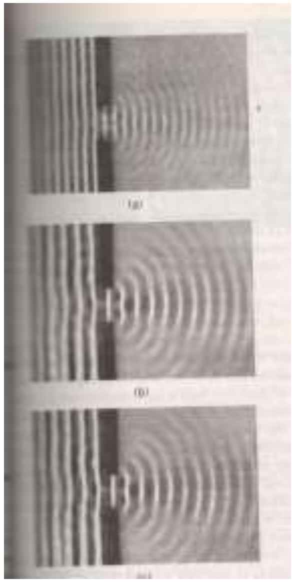
Sugar crystal imaged using electron microscope !



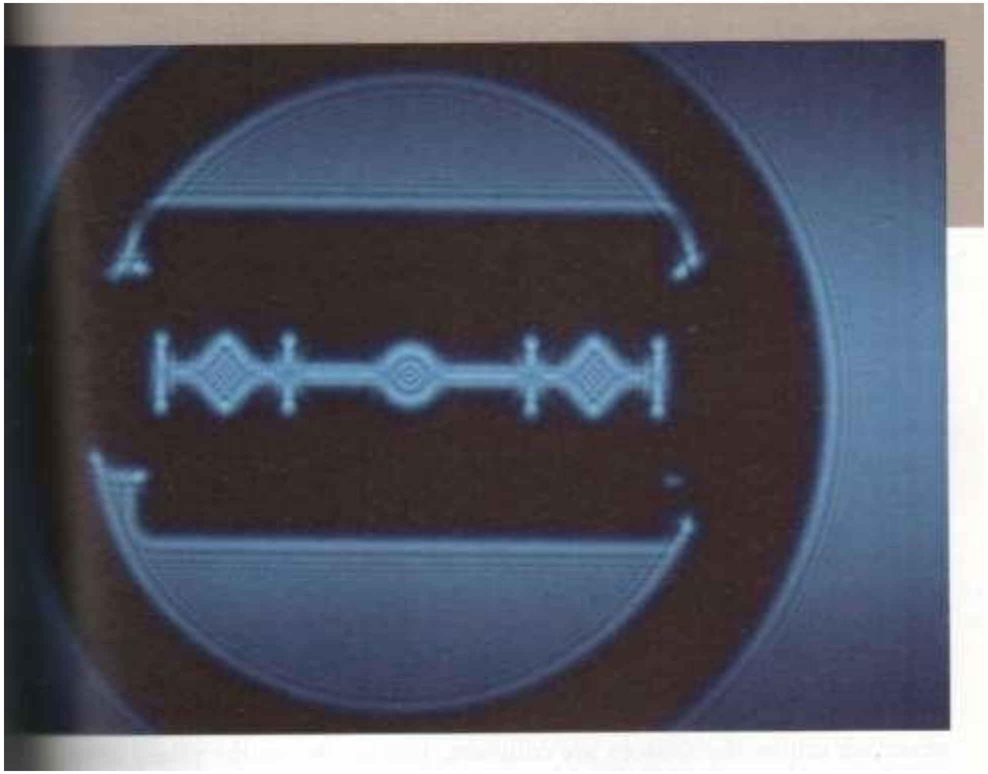


X ray diffraction, $2dsin\theta = m\lambda$

Some Examples of Diffraction

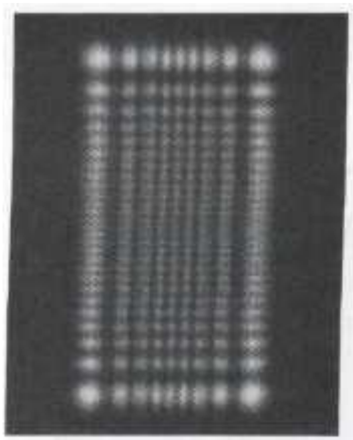


Diffraction of water waves, Wavefront is flaring out. Parallel wavefront becomes spherical



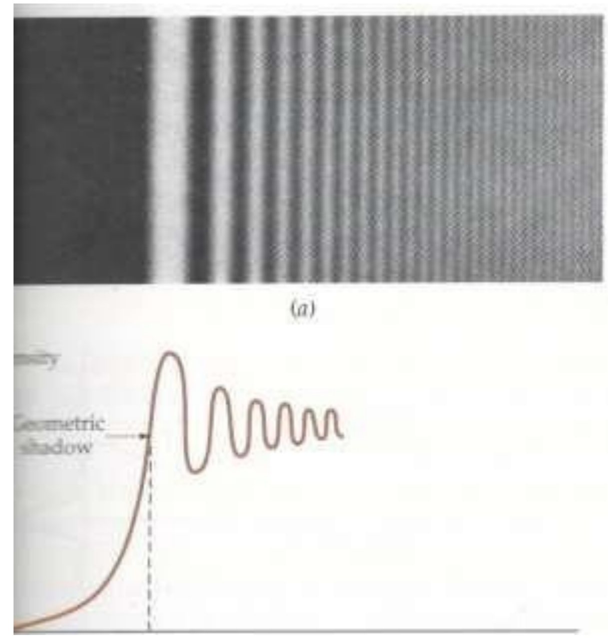
Diffraction results in to blurred images

