Polarization
of light

Significance

- Interference and Diffraction so far tells us that light is a form of wave motion but it does tell nothing about whether these waves are longitudinal or transverse...... **Polarization** is that phenomenon which established beyond doubt that light waves are transverse waves.
- **Polarization** is the phenomenon by which the vibrations in a transverse wave are confined to one particular direction only.
- **Polarization** is exhibited only by transverse waves. As light can be polarized, the phenomenon confirms transverse nature of light.

Overview of light wave

- Light is a transverse wave, an **electromagnetic** wave
- The magnetic field vector B vibrates in a direction perpendicular to that of the electric field vector and to the direction of propagation of the wave
- Light wave can be traced by a point that oscillates sinusoidally in a plane, such that the direction of oscillation is perpendicular to the direction of propagation of the wave.
- The oscillating point can describe the vibration of E

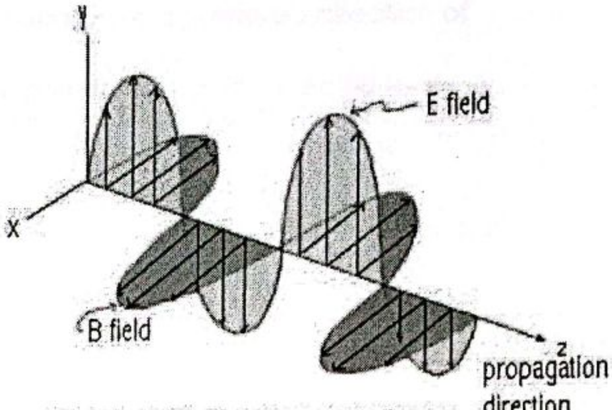
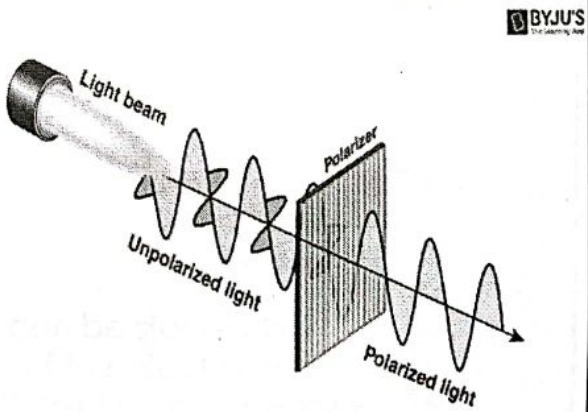


Figure 1 (b) An electromagnetic wave

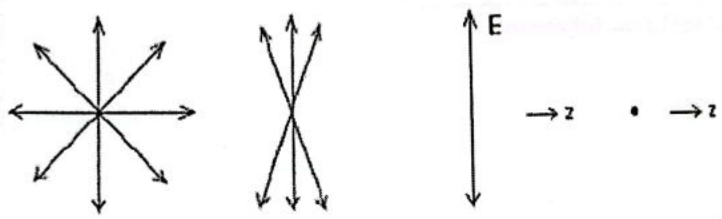
Polarization .....

- Light emitted from an actual/ordinary source (such as the Sun) consists of many such electric field vectors.
- The electric field vectors vibrate randomly in all directions. Such sources of light are **unpolarized.**
- The other kind of light waves in which the vibrations occur in a single plane are polarized light.
- **Polarization is the phenomenon by which the vibrations in a transverse wave are confined to one particular direction only.**
- The process of transforming unpolarized light into polarized light is known as polarization.



Polarization .....

- **Partially polarized** light occurs if the E vectors have a preferred direction of oscillation
- Light is totally **linearly polarized (or plane polarized)** if all the electric field vectors oscillate in the same plane, parallel to a fixed direction referred to as the polarization direction.
- vertically polarized light is represented by a vertical arrow
- horizontally polarized light is represented by a dot indicating that the E vector oscillates into and out of the page



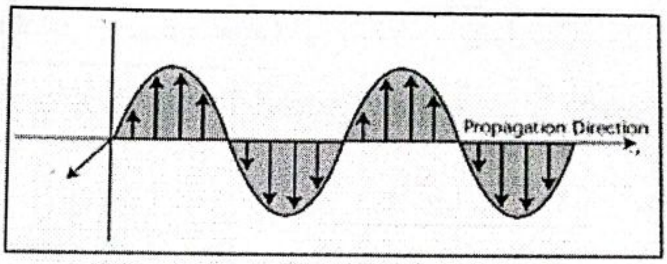
Types of Polarization

- Linear polarization
- Circular polarization
- Elliptical polarization

The behavior of electromagnetic waves can be studied by considering two orthogonal components of the electric field vector. The phase relationship between these two components can explain the different states of polarization.

