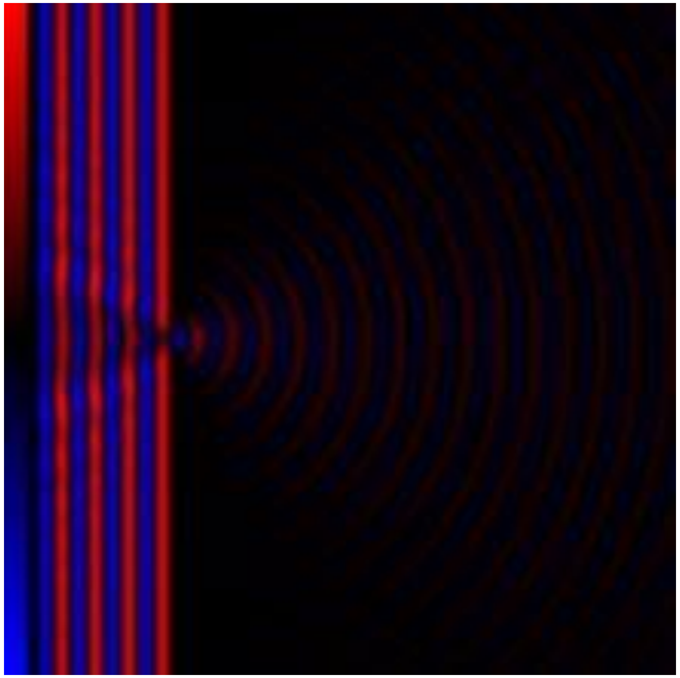


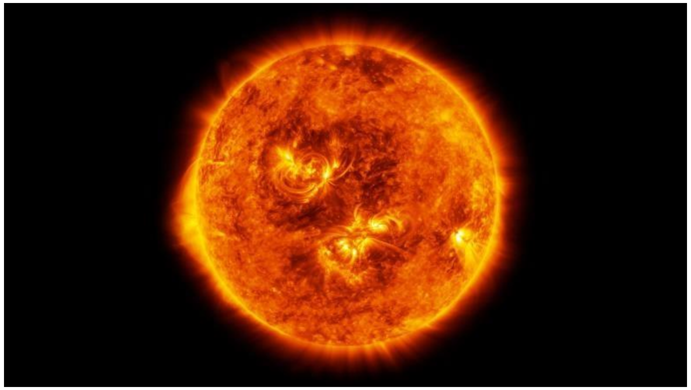
# Diffraction: Lecture #2

# Diffraction #2: Outline

1. Diffraction grating and its pattern
2. Formulae for Diffraction Grating
3. Dispersive power and resolving power of grating
4. Diffraction due to circular aperture and a brief glance at Resolving powers of Optical Instruments (Beyond the syllabus but value addition)

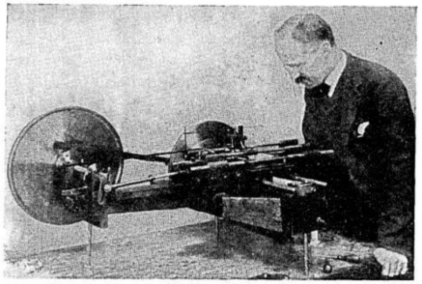
# Check point

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

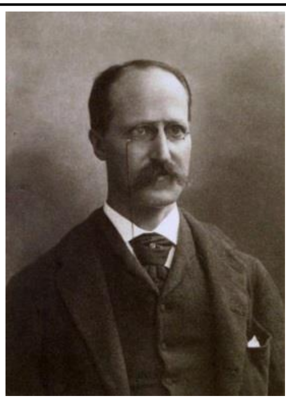
- Can a pocket comb behave like a diffraction grating?
- Crystals have periodic arrangement of atoms: can they be used as diffraction grating?

Why compact discs appear colored?