Some Examples of Diffraction



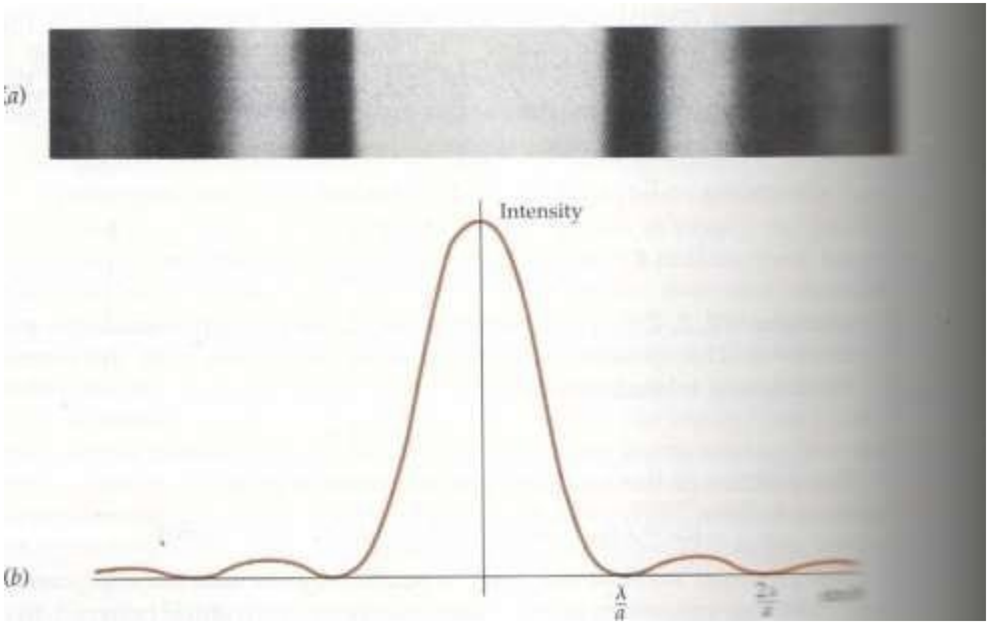
Diffraction due to a rectangular mesh

Diffraction due to a Straight edge



Diffraction due to a single slit. Look at principle maxima and secondary maxima

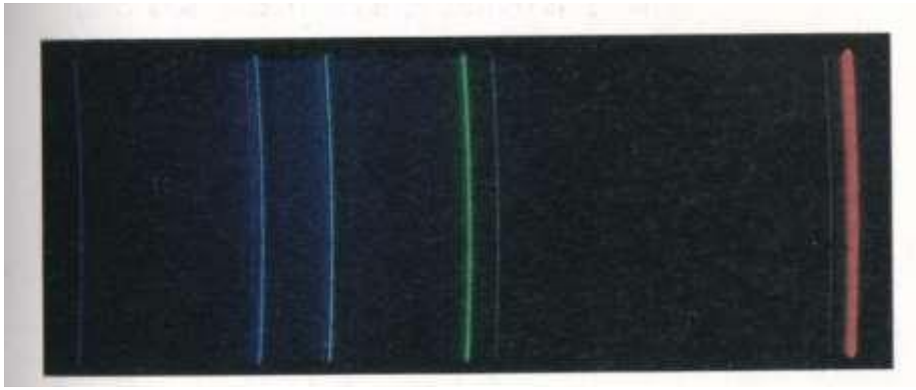
Some examples of Diffraction



Diffraction due to a rectangular aperture

Diffraction due to a Circular aperture

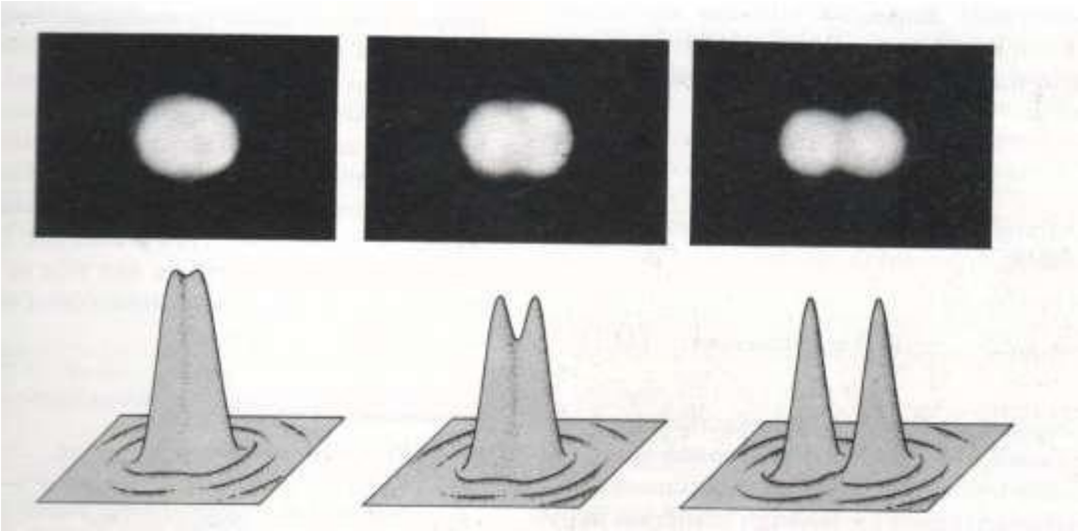
Some examples of diffraction



Spectrum of Cadmium through diffraction grating