Linear Polarization

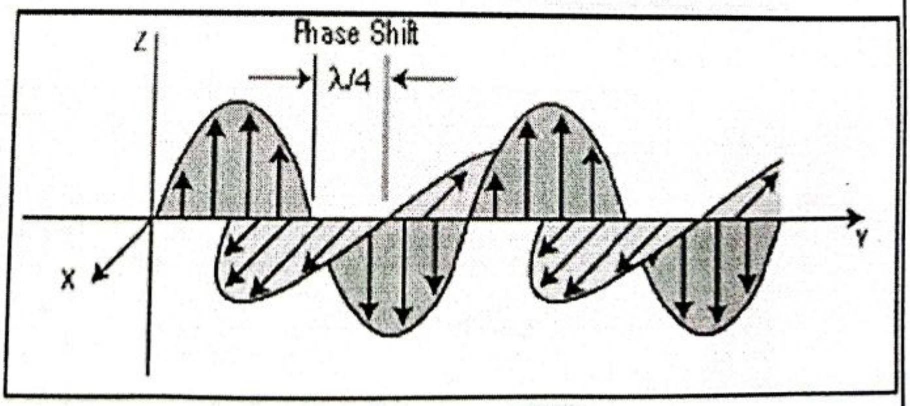
- In linear polarization, the electric field of light is limited to a single plane along the direction of propagation.
- If there is no amplitude in x (Eox = 0), there is only one component, in y (vertical).
- If there is no phase or difference or the phase difference is 180 degrees, the light is linearly polarized



A. Linearly Polarized Light in the Vertical Direction

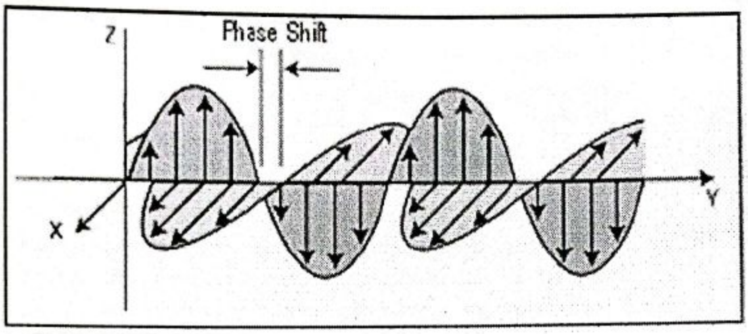
Circular Polarization

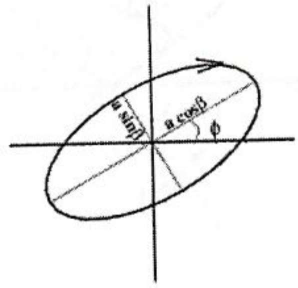
- If the phase difference is 90 or 270 degrees and both components have the same amplitude, the light is circularly polarized.
- The propagation of the occurring electric field will be in a circular motion.



Elliptical Polarization

- If a constant phase difference other than 0, 90, 180 or 270 degrees exists and/or the amplitudes of the components are not equal, then the light is elliptically polarized.
- The electric field of light follows an elliptical propagation. T





In case of circular or elliptical polarization, the plane of polarization rotates, in contrast to linear polarization where the plane of polarization is fixed.

Linear polarizers

- Certain materials have the property of transmitting an incident unpolarized light in only one direction. Such materials are called dichroic.
- Polarizing sheets transmits the only component of the electric field vector, parallel to its transmission axis. The component perpendicular to the transmission axis is completely absorbed.
- Light emerging from the polarizer is linearly polarized in the direction parallel to the transmission axis.
- polarizers reduce the intensity of the incident light beam to some extent.

