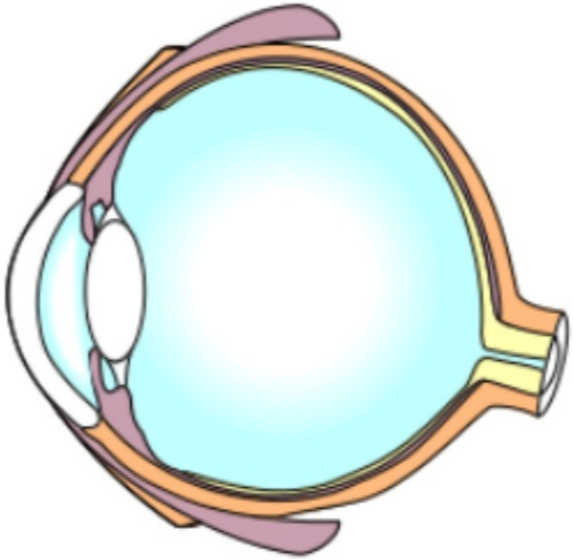
The Eye and Sight

Structure

The eye is a very complex organ that sends a huge amount of information to the brain. It has a very specific design to capture and analyze light. In its simplest description, the eye is a box, with a lens to focus the light that enters it, and cells to process the light.

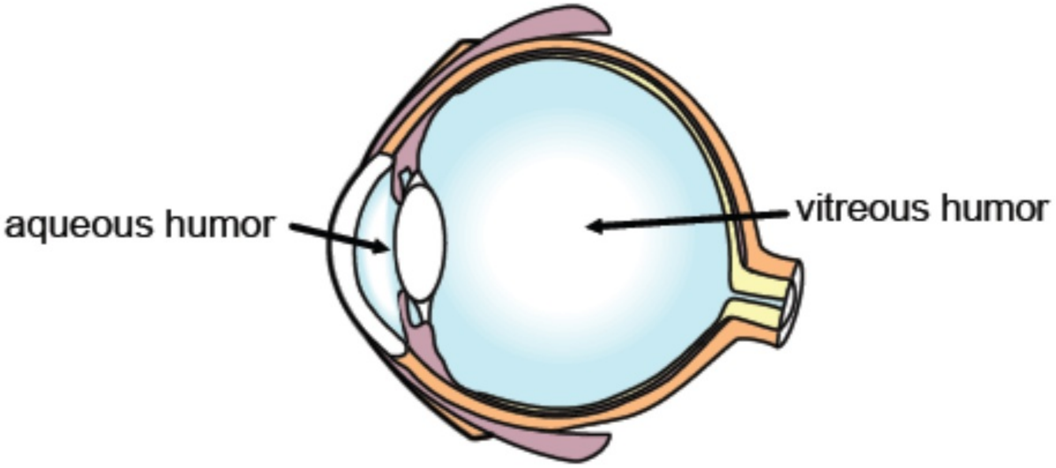
Almost the entire exterior of the eye is a"light-tight" box. Its outer walls are formed by a hard, white substance called sclera . The outside of the eye is light-tight so that light can only enter through a small opening. This produces clearer vision, because a smaller opening, or aperture, creates a sharper image.

Prove it to yourself: Take an index card and puncture it using a pin. Be careful not to allow the hole to be too large! Look at something just far enough away that you cannot focus clearly on it. Hold your index card up to your eye and look through the tiny hole. While the aperture, the hole, blocks most of the light hitting your eye, it makes the far away object look clearer!