Colored appearance of CDs is also due to diffraction

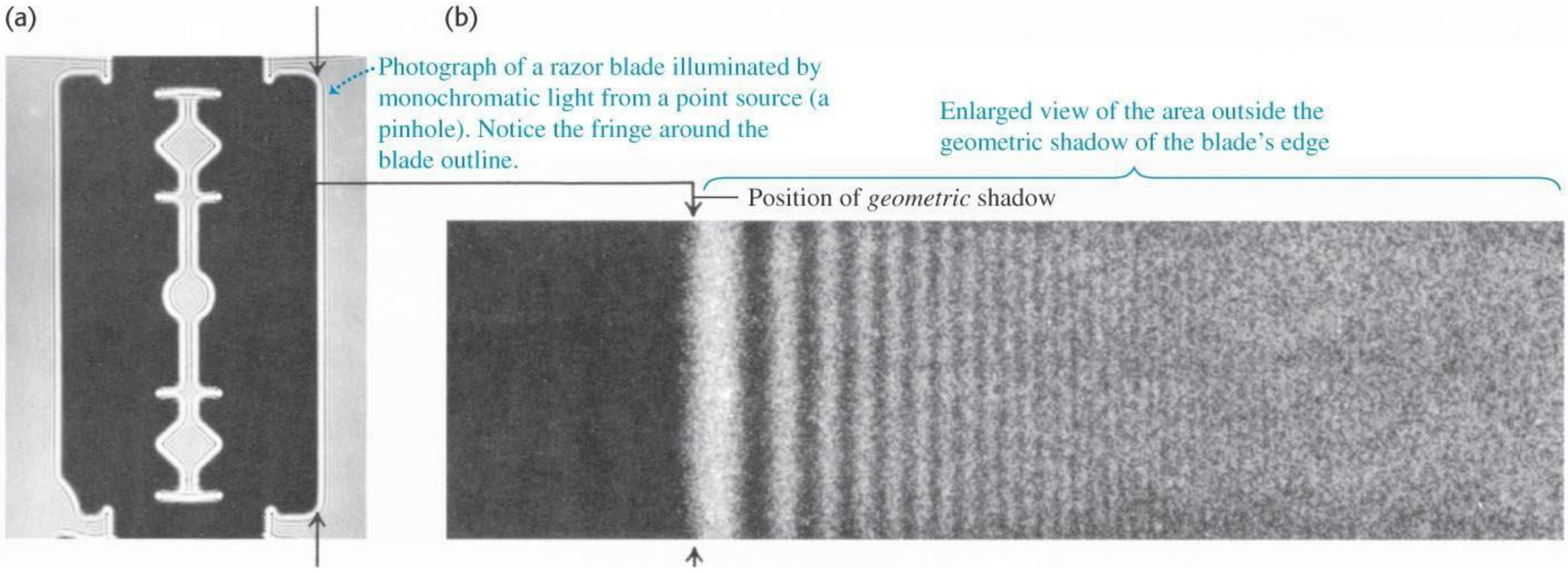
Some examples of Diffraction



Rayleigh's Criterion of Resolution. Resolution effects are diffraction dependent

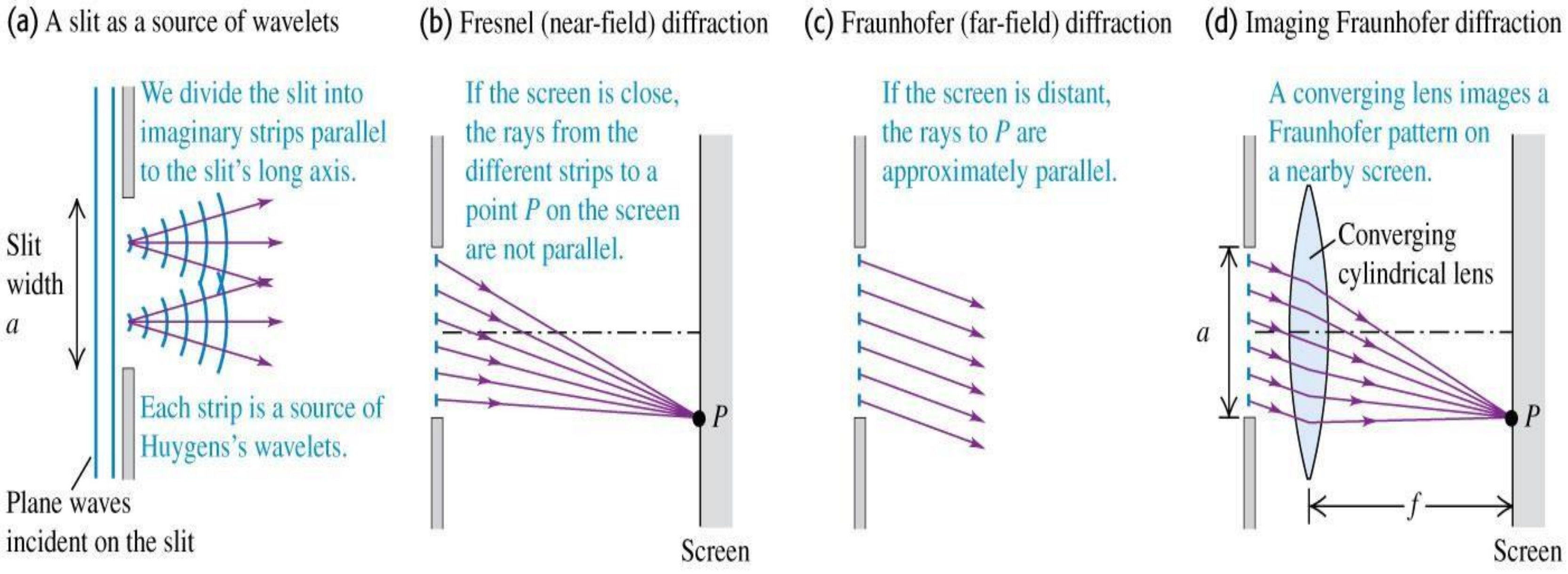
Diffraction and Huygen's Principle

- Huygens's principle can be used to analyze diffraction.
- *Fresnel diffraction*: Source, screen, and obstacle are close together.
- *Fraunhofer diffraction*: Source, screen, and obstacle are far apart.
- Figure shows the diffraction pattern of a razor blade.



