Lecture (6)

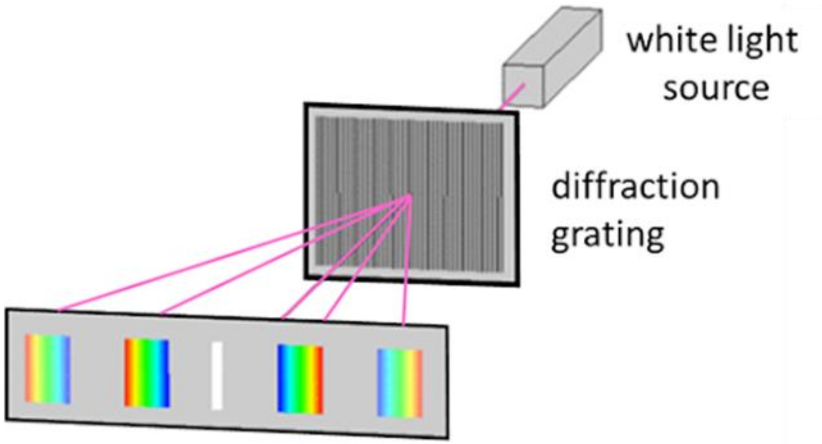
Diffraction and polarization of light

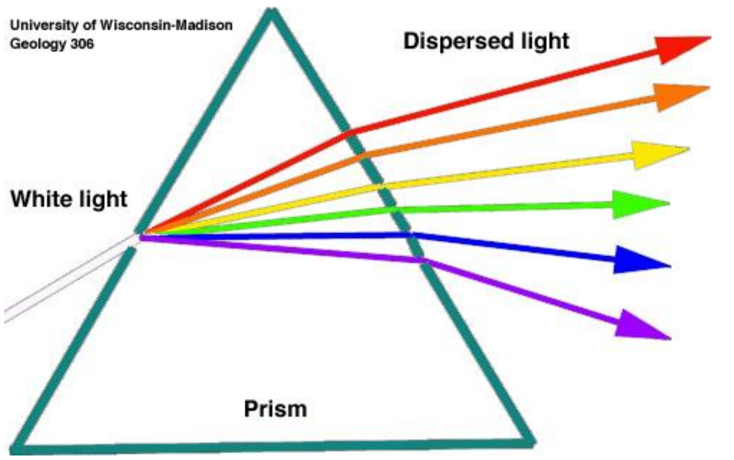
Dispersion

❖A grating must spread apart the diffraction lines associated with the various wavelengths. This spreading, called Dispersion

❖Dispersion is sometimes called the separation of light into colors.

$$\boxed{D = \frac{\Delta\theta}{\Delta\lambda}}$$

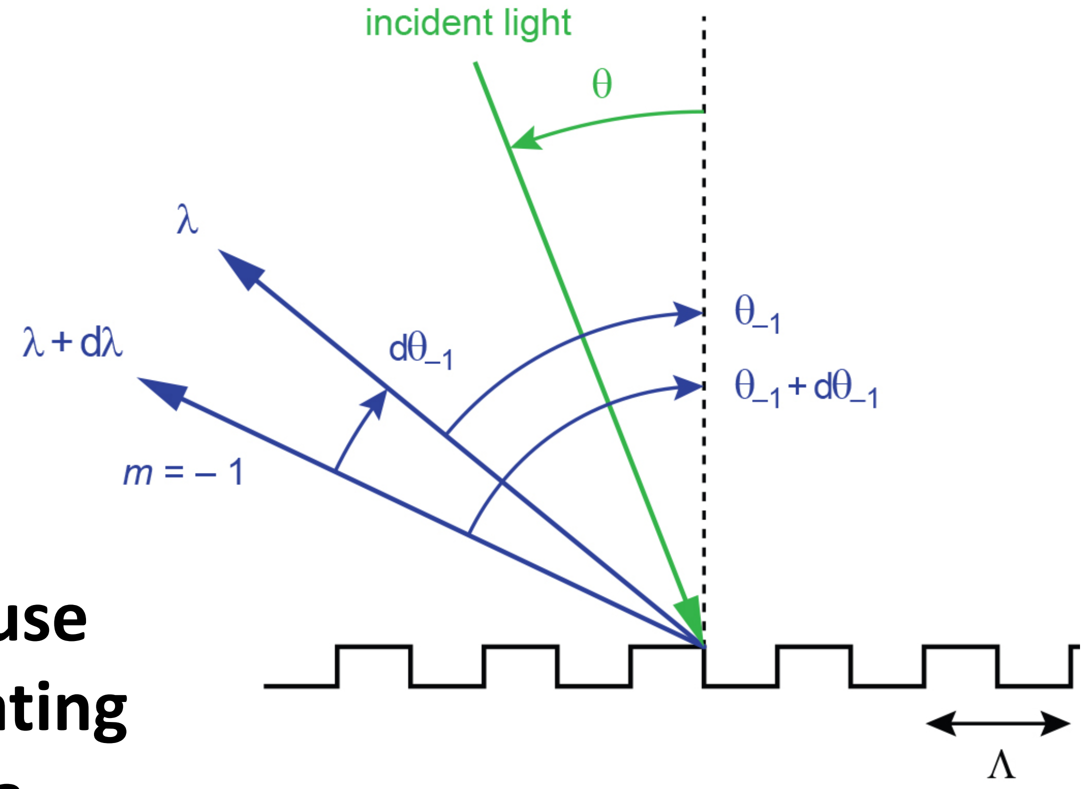




Here $\Delta\theta$ is the angular separation of two lines whose wavelengths differ by $\Delta\lambda$

