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Date: 13.4. 2007

Visual illusions

Contents:

What are we going to write about?

Well, we have chosen this topic right because it seems to be interesting and we have hoped it could be good for an interactive presentation as well.

First of all, we are going to explain to you what the optical illusion means. Then, we will try to say something little about the history and the principe of the vision. After that, we will get over the division of optical illusions – they are five, by the way.

Finally, we will show you some pictures and examples of different kinds of visual illusions including the explanation to each of them.

Now, there is no other way then hoping we will take your attention and you will be as interested in that as we do at least.

Introduction

An optical illusion is always characterized by visually perceived images that, at least in common sense terms, are deceptive or misleading.

Therefore, the information gathered by eye is processed by the brain to give, on the face of it, a percept that does not tally with a physical measurement of the stimulus source.

A conventional assumption is that there are physiological illusins that occur naturally and congnitive illusions that can demonstrate by specific visual hides that say something more basic about how human perceptual system work.

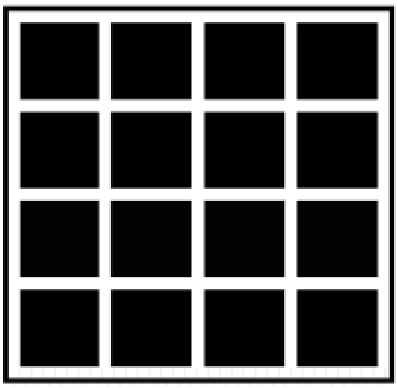
Illusions are fascinating to most people. Some of the illusions have been known since antiquity. The scientific study of illusions dates back to the beginning of the nineteenth century when scientists got interested in perception. Since then there has been enduring interest, and illusions have been used as tools in the study of perception. An important strategy in finding out how perception operates is to observe situations in which misperceptions occur. By carefully altering the stimuli and testing the changes in visual perception psychologists tried to gain insight into the principles of perception.

Theories about illusions have been formulated ever since their discovery.

History of optical illusions

Optical illusions were first used by the Greeks. They built their temples so that the roof was slanted. This gave the illusion that the temple was actually standing straight. They also made the columns bulge so that from a distance they would look perfectly proportioned. In the course of history, people have encountered illusions in many ways. Many of these illusions appear in very common, everyday experiences.

An example of an identification of such an illusion occurred when L. Herman was reading a book on sound by John Tyndall. He saw grey smudge spots in the intersections of spaces among the figures that Tyndall had arranged in a matrix. The same intensity of light is reflected all the way along the white spaces in the grid but the intersections appear gray.



These optical illusions which occur in our everyday lives have become the subject of study by psychologists. This field involves aspects of the arts, architecture, and even physiology and physics. The study of illusion includes both how we perceive what is around us and how we project our own concepts onto what we see.

In the beginning, people didn't know when they were looking at an optical illusion if their brain was playing tricks on them or if their eyes were playing tricks on them. A lot of people thought they could explain why we see optical illusions.

Epicharmus and Protagorus both lived around 450 B.C. Epicharmus believed that our senses (seeing, hearing, smelling, tasting and touching) were not paying enough attention and were messing up. His exact words were, "The mind sees and the mind hears. The rest is blind and deaf." Protagorus went against what Epicharmus said. He thought that our senses and body were just fine. He believed that it was the environment that was messing us up. He said, "Man is nothing but a bundle of sensations."

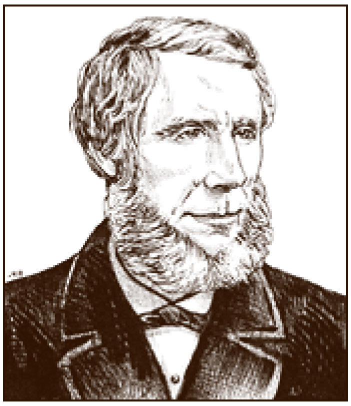
Aristotle, who lived around 350 B.C. said both Epicharmus and Protagorus were both right and wrong. He said our senses can be trusted, but they can be easily fooled. For example, when it's a very hot day and you stand near the road, heat waves rise and we can see them. Our senses are right, we can see the waves. But, if you look through the waves at a tree, the tree appears to be wiggling. That is when our sense get fooled.

Another Greek was Plato. Plato lived around 300 B.C. He said our five sense need our mind to help interpret what they see. In other words, that the eyes and mind need to work together. That is exactly what we think now.

A long time passed until someone got into optical illusions again. In 1826, a psychologist Johannes Mueller wrote two books about visual illusions. But, few people knew what he was talking about because he was the first person to call distortions visual illusions. In 1854, another psychologist J.J. Oppel continued were Mueller left off. He published a paper with ten pages about line illusions. Perhaps the simplest of these is the "vertical-horizontal" or "T-illusion" attributed to J. J. Oppel, in which the vertical line appears longer than the horizontal line, despite the fact that they of equal length . Oppel is also credited with having coined the term "geometrical illusion". Nobody had ever seen the illusions he talked about.

Today we see optical illusions everywhere when we look at a t.v. The pictures are not really moving. It is really many pictures moving so fast that our brain cannot comprehend each individual picture. Also with computers, magazines, and t.v we see millions of colors but it is really just dots colored red, green, and blue. If you look closely enough at a magazine or t.v or computer screen you can see the little dots.

