Group of Scholars tutorial

Refraction Of Light.

Index of refraction

- When light travels from one material to another it usually changes direction
- The bending of light that occurs at the borderline of two materials is called **refraction**
- the amount of bending depends on the optical properties of the two materials --> characterized by their **index of refraction: n**
- n is a number: n=1 for vacuum, n=1.33 for water, n=2.42 for diamond, n=1.5-1.9 for different types of glass …….
- when the amount of bending is bigger, the difference in n is bigger for the two materials

Geometrical concepts:

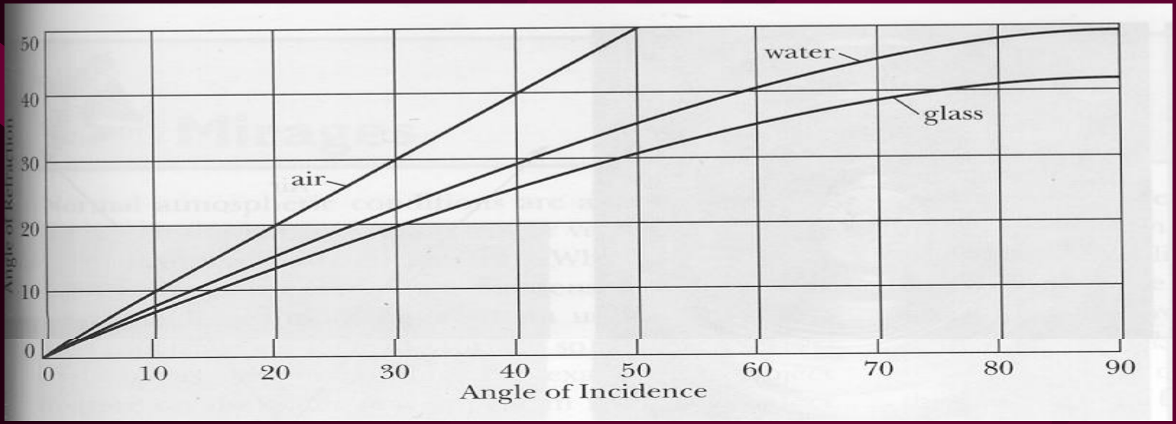
-incident ray

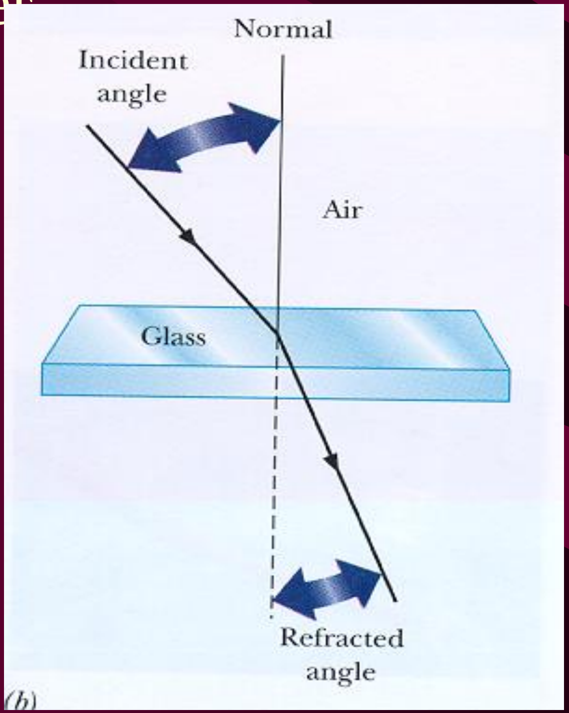
-refracted ray

-normal to the point of incidence

-incident angle

-refracted angle



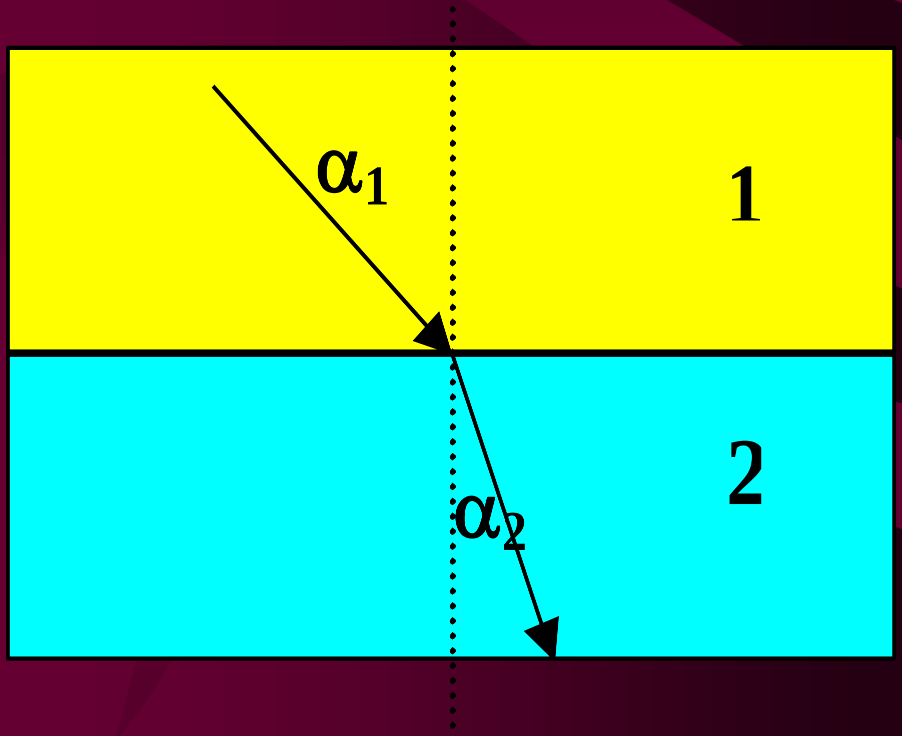


The laws of refraction: Snell's laws

