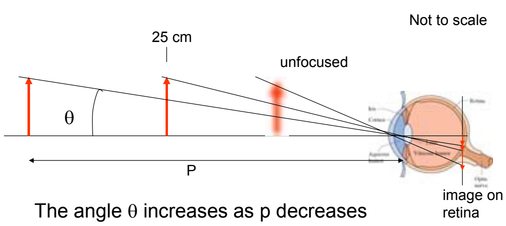
5.2 Optical Instruments - Polarization

- Optical Instruments
  - Simple magnifier
  - Compound microscope
  - Telescope
- Wave optics
  - Polarization

Magnifiers

- We magnify the image a small object by bringing it close to our eye.
- But we cannot bring it closer than the near point.
- A magnifier can produce a larger image of the object at the near point (or farther away) that can be focused on by the eye.
- The larger image is due to Angular Magnification

Angular size

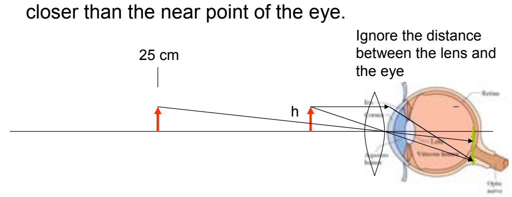


The angle θ increases as p decreases
The image size increases

Objects closer than the near point are not in focus.

Simple Magnifier

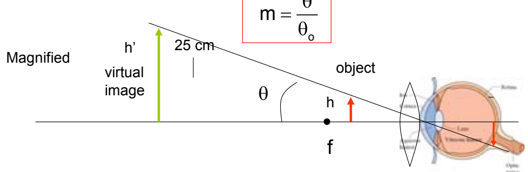
A converging lens in combination with the lens of the eye forms an image on the retina from an object closer than the near point of the eye.

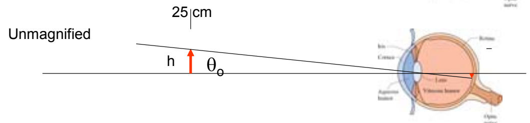


Angular Magnification

The angular magnification is the ratio of θ for the magnified image compared to value of θ_o for the object at the near point of the eye. (25 cm)

$$m = \frac{\theta}{\theta_o}$$



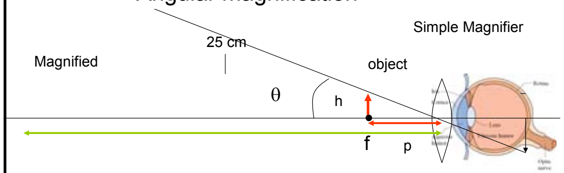


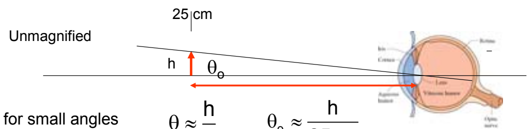
Angular magnification

The angular magnification for the simple magnifier can have a range of values because the focal length of the eye can vary due to accommodation.

The simplest case is the magnification for the relaxed eye. (focused at infinity)

Angular magnification





for small angles
$\tan\theta \sim \theta$

$$\theta \approx \frac{h}{f} \qquad \theta_o \approx \frac{h}{25cm}$$

Angular magnification

$$m = \frac{\theta}{\theta_0} = \frac{25cm}{f}$$

f is the focal length of the lens in cm.

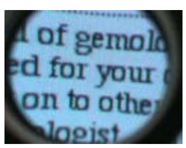
Simple magnifier.

A simple magnifier with a focal length of 5.0 cm is used to view an insect. What is the angular magnification for a relaxed eye?

$$m = \frac{25cm}{f} = \frac{25cm}{5.0cm} = 5.0$$

Simple magnifiers.

The angular magnification for a single lens is limited by aberration to about 4. Combination lenses can have magnification to about 20.



