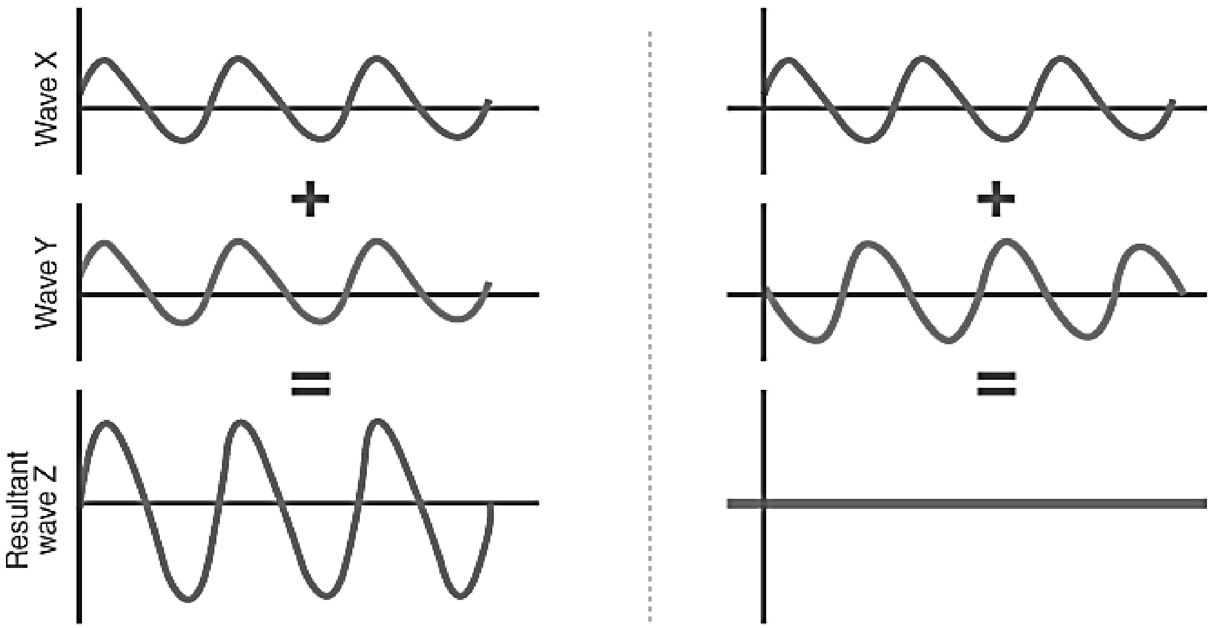
Unit-1
Wave Optics

CONCEPT OF INTERFERENCE

When two light waves of the same frequency and having zero or constant phase difference travelling in same direction super impose each other then resultant intensity gets maximum at same points and minimum at other points. This redistribution of energy is called interference.
Interference is of two types are:

1. *Constructive interference:* when two waves superimposed at same point such that the resultant amplitude and intensity are maximum then it is called constructive interreference.
2. *Destructive interference:* when two waves are superimposed at same point such that the resultant amplitude and intensity are minimum then it is called destructive interference.

