Lenses and Optical Instruments

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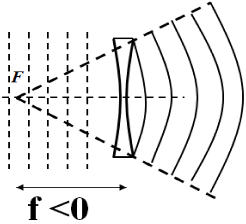
Diverging Lenses

- - combining equations 9 and 10 we get:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}; \tag{1}$$

- - this equation is called: - the lens equation;
- - the focal point F of a diverging lens is defined as
  - that point from which refracted rays,
  - originating from parallel incident rays,
  seem to emerge;



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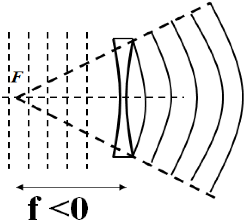

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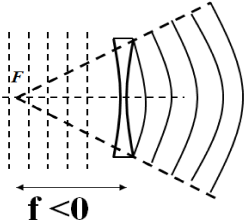
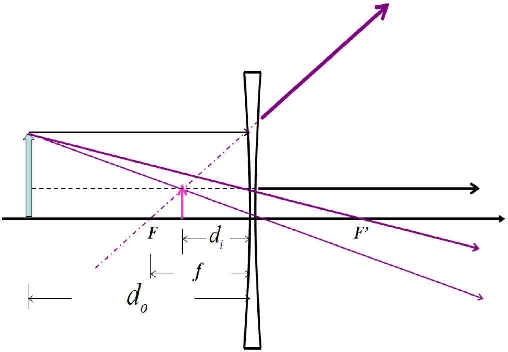


Diverging Lenses

- - to find the image formed by a diverging lens for a given object
  - we can use three particular rays:
- - the ray which is parallel to the axis,will be difracted in that direction in which the light would arrive to that point of the lens, coming from the focal point *F* in front of the lens;



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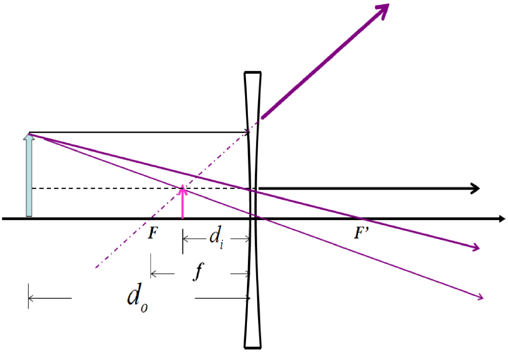

Diverging Lenses

- - the ray, which is directed toward $F^{'}$ is refracted parallel by the axis;
- - the ray, which passes through the center of the thin lens, emerges under the same angle;
- - the three difracted rays seem to emerge from a point on the left of the lens;
- - since the rays do not intersect at this point, the image is a virtual image;
- - using the similarity of the triangles and the convention that $d_i < 0$, we obtain for the diverging lens:

$$\frac{1}{d_o} + \frac{1}{d_i} = -\frac{1}{f}; \qquad (2)$$

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Lenses and Conventions

- - the focal length of a converging lens is considered positive;
- - the focal length of a diverging lens is negative;
- - the radius of curvature is considered to be positive,
  - when light strikes a convex surface
  - and negative when it strikes a concave surface;
- - the object distance is considered to be positive
  - if the object is on that side of the lens from which the light is coming;
  - negative othervise;
- - the image distance is positive for a real image and
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Lenses and Conventions

- - or equivalently, the image distance is positive if it is on the opposite side of the lens from where the light is coming;
- - object and image heights are positive if they are above the axis, negative othervise;
- - the lateral magnification is given by:

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}; \tag{3}$$

- - it is important to mention, that when light passes through several lenses,

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- - the image formed by one lens becomes the object for the next lens;
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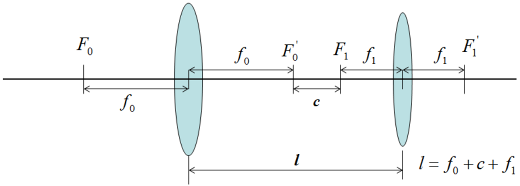
- - nowadays cameras and other optical instruments consist of a combination of lenses;