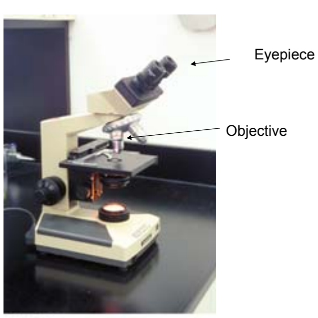
Compound Microscopes.

Magnification by 2 lenses.

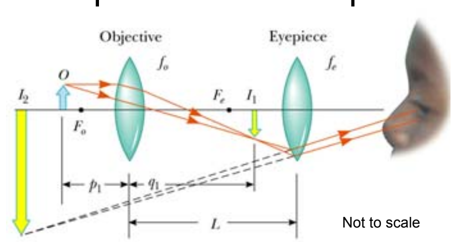
- Objective lens – Produces an enlarged real image of the object.
- Eyepiece – Used like a simple magnifier to view the image.

The net angular magnification of the product of the two magnifications.

Compound microscope



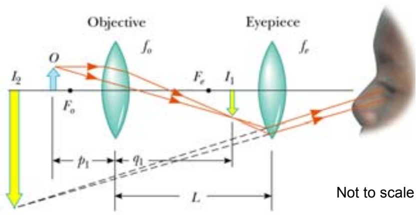
Compound microscope



The objective lens produces a magnified real image I_1
The image is viewed through the eyepiece.

M
a

Two stages of magnification by 1) objective and 2) eyepiece.

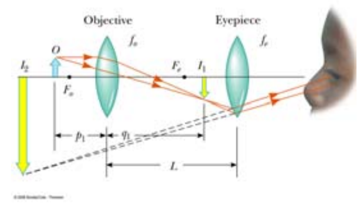


Not to scale

The objective lens produces a magnified real image I_1
The image is viewed through the eyepiece.

$$M_o = -\frac{q_1}{p_1} \approx -\frac{L}{f_o} \qquad m_e = \frac{25\text{cm}}{f_e}$$ For relaxed eye

Total Magnification is the product



$$m = M_1 m_e = -\frac{L}{f_o}\frac{(25\text{cm})}{f_e}$$

Magnification increases when f_e and f_e get smaller.

Magnification

A compound microscope has an objective lens and eyepiece with a focal lengths of 1.5 cm and 2.0 cm respectively. The microscope is 20 cm long. Find the angular magnification

$$m = -\frac{L}{f_o}\frac{(25\text{cm})}{f_e} = -\frac{20}{1.5}\frac{(25\text{cm})}{2.0} = -167$$

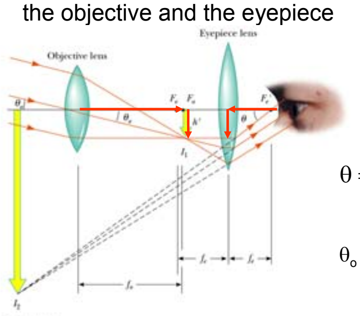
Refracting Telescope

Two lenses

Objective lens – produces a reduced image of a distant object near the focal point.

Eyepiece – used to magnify the image.

Angular magnification - ratio of the focal length of the objective and the eyepiece



$$\theta = \frac{h'}{f_e}$$

$$\theta_o = \frac{h'}{f_o}$$

focus at infinity

Angular magnification

$$m = \frac{\theta}{\theta_o} = \frac{f_o}{f_e}$$

Telescope

The Hubble space telescope has an objective mirror with a focal length of 57.8 m viewed with optics equivalent to an eyepiece with a focal length of $7.2\text{x}10^{-3}$m What is the angular magnification?

$$m = \frac{f_o}{f_e} = \frac{57.8}{7.2\text{x}10^{-3}} = 8.0\text{x}10^3$$

Hubble Telescope Image of M100 Spiral Galaxy (NASA)

Limits to magnification

Why can't we use light microscopes to see atoms?

- For refracting optics there are problems of chromatic and spherical aberration.
- Problems in precision in constructing the refracting and reflecting surfaces.
- Diffraction – A basic problems having to do with the wave nature of light (discussed next week)

Polarization

Polarized Light
Polarization by absorption
Polarization by reflection
Polarization by scattering

Wave Properties of Light

Wave optics or Physical optics is the study of the wave properties of light.