❑ The dispersion of a grating at angle θ is given by

$$D = \frac{m}{d \cos \theta}$$



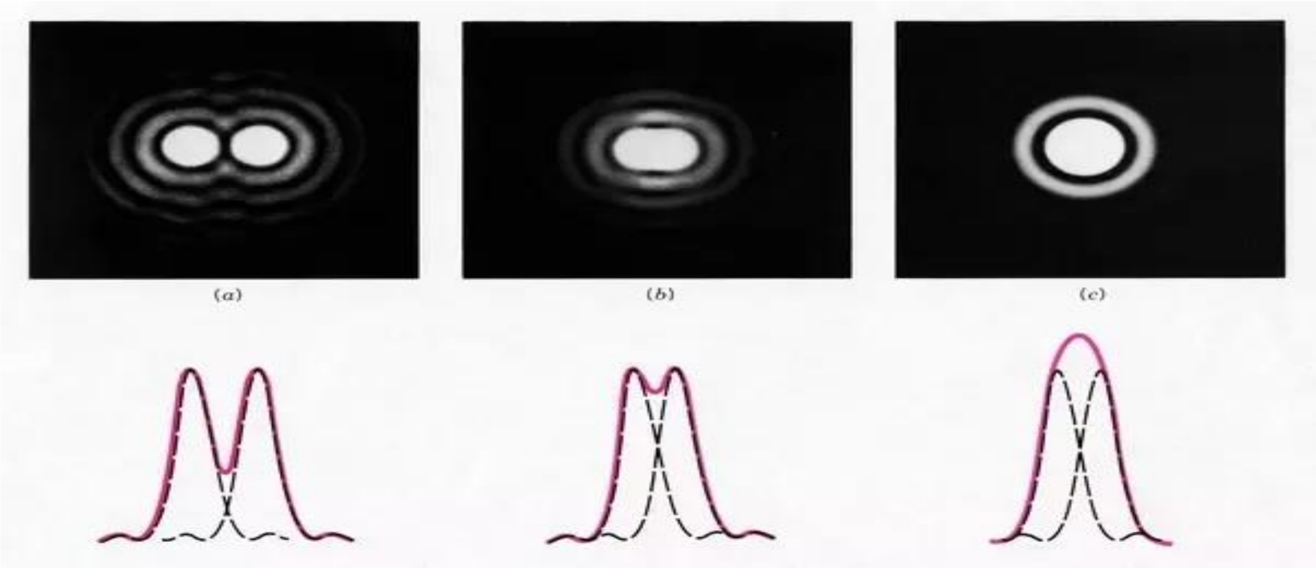
- ❖ So, to achieve higher dispersion **D** we must use a grating of smaller grating spacing **d** and work in a higher-order m

- ❖ Note that the dispersion does not depend on the number of rulings N in the grating

Resolving Power

$$R = \frac{\lambda_{avg}}{\Delta\lambda}$$

Here λ_{avg} is the mean wavelength of two emission lines that can barely be recognized as separate, and $\Delta\lambda$ is the wavelength difference between them

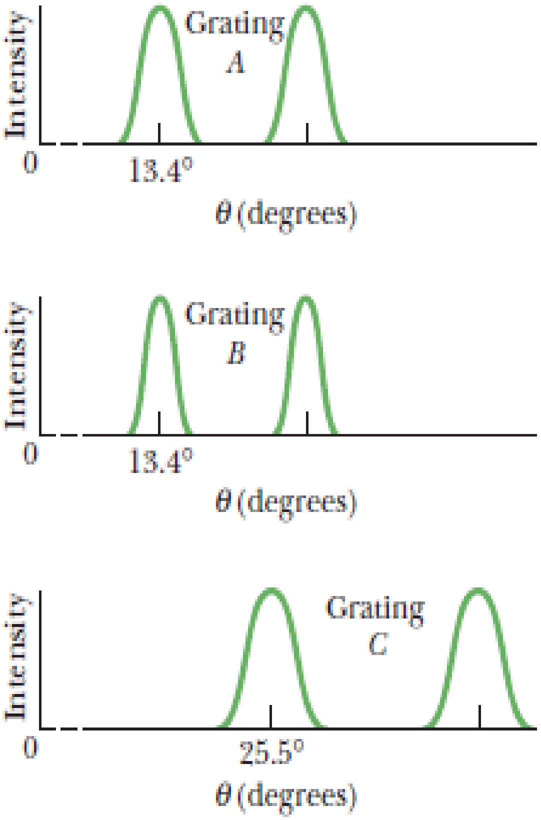


❑ **The resolving power of a grating is given by the simple expression**

$$\boxed{R = Nm}$$

Grating	N	d (nm)	θ	D (°/μm)	R
A	10 000	2540	13.4°	23.2	10 000
B	20 000	2540	13.4°	23.2	20 000
C	10 000	1360	25.5°	46.3	10 000