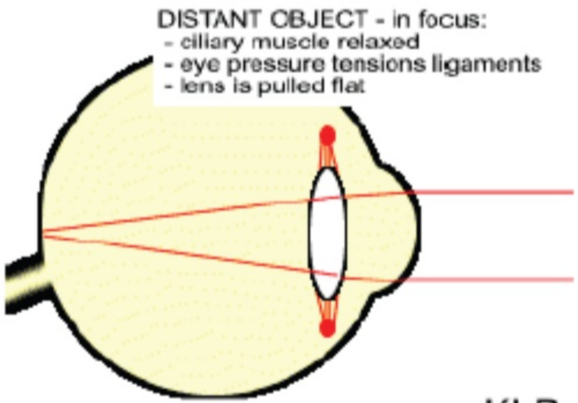
The eye is filled with two liquids. These provide nourishment to the other cells in the eye, just as blood vessels provide nourishment to most cells in the body. The difference between these liquids and blood is that they are nearly transparent, so they can nourish the cells of the eye without interfering with the light that enters. The two liquids in the eye are called the vitreous humor and aqueous humor.

Prove it to yourself: Rapidly move your eyes (NOT YOUR HEAD!) back and forth. Suddenly stop moving your eyes, close them, and look at a bright light. You should see what appears to be little bubbles or chains floating across your closed eyes. These are dead cells floating in your vitreous and aqueous humors. The older you are the better this experiment will work. If you are young or have healthy eyes, try moving your eyes for a longer period of time.



Focusing (accommodation)

Light entering the eye is focused by two lenses: the *cornea* and the eye *lens*. The lenses hold their shape due to pressure from the vitreous humor and aqueous humor, as well as a muscle group called the ciliary muscles. Light is bent by the lenses to focus at the back of the eye. You can learn more about the bending of light in refraction. As objects get further away from the eye the ciliary muscles relax, allowing the eye lens to become flatter and bend the light differently. Sometimes, due to age or genetics, the ciliary muscles will not bend the eye lens correctly, causing a blurred image. This condition is called either myopia (nearsightedness) or hyperopia (farsightedness).



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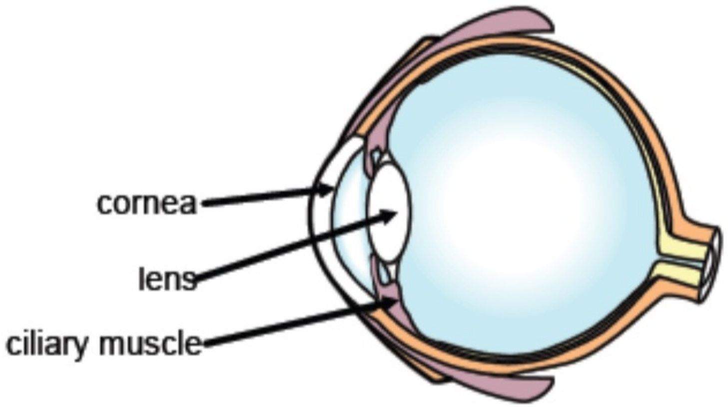
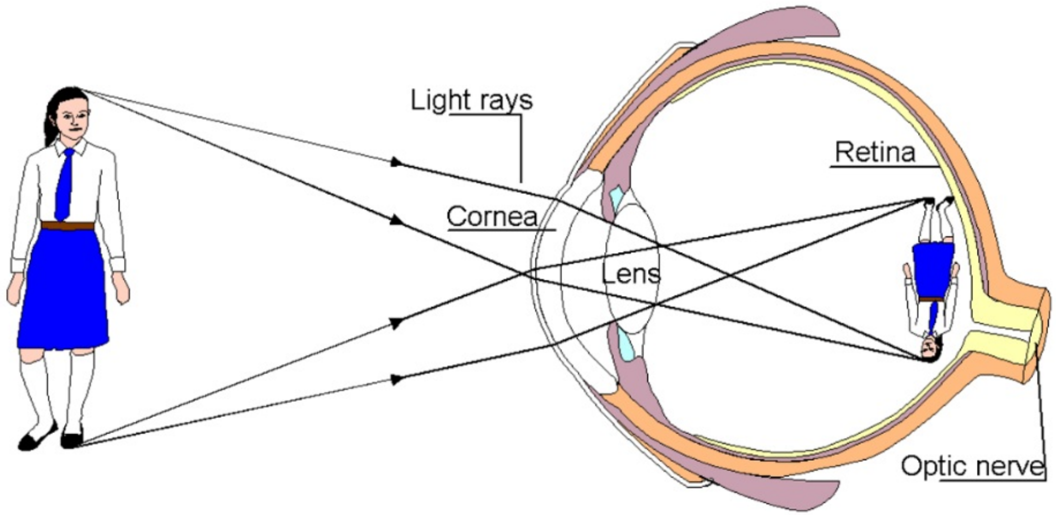