- If light travels from material 1 with index of refraction n_1 to material 2 with index of refraction n_2 the following laws determine the direction of the refracted ray:

The incident ray, the normal to the incidence point and the refracted ray are all in one plane

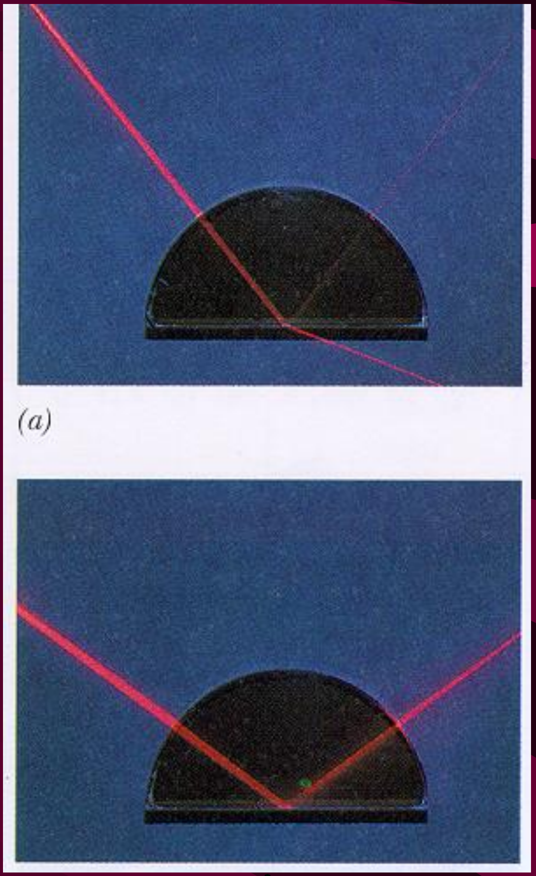
$$\sin(\alpha_1)n_1 = \sin(\alpha_2)n_2$$

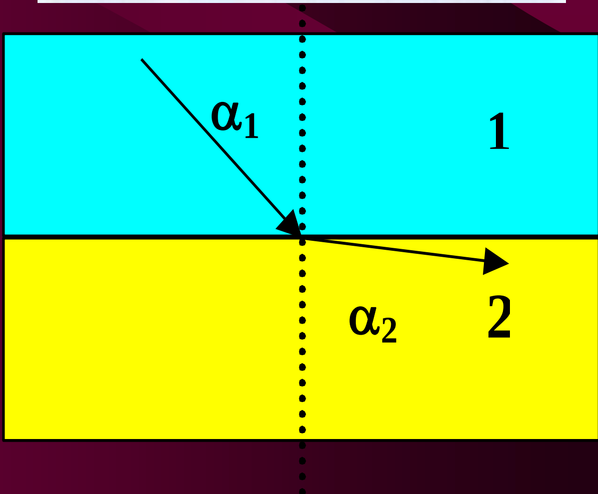


Total Internal Refraction

- At the border of two materials usually both reflection and refraction appears
- In some peculiar situations however the refracted light is also reflected! --> **reflection is total!**
- This can happen when light travels from a medium with bigger index of refraction to one with a smaller index of refraction, and the incident angle is big enough
- for high enough $\alpha_1 = \alpha_0$ --> $\alpha_2 = 90^0$
- if $\alpha_1 > \alpha_0$:no refracted ray --> total reflection