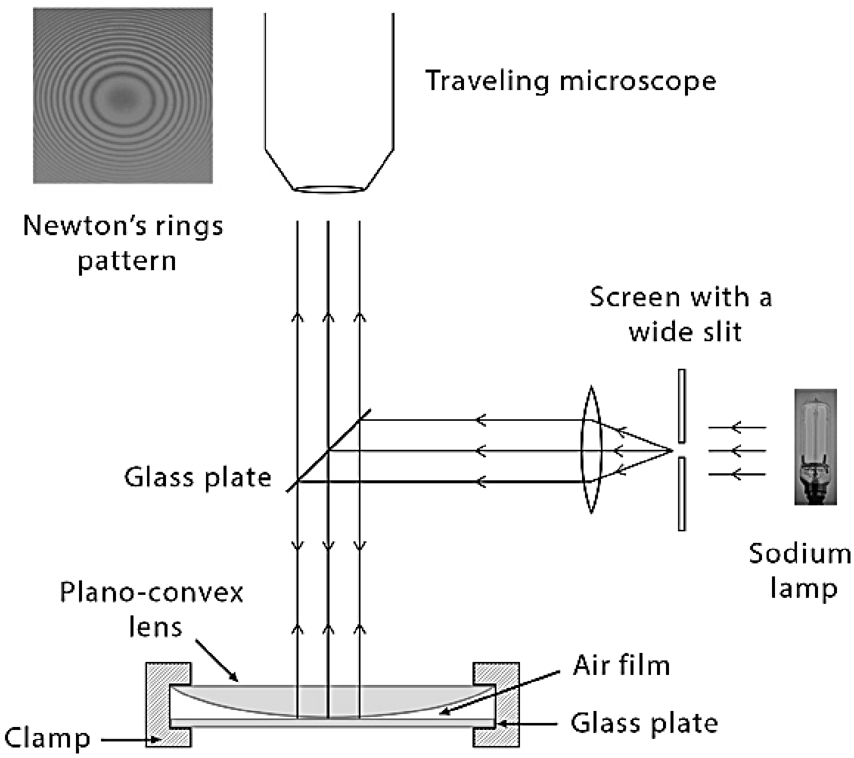


Constructive interference Destructive interference

INTERFERENCE IN THIN FILMS (REFLECTED LIGHT) – NEWTON'S RINGS AND MICHELSON'S INTERFEROMETER

Newton's Rings

Newton's Rings are a pattern of concentric alternate bright and dark fringes (rings) formed due to interference of light between a convex lens and a flat glass plate.
These rings are observed in reflected light and are named after Sir Isaac Newton, who first studied them.
Experimental Setup
A plano-convex lens is placed gently on a flat glass plate. A thin air film is formed between the curved surface of the lens and the flat surface of the glass.
Light is made to fall normally through a monochromatic light source. The light reflects from both the top and bottom surfaces of the air film, leading to interference.



The thickness of the air film varies from zero (at point of contact) to more as you move outwards. The path difference between the rays reflected from:

- Top surface of the air film and
- Bottom surface of the air film gives rise to interference.

Path Difference

In reflected light, one reflection involves a phase shift of π (half wavelength). So, the effective path difference is:

$$\Delta = 2t + \frac{\lambda}{2}$$

Where:

- t = thickness of air film
- λ = wavelength of light used

Radius of the Ring – Derivation

Let:

- R = radius of curvature of the plano-convex lens
- r_n = radius of the nth dark ring
- t = thickness of the air film at a distance r from the centre

Using geometry:

$$t = \frac{r^2}{2R}$$

For destructive interference (dark ring) in reflected light:

$$2t = (2n-1)\frac{\lambda}{2} \Rightarrow t = \frac{(2n-1)\lambda}{2}$$

Substitute:

$$\frac{\mathrm{r}_\mathrm{n}^2}{2\mathrm{R}} = \frac{(2n-1)\lambda}{4}$$

$$\mathrm{r}_\mathrm{n}^2 = \frac{(2n-1)\lambda R}{2}$$

For nth bright ring:

$$r_n^2 = n\lambda R$$

Diameter of nth Dark Ring

$$D_n = 2r_n = \sqrt[2]{\frac{(2n-1)\lambda R}{2}} = \sqrt{(2n-1)\lambda R}$$

Or for diameter squared:

$$D_n^2 = 4r_n^2 = 2(2n-1)\lambda R$$

Fringe Pattern

- At centre: Film thickness is 0 → path difference = $\frac{\lambda}{2}$ → Destructive interference → Dark spot at centre
- As you move outward, bright and dark fringes alternate.

Michelson's Interferometer

Michelson's interferometer is an instrument in which the phenomena of interference is used to make praise measurements of wavelengths, refractive index and distance.

