LAB 8: THE EYE

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Until relatively recently, the eye was the only optical imaging detector of any high quality. While the situation has changed dramatically, state-of-the-art cameras still don't come close to matching the optical performance of the human visual system. In addition, the majority of optical instrumentation is still designed for visual use, to be looked through. Consequently, some knowledge of the eye is helpful when trying to understand the performance of an optical system.

Anatomy

Refer to Fig. 8.3 to review the basic anatomy of the human eye. Figure 8.4 shows an "optical schematic" of the human eye. Both figures are taken from *Optical Design*, MIL-HDBK-141. The front, or *anterior* surface of the cornea is the major refracting surface. This is due to the large difference in refractive index between air and the cornea. The rear or *posterior* corneal surface actually functions as a weak negative lens. The iris is the aperture stop, located just in front of, or anterior to the crystalline lens. This name is something of a misnomer, as the lens is pliable, changing shape to account for the focusing capability of the eye. This process is called accommodation. Finally, the image plane is the retina.

If resources permit, obtain a fresh (or preserved) cow's eye for dissection. Using scissors and a scalpel, trim away any fat and muscle tissue from the outside of the globe. At this point, the optic nerve should be visible at the point where it enters the eye. Next, carefully cut into the eye around its circumference, in a plane vertical and perpendicular to the optic axis of the eye. The sclera is tough and somewhat difficult to cut through. The immediate discovery will be that the vitreous fluid is jelly-like, and tends to actually remain inside of the eye. Carefully remove the vitreous and observe the two halves of the eye. The retina and optic nerve will be visible on the back half. The posterior side of the lens and iris will be visible on the front half. Carefully dissect out the lens, trying not to puncture its outer layer, the (clear) capsule. Take note which side of the lens was anterior and posterior. Observe the shapes of the two surfaces. As in the human eye, the posterior surface is more highly curved than the anterior surface. If you were fortunate to obtain a fresh eye, the lens will be relatively clear (preservatives quickly turn the lens cloudy). Carefully support the lens around its circumference, using tweezers. Try to form a real image with the lens! (the back focal distance is quite small). Cut the lens in half, in the same manner you cut the globe. Observe the many "onion-skin" layers that make up the lens (here is where a preserved specimen is easier to work with, because it is harder). If a microscope is available, take the time to look at various parts of the eye under magnification.

Refractive Error

By definition, refractive status refers to the unaccommodated eye's ability to image distant (>20 ft or 6 m) objects clearly on the retina. If the retina coincides with the eye's rear focal plane the eye is normal or *emmetropic*.

If the retina is posterior to the rear focal plane the eye is near-sighted or *myopic*. As an object is brought closer to the eye it will eventually be clearly imaged on the retina. Hence the use of the term near-sighted. This condition is treated with negative corrective lenses to reduce the overall power of the eye.

If the retina is anterior to the rear focal plane the eye is far-sighted or *hyperopic*. In this case, distant objects will be seen more clearly than nearby objects. Hence the use of the term far-sighted. Actually, if the degree of hyperopia is mild, the eye compensates by accommodating, and both near and far objects can be focused. However, since accommodation is lost over time, these people require reading glasses at a younger age. High degrees of hyperopia are treated with positive corrective lenses to increase the overall power of the eye.

Astigmatism is confusing because the term has a couple of meanings. Generally in optics, it refers to one of the off-axis third-order aberrations, but with respect to the eye it refers to a lack of radial symmetry. In other words, the power of the cornea or lens varies with radial direction. This is due to the surfaces being toric instead of spherical in shape, producing astigmatism.

HUMAN EYE EXPERIMENTS

Light Response

Observe a subject's pupils when varying amounts of light are shined in one of their eyes (a small penlight works well for this). Notice that both pupils constrict with increasing light, and to the same degree. Many factors affect pupil size, but the entrance pupil of the eye averages about 3 mm in diameter.

Accommodation

If one focuses on a distant object, its image will be formed on the retina. At the same time, the image plane of a nearby object will be well behind the retina. In other words, nearby objects will appear blurry. Experience tells us, however, that we are able to change our point of focus, seeing clearly over a great range of object distances. This is because the power of the crystalline lens changes to keep objects imaged on the retina. The change of power is due to the lens changing shape, a process known as accommodation. This is controlled unconsciously just as breathing and heart rate are.

The power of the lens cannot increase beyond a certain limit. As a result, there is a lower limit to object distance. Objects too close to the eye cannot be seen clearly, and appear blurry. Observe this for yourself. Look at the tip of a finger and slowly bring it towards your eyes. At some point it begins to blur. This point is called the *near point*, and has a standard average value of 25 cm. This distance increases with age, as the lens loses its ability to increase in power (it becomes less pliable). With time, it becomes difficult to read at a close, comfortable distance. Reading glasses of positive power are needed to treat this condition.