The Image

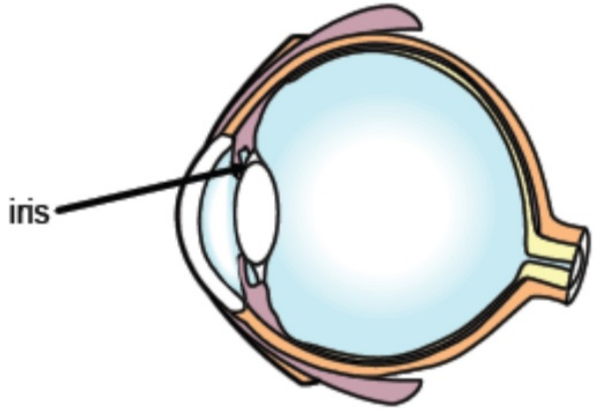
The image created by the eye is real and inverted. Many people are surprised to learn that the images we always see are inverted. The reason we do not notice this is that we know no other reality. Studies have been performed where subjects have worn special goggles that distort their vision in certain ways. After along period of time, the brain accommodates for the goggles, and the subjects are able to do everyday tasks without difficulty!

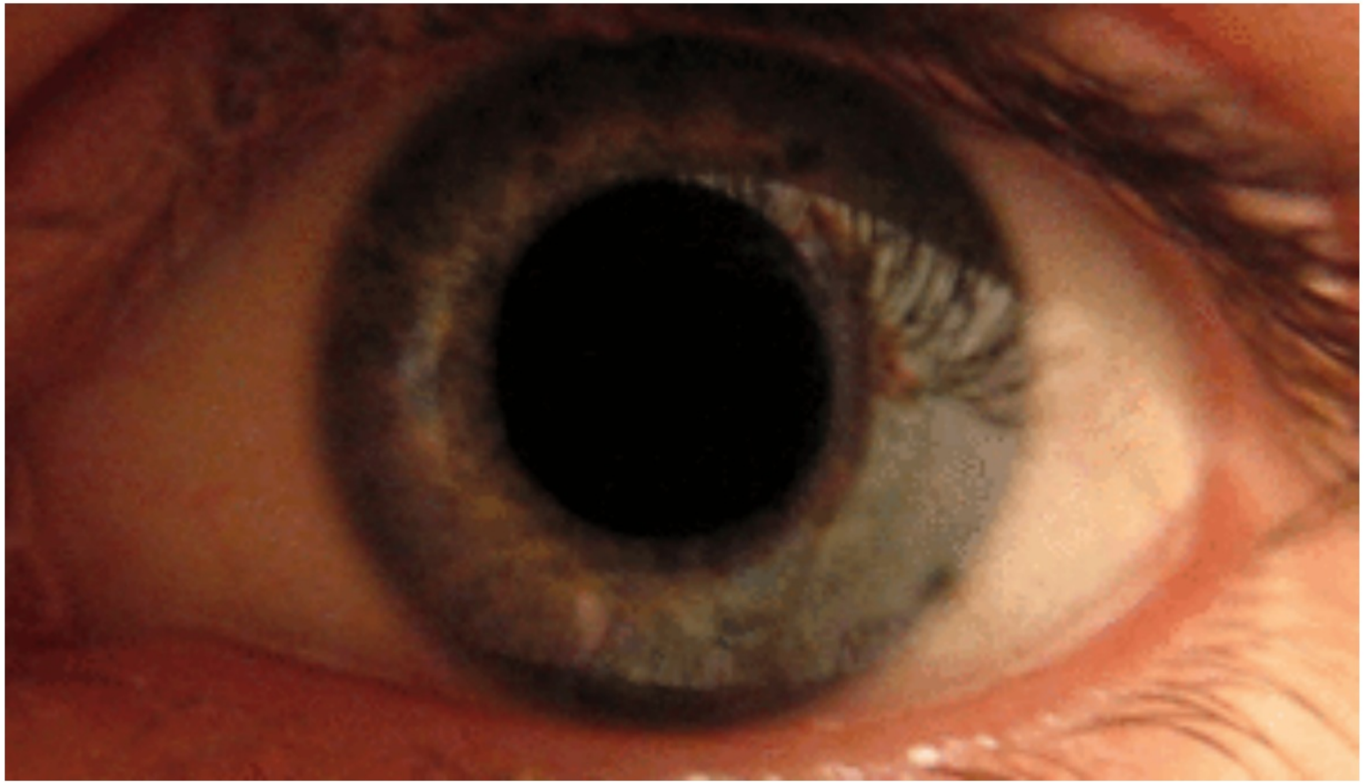


Light Control

One of the wonders of the human eye is that it can respond to a wider range of light than any artificial device ever created. In other words, it is possible to see not only in very low light levels (such as a darkroom) but also in very high light levels (such as a sunny day). In fact, the brightest conditions under which an eye can operate are around 10^{13} times as bright as the dimmest conditions.

How does the eye do this? One way is by using the iris. The iris changes in size to allow different amounts of light to enter your eye.When there is more light, the iris shrinks. This blocks out much of the light,and as is demonstrated by the first activity, this increases the sharpness of your vision. If there is less light, the iris increases in size, allowing more light to enter the eye to be processed.





The Retina

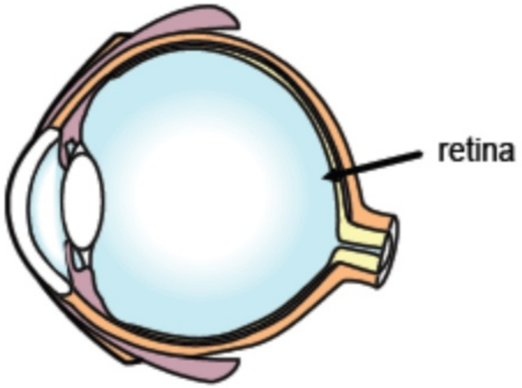
The retina, a 5 square centimeter area in the back of the eye, is where all light detection takes place. The retina is a network of nerves connected to over 100 million photo-sensitive rods and cones . The signals created by these rods and cones are then sent via the optic nerve to the brain.