- - in these systems the effective focal length f is given by:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{l}{f_1 f_2}; \tag{4}$$

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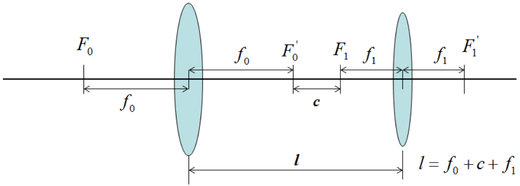

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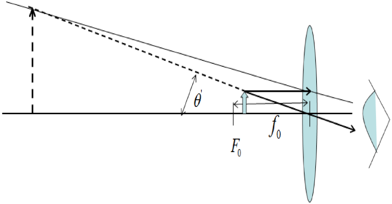
The Magnifying Glass

- - a magnifying glass is a converging lens;
- - if the object is placed between the focal point and the lens
- - the converging lens produces a virtual image;



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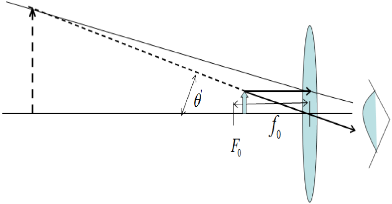

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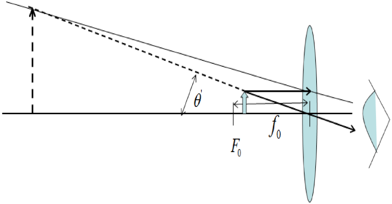

The Magnifying Glass

- - a magnifying glass allows us to place an object closer to the eye
- - so that it subtends a greater angle θ';
- - if we denote by θ the angle that subtends the unaided eye looking at the same object, then
- - the angular magnification or magnifying power is given by:

$$M = \frac{\theta'}{\theta}; \tag{5}$$

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Telescopes

- - a telescope is used to magnify objects which are very far away;
- - the first telescopes seem to date as early as the 16*th* century;
- - the first telescopes magnified only 3 to 4 times, - but Galileo made a 30 - power instrument;
- - it was Kepler who gave a ray description of both
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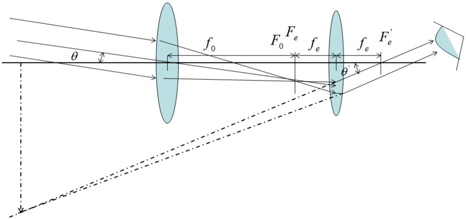
Telescopes

- - that is, those with two lenses;
- - the lens which is closer to the object is called
- - objective lens,
- - the lens, which is closer to the eye, is called eyepiece, and acts as a magnifier;



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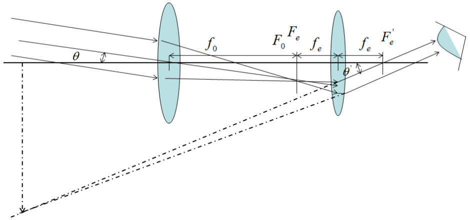

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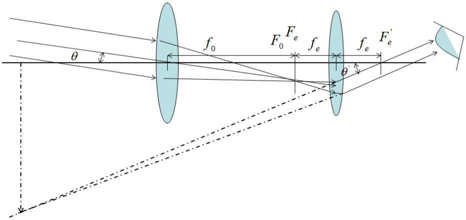

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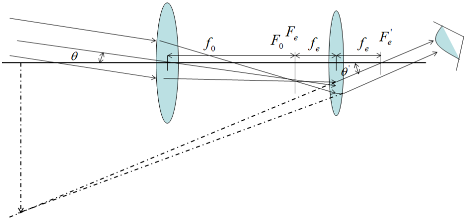

