Lenses

A lens is an optical device used to direct light rays. Anton Van Leeuwenhoek is perhaps the most famous lens grinder – his work still amazes lens technicians and his techniques remain a mystery. Galileo might be one of the most famous users of lenses. As the rays enter and exit a lens, refraction changes their path. The lens' shape and index of refraction determine where the light rays go as they exit the lens. There are two main shapes of lenses and each has a few variations. A converging lens focuses rays to a point as they exit it; light leaving diverging lenses spreads out (diverges.) Look at the shapes below.

Lens Shapes

Eye Structure

A lens of major importance to us is the one in our eye. The following diagram summarizes the major parts of our eye.

1. Sclera: the hard, white outer layer of the eye. It helps maintain the eye's circular shape and protect its inner layers.
2. Choroid layer: this pigmented layer blocks stray rays that would blur the image on the retina.
3. Retina: this layer covers the rear portion of the eye and contains light sensitive cells that change light into electrical signals that travel to the visual cortex in the brain. There, the pattern of signals is interpreted as an image.
4. Lens: our lens is a flexible double convex lens that projects a real, inverted image back onto the retina.
5. Iris: this is the colored circle surrounding the pupil. It is a diaphragm that opens or closes to regulate the amount of light entering the eye.
6. Pupil: this is the dark opening through the center of the iris. It admits light to the lens.
7. Cornea: this is the transparent, convex front of the sclera. The cornea is at least as important as the lens in refracting light rays onto the retina.
8. Ciliary muscles: these are a miniature belt around the edge of the lens. For close focusing, the lens must become more convex by budging out more; this happens when the ciliary muscles tighten. The lens in an average eye can become convex enough to allow one to see as close as 25 cm. To see objects beyond 6 m, the lens must be as flat as possible and so the ciliary muscles are completely relaxed.
9. Optic nerve: this carries the electrical signals from the retinal cells to the visual cortex. Since the lens projects an inverted image onto the retina, the optic nerve twists 180^0 so the brain gets "upright" signals.
10. Vitreous humor: this crystal clear "jelly" provides internal pressure helping maintain eye shape.

Eye Diagram

Chromatic aberration

Look at the upper or lower half of a lens side on – they look like prisms. This is because a lens has curved surfaces, especially at the edges, where the front and back sides are not so parallel as they are through the center. The result is light moving through the edges of the lens will be refracted into its components, just it would if it passed through a prism. This causes colored fringes around the central portion of the image. To minimize this effect, many lens makers grind off the edges or apply a coating to the lens surface to cut down the degree of color separation. The coating acts like another lens that refracts the colors back together, eliminating the colored fringe effect.

Lens Cases

When an object is moved closer or farther from a lens, an image is created at different but predictable spots. As with mirror behavior, the behavior of lenses can also be classified into cases. A convex lens creates 6 refraction cases while a concave lens has just one case. Your text has diagrams of all of the possibilities.

To create your <u>own understanding</u> of the lens cases, make your own versions in your notebook. <u>Work</u> with your diagrams until, for <u>each</u> lens and case, you can <u>confidently</u>:

a) state the shape and behavior name of the lens.
b) describe the object and image location with respect to the lens,.
c) describe the object and image location with respect to each other.
d) state if the image is real or virtual.
e) state the relative sizes of the object and image.

Lens Equation

Note that it is the same as the mirror equation. The positions of the object, image and lens are easily related by:

$$\frac{1}{f} = \frac{1}{Si} + \frac{1}{So}$$

where f = lens focal length, Si = distance of image to lens surface, and So = distance from object to lens surface. The difficulty in using this equation is the same as with the mirror equation, negative terms. The following chart may help may help you remember in which cases to input – values for f or Si and when to expect them to show up in your answers. See that So is always +.

Lens shape	**sign**	**image type**

	f	Si	So	
converging	+	+ (c. 6, –)	+	real (c. 6, virtual)
diverging	–	–	+	virtual

Q. What type of image is associated with a – Si? with a – f?

Eye Defects

It is a good thing our eye lens is flexible. If it were rigid, always with the same focal length, we would always have to stand at exactly the same distance from every object we wanted to see it clearly. Our flexible eye lens changes shape and focal length according to our distance from objects. As we approach something, our ciliary muscles tighten around the edge of our lens causing it to become more bulgy because we need a small focal length to see close up. As we retreat from something, our ciliary muscles loosen around the edge of our lens causing it to become flatter because we need a larger focal length to see distant objects. But, sometimes, our eye lens is just not able to project a clear image onto the retina and we need corrective lenses.

<u>Nearsightedness</u>: we can see clearly closeup with no corrective lenses. The eye is too long for the lens and so the image is formed in the middle of the eye, out in front of the retina. To push the image back onto the retina, i.e., to make the image form farther from the eye lens, we wear diverging lenses (thicker at the edges.)

<u>Farsightedness</u>: we can see distant objects clearly with no corrective lenses. The eye is too short for the lens and so the image is formed behind the retina. To pull the image ahead onto the retina, i.e., to make the image form closer to the eye lens, we wear converging lenses (thinner at the edges.)

Simple Optical Devices

1. Simple magnifier, hand lens, magnifying glass

$M = \frac{25\text{ cm}}{f}$ A bulgy converging lens has a short focal length and therefore high magnification but it suffers from images distorted around the edges.

2. Microscope

$M = \frac{25\text{ cm} * \ell}{fo * fe}$ A microscope is just a pair of converging lenses at opposite ends of a tube. Sharp images and high magnification occur when the large eyepiece lens is flat (less magnification) and the small objective lens is bulgy (higher magnification.). This means the fe > fo.

3. Telescope

$M = \frac{fo}{fe}$ The arrangement of lens in a telescope is opposite that of the microscope. A large flat objective (long focal length) faces the stars while the eyepiece is small and bulgy (short focal length.) So now, the fo > fe.

4. Camera lens

$F\text{ stop} = \frac{f}{d}$ An important part of a photograph's look is its depth of field, i.e., the zone in front of the lens in which all objects are in focus. Objects too close or too far from the camera may be are blurry. A wide depth of field is good for grand landscapes while a narrow depth of field is useful in portraits to keep our attention on the subject. Although the camera lens' degree of curvature gives it a set focal length, its effective focal length and diameter can be altered by opening or closing an iris diaphragm set in front of it. A small diameter iris aperture allows light to pass through just the central portion of the lens. The geometry of this situation means the light's path takes it through the portion of the lens where its front and back walls are nearly parallel. The lens behaves like it has not much curvature, i.e., like a lens with a long focal length. The result is light rays passing through the lens' central zone will refract to a point at some distance from the lens. This creates a wide depth of field – objects in the foreground, middle ground and background are all in focus. Now, if the iris aperture is larger, more light can move through the edges of the lens where the front and back walls are at much more of an angle to each other. The geometry now causes light rays to refract to a point closer to the lens – the lens behaves like it has a short focal length. The result is a narrow depth of field and the photographer can bring into focus objects at just a certain depth into the picture – objects at other distances into the picture are blurry. So, changing the iris aperture changes the F stop setting because the apparent focal length and diameter of the lens are altered.