$$\sin(\alpha_o) = \frac{n_2}{n_1}$$





Total refraction in everyday life

- **Atmospheric refraction**

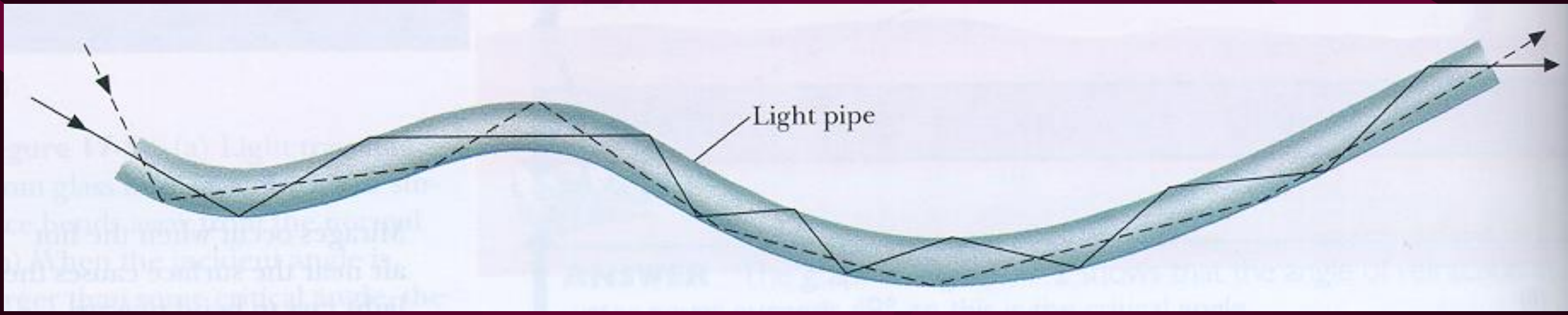
 - the atmosphere made up of layer with different density and temperature air -->these layers different index of refraction --> light refracted

 - distortion of the shape of Moon or Sun at horizon

 - apparent position of stars different from actual one

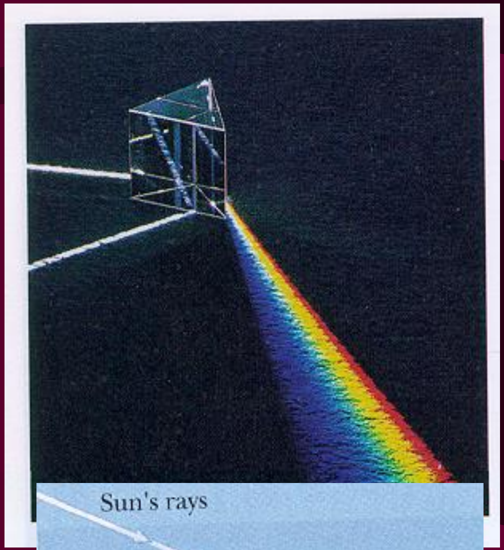
 - if light goes from layers with higher n to layers with lower --> total refraction: -mirages, looming

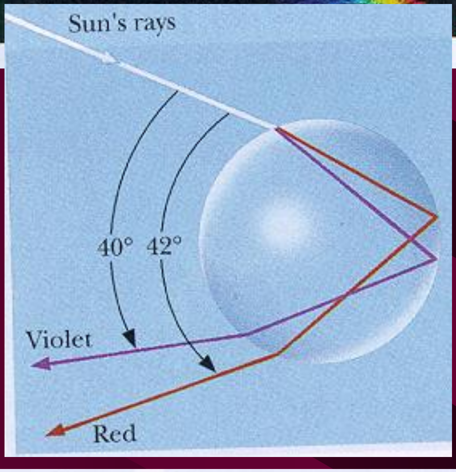
- **Light guides**: optical fibers: used in communication, medicine, science, decorative room lighting, photography etc…..

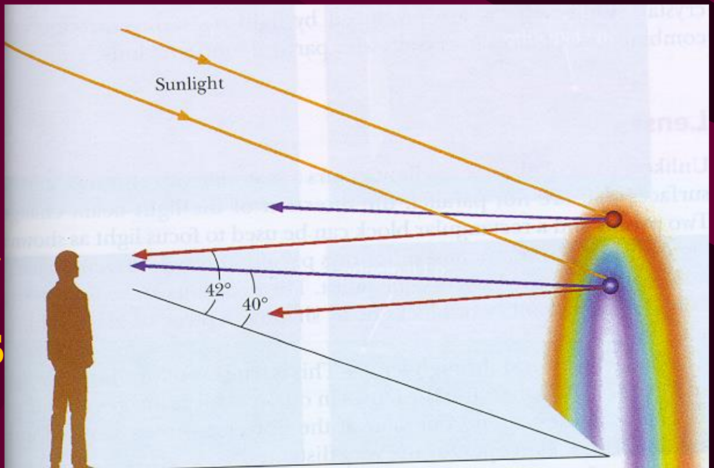


Dispersion

- The index of refraction of a medium depends in a slightly manner on the frequency of the light-beam
- **Different color rays deflect in different manner** during refraction: violet light is deflected more than red…..
- By refraction we can decompose the white color in its constituents--> A prism separates white light into the colors of the rainbow: ***ROY G. BIV***
- We can do the opposite effect too…..recombining the rainbow colors in white light
- Atmospheric dispersion of light: **rainbow** (dispersion on tinny water drops) or **halos** (dispersion on tiny ice crystals)