Some wave properties are:

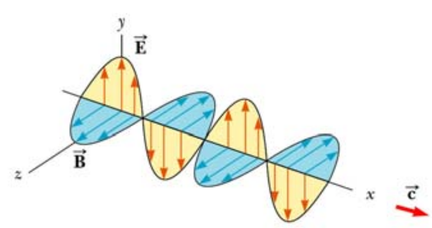
Interference, diffraction, and polarization.

These properties have useful applications in optical devices such as compact discs, diffraction gratings, polarizers.

Polarization

- Polarized light has it E field along one direction.
- Light can be polarized by several different processes
  - Absorption – Polaroid filter
  - Reflection – Brewster's angle
  - Scattering – Light from the sky
- Polarized light has many applications
  - Polaroid sunglasses, Polarization microscopy, liquid crystal display.

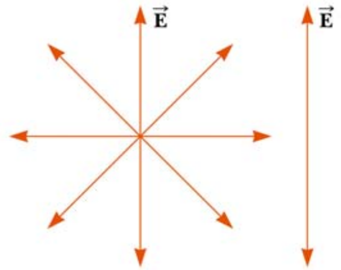
Light is a transverse wave



A plane wave with Electric field in the y direction

There is no E field in the direction of propagation

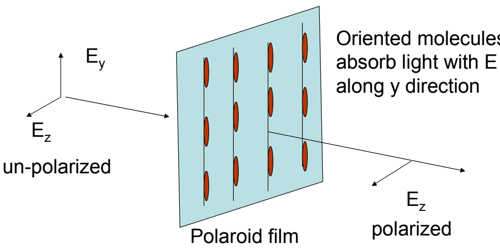
Polarized and un-polarized light



Unpolarized Light has E field at any instant can have E in any direction.

Polarized Light has E field in a certain direction

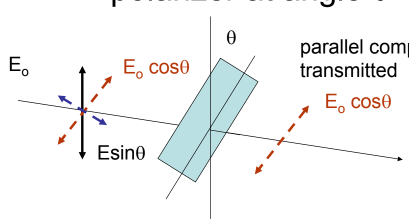
Polarization by absorption



for an ideal polarizer the intensity is reduced by 1/2

$$I_{polarized} = \frac{1}{2} I_{unpolarized}$$

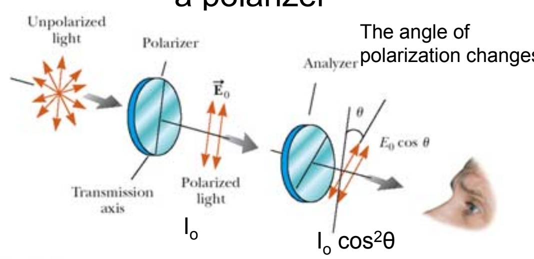
Polarized light passing through a polarizer at angle θ



But $I \propto E^2$

Therefore transmitted intensity
$I = I_o \cos^2\theta$

Polarized light passing though a polarizer



Decrease in intensity when polarized light passes through a polarizer

$I = I_o \cos^2\theta$

Law of Malus

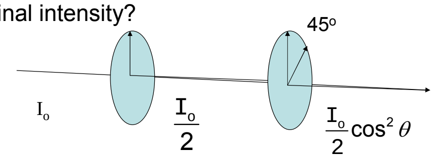
Two polarizers

$I = I_o \cos^2\theta$

θ=0 | θ=45° | θ=90° "Crossed-polarizers"

Example

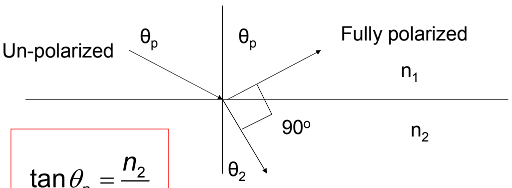
Un-polarized light is incident upon two polarizers that have their polarization axes at an angle of 45°. If the incident light intensity is I_o what is the final intensity?