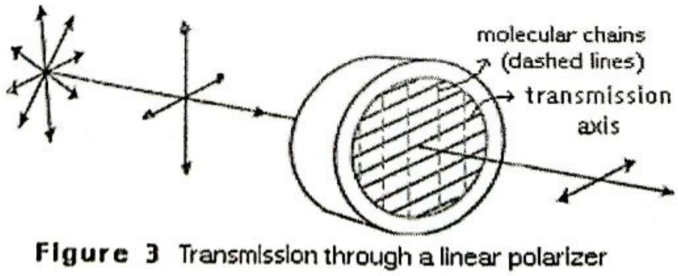


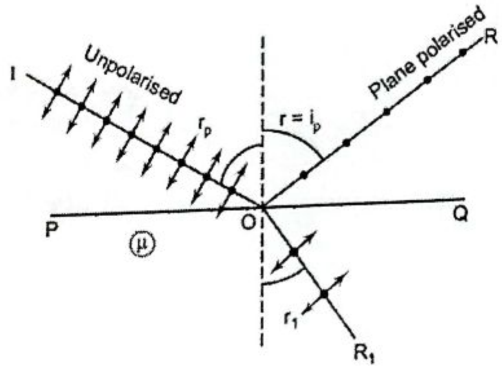
Figure 3 Transmission through a linear polarizer

Polarization by reflection

- Unpolarized monochromatic light I incident on a transparent refracting surface *PQ* with refracting index μ.
- The electric vector in incident light has two components,

1. one parallel to the plane of incidence (arrows)
2. another normal to the plane of incidence (dots).

- Dot components are always parallel to the reflecting surface *PQ* so, they are irrespective on the value of angle of incidence.
- Arrow components make different angles with *PQ* so their condition for reflection and refraction change.
- For a specific value of ***∠i = ip*** (called polarizing angle), the arrow components get totally transmitted
- hence the reflected light contain only the dot components
- i.e; the reflected light is completely polarized for the angle ***ip*** called polarizing angle



Brewster's Law

- Brewster performed several experiments on polarization of light by reflection from different surfaces
- He found that ordinary light becomes completely polarized when it is reflected from a transparent medium at a particular angle (polarizing angle)
- and also proved that

$$\mu = \tan ip$$

- Where reflected and refracted rays are at right angles to each other.

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Optics

INTERFERENCE OF LIGHT

Topics:

- Interference
- Conditions of Interference
- Coherent Sources
- Types of Interference
- Theory of Interference
- Youngs's Double slit experiment
- Determination of fringe width

Interference:

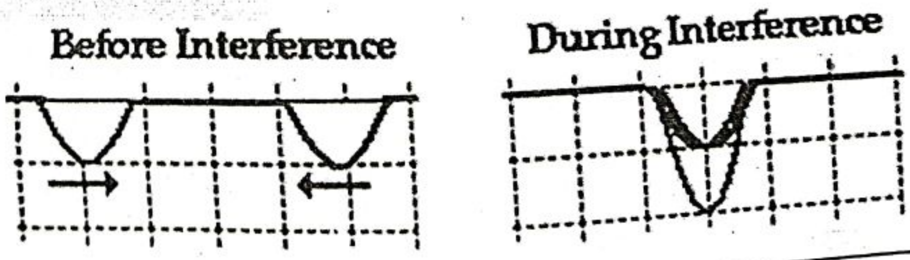
What is Interference and how it occurs.......

- **Wave interference** occurs when two waves meet while traveling along the same medium.
- Interference is the phenomenon in which two monochromatic waves superpose to form the resultant wave. Its the redistribution of energy due to superposition of light from two coherent sources.

- **Constructive Interference:**

occurs at any location along the medium where the two interfering waves have a displacement in the same direction.

- Suppose if the crest (or trough) of one wave falls on the crest (or trough) of another wave, then the amplitude is maximum(up/down ward).
- Here both the waves have the same displacement and the waves are in phase.



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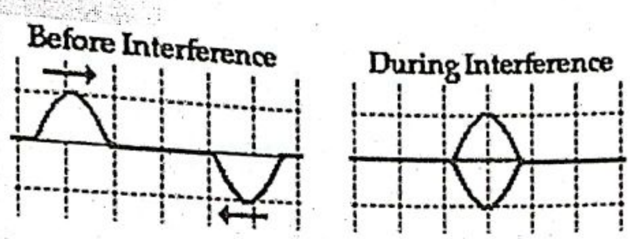
- **Destructive interference:** occurs at any location along the medium where the two interfering waves have a displacement in the opposite direction.
- Suppose if the crest of one wave falls on the trough of another wave, then the amplitude here is minimum.
- This is destructive interference. Here the waves do not have the same displacement and the waves are out of phase.