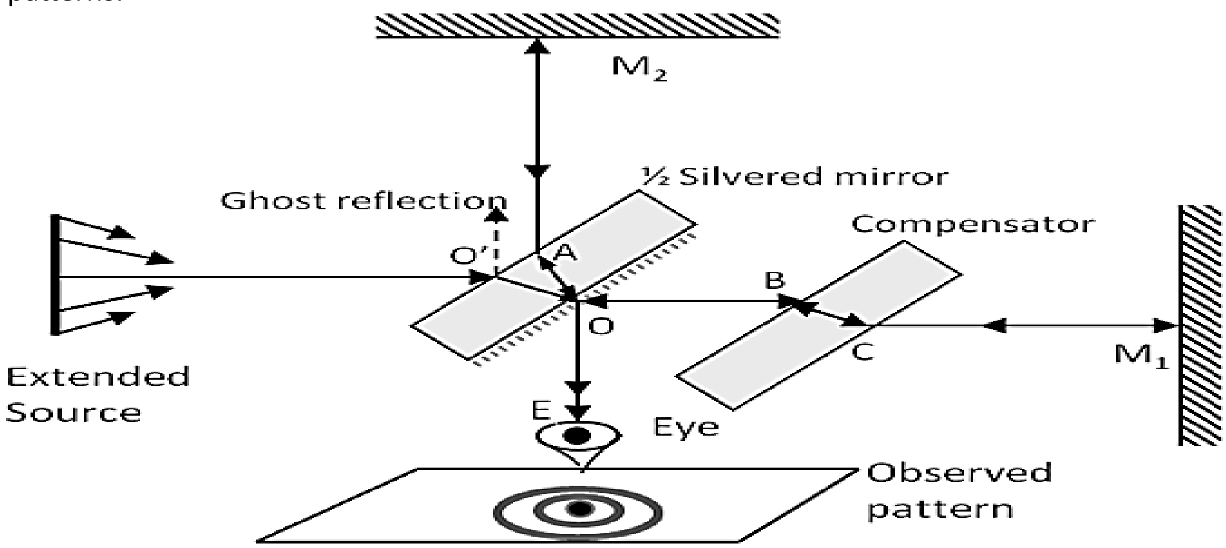
Principle

The principle of Michelson's Interferometer is based on the interference of light waves.
A beam of monochromatic light is split into two beams using a partially silvered mirror (beam splitter).
These beams travel along perpendicular paths, reflect off mirrors (M1 and M2), and then recombine.
If the path difference between the two beams is an integral multiple of wavelength, constructive interference occurs (bright fringe); if it's a half-integral multiple, destructive interference occurs (dark fringe).

Construction

The interferometer consists of the following main components:

- *Beam Splitter:* A partially silvered mirror that divides the incoming light beam into two separate beams.
- *Mirrors:* Two fully reflective mirrors (commonly referred to as Mirror M1 and Mirror M2) positioned perpendicularly to each other.
- *Compensator Plate:* A glass plate of the same thickness as the beam splitter, placed in the path of one of the beams to equalize the optical paths.
- *Screen or Detector:* A surface or device where the recombined beams produce interference patterns.



Working

A monochromatic light source is directed towards the beam splitter, which divides the light into two beams traveling along different paths:

- Path 1: The beam reflects off the beam splitter, travels to Mirror M1, reflects back to the beam splitter, and then passes through it towards the detector.
- Path 2: The beam passes through the beam splitter, reflects off Mirror M2, returns to the beam splitter, and reflects towards the detector.

Upon recombination at the beam splitter, the two beams interfere, producing a pattern of bright and dark fringes on the detector. The nature of these fringes depends on the difference in the optical paths of the two beams.

APPLICATIONS OF WAVELENGTH MEASUREMENT

- *Young's Double-Slit Experiment: Measures wavelength by analyzing fringe patterns formed due to interference.*
- *Newton's Rings:* Determines wavelength using the circular interference pattern in thin films.
- Diffraction Grating: Uses multiple slits to accurately measure wavelengths of light sources.
- *Michelson's Interferometer:* Measures wavelength and small displacements using interference fringes.
- *Thin Film Interference:* Helps in optical coatings and wavelength filtering in engineering applications.