Lenses

- For materials that have the entrance and exit surfaces non-parallel: the direction of light beam changes
- The best results obtained by **lenses**: piece of glass with spherical surfaces
- Two main groups:

  - those that converge light rays (like concave mirrors)

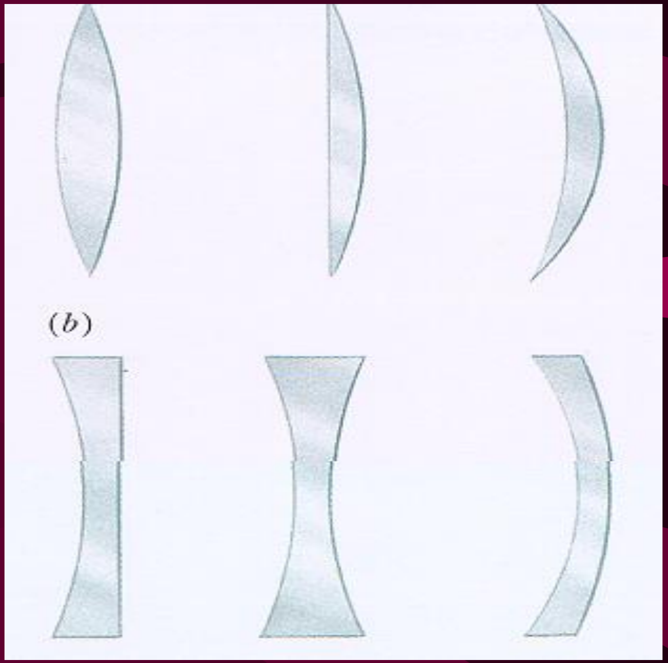
  - those that diverge the light rays (like convex mirrors)
- **Converging** and **Diverging** lens
- Characteristic points and lines:

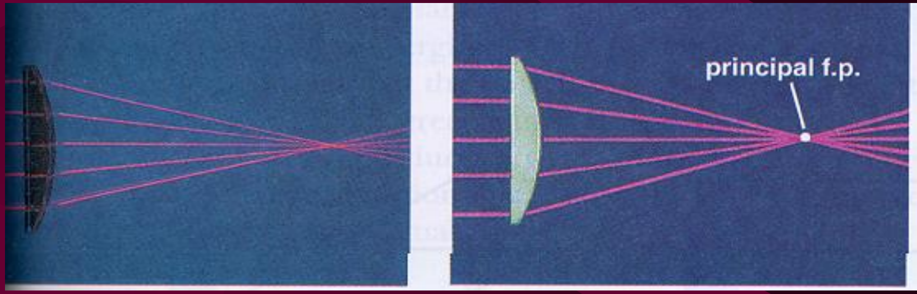
  - **center of lens**

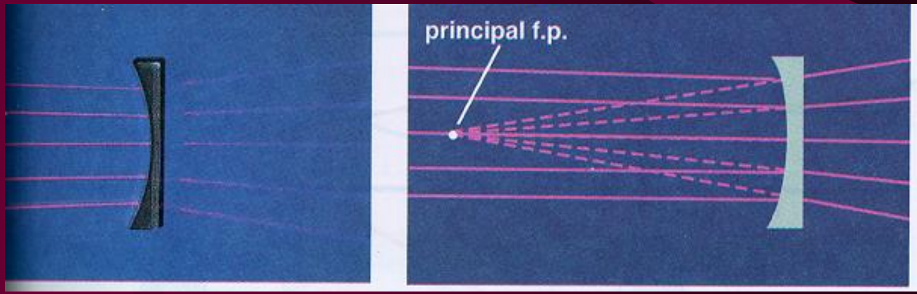
  - **optical axis**

  - **focal point** (on both sides)

  - **focal length** (equal on both sides)