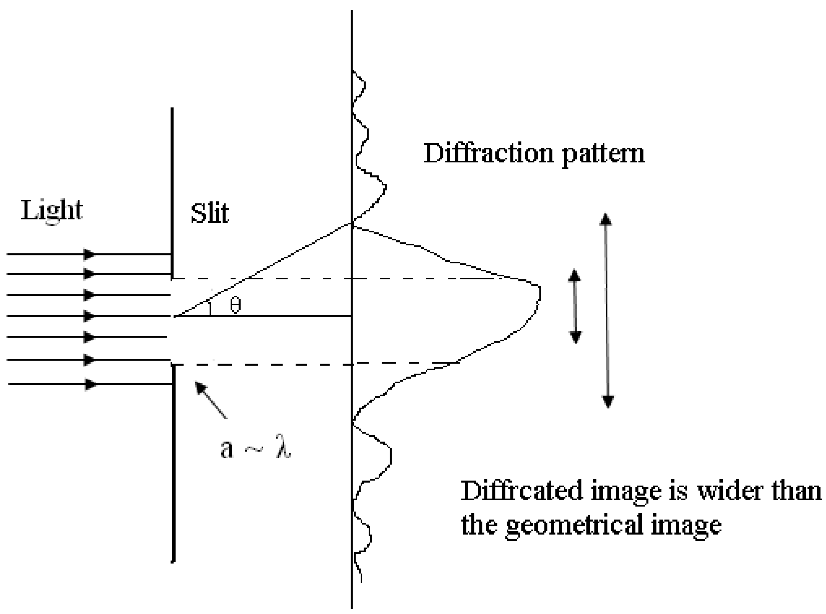
Fresnel and Fraunhofer Diffraction by a single slit

- Fresnel (near-field) and Frauenhofer (far-field) diffraction for a single slit.



Single Slit Diffraction

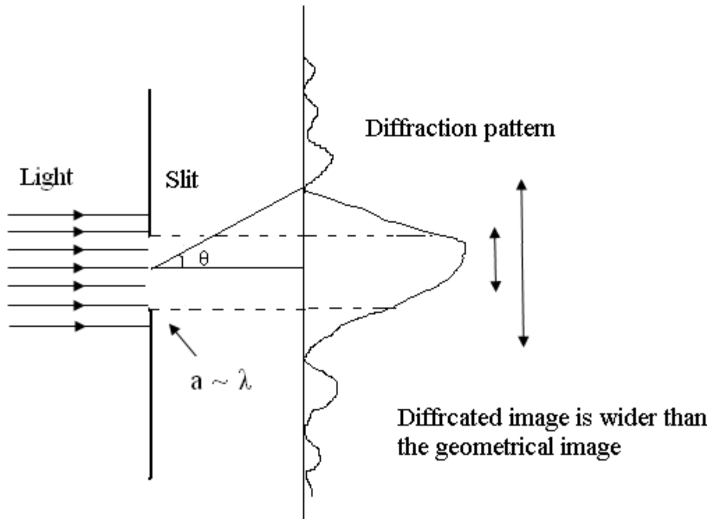
Our main aim is to learn multiple slit diffraction. But it can not be understood directly So we begin with single slit diffraction and then extend it to multiple slits



When a wavefront is obstructed by a slit, diffraction takes place and a diffraction pattern is produced

When a wavefront passes through a slit every point in the slit becomes a source of secondary wavelets. These wavelets generate waves passing in all directions. When these diffracted waves interfare a diffraction pattern of maxima and minima is produced

Equations of Single Slit Diffraction



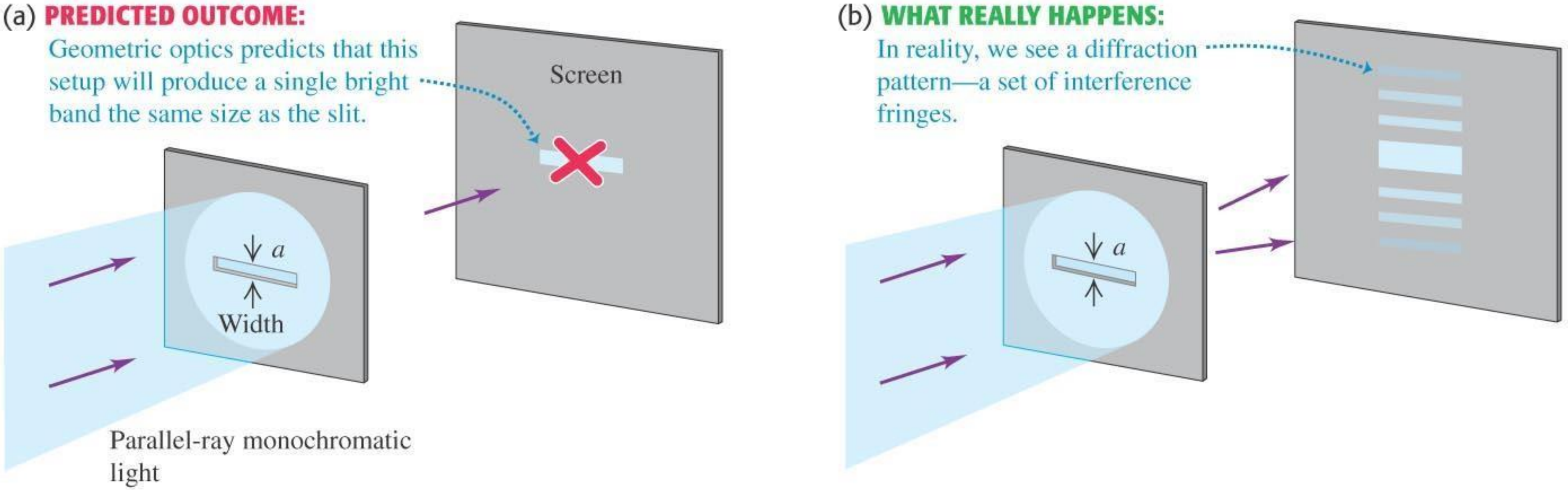
$$I_\theta = I_m \left(\frac{\sin\alpha}{\alpha}\right)^2$$