The top layer of the retina surprisingly does not interpret the light that strikes it. This layer, called the Plexiform layer , is a web of optical nerves. These nerves carry the signals of rods and cones to the optic nerve. This web is located between the photo-sensitive cells and the vitreous humor so that the web's cells can be nourished. Fortunately, these cells are nearly transparent so only minimally interfere with light striking the photo-sensitive cells.

The bottom layer of the retina is called the choroid. The choroid serves a double purpose: nourishment and absorption. The choroid carries blood to the retina and the humors, providing nourishment to the eye. In addition, the choroid absorbs any light that strikes it. This is extremely important, because light that passes through the rods and cones does not reflect back. If the light did reflect, the photo-sensitive cells would receive the light message twice, and would think that there was twice as much light as there really was.

Here's some evidence:

- The eye pupil appears black. This is because all light that enters the pupil is absorbed by either the photo-sensitive layer or the choroid. Since no light is reflected, the pupil appears extremely dark or black.
- A sudden burst of intense light cannot be absorbed completely by the photo-sensitive layer and the choroid. When a flash photograph is taken, much of the light is reflected back. The light reflected is red because of the blood in the choroid, causing red eye!
- The choroids of cats are slightly different from those of humans: they reflect light instead of absorbing it, allowing the cat to see better in dimmer light. This accounts for cats' eyes often being described as luminous .