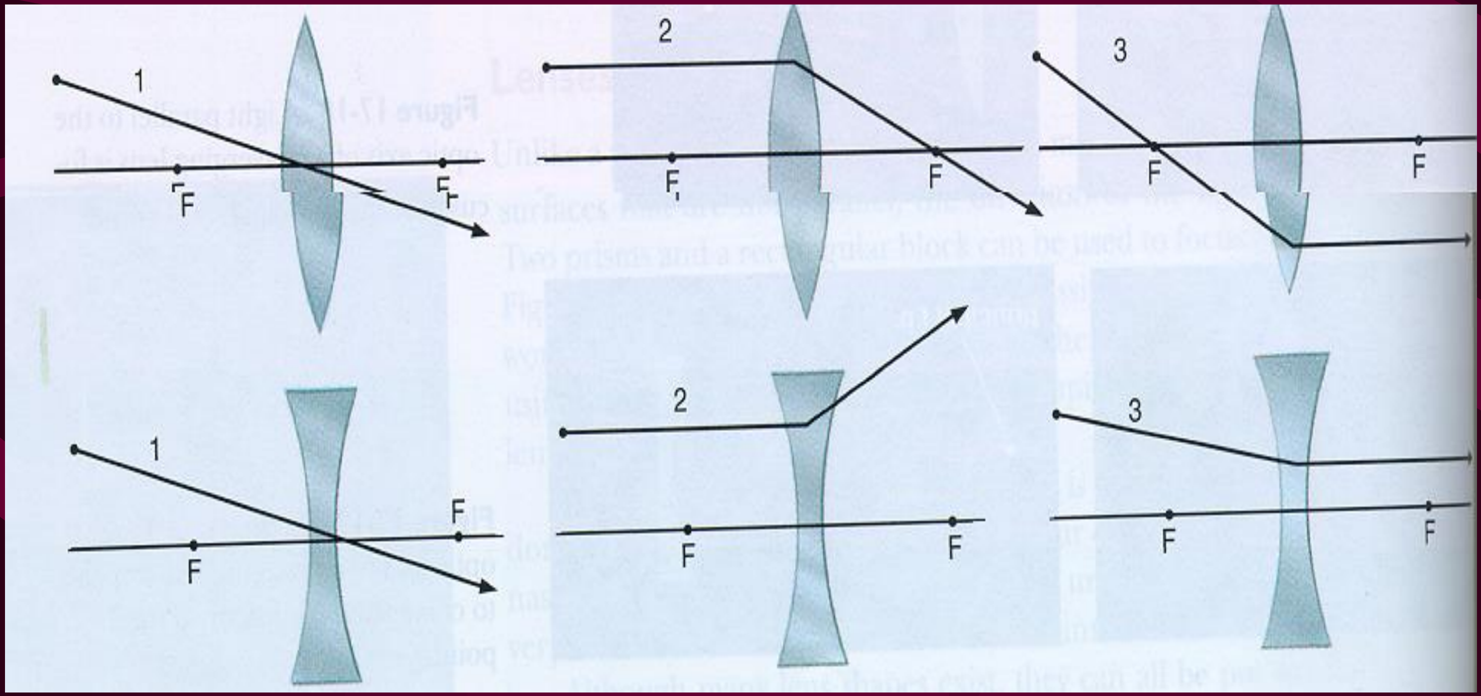




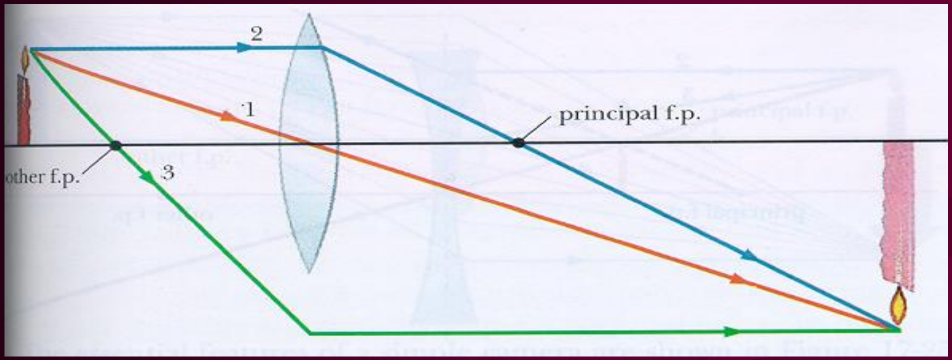


Constructing the images produced by lenses

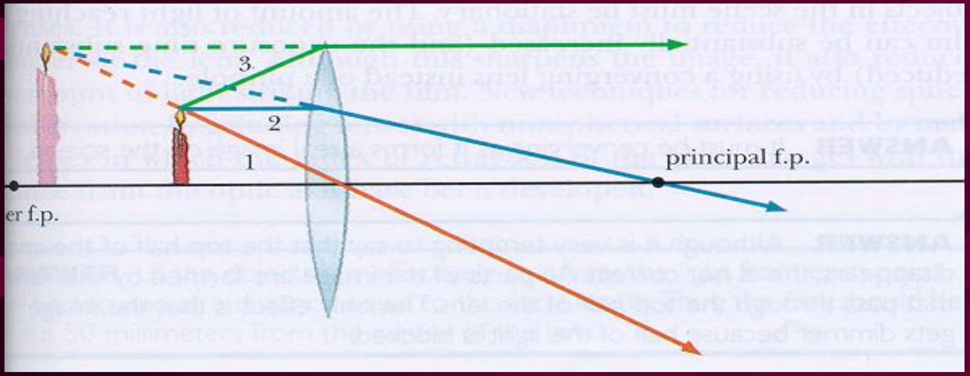
- We can construct the images by the same principles that we used in curved mirrors
- **If the lens are ideal ones for each object point we have one image point**
- Following **<u>two special rays are enough</u>** to get the picture
- special rays: - 1. going through the center of the lens (no refraction);
- -2. through the focal point (parallel to the optical axis);
- - 3. parallel with the optical axis (through the focal point)