$$\alpha = \pi \frac{a}{\lambda} \sin\theta$$

Type of maxima/minima	Intensity	α	θ
Central maximum,	$I_\theta = I_m,$	$\alpha = 0^o,$	$\theta = 0^o$
Minima,	$I_\theta = 0,$	$\alpha = m\pi,$	$a\sin\theta = m\lambda$
Secondary maxima	I_θ : very small,	$\alpha = \left(m + \frac{1}{2}\right)\pi,$	$a\sin\theta = \left(m + \frac{1}{2}\right)\lambda$

Diffraction from a single slit

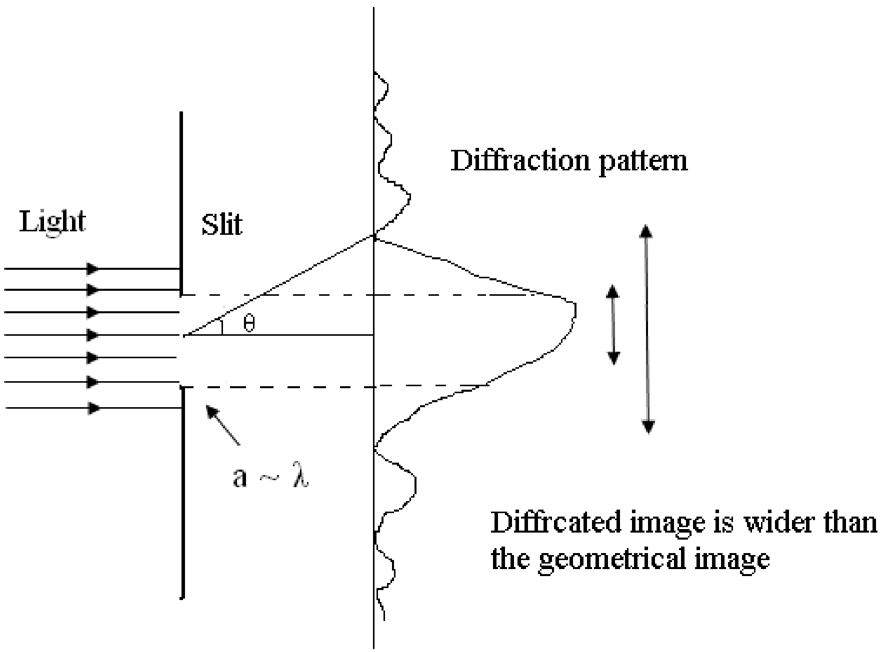
- In Figure, the prediction of geometric optics in (a) does not occur. Instead, a diffraction pattern is produced, as in (b).



- The *narrower* the slit, the *broader* the diffraction pattern.

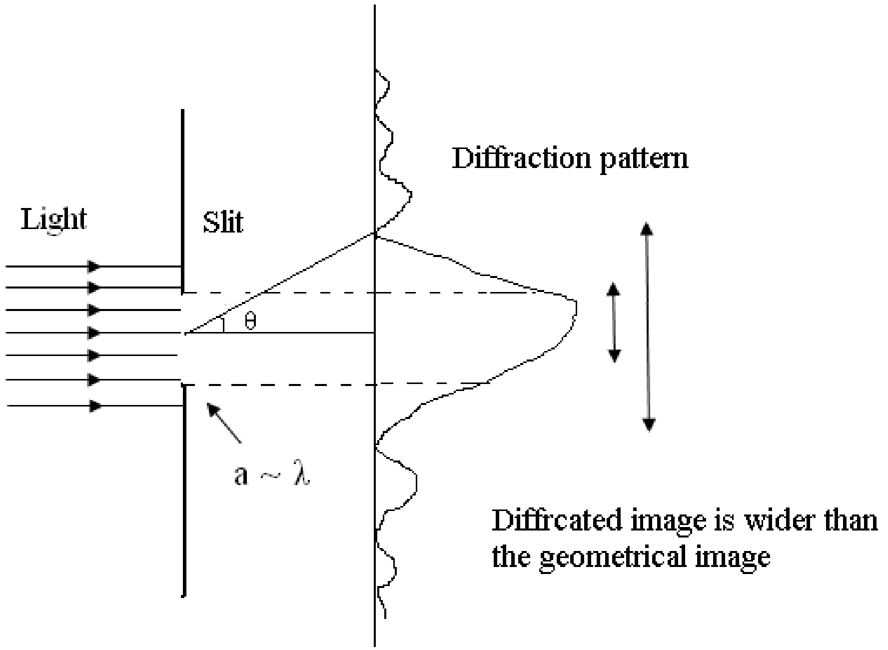
Characteristics of Single Slit Diffraction

1. Diffraction results in to widening of images (or even shadows!)
2. Diffraction effects become weak as the obstacle become bigger than the wavelength of wave being diffracted. On the contrary, diffraction is strengthened when the width of obstacle approaches the wavelength of wave being diffracted
3. The angle of diffraction changes with the wavelength. Thus diffraction separates the colors of light.