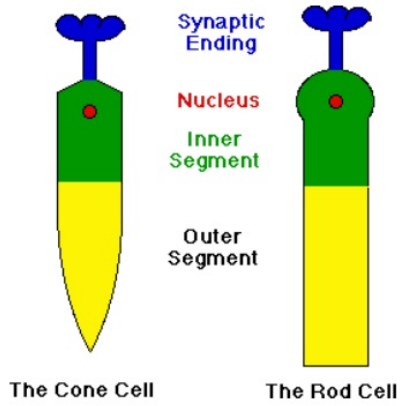


Rods and Cones

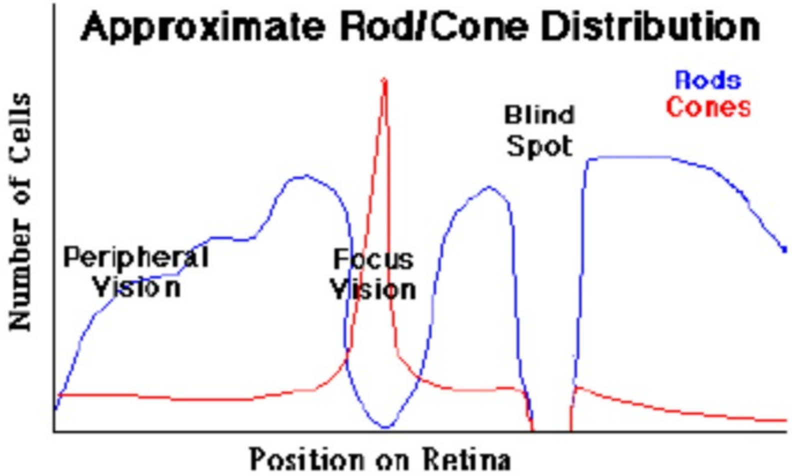
The final layer of the retina is the photo-sensitive layer, made up of rods and cones. When they are exposed to light, rods and cones send signals to the plexiform layer. This signal is then transferred via the optic nerve to the brain to be interpreted.

Rods and Cones react to different levels of light. Cones are photopic, which means that they respond to high light levels. Rods are scotopic, which means they respond to low levels of light. Depending on the amount of light striking the retina, one kind of cell will become more responsive, while the other will "turn off." The human eye has about 7 million cones and 120 million rods. Nocturnal animals, such as cats, have more rods and fewer cones. Many diurnal animals, such as pigeons, only have cones.

Each rod and cone is made up of four segments. The cell nucleus keeps the cell alive and causes cell reproduction. The inner segment manufactures a light sensitive chemical made up of Vitamin A and protein. The outer segment uses this chemical to absorb light. When light strikes the chemical, it undergoes a reaction in the fourth segment, the synaptic ending. This reaction produces a neuro-transmitter that is then sent to the plexiform layer and the brain.

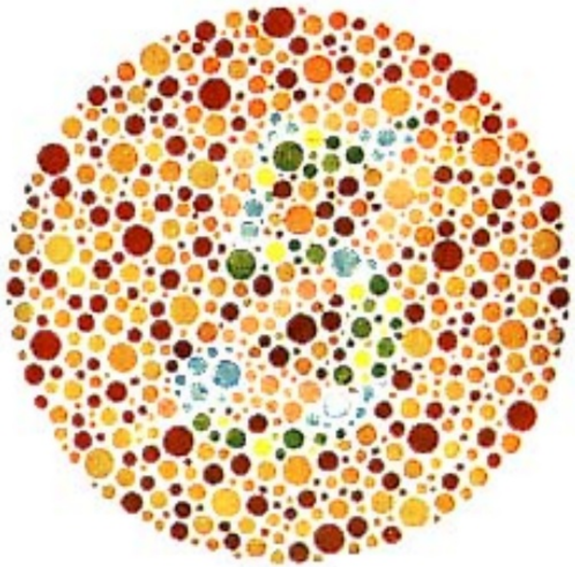


Cones are the cells that we use to distinguish color. This has several very interesting effects. Almost all cones are located at the middle of the retina, so it is very difficult to distinguish color in our *Peripheral vision*. In addition, it makes it impossible to see color in low levels of light when the cones are "turned off."