CONCEPT OF DIFFRACTION

The bending of the light around an absolute on slit and spreading out in the geometrical shadow is called diffraction. It depends on the size of obstacle and wavelength of light.

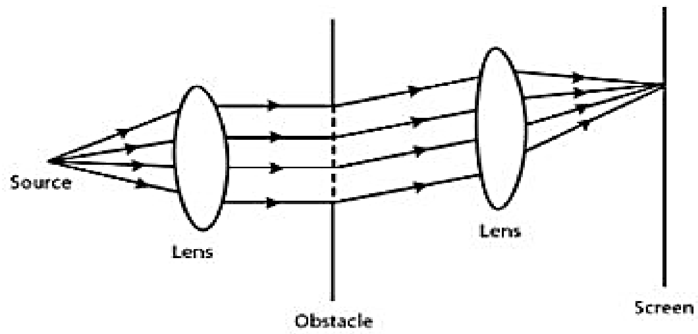
Difference Between Interference and Diffraction

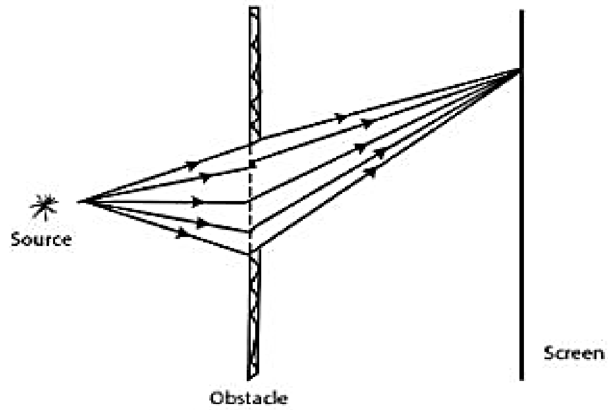
Interference	*Diffraction*
• The phenomenon results from superposition of secondary wavelets originating from two coherent sources. • Interference fringes are of equal width. • All bright fringes are of equal intensity. • The intensity of all dark fringes is zero, i.e. all dark fringes are perfectly black.	• The phenomenon results from superposition of secondary wavelets originating from single coherent source. • Diffraction fringes are never of equal width. • The intensity of all bright fringes is not equal. • The intensity of all dark fringes is not zero, i.e. all dark fringes are not perfectly black.

Types of Diffraction

1. *Fraunhofer Diffraction:*
   - Source and screen are at infinite distance or are made to act as such using lenses.
   - Incident wavefront is *plane*.
   - Easier to analyse mathematically.
2. *Fresnel Diffraction:*
   - Source and screen are at finite distances.
   - Wavefronts are *spherical* or *cylindrical*.
   - Requires complex analysis using *zone plates*.