Telescopes

- - the construction and grinding of large lenses is very difficult;
- - because of this reason the very large telescopes are reflecting telescopes using a curved mirror as the objective;
- - a mirror has only one surface to be to be ground and can be supported along its entire surface;
- - a terrestrial telescope, unlike the astronomical, must provide an upright image;
- - the Galileian telescope used by him for his great astronomical discoveries, has a diverging lens as an eyepiece;

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Telescopes

- - onother type called the spyglass
  - makes use of a third lens called "field lens"
- - this field lens is used to make the image upright;
- - a disadvantage of this second type of telescope is
  - that must be quite long;
- - the prism binocular is a practical design;
- - the objective and eyepiece are converging lenses
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  - and shorten the physical size of the device;

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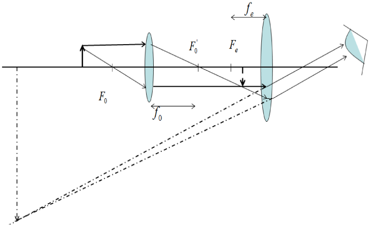
The Microscope

- - the microscope as well as the telescope
  - has an objective lens and an eyepiece;
- - a microscope is used to view objects
  - which are very close;
- - that is, the object distance is very small;
- - the object is usually placed just beyond the focal point of the objective lens;



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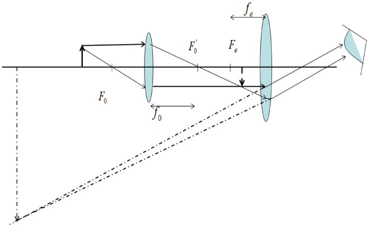

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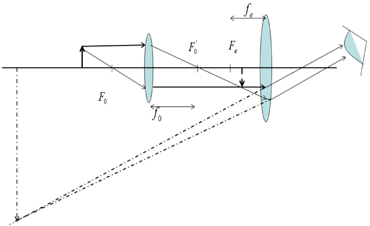

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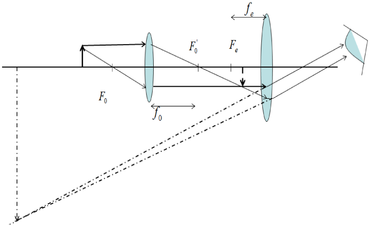

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- - the product of the magnifications of the two lenses:

$$M = M_e M_o = \frac{N}{f_e} \frac{l - f_e}{d_o}; \tag{6}$$

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The Human Eye

- - the human eye is an enclosed volume into which light passes through a lens;
- - there is a diaphragm called iris (the colored part of the eye) which adjusts automatically to control the amount of light entering the eye;
- - the hole in the iris through which light passes, the pupil
- - appears black because very little light is reflected back from the interior of the eye;
- - the retina is on the curved rear surface
  - and plays the role of the film in a camera;

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- - the retina is on the curved rear surface
  - and plays the role of the film in a camera;

The Human Eye

- - the human eye is an enclosed volume into which light passes through a lens;
- - there is a diaphragm called iris (the colored part of the eye) which adjusts automatically to control the amount of light entering the eye;
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- - the retina consists of a complex array of nerves and receptors;
- - they change light energy into electrical signals;
- - the image is formed by the brain using signals from all these tiny receptors;
- - but some analysis is also done by the retina too;
- - the lens of the eye does not contribute to much to the bending of the light;

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The Human Eye

- - the light is mainly refracted at the front surface of the cornea;
- - which also acts as a protective covering;
- - the lens of the eye acts as a fine adjustment for focusing at different distances;
- - two common defects of the eye are:
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- - nearsightedness or myopia refers to an eye that can focus only on nearby objects;
- - images of distant objects are focused in front of the retina;
- - can be corrected by a diverging lens;
- - farsightedness or hyperopia refers to an eye that cannot focus on nearby objects;
- - distant objects are usually seen clearly
  - and the near point of the eye is greater than 25 *cm*;