The rods and cones are not evenly distributed across the retina. The density of the cones is at a maximum in the center whereras rods peak in density at an angle of about 20^{o} away from the center. There are no rods or cones in the region where the optic nerve leaves the back of the eye. This is known as the ***blind spot***. The graph above shows the vertical variation of the density of the cells.

Are you color blind?



Normal vision sees: 5
Red/Green color blind sees: 2

What is color blindness?

The normal human retina contains two kinds of light cells: the rod cells (active in low light) and the cone cells (active in normal daylight) . Normally, there are three kinds of cones, each containing a different pigment. The cones are activated when the pigments absorb light. The absorption spectra of the cones differ; one is maximally sensitive to short wavelengths, one to medium wavelengths, and the third to long wavelengths (their peak sensitivities are in the blue, yellowish-green, and yellow regions of the spectrum, respectively).

The different kinds of inherited color blindness result from partial or complete loss of function of one or more of the different cone systems. When one cone system is compromised, dichromacy results. The most frequent forms of human color blindness result from problems with either the middle or long wavelength sensitive cone systems, and involve difficulties in discriminating reds, yellows, and greens from one another. They are collectively referred to as "red-green color blindness", though the term is an over-simplification and is somewhat misleading. Other forms of color blindness are much more rare. They include problems in discriminating blues from yellows, and the rarest forms of all, complete color blindness or *monochromacy* , where one cannot distinguish any color from grey , as in a black-and-white movie or photograph.

Perception of Visual Depth

There are many visual clues used by our eye/brain system that result in our sense of three dimensions. One very important process is the perception of depth is the brain's interpretation of the different images that are seen be each of our two eyes. Each one views any given scene from a slightly different perspective. When an object is far away, the relative difference between the locations of these two images will be small whereas a close object will have a greater difference between its two locations. This process of stereoscopic vision requires both eyes to be functioning properly.

Other clues of the location for an unknown object come from the extent to which eyes are "crossed" when focused on it, from a comparison between objects of known size, and from an analysis of the order in which objects must be located gained from knowing that closer objects can "get in the way" of seeing more distant ones.

A normal human eye can focus on objects located between the ***near point*** (the closest point that can be focused without straining - usually taken as 25cm) and the ***far point*** (the furthest point that can be focused upon - usually taken as infinity.)

<u>Perception of Color</u>

Every monochromatic frequency in the visible portion of the electromagnetic spectrum is perceived by the eye as a different color of the spectrum (red, orange, yellow, etc...) When two or more frequencies of light enter the eye at the same time the eye perceives the mix as a single color (*additive mixing*).