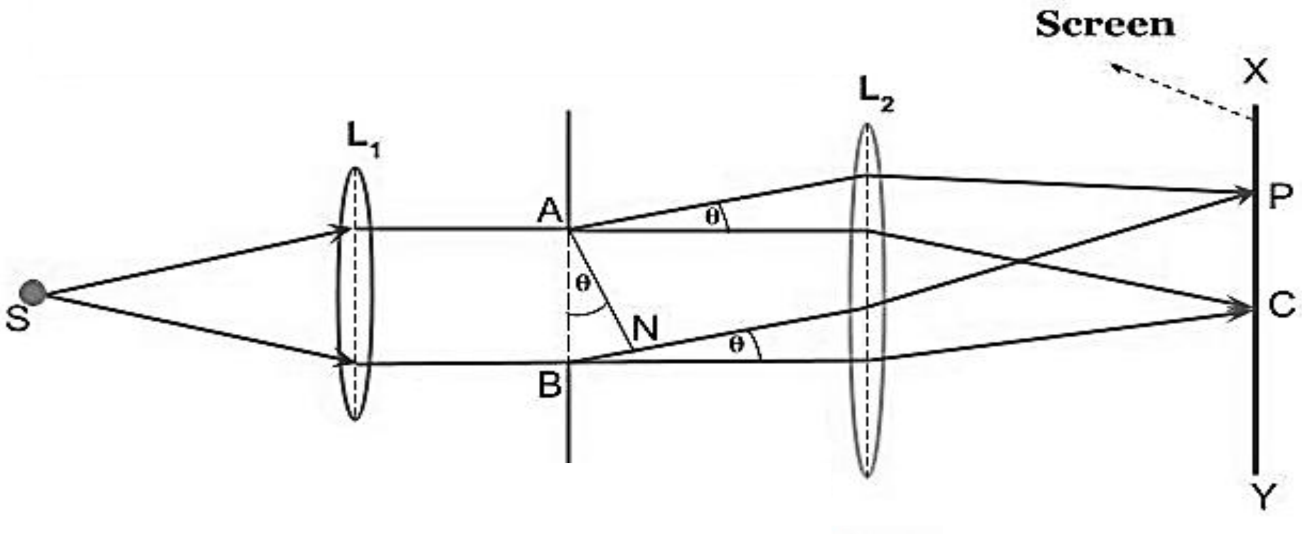
Fraunhofer and Fresnel Diffraction





SINGLE SLIT FRANUNHOFFER'S DIFFRACTION

A monochromatic plane wave (from a laser or a filtered source) is incident normally on a single narrow slit of width *a*. A converging lens is used to focus the diffracted rays on a screen placed at its focal plane.



Conditions

- Light is monochromatic and coherent.
- Slit width *a* is comparable to the wavelength λ of light.

Intensity Distribution Formula

Let:

- θ = angle of diffraction,
- *a* = width of slit,
- λ = wavelength of incident light.

The intensity at angle θ is given by:

$$I(\theta) = I_0\left(\frac{sin\beta}{\beta}\right)^2$$

where,

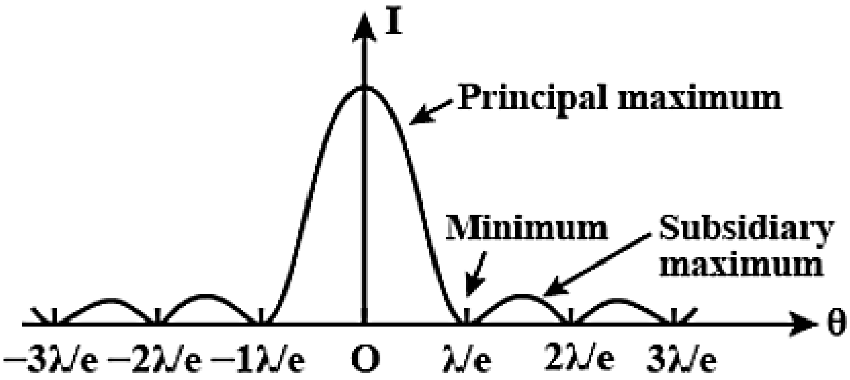
$$\beta = \frac{\pi a sin\theta}{\lambda}$$

Conditions for Minima

The minima (dark fringes) occur when:

$$a sin\theta = m\lambda \qquad\qquad where\ m = \pm1, \pm2, \pm3, \ldots$$

There is no central minimum; the central maximum is always the brightest.



Key Features

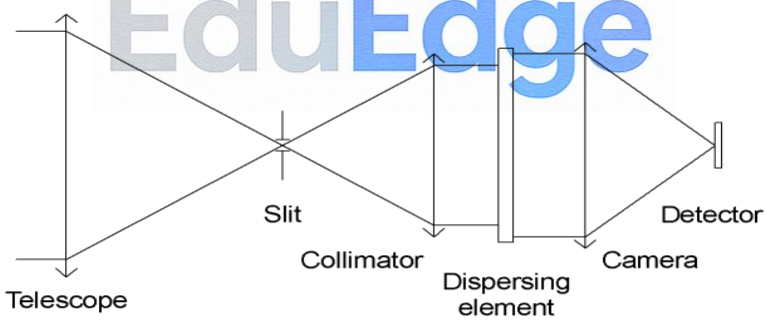
- *Central Maximum:* Bright and twice as wide as the others.
- *Subsidiary Maxima:* Less intense, located between minima.
- *Intensity falls rapidly with angle.*

DIFFRACTION GRATING AND SPECTRUM

What is a Diffraction Grating?