Measure the distance from your nose to your near point (keeping your corrective lenses on if you use them). Remember this number and check it every five years. You will notice it increasing.

An interesting experiment is to observe your lens accommodating. Place a positive lens of 200-500 mm focal length in front of one eye and block the other eye. (If you wear corrective lenses, leave them on for this experiment.) Observe a distant point source (NOT A LASER!) in an otherwise darkened room (a street light at night also works well). The point source is seen as a blurry circle. As you stare at the point source the diameter oscillates, due to the changing power of the lens as it tries to focus.

The Blind Spot

There are no photoreceptors in the region of the retina where the optic nerve enters the eye. Thus, a blind spot appears in the field of view, about 15 degrees lateral to fixation (the point at which you are focused). The blind spot is lateral to fixation because the optic nerve enters the eye medially to the fovea, the region where the image is being formed. Think about this and use geometrical optics to convince yourself that the blind spot should appear laterally to the point of fixation.

Use Fig. 8.1 to investigate your blind spot for each eye. Close your left eye, hold the figure at arms length, and look at the X (putting its image on your fovea). Slowly bring the page closer, and at some point the circle is not visible, because its image is falling on the optic nerve. Notice that the X simply disappears. You still see the white paper, and not a black spot. The brain "fills in" the blind spot with the surrounding image, in this case the color white. To repeat the experiment with your left eye, rotate the page 180 degrees and again focus on the X. Explain why rotating the page was necessary.

Figure 8.1. Pattern to demonstrate the blind spot.

Fusion

We have two eyes but see objects singly because of fusion. The process can be interrupted by a wedge prism. Place the apex of a thin wedge horizontal in front of one eye. You will see two vertically displaced images. We can partially compensate for image disparity to some degree, particularly if the disparity is horizontal. Hold the wedge so the apex is vertical and you will see singly, although it may take a moment to fuse the images. Observe the eyes of a subject looking at a distant object while one eye is covered with a wedge, oriented with the apex vertical. Remove the prism and observe the eye moving to pick up fixation again.

Stereopsis

There are many fascinating demonstrations of binocular depth perception, but the simple one in Fig. 8.2 suffices to prove the point. View the two diagrams with a stereoviewer, or preferably by relaxing your eyes to fuse the two. Notice how two dots appear closer than the other two and none are in the plane of the paper.

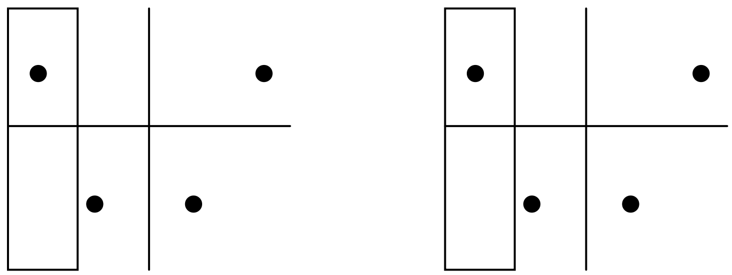

Figure 8.2. Demonstration of stereopsis.

Blue Field Entoptic Phenomenon

You can see white blood cells traverse the capillaries in your retina. Look at a clear blue field of light (the blue sky on a clear day works well--just don't look at the sun!). Cover one eye and fill the field of your open eye with the blue light. After some observation you will see small black circles moving rapidly in a random fashion about your view. These are the white corpuscles (actually, the shadows of them cast across your retina)! Notice that no circles appear in the very center of your vision, since there are no capillaries in the very center of the fovea. Also notice that the circles do not move at a constant speed but oscillate in phase with your pulse.

Physiological Zoom and the Moon Illusion

Look at your hand at arms length and then bring your hand to your near point. The image of your hand on the retina has doubled or tripled, but the apparent size of your hand is marginally changed. This is because the visual system is constantly scaling the retinal image to make it "look right."

When the moon is low over the horizon, it is scaled relative to the surroundings (mountains, trees, etc.) and appears larger than when it is high overhead and is scaled arbitrarily. This is the so-called moon illusion, and has nothing to do with refraction of the atmosphere, etc. It is the result of scaling within the visual system. Observe this phenomenon some night, especially pronounced when there is a full moon.

If a camera is available, take sequential pictures of the full moon as it traverses the sky. (Make sure all pictures are taken without changing the camera's focus or zoom settings.) Develop the film and measure the sizes of the various moon images. They will all be the same!

