Physics 1230: Light and Color

• The Eye: Anatomy of the Eye and Vision

http://www.colorado.edu/physics/phys1230
How Do We See?

Take a look around the room that you are in. Notice how the various images and colors that you see update constantly as you turn your head and re-direct your attention. Although the images appear to be seamless, each blending imperceptibly into the next, they are in reality being updated almost continuously by the vision apparatus of your eyes and brain. The seamless quality in the images that you see is possible because human vision updates images, including the details of motion and color, on a time scale so rapid that a "break in the action" is almost never perceived. The range of color, the perception of seamless motion, the contrast and the quality, along with the minute details, that most people can perceive make "real-life" images clearer and more detailed than any seen on a television or movie screen. The efficiency and completeness of your eyes and brain is unparalleled in comparison with any piece of apparatus or instrumentation ever invented. We know this amazing function of the eyes and brain as the sense of vision.

So let's first look at what the eye is, and then see how it works.................

By: Diane M. Szaflarski, Ph.D.
Survey: How Do We See?

We can see objects around us because
A. Light travels outward from our eyes to the objects
B. Light travels from the objects to our eyes
C. Light travels both into and out of our eyes
D. Seeing does not depend on light at all
The Ancient Greeks

“Sight is the noblest faculty of man.”
- Aristotle

Aristotle rejected Plato’s theory that light was emitted from the eyes.

“Democritus and Epicurus suppose that sight is caused by the insertion of little images into the visive organ, and by the reception of certain rays which return to the eye after meeting the object. Empedocles supposes that images are mixed with the rays of the eye; these he styles the rays of images. Hipparchus, that the visual rays extend from both the eyes to the superfcies of bodies, and give to the sight the apprehension of those same bodies, after the same manner in which the hand touching the extremity of bodies gives the sense of feeling. Plato, that the sight is the splendor of united rays; there is a light which reaches some distance from the eyes into a cognate air, and there is likewise a light shed from bodies, which meets and joins with the fiery visual light in the intermediate air (which is liquid and mutable); and the union of these rays gives the sense of seeing. This is Plato’s corradiancy, or splendor of united rays.” (Plutarch)

http://www.mlahanas.de/Greeks/Optics.htm
Al Hazan’s Theory of Vision (1021)

The Arabian physicist, astronomer, and mathematician al-Hasan ibn al-Haytham (ca. 966-1039 in Basra, Iraq), or Alhazen, established the theory of vision that prevailed till the 17th century. Euclid, Ptolemy, and other ancient Greek scientists had believed that vision resulted from light rays emitted by the eye. Al Hazan originated the theory that vision was the result of illuminated rays reaching the eye. He believed that light rays emanated in straight lines, in a spherical direction, from every point of a luminous object.
Descartes' Theory of Vision

René Descartes: French philosopher, mathematician and scientist (1596 -1650)
A CAT-BOY has stunned medics with his ability to SEE in pitch black with eyes that GLOW in the dark. Doctors have studied Nong Youhui’s amazing eyesight since his dad took him to hospital in Dahua, southern China, concerned over his bright blue eyes. Dad Ling said: "They told me he would grow out of it and that his eyes would stop glowing and turn black like most Chinese people but they never did." Medical tests conducted in complete darkness show Youhui can read perfectly without any light and sees as clearly as most people do during the day. Experts believe he was born with a rare condition called leukokemia which has left his eyes with less protective pigment and more sensitive to light. The SUN: 23 Feb 2009
the Eye: a fairly sophisticated optical sensor

“Eyes can be eaten by humans: seal eyes are a source of zinc for the Inuit”
- Wikipedia
Human Vision and Color Perception – Anatomy of the Eye
http://microscope.fsu.edu/primer/lightandcolor/humanvisionintro.html

Image Formation and Human Vision – Magnification of the Eye
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/eyeball/index.html
Can you name the parts of the Eye?

http://micro.magnet.fsu.edu/optics/lightandcolor/vision.html
Focusing and Accommodation

• Good cameras adjust the position of the lens to focus on close or far objects.

• The human eye cannot move - but can change its focal length and thus focus on close and far objects because the eyelens is elastic.

• This process is called accommodation, and is performed by the ciliary muscles.
Taking a photograph

If the camera is all set up to take a photo of the tree, and then your friend wants a head portrait, do you need to -

A. Move lens away from film
B. Move lens towards film
C. Leave lens in same place
D. Other
Taking a photograph

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D. Other
Focusing your eye

Your eyelens cannot move away from your retina. How do we form an image of something closer to us?

A. Eyelens gets stronger
B. Eyelens gets weaker
C. Eyelens does not change
D. Other
Focusing your eye

Your eyelens cannot move away from your retina. What happens?