## Fraunhofer was the first to make a diffraction grating

| | |
|---|---|
|  Joseph von Fraunhofer (1787-1826) | **Joseph Von Fraunhofer** 1787 -1826 Once an undereducated apprentice, he established his own optical industry, where he designed and fabricated several devices and instruments such as loupes, prisms, microscopes, telescopes, astronomical reflectors etc. He worked with several contemporary Opticians. Fraunhofer described his investigations of light by gratings which were initially made by winding wires around parallel screws, a device called as diffraction grating. Indeed he was the first to make a diffraction grating. Using his grating he rediscovered almost 574 dark lines in the solar spectrum, which are called Fraunhofer lines. |

## The modern grating ruling machines were first made by Rowland

| | |
|---|---|
|  | **Henry Augustus Rowland** (1848–1901): He was an American Physicist, who is best known for construction of Rowland machine, which is used to construct sophisticated and high quality diffraction gratings. Rowland machines are known for extraordinary trueness and delicacy. In between 1899 to 1901, he was the president of the famous American Physical Society. His contributions in Thermodynamics, Electricity and Magnetism are also noteworthy. |

# Quality parameters of Diffraction Grating

$$\boldsymbol{Dispersive\ power\ of\ a\ grating} = \frac{d\theta}{d\lambda} = \frac{m}{d cos\theta} \approx mN'$$

**How much angular separation (dispersion) can be produced between adjacent spectral lines**

$$\boldsymbol{Resolving\ power\ of\ grating} = R.P. = \frac{\lambda}{d\lambda} = mN$$

**If the wavelengths of two spectral lines are very close, then they overlap. Can they be resolved**

**Note**: N' (***N′*** = 1/d; d – grating element = a+b) is the number of slits per unit length, while ***N*** is the total number of slits be produced between adjacent spectral lines

# Check point

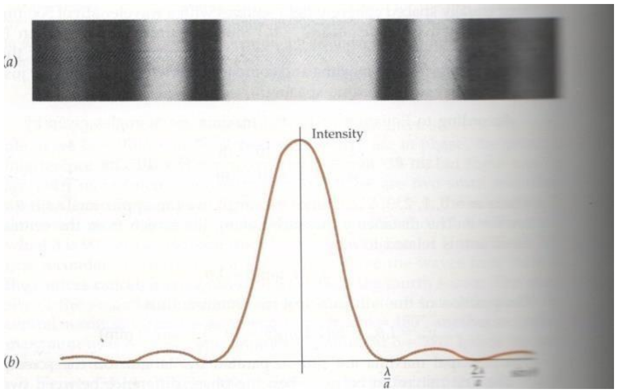
| | Grating A | Grating B | Grating C |
|---|---|---|---|
| **Total length** | 1 inch | 2 inch | 1 inch |
| **Slits** | 10000 per inch | 20000 per 2 inch | 20000 per inch |

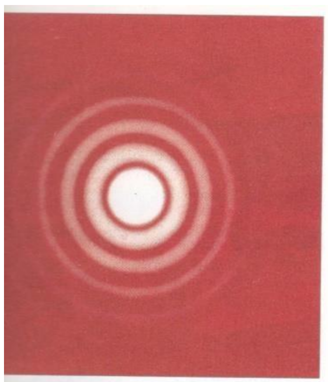
1. Which two gratings have same resolving power?
2. Which two gratings have same dispersive power?
3. Which grating is the best w.r.t. resolving power as well as dispersive power?

# Always remember

- Larger the slit density: Better is the dispersive power
- Smaller the grating element stronger is the diffraction effects hence better is the dispersive power
- Larger the total number of slits, more sharp the spectral lines are hence better is the resolving power


# Diffraction due to circular aperture



When a rectangular slit is replaced by circular aperture, circular diffraction pattern having disc at the center and surrounded by dark and bright rings is produced