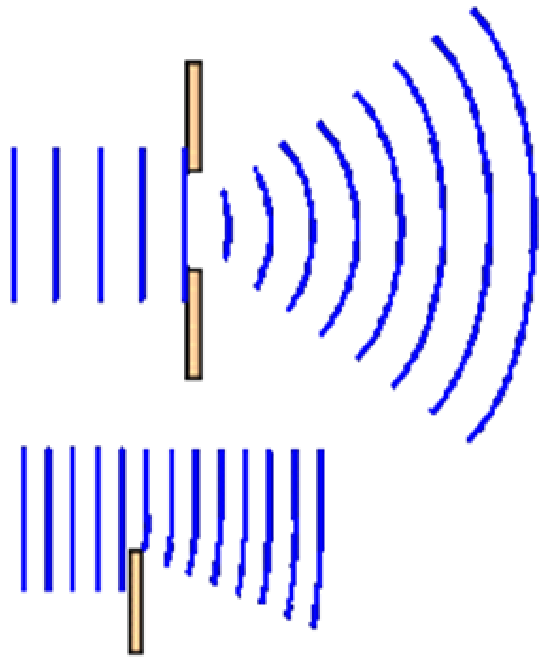
[a]Data are for λ = 589 nm and m = 1.



Light diffraction

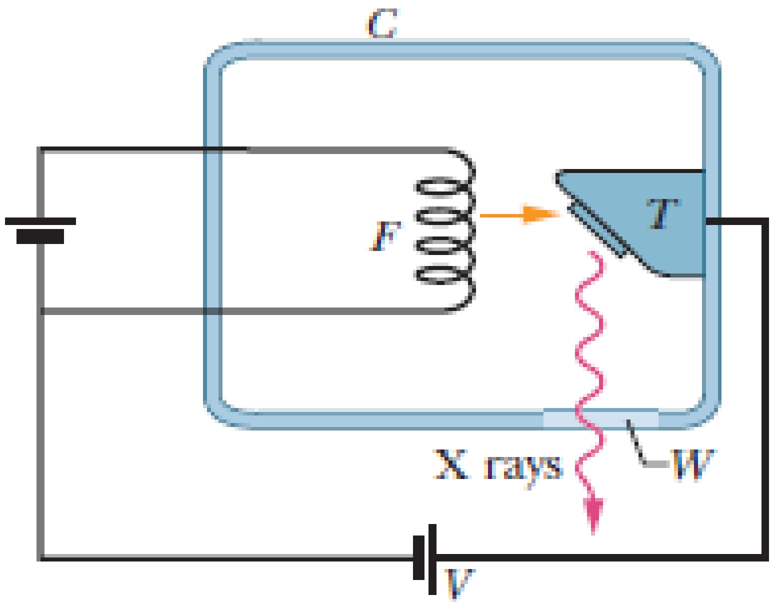
Light waves can also bend around obstacles, or when waves pass through small openings, or by sharp edges

- **Diffraction takes place with sound and electromagnetic radiation, such as light, X-rays, and gamma rays; and with very small moving particles such as atoms, neutrons, and electrons, which show wavelike properties**



X-Ray Diffraction

X rays are electromagnetic radiation whose wavelengths are of the order of A^0 (= 10^{-10} m). Compare this with a wavelength of 550 nm (= 5.5×10^{-7} m) at the center of the visible spectrum.