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- - can be corrected by a converging lens;
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- - astigmatism is usually caused by an out-of-round cornea or lens
- - so that point objects are focused as short lines;
- - it is as if the cornea were spherical with a cylindrical section superimposed;
- - a cylindrical lens focuses a point into a line parallel to its axis;
- - an astigmatic eye focuses rays in a vertical plane, say, - at a shorter distance than it does for rays in a horizontal plane;

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Lens Aberrations

- - when we derived the lens equations we made some assumptions like:
- - all the lenses are thin lenses and the rays are paraxial rays;
- - all rays make small angles with one another and we can use $sin\theta \simeq \theta$;
- - because of these approxiamtions in reality we have deviations from these theoretical results, which are referred to as lens aberrations;

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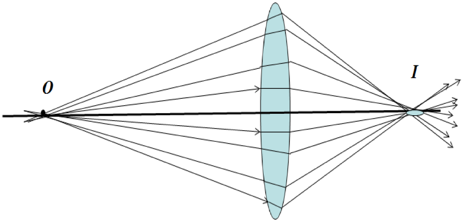
- - let us consider a point object on the axis of the lens;
- - rays from this point that pass through the outer regions of the lens are focused at different points than those that are paraxial rays;
- - this kind of aberration is called: spherical aberration;
- - instead of getting a pintlike image we will have a tiny patch of light;



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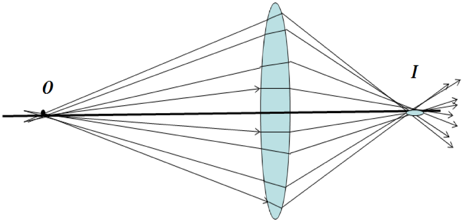

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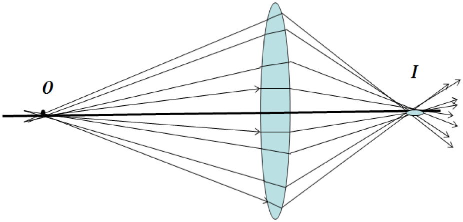

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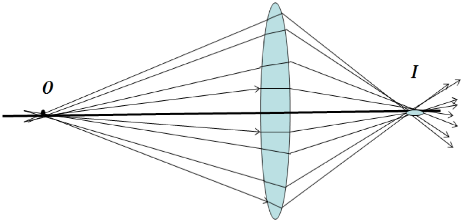

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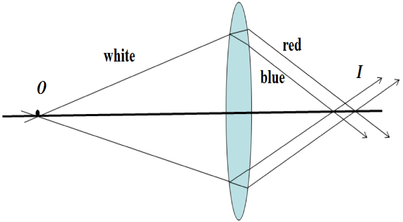
- - all these aberrations occur for monochromatic light and are referred to as monochromatic aberrations;
- - if the light is not monochromatic, there will also be chromatic aberrations;
- - this type of aberration arises because of dispersion;
- - that is because of the variation of the index of refraction of transparent materials with wavelength;



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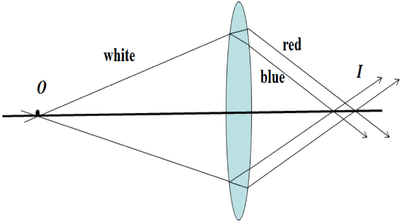

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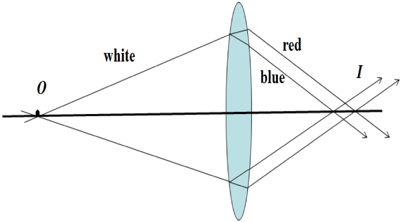

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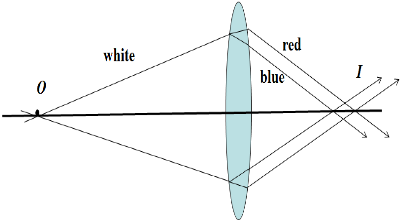

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