A. Eyelens gets stronger to shorten image distance so that it is focused on the retina
B. Eyelens gets weaker
C. Eyelens does not change
D. Other
What does *accommodation* of the eye have to do with looking at me or your thumb? How does it work? (Lens represents combined cornea-eyelens system)

Focusing your eye on a nearby thumb requires shorter focal length (more bulgy) eyelens than focusing on a person far away, since rays must be bent more for image to fall on retina.
the Eye: Focusing and Accommodation

Concept Question: For viewing distant objects, the eyelens is -

A. Thin (long focal length)
B. Thick (short focal length)
Concept Question: For viewing distant objects, the ciliary muscles are -

A. Relaxed

B. Tense
Concept Question: When viewing distant objects, the image is -

A. In front of the retina
B. On the retina
C. Behind the retina
the Eye: Focusing and Accommodation

Concept Question: For viewing close objects, the eyelens is -

A. Thin (long focal length)

B. Thick (short focal length)
the Eye: Focusing and Accommodation

Concept Question: For viewing close objects, the ciliary muscles are -

A. Relaxed
B. Tense
the Eye: Focusing and Accommodation

Concept Question: When viewing close objects, the image is -

A. In front of the retina
B. On the retina
C. Behind the retina
Focusing and Accommodation

When the ciliary muscles are tense [pulled in towards the center of the Eye], they release tension in the suspensory ligaments. This allows the eyelens to bulge out into the shape it prefers naturally - with a shorter focal length for close-up viewing.

**FIGURE 5.6**

Accommodation. (a) Relaxed ciliary muscles allow the suspensory ligaments to stretch the eyelens, which then has a long focal length for viewing distant objects. (b) Tense ciliary muscles release the suspensory ligaments and the eyelens bulges for viewing near objects.
Focusing and Accommodation

- So the eyelens makes small corrections to the large bending produced by the cornea.
- Normal eyes are able to accommodate for objects between 25 cm and infinity.
- Eye problems develop if the cornea bulges too much or too little.

**FIGURE 5.6**

Accommodation. (a) Relaxed ciliary muscles allow the suspensory ligaments to stretch the eyelens, which then has a long focal length for viewing distant objects. (b) Tense ciliary muscles release the suspensory ligaments and the eyelens bulges for viewing near objects.
Focusing and Accommodation: just how much does the Lens Adjust?

Dependence of eyelens $F$ on object distance (image distance is fixed at 1.70 cm)

<table>
<thead>
<tr>
<th>Object Distance</th>
<th>Focal Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25m</td>
<td>1.59 cm</td>
</tr>
<tr>
<td>1 m</td>
<td>1.67 cm</td>
</tr>
<tr>
<td>3 m</td>
<td>1.69 cm</td>
</tr>
<tr>
<td>100 m</td>
<td>1.70 cm</td>
</tr>
<tr>
<td>Infinity</td>
<td>1.70 cm</td>
</tr>
</tbody>
</table>

http://www.physicsclassroom.com/Class/refrn/U14L6c.html
How vision works - the eye and the camera

What are the similarities between the eye and the camera?
The EYE

The Human Eye - function of parts of the eye
http://www.youtube.com/watch?v=JunCyIGfreo
The EYE

- Retina
- Macula
- Optic Nerve
- Vitreous
- Iris
- Cornea
- Lens
- Pupil
The cornea is a transparent tissue in the front part of the eye. It is a curved spherical structure that is responsible for focusing the light onto the inside of the eye. Contact lenses sit on top of the cornea to change its curvature and eliminate the need for glasses.

The sclera forms the outer wall of the eye, and is white and light tight
The iris is the colored part of the eye. It opens up in dark rooms and at night to let more light into the eye. Conversely, in bright light the iris constricts to decrease the amount of light that enters the back of the eye.
The pupil is the black spot in the center of the iris. Actually, the pupil is the name given to the opening in the iris through which light passes.

The lens is responsible for helping to fine adjust the focus of the eye. The lens changes shape and focal length to allow clear vision both in the distance (far away) and for reading (close up).
Between the cornea and the iris is a space called the **anterior chamber**. This space is filled with a clear water-like solution called the **aqueous humor**. Behind the lens is a jelly-like fluid called the **vitreous humor**.
The vitreous humor is a clear jelly-like material which fills the inside of the eyeball. Light passes through the vitreous humor on its way to being focused onto the retina.

The retina is a thin film of tissue (like film in a camera) where images are brought into focus. The retina lines the inside surface of the eyeball, and contains over a hundred million light sensitive cells. The retina is connected to the brain where the visual signals are processed.
TEST FOR FLOATERS

You can often see dead blood cells floating in your humors by looking at a bright white wall or paper, or at a clear blue sky (not at the Sun!!). These are called floaters.
More detailed anatomy of the eye

Ciliary muscles (purple) control the focal length of the lens.