Minima in single slit diffraction $a sin\theta = m\lambda$

For first minima *m=1*. Thus $a sin\theta = 1 \times \lambda$

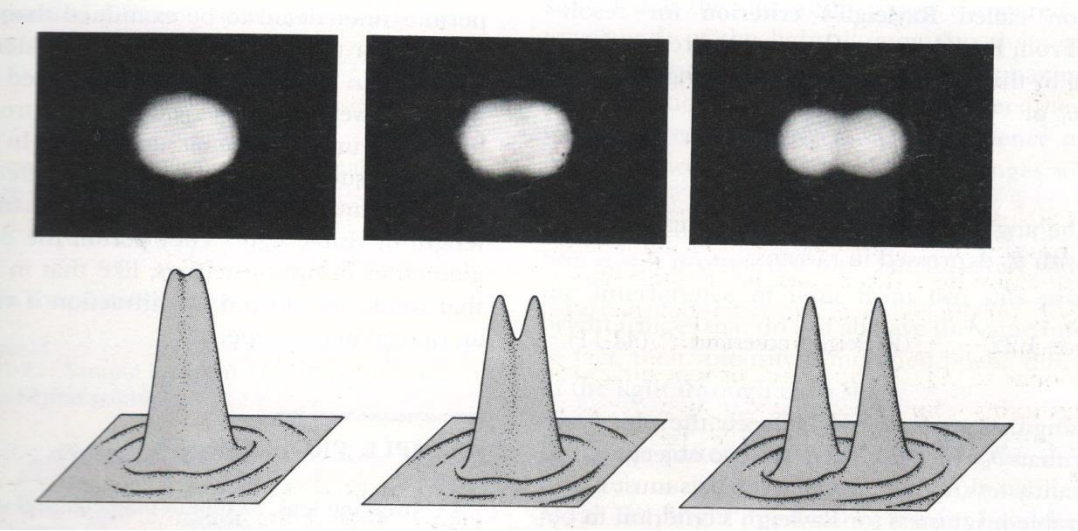
According to a Physicist Airy, when rectangular slit is replaced by circular aperture. 1 in above equation is replaced by 1.22 and ***a*** (the width of slit) is replaced by ***d*** (the diameter of circular aperture)

Thus the first minima in circular aperture $d sin\theta = 1.22 \times \lambda$

Generally $\theta \rightarrow 0$. Thus $sin\theta \rightarrow \theta \Rightarrow d\theta = .122\lambda \Rightarrow \frac{1}{\theta} = \frac{d}{1.22\lambda}$

When $\theta = \theta_R$ (limit of resolution) then $\frac{1}{\theta_R} = Resolving\ power = \frac{d}{1.22\lambda}$

# Rayleigh's Criterion of Resolution



1. Which case is well resolved?
2. Which one is barely resolved?
3. Which one is unresolved?

# How versatile the equation is

Telescope

Binocular

Microscope


Camera

All these instruments have circular apertures. Thus the Resolving Powers of all these optical instruments is given by

$$\boldsymbol{R.P.=\frac{1}{\theta_R}=\frac{d}{1.22\lambda}}$$

Eye

# Why bigger telescopes are better?

When $d$ increases, resolving power increases

$$R.P. = \frac{1}{\theta_R} = \frac{d}{1.22\lambda}$$

Largest Telescope in the World

# Why radio telescopes are large?

- The wavelengths of radio waves are quite larger than light. $\lambda_{Radio\ Waves} \cong cm\ to\ m$ and $\lambda_{light} \cong \mu m$
- When $\lambda$ increases, R.P. will drop down, so $d$ has to be increased to maintain the resolving power

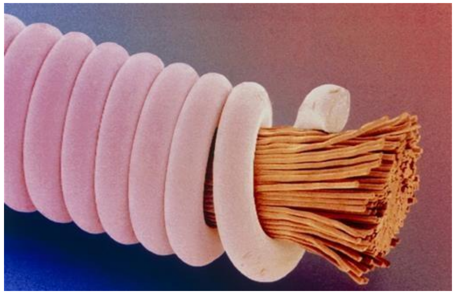
$$R.P. = \frac{1}{\theta_R} = \frac{d}{1.22\lambda}$$

GMRT

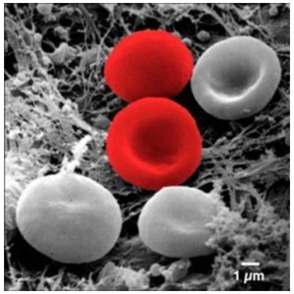
# Why electron microscope is incredibly superior to Optical microscope?

In electron microscope, electrons are used for imaging instead of light. The wavelength of electrons is extremely small $(100000\ times)$ as compared to light. Therefore electron microscope is incredibly superior to optical microscope

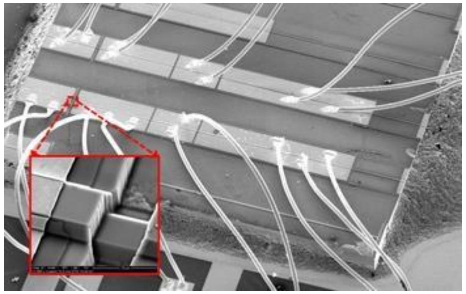
$$R.P. = \frac{1}{\theta_R} = \frac{d}{1.22\lambda}$$