A diffraction grating is an optical component with a regular pattern of equally spaced slits or grooves.

- Each slit acts as a source of secondary wavelets.
- The interference between these wavelets leads to a well-defined pattern.
- Can be transmission or reflection type.



Working Principle

When monochromatic light passes through a grating, constructive interference occurs at specific angles, forming bright maxima.

Grating Equation

Let:

- *d* = grating spacing (distance between two adjacent slits),
- θ = diffraction angle,
- *n* = order of diffraction,
- λ = wavelength of incident light,

Then:

$$n\lambda = d\sin\theta$$

This is known as the grating equation.

Spectral Orders

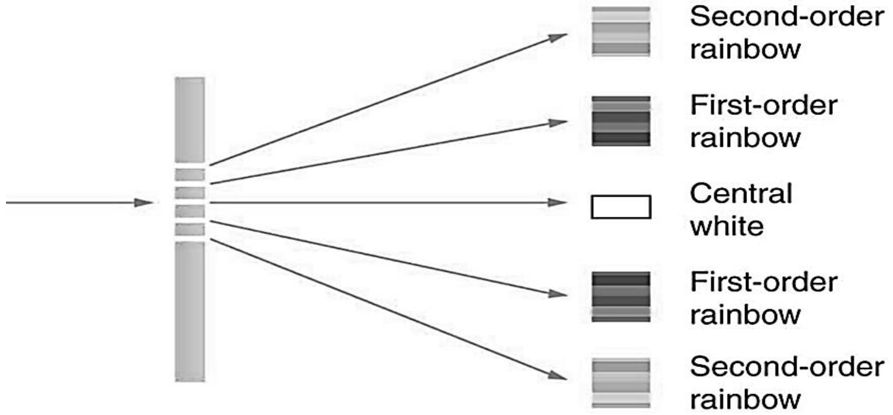
- *n = 0* → Central maximum (undeviated).
- *n = 1, 2, 3...* → First-order, second-order, etc., spectra.

The higher the order, the more angular separation between wavelengths.

Diffraction Spectrum

When polychromatic light (e.g., white light) passes through the grating:

- Each wavelength satisfies the condition at a different angle.
- The result is a spatial separation of colors.
- This is used in spectrometers to analyse light from stars, chemicals, etc.



DETERMINATION OF WAVELENGTH

Grating as a Wavelength Splitter

A diffraction grating acts as a high-precision wavelength separator due to:

- High angular dispersion,
- Ability to separate closely spaced wavelengths.

This property is utilized in:

- Spectroscopy,
- Laser wavelength tuning,
- Optical Communication (WDM systems).

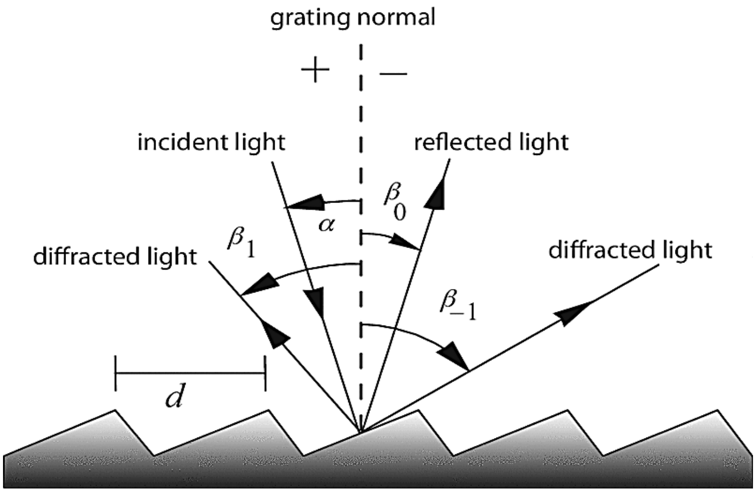
Advantages Over Prism:

Feature	Prism	Grating
Dispersion Type	Refractive	Diffractive
Angular Dispersion	Non-uniform	Uniform
Overlapping Spectra	Yes	No (in lower orders)
Accuracy	Moderate	High

Wavelength Determination Using Diffraction Grating

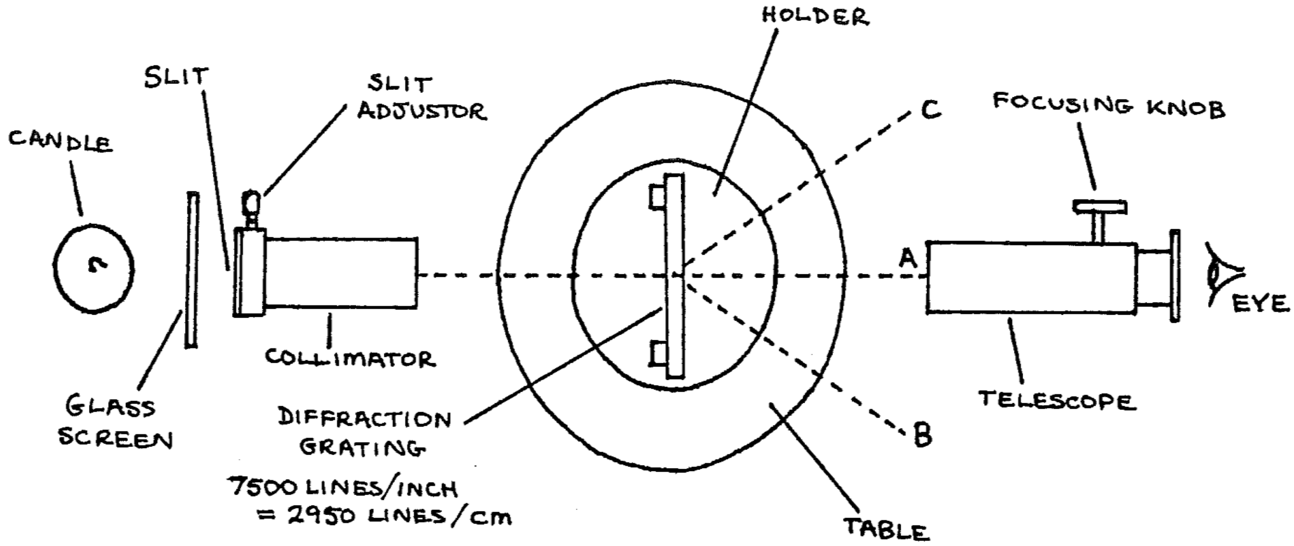
To find the unknown wavelength λ, use the grating formula:

$$\lambda = \frac{d\sin\theta}{n}$$



Experimental Setup:

- Monochromatic light → slit → collimator → diffraction grating.
- Use a telescope or screen to observe diffracted beams.
- Measure the diffraction angle θ for a particular order *n*.
- Use the known value of grating spacing d = $\frac{1}{N}$, where *N* = number of lines per unit length.



Example:

A grating has 5000 lines/cm →

$$d = \frac{1}{5000} cm = 2 \times 10^{-6}\, m$$

If the first-order diffraction angle is 30°, then:

$$\lambda = \frac{d \sin 30°}{1} = (2 \times 10^{-6}) \times 0.5 = 1 \times 10^{-6}\, m = 1000\, nm$$

APPLICATION OF GRATING AS A WAVELENGTH SPLITTER

- **Spectroscopy**: To analyse atomic and molecular spectra.
- **CD/DVD players**: Use diffraction for data reading.
- **Telecom (WDM)**: For separating different light channels.
- **Holography and Interferometry**
- **Laser Wavelength Measurement**