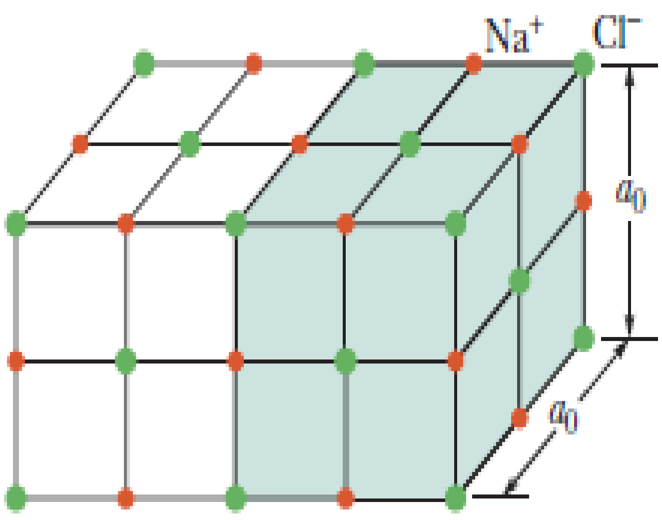


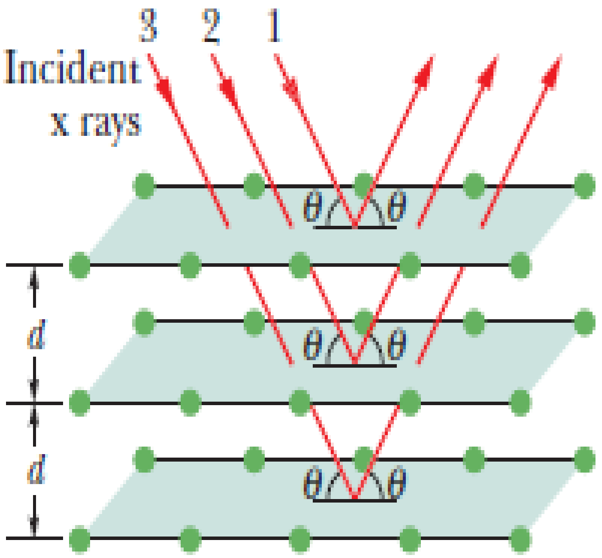
- **A standard optical diffraction grating <u>cannot</u> be used to discriminate between different wavelengths in the x-ray wavelength range. For λ = 1 A^0 (= 0.1 nm) and d =3000 nm, for example, Eq. shows that the first-order maximum occurs at**

$$\theta = \sin^{-1}\frac{m\lambda}{d} = \sin^{-1}\frac{(1)(0.1\text{ nm})}{3000\text{ nm}} = 0.0019^{\circ}.$$

A grating with d $\approx \lambda$ is desirable, but, because x-ray wavelengths are about equal to atomic diameters.

When an x-ray beam enters a crystal such as NaCl, x rays are scattered that is, redirected in all directions by the crystal structure. In some directions the scattered waves undergo destructive interference, resulting in intensity minima; in other directions the interference is constructive, resulting in intensity maxima. This process of scattering and interference is a form of diffraction.