$$I = \frac{I_o}{2}\cos^2 45 = \frac{I_o}{2}\left(\frac{1}{2}\right) = \frac{I_o}{4}$$

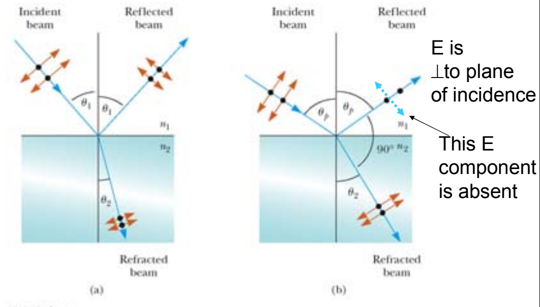
Polarization by reflection

Un-polarized light can be polarized by reflection at a specific polarization angle θ_p (Brewster's angle)



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

Polarization by reflection

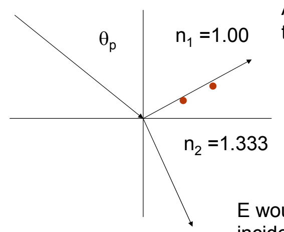


Reflected beam is Partially polarized

Reflected beam is Fully polarized

Example

Suppose you wanted to have fully polarized light by reflection at the air water interface. What conditions would you use? What would be the direction of the polarized E field?



Angle of incidence equal to the polarizing angle

$$\tan\theta_p = \frac{n_2}{n_1} = 1.333$$

$$\theta_p = 53^o$$

E would be ⊥ to the plane of incidence.

Polarization by reflection

no filter

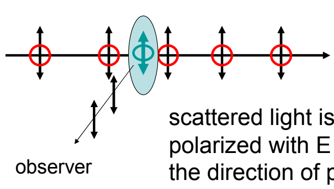
polarizing filter

The reflected light is polarized -

Polarization by scattering

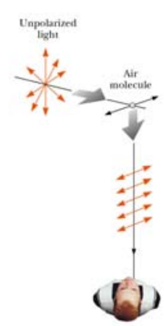
Plane wave has no E field in the direction of propagation

Scattering particle has oscillations partially polarized in the plane ⊥ to the direction of propagation



scattered light is partially polarized with E field ⊥ to the direction of propagation of the incident light

Polarization of light by air

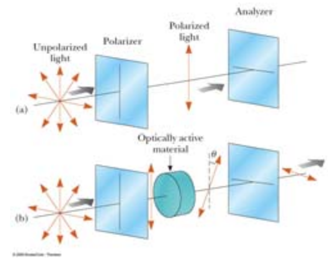


Polarization of scattered light

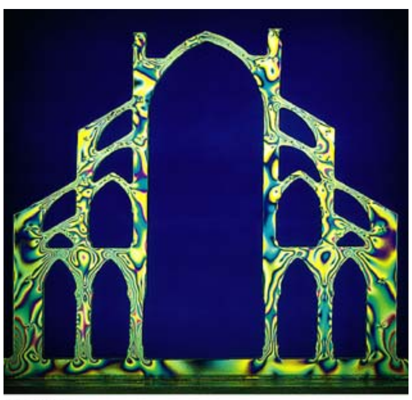
Light from the sky is partially polarized

no filter polarizing filter

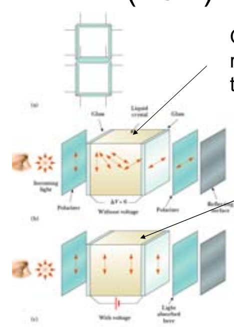
Applications- Crossed Polarizers



Crossed polarizers used to detect materials that rotate the plane of polarized light (optically active materials) including many biological materials and materials under mechanical stress



Applications – Liquid crystal display (LCD)



Oriented molecules rotate the plane of the polarized light

When an electric field is applied the molecules reorient so that the light is not rotated.

LCD displays