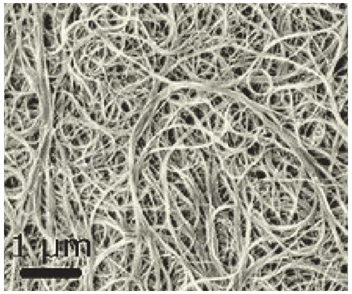
String of a guitar




Blood cells



Integrated circuit




Carbon Nanotubes

# Why multi-array telescopes and radars have enhanced resolving power?

Why a multi-slit diffraction grating has better resolving power than a single slit? Images become sharp. Same is the reason here

26 huge antennas at in GMRT

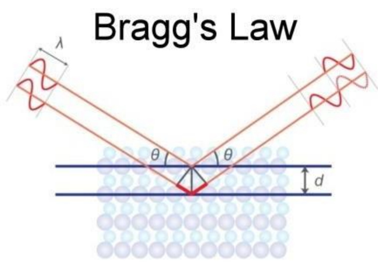
VLA at New Mexico. The images from the telescopes interfere constructively when the condition $dsin\theta = m\lambda$ is satisfied

# Grating Concept for Better Resolution

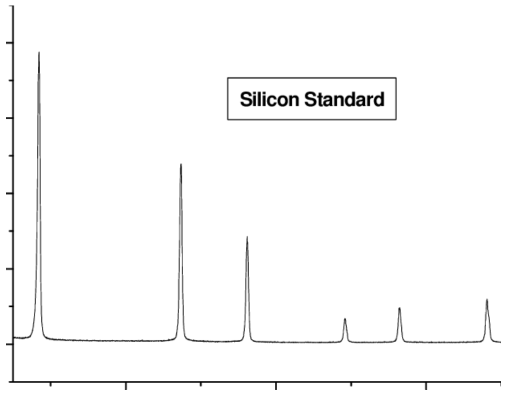
Multi-array Telescope

Multi-array Radar

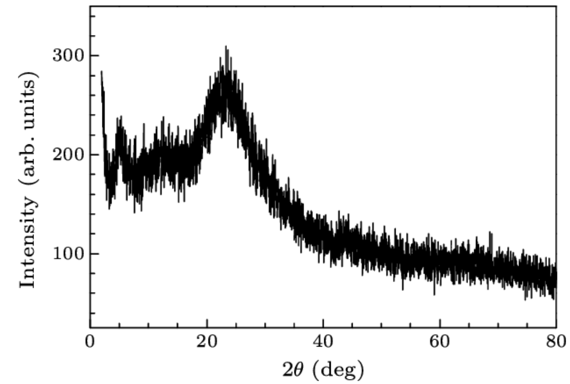
# And Finally …X ray Diffraction !