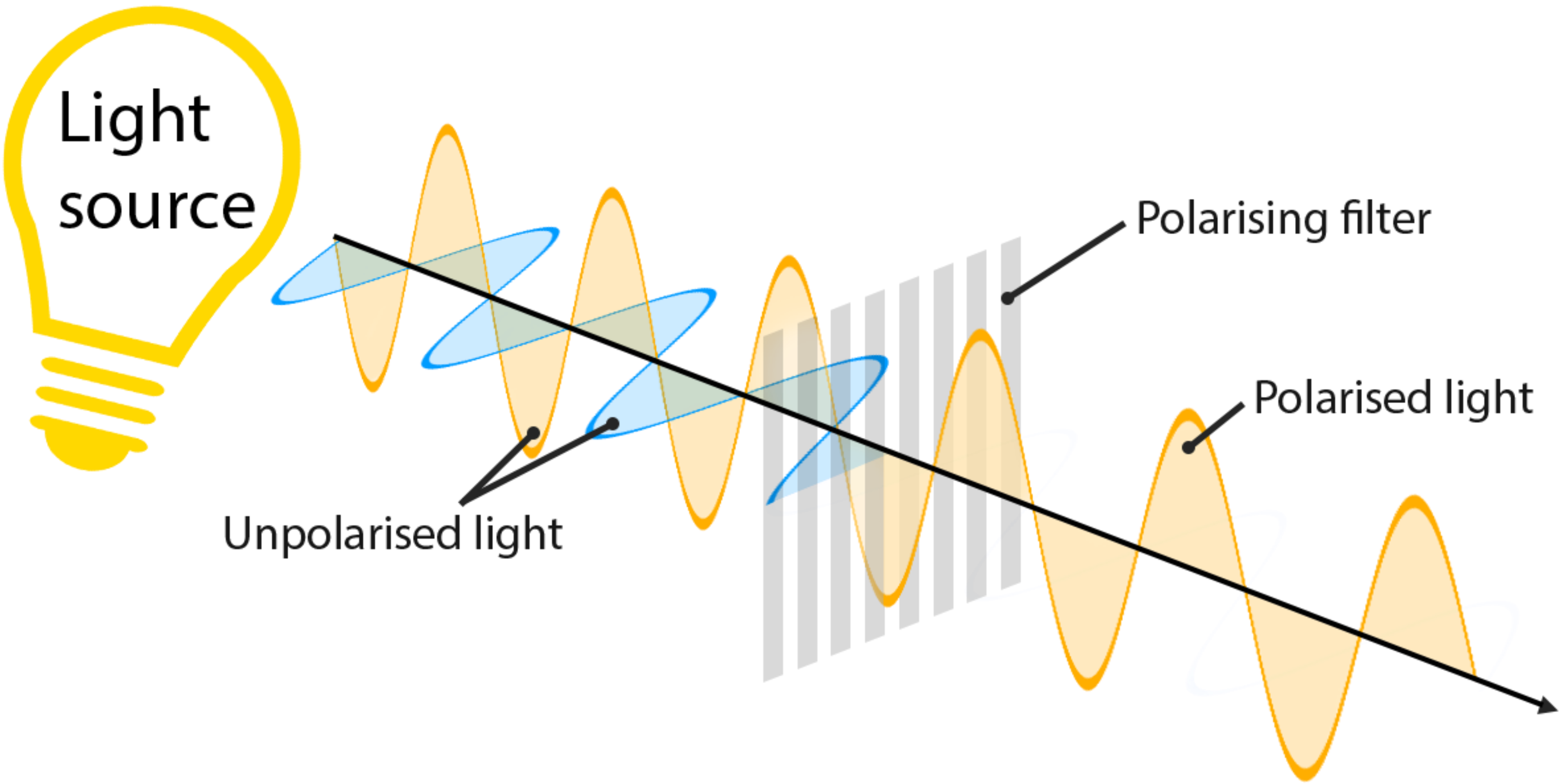
Bragg law

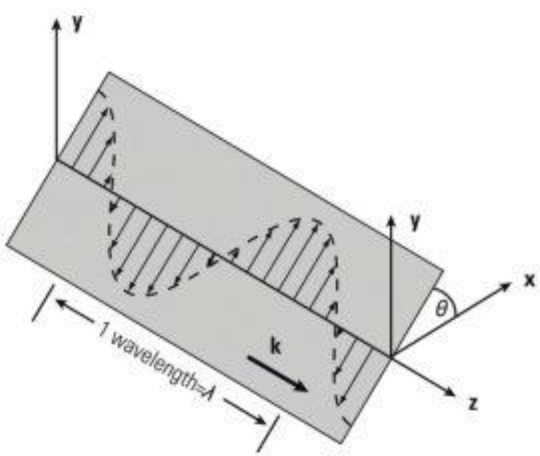
$$m\lambda = 2d \sin\Theta$$

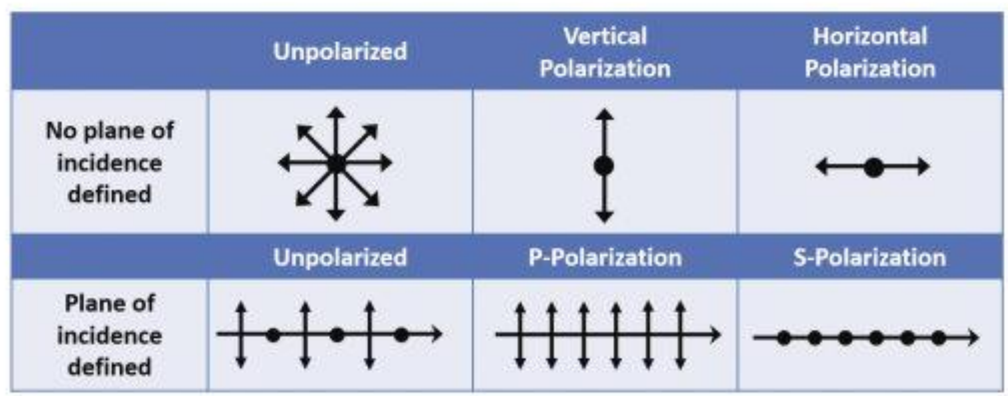
where m (an integer) is the "order" of reflection, λ is the wavelength of the incident X-rays, d is the interplanar spacing of the crystal and θ is the angle of incidence.

Polarization of Light

Light is an electromagnetic wave, and the electric field of this wave oscillates perpendicularly to the direction of propagation. Light is called unpolarized if the direction of this electric field fluctuates randomly in time. Many common light sources such as sunlight, halogen lighting, LED spotlights, and incandescent bulbs produce unpolarized light. If the direction of the electric field of light is well defined, it is called polarized light. The most common source of polarized light is a laser.

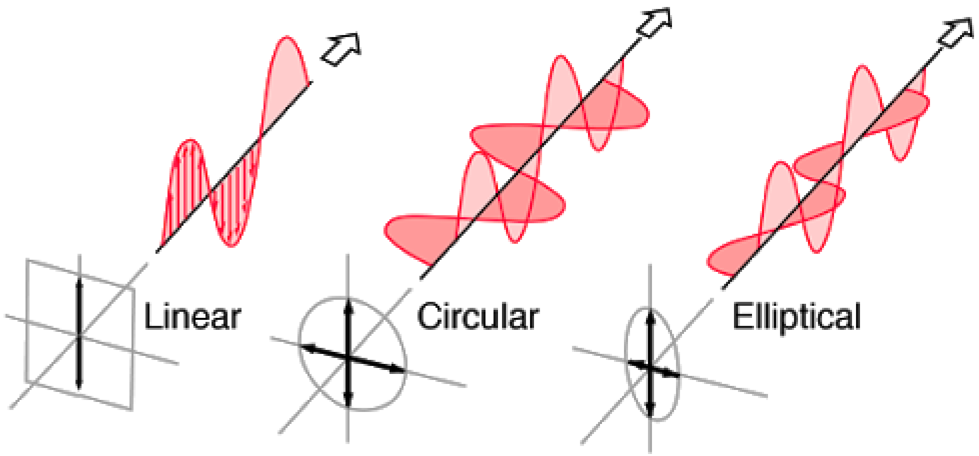

Light source
Polarising filter
Polarised light
Unpolarised light


y
y
x
θ
k
z
1 wavelength=λ


Unpolarized
Vertical Polarization
Horizontal Polarization
No plane of incidence defined
Unpolarized
P-Polarization
S-Polarization
Plane of incidence defined