Conditions of Interference

- The light sources must be **coherent.**
- The light must be monochromatic. This means that the light consists of just one wavelength $\lambda = 2\pi/k$.

Coherent source means that, the plain waves emitted from the source will be of same frequency/ wave length (Monochromatic), and will keep a constant phase relation . For example, if two waves are completely out of phase with $\varphi = \pi$, this phase difference must not change with time.

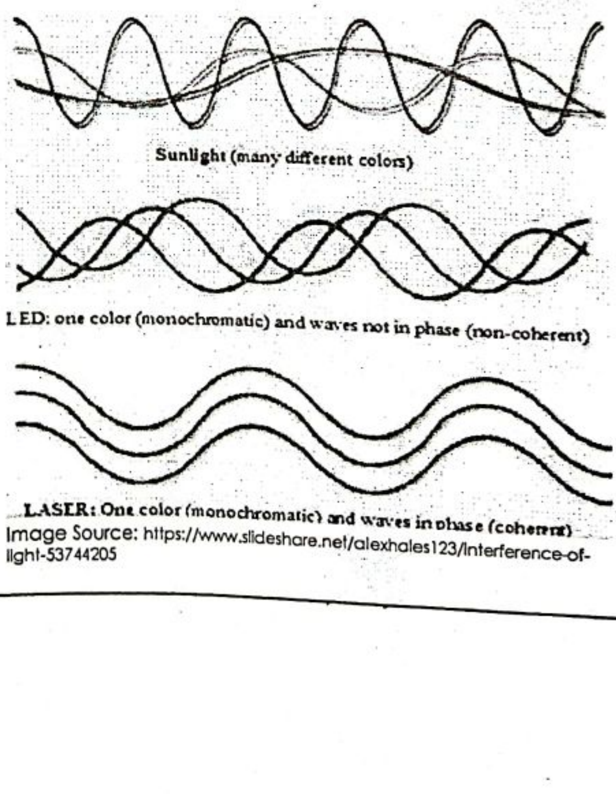
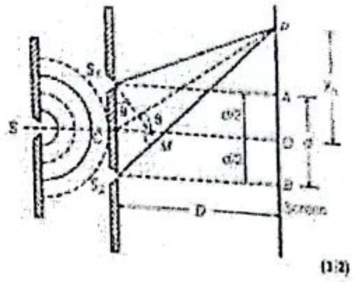


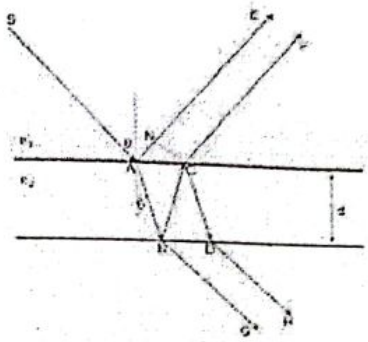
Image Source: https://www.slideshare.net/alexhales123/interference-of-light-53744205

Types of Interference:

1. Division of wave front.
   Ex: Young's double slit experiment.

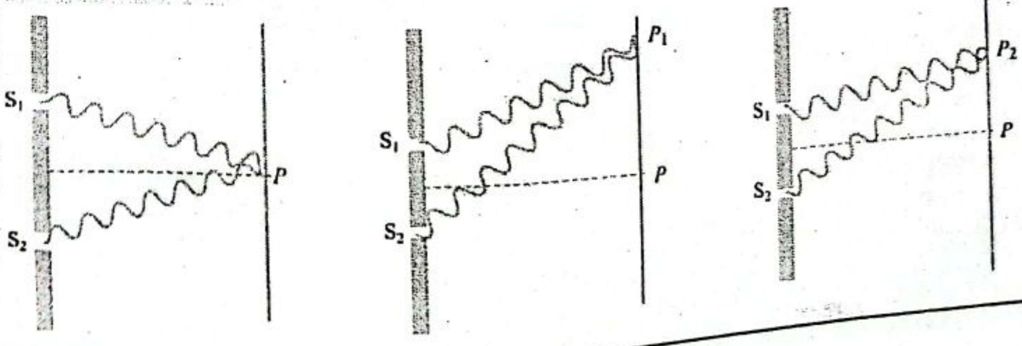


2. Division of amplitude.
   Ex: interference on a thin film, Newton's rings experiment, Michelson interferometer



Young's Double-Slit Experiment

- In 1801 Thomas Young carried out an experiment in which the wave nature of light was demonstrated



IMPACT OF YOUNG'S DOUBLE SLIT EXPERIMENT

- There are two possible results of this experiment: Particle interpretation: If light exists as particles, the intensity of both slits will be the sum of the intensity from the individual slits. Wave interpretation: If light exists as waves, the light waves will have interference under the principle of superposition, creating bands of light (constructive interference) and dark (destructive interference).