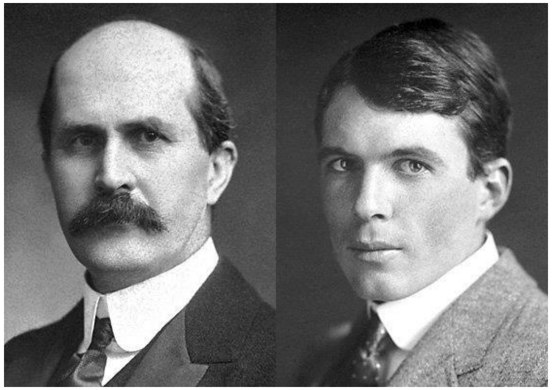

$$n\lambda = 2d \cdot \sin\theta$$



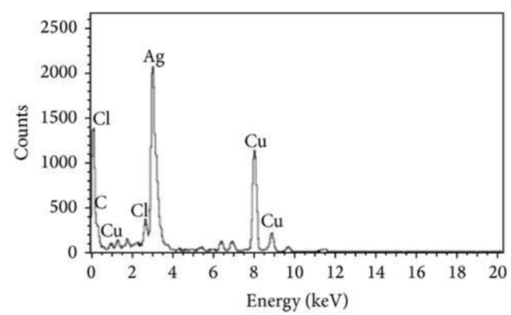

XRD of silicon
Silicon is crystalline



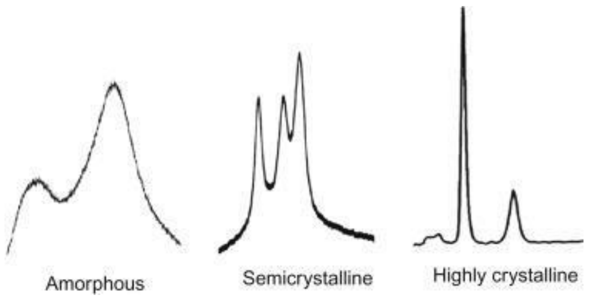

XRD of glass
Glass is amorphous



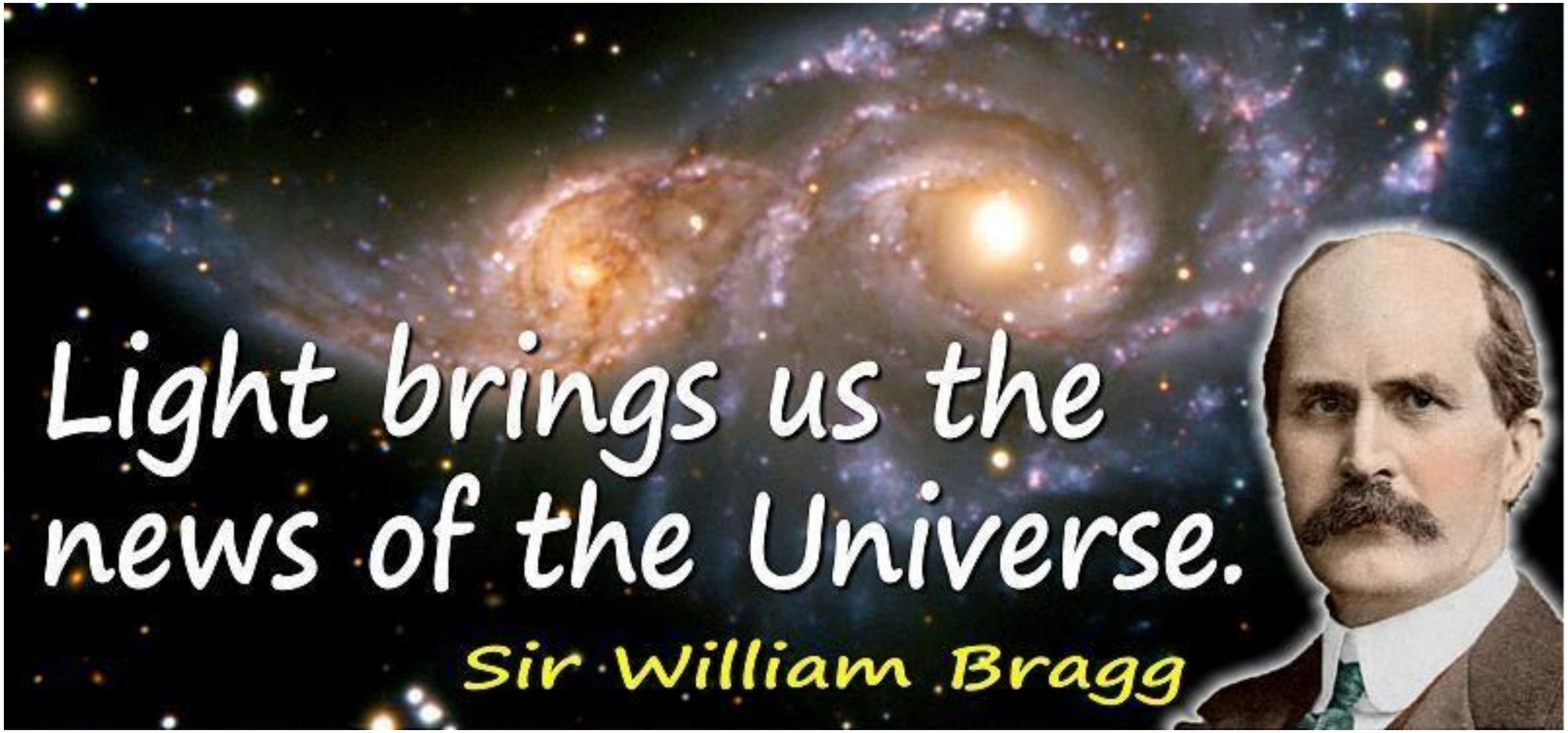
William Bragg and Lawrence Bragg, [NobelPrize ]1915




X ray spectroscopy : elements can be identified along with their atomic numbers!




Polymers are semicrystalline




# Thank You !