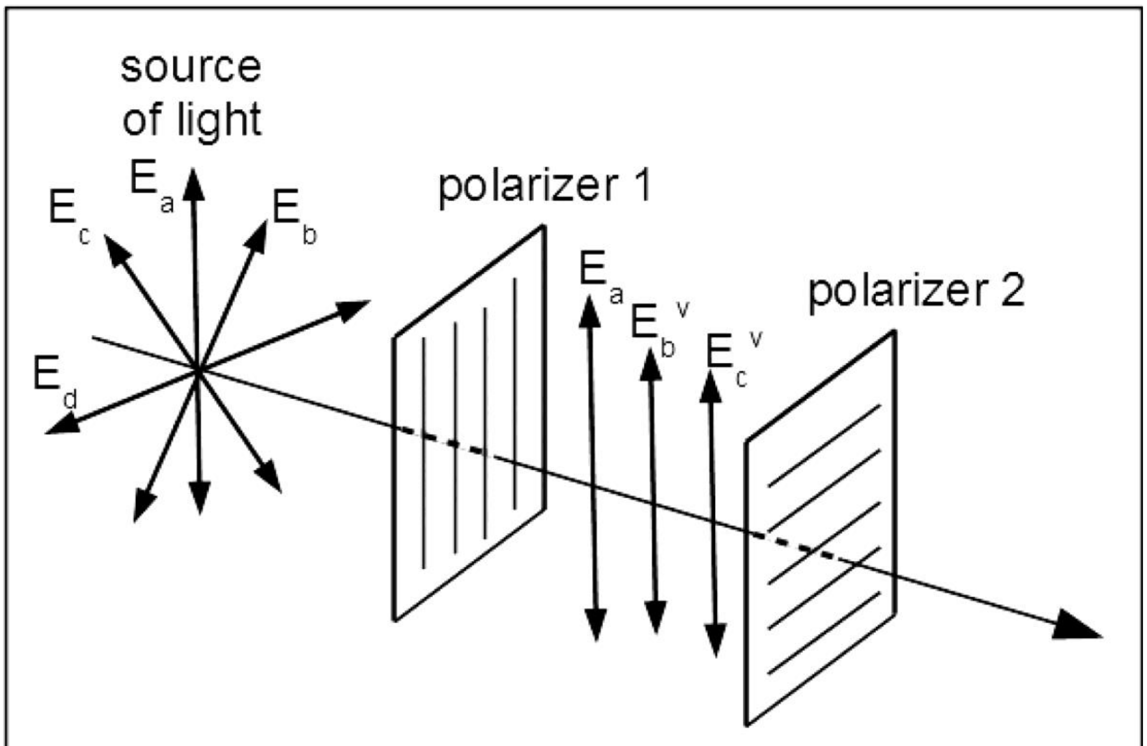
- Depending on how the electric field is oriented, we classify polarized light into three types of polarizations

  - <u>Linear polarization</u>: the electric field of light is confined to a single plane along the direction of propagation.
  - <u>Circular polarization</u>: the electric field of light consists of two linear components that are perpendicular to each other, equal in amplitude.
  - <u>Elliptical polarization</u>: This results from the combination of two linear components with differing amplitudes.



1- Polarization by Selective Absorption

The most common technique for producing polarized light is to use a material that transmits waves whose electric fields vibrate in a plane parallel to a certain direction and that absorbs waves whose electric fields vibrate in all other directions.