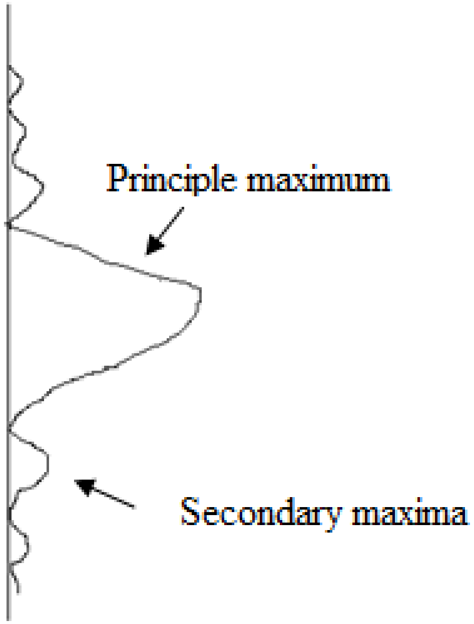
Characteristics of Single Slit Diffraction

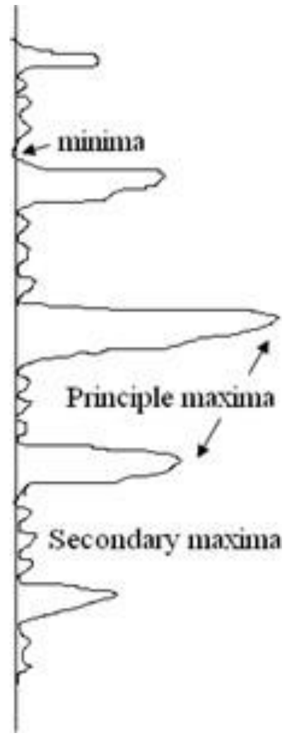
4. A single slit can separate the colors of light but the spectral lines are too broad to be resolvable
5. Though principally a single slit can be considered as a dispersive device, it's dispersive power is too small for it to be practically useful
6. Though, a single slit can be used to form the spectrum of light, the intensity of these spectra are too weak for a single slit to be used as a dispersive device



When a single slit is replaced by multiple slits

Single Slit **Multiple Slits**

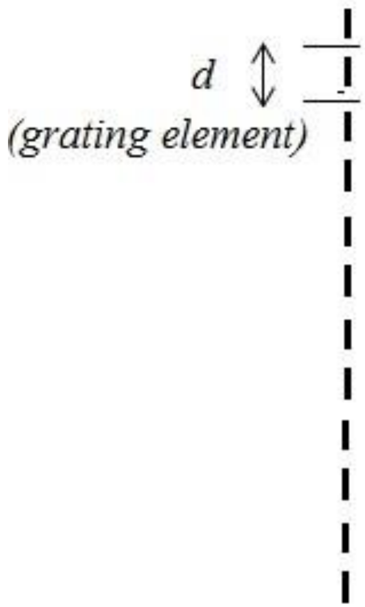


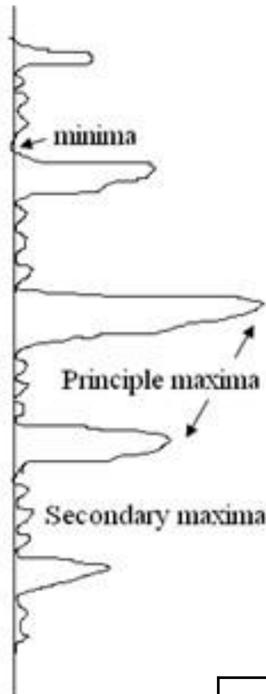


1. Maxima become more bright
2. Maxima become more sharp
3. Several secondary maxima are introduced between the consecutive principal maxima

4. In a system of N number of slits, there are $N - 1$ minima and $N - 2$ secondary maxima in between consecutive principle maxima. This clearly means that as the number of slits are increased, the minima and secondary maxima increase in number. This requires more space and as a consequence the principle maxima are encroached and become sharp.

Diffraction Grating and Associated Theory





Intensity formula

$$I_\theta = I_m \left(\frac{\sin\alpha}{\alpha}\right)^2 \left(\frac{\sin N\beta}{\sin\beta}\right)^2$$

$$\alpha = \pi\frac{a}{\lambda}\sin\theta, \qquad \beta = \pi\frac{d}{\lambda}\sin\theta$$

Grating Element

$$d = \frac{a}{2} + \frac{a}{2} + b = a + b$$

Principle maxima

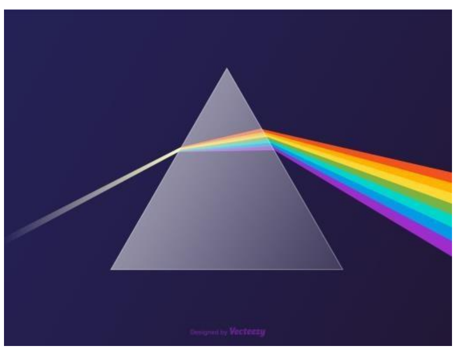
$I_\theta = N^2 I_m \left(\frac{\sin\alpha}{\alpha}\right)^2$	$\beta = m\pi$	$d\sin\theta = m\lambda$

Minima

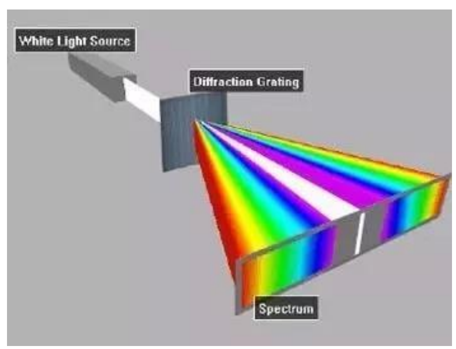
$I_\theta = 0$	$N\beta = m'\pi$	$d\sin\theta = \frac{m'}{N}\lambda, (m' \neq mN)$