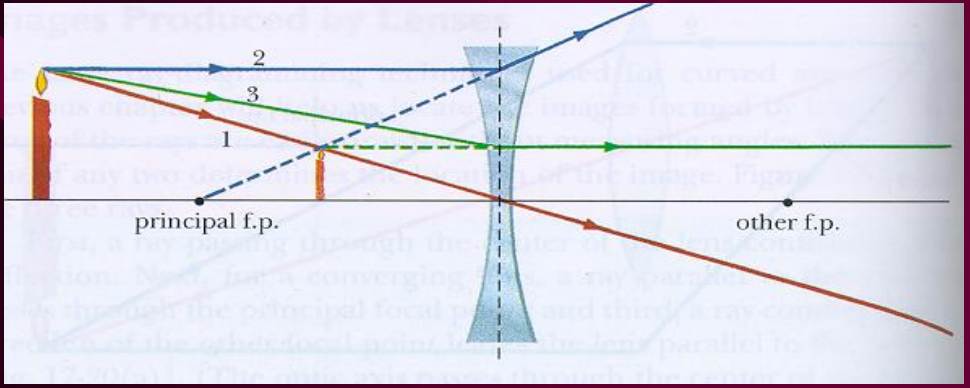
Constructing the image in some special cases



- Converging lens, object outside the focal point. Real and inverted image. Can be magnified or reduced



•Converging lens, object inside the focal point. Virtual, erect and magnified image



•Diverging lens, object outside the focal point. Image is virtual, erect and reduced in size

Calculating the properties of the image

- **Equation is the same as for the curved mirrors!!!!**
- **Notations and signs**

f: focal distance (distance from the focal point to the center of the lens) f>0 for converging lens, f<0 for diverging len

o: distance of object to the center of the lens (o>0 for real object, o<0 for imaginary objects)

i : distance of image to the center of the lens (i>0 for real images, i<0 for imaginary images)

m: magnification: size of image/size of object (m>0 image is erect, m<0 image is inverted)

d: diopters of the lens, **d=1/f**, if combining several lenses, the resulting lens will have $\mathbf{d=d_1+d_2+d_3+\ldots}$

$$\frac{1}{f}=\frac{1}{i}+\frac{1}{o}$$

$$m=-\frac{i}{o}$$

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Non-perfect lens: aberrations

- Simple lenses are not ideal:

  - usually one object point creates not an image point but a spot

  (as the diameter of the lenses are bigger, this error is more and more obvious)

  - different color light rays are producing different images
- Correcting for aberrations:

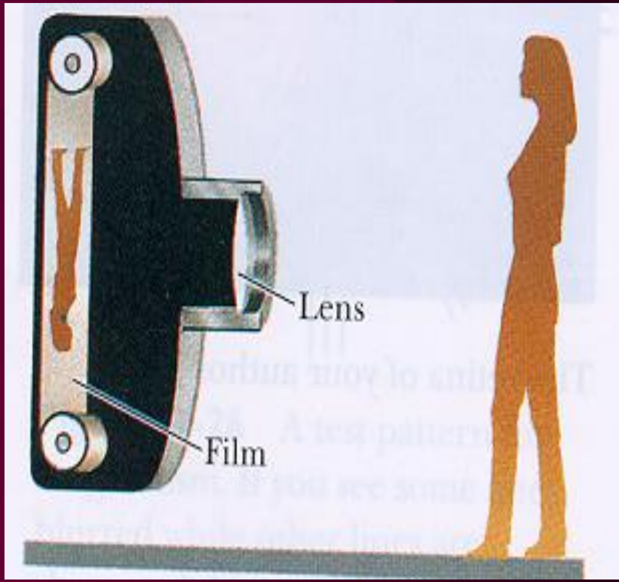
  - making lens by combining many lens (diopters simply add)

  - making lens with special covers

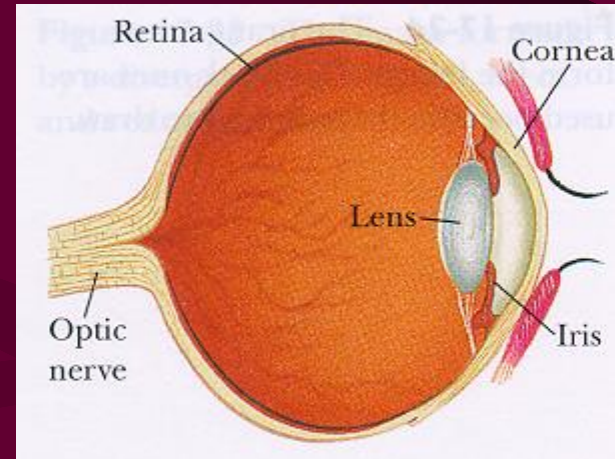
  - making lens with special and not spherical surfaces
- Using sometimes curved mirrors instead of lenses (no color aberrations)
- Aberration free lenses are very expensive ...