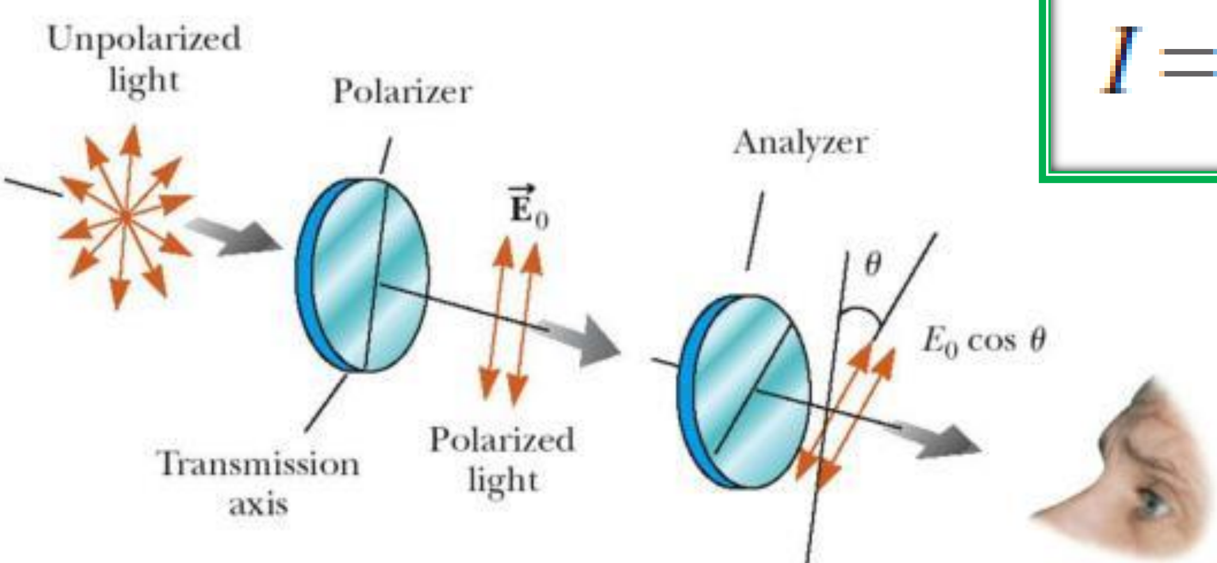


Mechanism of absorption polarization

If light whose electric field vector is parallel to the chains is incident on the material, the electric field accelerates electrons along the chains and energy is absorbed from the radiation. Therefore, the light does not pass through the material. Light whose electric field vector is perpendicular to the chains passes through the material because electrons cannot move from one molecule to the next. As a result, when unpolarized light is incident on the material, the exiting light is polarized perpendicular to the molecular chains.

Malus.law

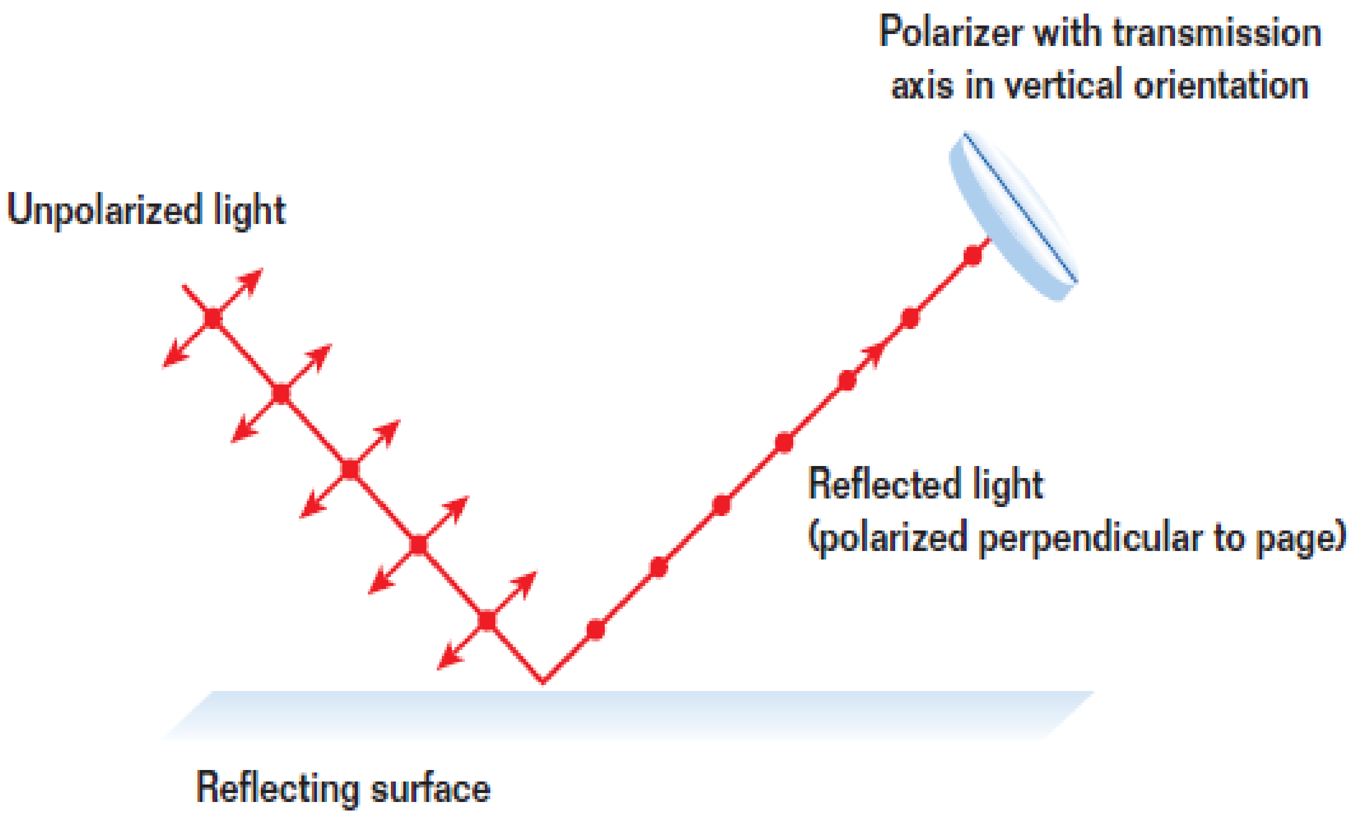
Figure represents an unpolarized light beam incident on a first polarizing sheet, called the polarizer. Because the transmission axis is oriented vertically in the figure, the light transmitted through this sheet is polarized vertically. A second polarizing sheet, called the analyzer, intercepts the beam.