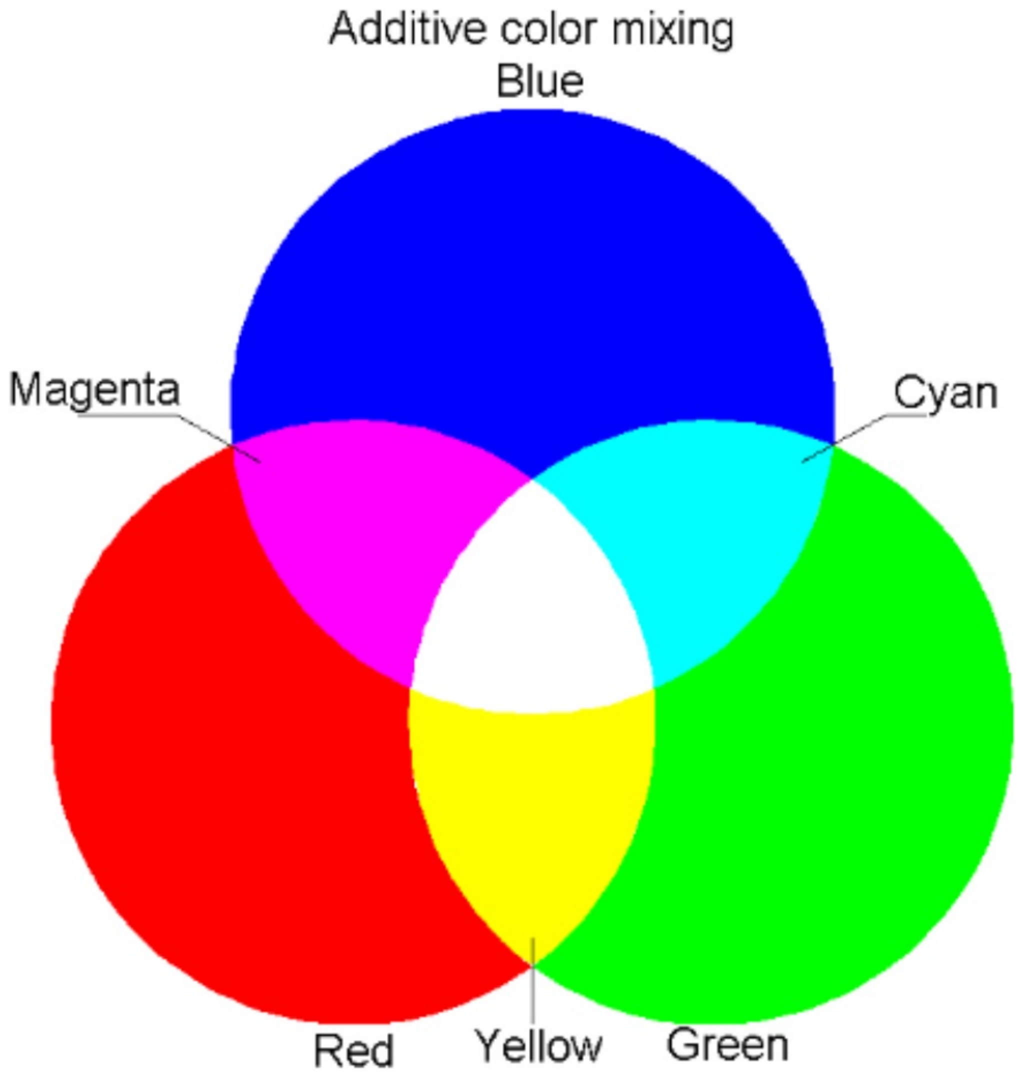
In ***Additive Mixing***, red, green and blue are know as the primary colors. In combination, they produce the secondary colors, magenta (purple) cyan and yellow.

The ***trichromatic*** theory of color vision explains our perception of color by the brain interpreting the different information received from the three different types of cones. The cones that are most responsive to short , medium and long wavelengths of light are sometimes referred to as the blue, green and red sensitive cones, although these colors do not correspond exactly to the wavelengths at which the cones are most sensitive.