- At the time, this seemed to conclusively prove that light traveled in waves, causing a revitalization in Huygen's wave theory of light, which included an invisible medium, ether, through which the waves propagated. Several experiments throughout the 1800s, most notably the famed Michelson-Morley experiment, attempted to detect the ether or its effects directly. They all failed and a century later Einstein's work in the photoelectric effect and relativity resulted in the ether no longer being necessary to explain the behavior of light. Again a particle theory of light took dominance.

Theory of Interference

Let us consider two monochromatic waves coming from two coherent sources incident on a screen with a phase difference $\varnothing$ at a point.

Let y_1 and y_2 are displacement of the two waves respectively such that

$$y_1 = a \sin\omega t \text{..............................(i)}$$

$$y_2 = a \sin(\omega t+\varnothing) \text{.......................(ii)}$$

Then the resultant displacement at that point is

$$\begin{aligned} y &= y_1+y_2 \\ &= a \sin\omega t + a \sin(\omega t+\varnothing) \\ &= a \sin\omega t + a \sin\omega t \cos\varnothing + a \cos\omega t \sin\varnothing \\ &= a \sin\omega t\,(1 + \cos\varnothing) + \cos\omega t\,(a \sin\varnothing) \end{aligned}$$

Assuming, $a(1 + \cos\varnothing) = R\cos\theta$ ....(iii)

And, $a\sin\varnothing = R\sin\theta$ ....(iv)

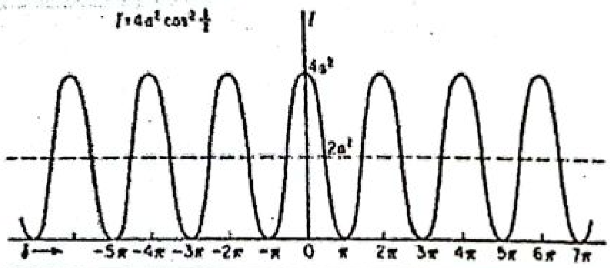
Theory of Interference....................

Intensity/Energy distribution curve:

Intensity at any point of the screen is expressed as

$I = 2a^2 (1+ \cos\varnothing) = 2a^2 .2\cos^2(\varnothing/2) = 4a^2 \cos^2(\varnothing/2)$

And, $I= 4a^2$ for bright fringe and for dark fringe $I=0$. Infact as $\varnothing$ increases gradually from 0 to π, $\cos\varnothing$ decreases from +1 to -1 through 0 and intensity decreases gradually from $4a^2$ to 0 . The shape of the intensity distribution curve be like.....



There is no destruction of light energy but redistribution of energy occurs in this phenomenon. Actually the energy disappeared in the dark fringe appears in the bright fringe. The intensity of bright fringe is $4a^2$ and the dark fringe is 0. However, **the average value of energy over any numbers of fringes is same i.e. $2a^2$.**

Theory of Interference.....................

The average value of the intensity on the screen over the range Ø=0 to Ø=2π is given by

I

$average =$

$Id\theta\ 2\pi$

0

$d\theta\ 2\pi$

0

$= a_1^2 + a_2^2$

= sum of intensities of the individual waves.

If $a_1 = a_2 = a$ then average intensity is $2a^2$. So we can say that the principle of conservation of energy is strictly followed in the interference phenomenon.

****

X-ray Diffraction (XRD)

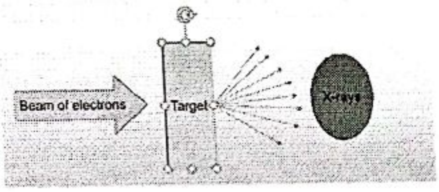
- **X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell.**
- X-ray diffraction is now a common technique for the study of crystal structures and atomic spacing.