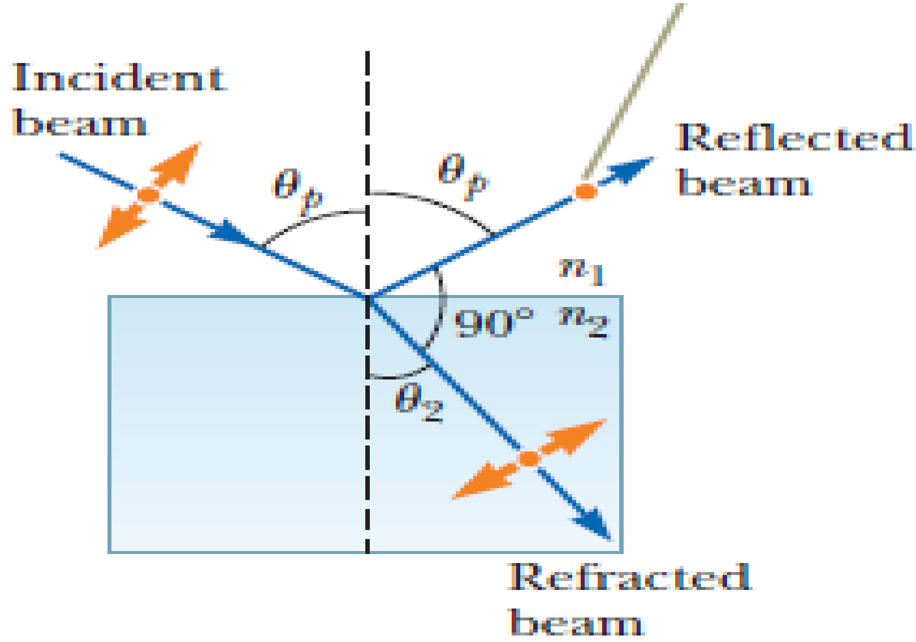
$$\boxed{I = I_{max} \cos^2 \theta}$$

2- Polarization by Reflection

When an un-polarized light beam is reflected from a surface, the polarization of the reflected light depends on the angle of incidence



$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} = \frac{\sin\theta_p}{\sin\theta_2}$$



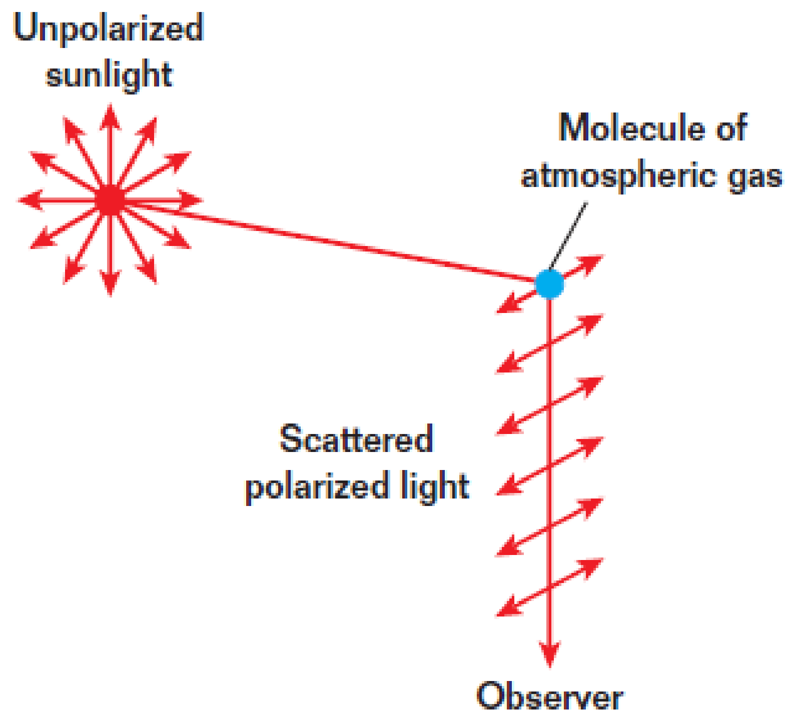
Because $\sin\theta_2 = \sin(90 - \theta_p) = \cos\theta_p$, we can write this expression as $n_2/n_1 = \sin\theta_p / \cos\theta_p$

$$\boxed{\tan\theta_p = \frac{n_2}{n_1}}$$

This expression is called <u>Brewster.s law</u>, and the polarizing angle up is sometimes called <u>Brewster.s angle</u>

3- Polarization by Scattering

- When light is incident on any material, the electrons in the material can absorb and reradiate part of the light. Such absorption and radiation of light by electrons in the gas molecules that make up air is what causes sunlight reaching an observer on the Earth to be partially polarized.



❑ Variations in the color of scattered light in the atmosphere

❖ When light of various wavelengths λ is incident on gas molecules of diameter d, where $d << \lambda$. The condition $d << \lambda$ is satisfied for scattering from oxygen (O_2) and nitrogen (N_2) molecules.

❖ In the atmosphere, whose diameters are about 0.2 nm. Hence, short wavelengths (violet light) are scattered more efficiently than long wavelengths (red light).

❖ Your eyes, however, are not very sensitive to violet light. Light of the next color in the spectrum, blue, is scattered with less intensity than violet, but your eyes are far more sensitive to blue light than to violet light. Hence, **you see a blue sky**.

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