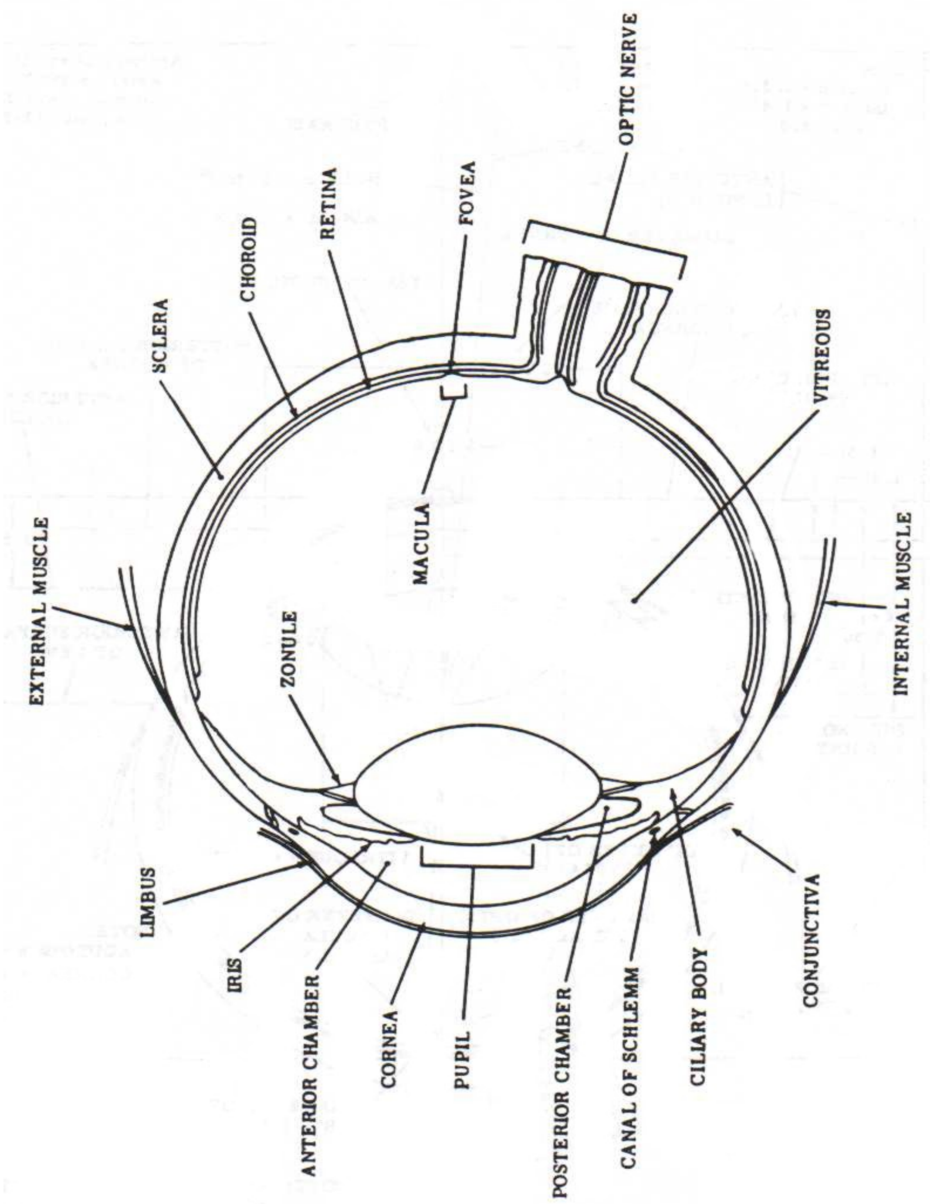

Figure 8.3. Horizontal cross-section of the right human eye.