Optic nerve (green) carries signals to the brain.
There are no light detecting rods and cones where the optic nerve leaves the eye. This is called the blind spot.
LOCATING YOUR BLIND SPOT

At a distance of about 25 cm, close your left eye and stare at the X with your right eye. Slowly move the tip of your pen from the X to the right. Keep looking directly at the X, and view the tip of your pen using your peripheral vision. At about 8cm to the right of the X, the tip of your pen should disappear, when its image falls on your blind spot.

See special instructions handed out in class!
LOCATING YOUR BLIND SPOT

There are no light detecting rods and cones where the optic nerve leaves the eye. This is called the blind spot.

See special instructions handed out in class!
How vision works - the eye and the camera

What are the similarities between the eye and the camera?

http://www.eyesearch.com/eye.camera.jpg
The IRIS

- The iris is the part of the eye that gives it color. Eye colors vary from light blue to dark brown, depending upon the amount of pigment, called melanin, that is contained in the iris.

- The iris is like the aperture (diaphragm) on an automatic camera, opening and closing automatically in response to ambient light. It can vary the exposure on your eye (retina) by a factor of ≈ 20. The iris can respond in 1/5 of a second.

- When your iris is fully open, your eye has an f-number between f/2 and f/3 (this compares with f/0.9 for a nocturnal cat!)

- The main function of the iris is to control the depth of field, not the intensity of the light on your eye (retina).
The RETINA

http://micro.magnet.fsu.edu/optics/lightandcolor/vision.html

130 million rods
7 million cones
The RETINA

• The retina is like the film in a camera, and is divided into two areas- the central area or "macula" and the peripheral retina.

• The macula has the highest concentration of retinal cells and provides the sharpest vision. We need our macula to read fine print and thread a needle. The leading cause of blindness in America, macular degeneration, causes damage to the macula.

• The peripheral retina is used for peripheral vision which is critical for many activities such as driving and playing sports. A common disease of the peripheral retina is the retinal tear. This can lead to a retinal detachment and loss of peripheral and ultimately central vision as well.
NAME the Photosensors in the RETINA

http://micro.magnet.fsu.edu/optics/lightandcolor/vision.html
The RETINA

- The retina has 3 main layers -
  - a light sensitive layer with photoreceptors
  - a plexiform layer with nerve cells that transmit the signal to the optic nerve
  - a choroid layer with blood vessels to nourish the retina

- Pupils look dark because the retina absorbs most of the light that enters the eye (except under bright camera flashes when they can look red!)
(c) Cross section of the central retina

- Bipolar cells
- Ganglion cells
- Fovea
- Retina
- Light direction
- Ganglion cells
- Bipolar cells
- Photoreceptor cells
- Pigmented epithelium
- Rods
- Cones
Focusing and Accommodation

- The cornea and eyelens form a lens system to produce REAL, INVERTED, images on the retina.

- The amount of bending (focusing) of the light depends on the difference between the index of refraction of air ($n_{\text{air}} \approx 1$) and the eye ($n_{\text{cornea}} \approx 1.376$, $n_{\text{humors}} \approx 1.336$, $n_{\text{eyelens}} \approx 1.406$).
FISHEYES

• Because $n_{\text{cornea}} \approx 1.376$ is close to $n_{\text{water}} \approx 1.33$, there is almost no bending of light in the cornea when you are underwater.

• So fish have almost spherical eyelenses that do all the focusing. The shape of their cornea is not important, and differs in different fish.

• For animals that need to see in air and in water (e.g. ducks), their cornea is almost flat.
Focusing and Accommodation

- Good cameras adjust the position of the lens to focus on close or far objects.
- The human eye does not change its distance from the retina (but some fish can!)
- The human eye can change its focal length and thus focus on close and far objects because the eyelens is elastic.
- This process is called accommodation, and is performed by the ciliary muscles.
Eye in 3-D

http://www.utexas.edu/depts/pharmacology/gonzales/eye.html
Movies about the Eye and Vision

The Human Eye - function of parts of the eye
http://www.youtube.com/watch?v=JunCyIgfre0

How the Eye Functions (1941) Part1
http://www.youtube.com/watch?v=UpLtf8IEJENJE

how the Eye Functions (1941) Part2
http://www.youtube.com/watch?v=PmD7Tjib6yKo

The Eye is too Complex! - argument for evolution
http://www.youtube.com/watch?v=ZPcwLyJ0hGU

How the Eye Evolved (National Geographic) -
Swedish scientist argues for evolution
http://www.youtube.com/watch?v=zI_oGu-2clE

Intelligent Design? - Dawkins and Nesse
http://www.youtube.com/watch?v=CZkPAnGXsc

How the Human Eye Works - woman with vision loss
http://www.youtube.com/watch?v=JadaWSDxBYk
Movies about the Bionic Eyes

Bionic Eye
http://www.youtube.com/watch?v=y0apm2NnNx8

Seeing Is Believing: World's First Bionic Eye
http://www.youtube.com/watch?v=696dxY6BYBM

Bionic Eye by 2020 –Australian researchers
http://www.youtube.com/watch?v=GZ0G9odShF4