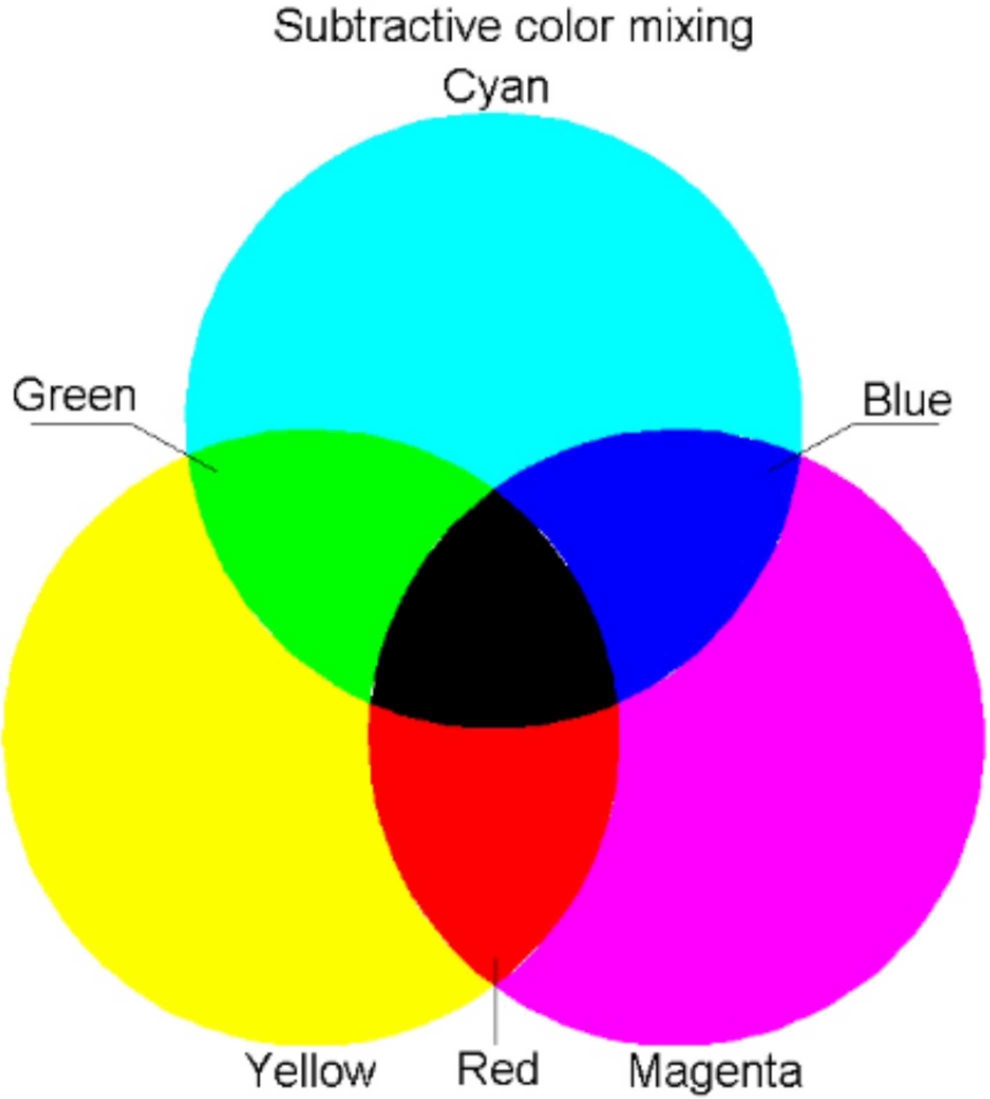
A ***filter*** placed in front of a light source absorbs most frequencies and only lets through a particular combination of frequencies.

A ***colored surface*** absorbs most frequencies and only reflects the color seen. (A blue surface will appear black in red light).

Mixing Colors of Light



Mixing Colors of Paint



Perception of light an shadow

As well as stereoscopic vision, the brain also interprets a wide variety of other visual signals to complete the perception of an object. For example:

- Architectural effects can be created by the use of light an shadow; deep shadow gives the impression of massiveness.
- The brain is very good at fitting blocks of color into an outline picture. When a line picture is 'colored in" using crayons, color that spreads over a line tends to be ignored.
- We perceive the color of an object to remain essentially constant even when the illumination used changes from sunlight to artificial light.
- Color can be used to give an impression of 'warmth' (blue tints are often perceived as cold)
- Color can be used to change the perceived size of a room (light-colored ceilings seem to heighten the room).