Applications of lenses: I. Cameras

- The pinhole camera can produce a sharp picture if the pinhole is small
- The amount of light striking the film is small. Very long exposure times are needed to make impression on the film
- By using **converging lens instead of a pinhole** the exposure time can be greatly reduced.
- Bigger lens better picture quality
- **Focus free** cameras: can form sharp images from objects far away (object distance fixed to infinity, image formed at the focal plane)
- **Auto focus** cameras: can vary the position of the lens relative to the film--> can focalize all images on the film

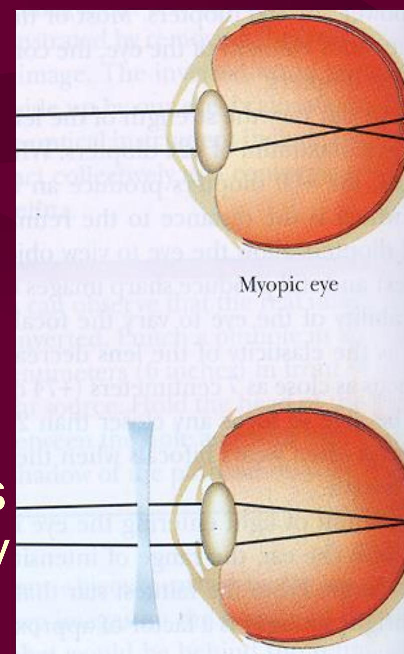


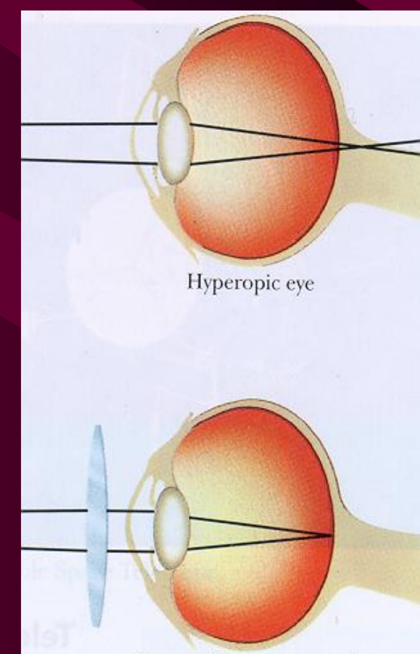
Applications: II. Our eyes and eyeglasses



- Eyes: an optical system that can form a real, virtual and reduced size image on the retina
- Multiple refractors: **cornea**, the **lens** and some **fluids** (total power: 60 diopters, lens only: 20 diopters)
- the lens can vary its focal length (20-24 diopters) (eyes like an auto-focus camera) (auto-focusing property decreases with age)
- eye problems:

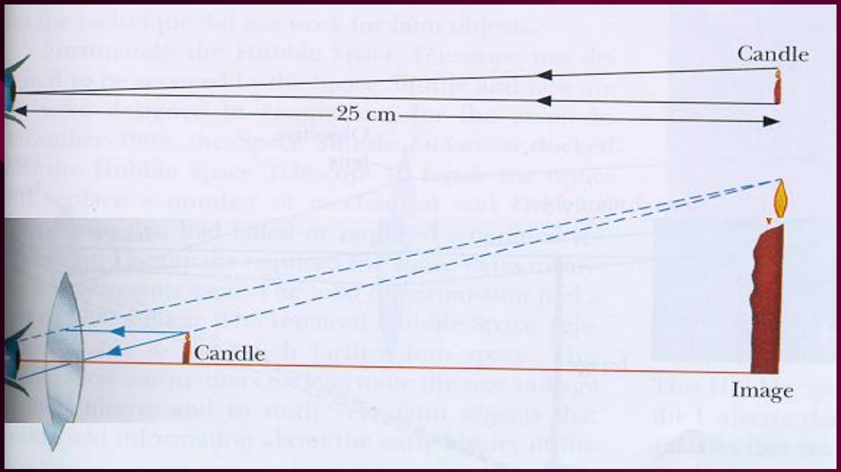
  - **myopia** (nearsightedness): clear images formed in front of the retina, corrected by eyeglasses with diverging lenses)
  - **hyperopia** (farsightedness): clear images are formed behind the retina, corrected by eyeglasses with converging lenses)