Characteristics of Multiple Slit Diffraction

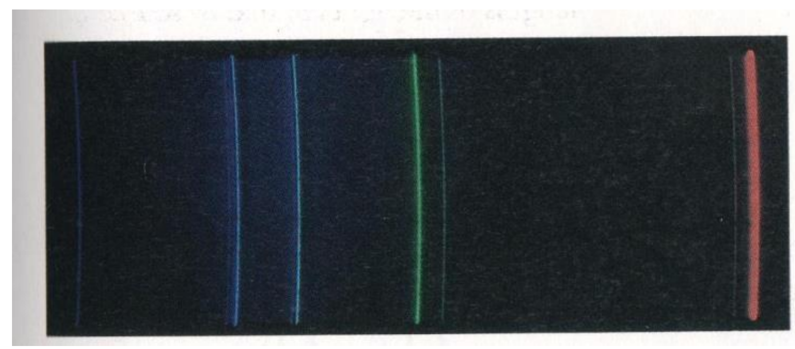
1. Maxima (Spectral lines) are bright
2. Maxima (Spectral lines) are Sharp
3. Colors can be separated and hence spectrum can be formed
4. Prism can also separate the colors of light, but diffraction grating is a super-prism, whose dispersive power and resolving power are incredibly high as compared to prism



Prism



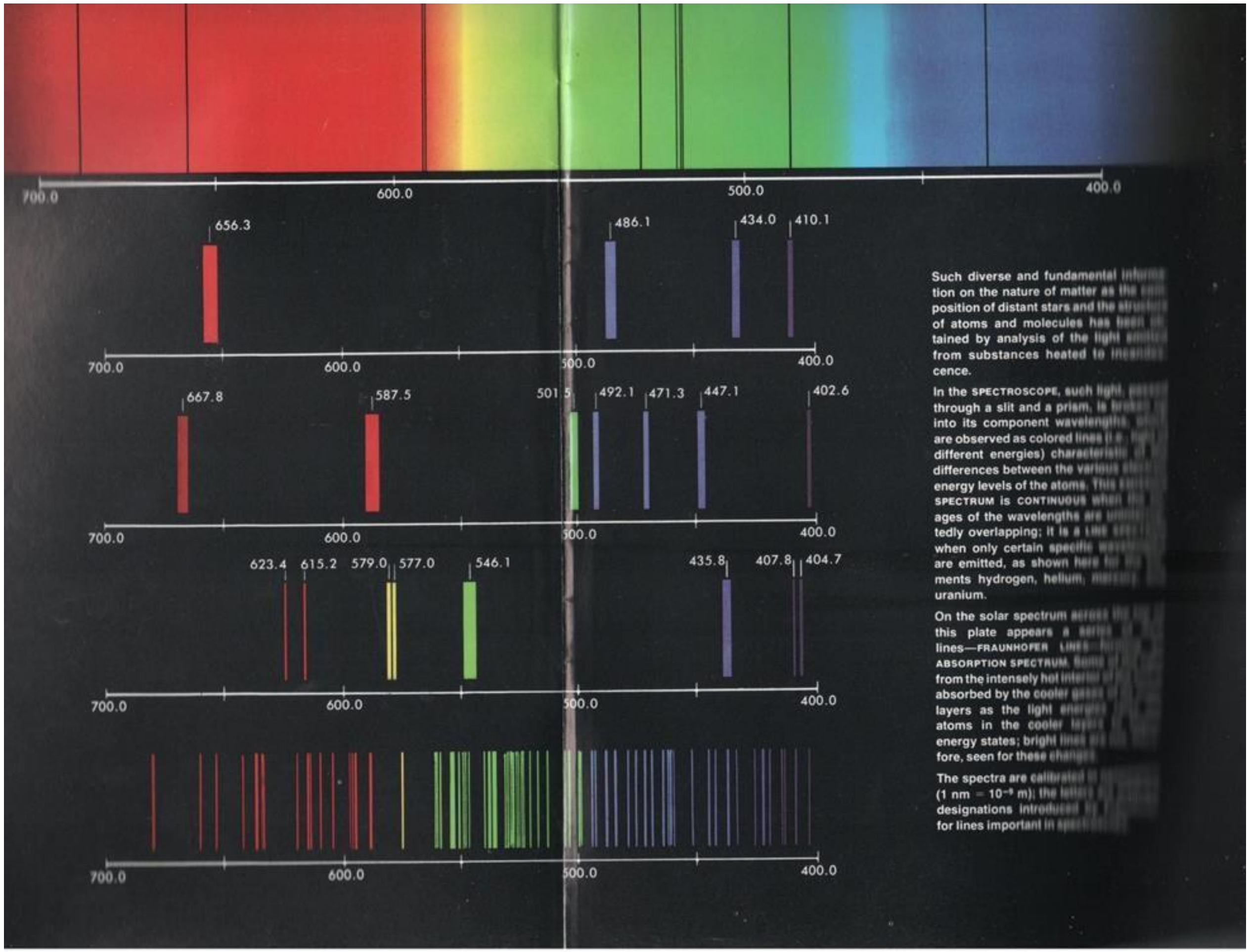
Grating



Spectrum of Cadmium through diffraction grating

Grating Spectra of Hydrogen, Helium, Mercury and Uranium

Each spectrum is as unique as a finger print ! Why?