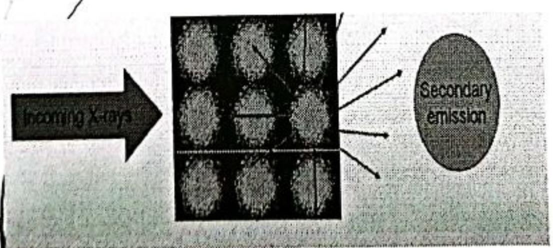
➢ **Why X-ray ?**

- Max von Laue, in 1912, discovered that crystalline substances act as three-dimensional **diffraction gratings** for **X-ray wavelengths which is similar to the spacing of planes** in a crystal lattice.
- For electromagnetic radiation to be diffracted by the spacing in the grating should be of the same order as the wavelength
- In crystals the typical interatomic spacing ~ 2-3 Å so the suitable radiation is X-rays
- Hence, X-rays can be used for the study of crystal structures

➢ **How produced?**

X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample.





- A beam of X-rays directed at a crystal interacts with the electrons of the atoms in the crystal
- The electrons oscillate under the influence of the incoming X-Rays and become secondary sources of EM radiation
- The secondary radiation is in all directions
- The emission will undergo constructive or destructive interference

- The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy **Bragg's Law.**
- This law relates the **wavelength of electromagnetic radiation** to the **diffraction angle** and the **lattice spacing** in a crystalline sample.
- These diffracted X-rays are then detected, processed and counted.
- d-spacings allows identification of the mineral because **each mineral has a set of unique d-spacings.** Typically, this is achieved by comparison of d-spacings with standard reference patterns.
- All diffraction methods are based on generation of X-rays in an X-ray tube. These X-rays are directed at the sample, and the diffracted rays are collected.

X-ray reflection in accordance with Bragg's Law

When a crystal is bombarded with X-rays of **a fixed wavelength** (similar to spacing of the atomic-scale crystal lattice planes) and **at certain incident angles,**

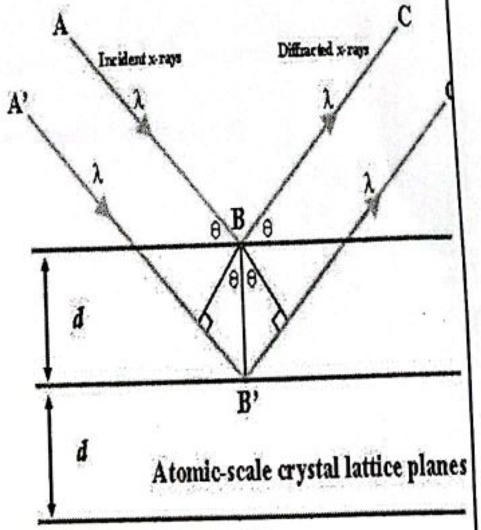
- **Intense reflected X-rays** are produced when the wavelengths of the scattered X-rays interfere **constructively**.
- In order for the waves to interfere constructively, the differences in the travel path must be equal to integer multiples of the wavelength. When this **constructive interference** occurs, **a diffracted beam of X-rays will leave the crystal at an angle equal to that of the incident beam.**

To illustrate this feature, consider a crystal with crystal lattice planar distances d (right). Where the travel path length difference between the ray paths ABC and A'B'C' is an integer multiple of the wavelength, constructive interference will occur for a combination of that specific wavelength, crystal lattice planar spacing and angle of incidence (Θ). Each rational plane of atoms in a crystal will undergo refraction at a single, unique angle (for X-rays of a fixed wavelength).

The general relationship between the wavelength of the incident X-rays, angle of incidence and spacing between the crystal lattice planes of atoms is known as Bragg's Law, expressed as:

$$n \lambda = 2d \sin\Theta$$

where n (an integer) is the "order" of reflection, λ is the wavelength of the incident X-rays, d is the interplanar spacing of the crystal and Θ is the angle of incidence.



- **Applications**
- X-ray powder diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to studies in geology, environmental science, material science, engineering and biology.
- Other applications include:
- characterization of crystalline materials
- identification of fine-grained minerals such as clays and mixed layer clays that are difficult to determine optically
- determination of unit cell dimensions
- measurement of sample purity

- **Strengths of X-ray Powder Diffraction (XRD)**
- Powerful and rapid (< 20 min) technique for identification of an unknown mineral
- In most cases, it provides an unambiguous mineral determination
- Minimal sample preparation is required
- XRD units are widely available
- Data interpretation is relatively straight forward
- **Limitations of X-ray Powder Diffraction (XRD)**
- Homogeneous and single phase material is best for identification of an unknown