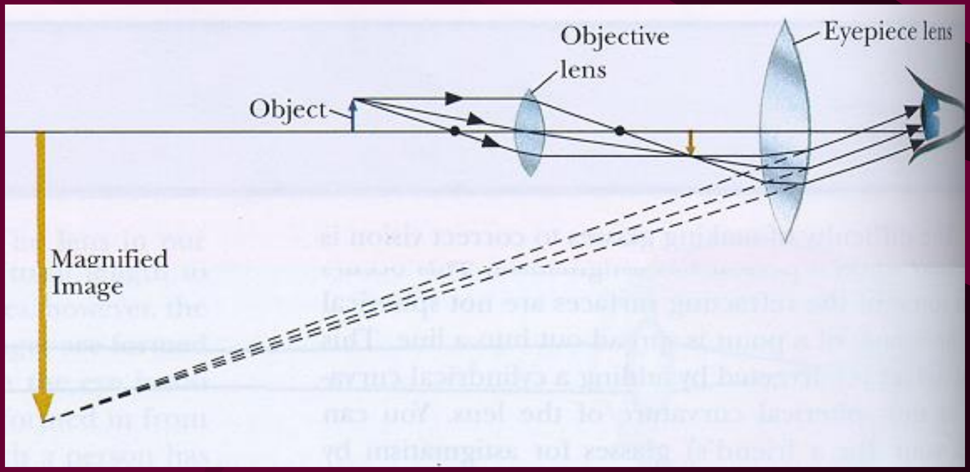




Applications: III. Magnifiers

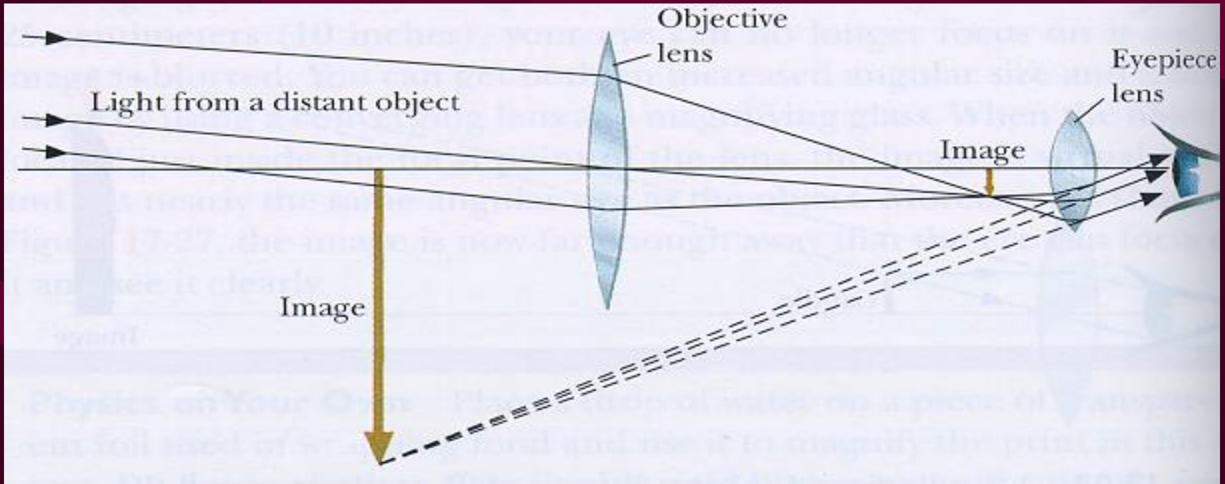
- The size of the images seen by our eyes depends on the objects actual size and on its distance away
- What really matters is the angular size of the object
- The angular size can be increased by bringing closer to the eye: if too close we cannot focus on it
- We can get both an increased angular size and sharp image by using converging lens.
- **Magnifying glass** and **microscope** (magnification is the product of the magnification of the objective and eyepiece lens)





Application: IV. Telescopes

- The idea is again to increase the angle through which we observe a distant object: impression of getting it closer
- Done by using converging lenses--> **refracting telescopes**
- magnification of the telescope: ratio of the focal lengths of the objective and eyepiece
- to get big magnification: long telescopes
- as magnification increases the brightness decreases
- to get big brightness --> big objective lens, BUT: but big lens --> big aberrations
- good telescopes: expensive! Cheaper possibility to use big curved mirror (no chromatic aberration)--> **reflecting telescopes**



Summary

- When light strikes the borderline between two materials, a part of it **reflects** and another part **refracts**
- the amount of refraction depends on the **indexes of refraction** of the two materials and can be calculated by using **Snell's law**
- for light in a material with larger index of refraction **total internal reflection** occurs, whenever the angle of incidence exceeds the critical angle.
- Lenses are glass pieces with curved surfaces, that are used to converge or diverge parallel light rays through refractions
- Lenses are characterized by their **focal lengths**, or **dioptries**
- Lenses can be **converging** or **diverging**
- The images of objects produced by lenses can be determined **constructing some special light rays**
- Lenses can produce real and virtual, magnified or reduced size images
- Ideal lenses are very hard to produce: lenses have **aberrations**
- Application of lenses: cameras, eyeglasses, magnifying glass, microscope, telescope