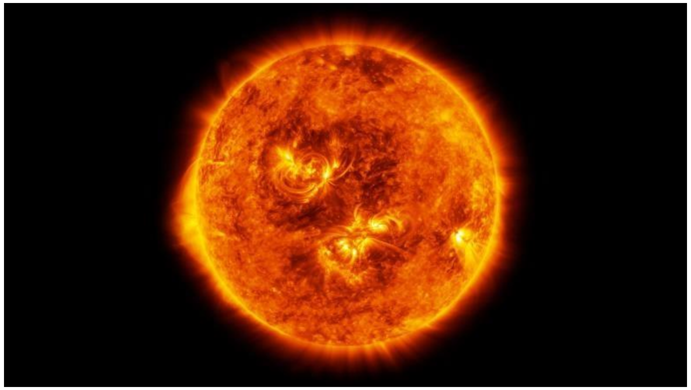
Gratings produce well defined, well resolved and well dispersed spectra: **Spectroscopy**

Phenomena related to spectrum analysis

1. **Raman effect**
2. **Zeeman effect**
3. **Stark effect**
4. **Mössbauer effect**

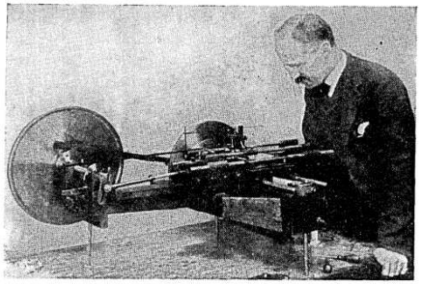
Check point

1. Each element and each compound produces a unique spectrum which can not be duplicated by any other element. Why?
2. How do we know that Sun contains 75 % hydrogen and 25 % helium?
3. Can an unknown element be recognized by looking at its spectrum?
4. Can it be identified whether a given element is pure or not?



How diffraction gratings are made?

- Ruling equidistant lines on a reflective or transmittive surface by using a fine diamond point attached to Rowland Machine
- Grooved parts become opaque. The un-grooved space between to scratched lines are transparent



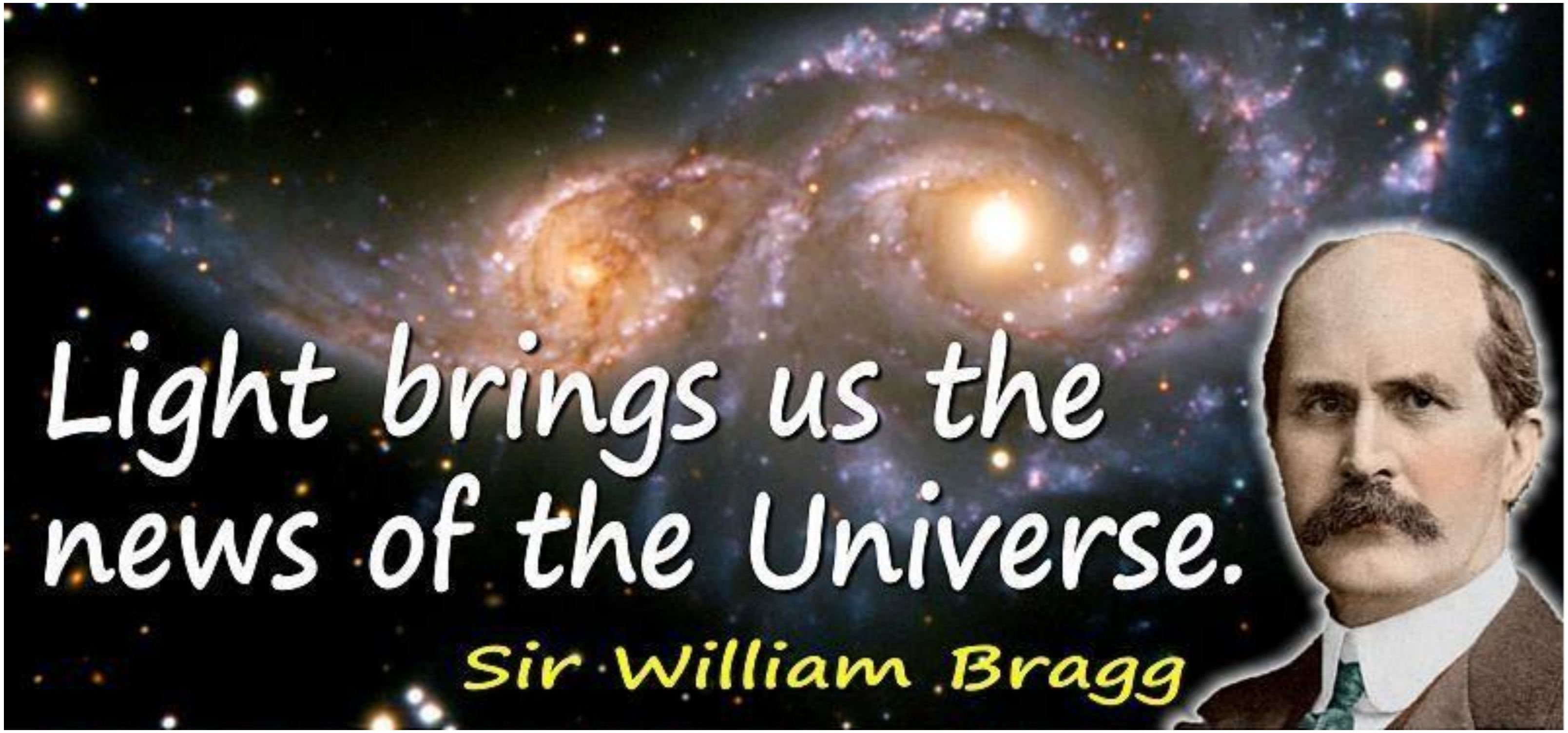
Rowland Machine

Rowland Grating

Check point

- Can a pocket comb behave like a diffraction grating?
- Crystals have periodic arrangement of atoms: can they be used as diffraction grating?

Why compact discs appear colored?



Thank You !