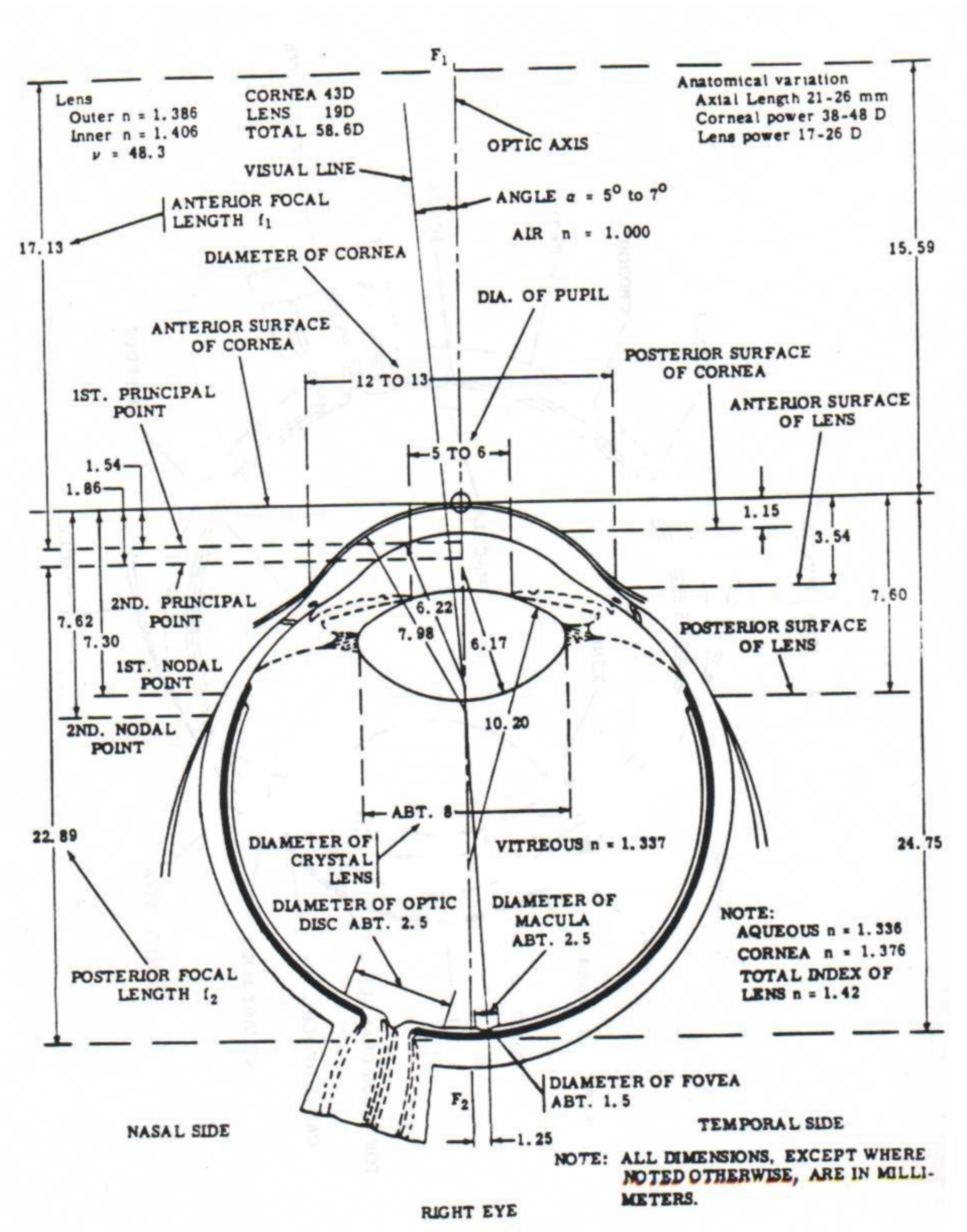
F1
Lens
Outer n = 1.386
Inner n = 1.406
ν = 48.3
CORNEA 43D
LENS 19D
TOTAL 58.6D
Anatomical variation
Axial Length 21-26 mm
Corneal power 38-48 D
Lens power 17-26 D
OPTIC AXIS
VISUAL LINE
ANGLE α = 5° to 7°
ANTERIOR FOCAL LENGTH f1
AIR n = 1.000
17.13
15.59
DIAMETER OF CORNEA
DIA. OF PUPIL
ANTERIOR SURFACE OF CORNEA
POSTERIOR SURFACE OF CORNEA
12 TO 13
1ST. PRINCIPAL POINT
ANTERIOR SURFACE OF LENS
5 TO 6
1.54
1.86
1.15
3.54
7.60
6.22
2ND. PRINCIPAL POINT
7.62
7.30
7.98
6.17
POSTERIOR SURFACE OF LENS
1ST. NODAL POINT
10.20
2ND. NODAL POINT
ABT. 8
22.89
DIAMETER OF CRYSTAL LENS
VITREOUS n = 1.337
24.75
DIAMETER OF OPTIC DISC ABT. 2.5
DIAMETER OF MACULA ABT. 2.5
NOTE:
AQUEOUS n = 1.336
CORNEA n = 1.376
TOTAL INDEX OF LENS n = 1.42
POSTERIOR FOCAL LENGTH f2
DIAMETER OF FOVEA ABT. 1.5
F2
NASAL SIDE
TEMPORAL SIDE
1.25
NOTE: ALL DIMENSIONS, EXCEPT WHERE NOTED OTHERWISE, ARE IN MILLIMETERS.
RIGHT EYE

Figure 8.4. Optical schematic for a "standard eye."