John Tyndall



John Tyndall was a man of science—draftsman, surveyor, physics professor, mathematician, geologist, atmospheric scientist, public lecturer, and mountaineer. Throughout the course of his Irish and later, English life, he was able to express his thoughts in a manner none had seen or heard before. His ability to paint mental pictures for his audience enabled him to disseminate a popular knowledge of physical science that had not previously existed. Tyndall's original research on the radiative properties of gases as well as his work with other top scientists of his era opened up new fields of science and laid the groundwork for future scientific enterprises.

In January 1859, Tyndall began studying the radiative properties of various gases. Part of his experimentation included the construction of the first ratio spectrophotometer, which he used to measure the absorptive powers of gases such as water vapor, "carbonic acid" (now known as carbon dioxide), ozone, and hydrocarbons. Among his most important discoveries were the vast differences in the abilities of "perfectly colorless and invisible gases and vapors" to absorb and transmit radiant heat. He noted that oxygen, nitrogen, and hydrogen are almost transparent to radiant heat while other gases are quite opaque.

Tyndall's experiments also showed that molecules of water vapor, carbon dioxide, and ozone are the best absorbers of heat radiation, and that even in small quantities, these gases absorb much more strongly than the atmosphere itself. He concluded that among the constituents of the atmosphere, water vapor is the strongest absorber of radiant heat

and is therefore the most important gas controlling Earth's surface temperature. He said, without water vapor, the Earth's surface would be "held fast in the iron grip of frost." He later speculated on how fluctuations in water vapor and carbon dioxide could be related to climate change.

Tyndall related his radiation studies to minimum nighttime temperatures and the formation of dew, correctly noting that dew and frost are caused by a loss of heat through radiative processes. He even considered London as a "heat island," meaning he thought that the city was warmer than its surrounding areas.

Over the course of his life, John Tyndall published numerous papers and essays on his scientific discoveries, as well as literature, religion, mountaineering, and travel. His accomplishments led him to receive five honorary doctorates and become a respected member of thirty-five scientific societies.

Johanes Peter Mueller

In 1819 he entered Bonn University, where he became Privatdozent in1824, extraordinary professor of physiology in 1826, and ordinary professor in 1830. In 1833 he went to the Humboldt University of Berlin, where he filled the chair of anatomy and physiology until his death. Müller made contributions in numerous domains of physiology, in particular increasing understanding of the voice, speech and hearing, as well as the chemical and physical properties of lymph, chyle and blood.

The appearance of his Handbuch der Physiologie des Menschen between 1833 and 1840 (translated into English by Dr William Baly, and published in London in 1842) marked the beginning of a new period in the study of physiology. In it, for the first time, the results of human and comparative anatomy, as well as of chemistry and other departments of physical science, were brought to bear on the investigation of physiological problems.

The most important portion of the work was that dealing with nervous action and the mechanism of the senses. Here he stated the principle, not before recognized, that the kind of sensation following stimulation of a sensory nerve does not depend on the mode of stimulation but upon the nature of the sense-organ. Thus light, pressure, or mechanical stimulation acting on the retina and optic nerve invariably produces luminous impressions. This he termed the law of specific energies of the sense. In the later part of his life he chiefly devoted himself to comparative anatomy. Fishes and marine invertebrata were his favorite subjects. Müller mentored such distinguished scientists and physiologists as Hermann von Helmholtz 1821-1894), Emil du Bois-Reymond (1818-1896), Theodor Schwann (1810-1882), Friedrich Gustav Jakob Henle (1809-1885), and Karl Ludwig (1816-1895).

Types of optical illusions

Optical illusions come in many different types such as Ambiguous, impossible, contrast and color, distortion, typography, and after effects.

1. **Ambioguous illusions**

   “ambiguous” illusions are the type that have more than one picture in them. These contain images such as the young woman/old women.

2. **Impossible illusions**

   the “impossible” illusions have no end to them as in the impossible staircase or triangle.

3. **Contrast and color illusions**

   The contrast and color illusions are the types that you can see more than one way such as the Necker cube.

4. **Distortion illusions**

   Distorsion is an illusion that appears as if it is changing size or shape off in the distance.

5. **Typography illusions**

   Typography illusions are the type you look at it one way and it may look like a B but in the other way it could be a 13.

6. **After effects**

   After effects are when you look at one thing then look at something else and the image will change.

Illusions are used in many different ways. Some are half-auditory and half-optical. One is used by a ventriloquist so they can use their voice with the movement of the dummy’s mouth and it tricks our brain into thinking that the dummy is talking. The people of Ancient Greece used optical illusions to build their temples by making the columns bulge so that from a distance they would look the perfectly proportioned.

The Eye and Optical Illusions

The visual sense gives us timely knowledge of our spatial surroundings, near and far, identifying all the objects in it to our consciousness. The world we see is inside us, an illusion, but we all share the same internal perception of a real and physical universe outside us. The sense is so well adapted to its purpose that we normally assume that what we perceive are the actual objects, as if by touching, and it was exceedingly difficult for philosophers to overcome this erroneous belief. The visual world is another illusion, like the movement of the sun and moon across the sky, where it is an effort to realize that it is the earth that is moving, not the heavens. What is apparent is not always true. The visual sense intimately combines memory with external stimulation. In this paper, I have endeavoured to collect as much lore on vision as I can find, and to interpret and express it compendiously. The references lead to more detailed discussions.

In spite of the fact that our eyes are now mainly used for the identification of static objects and for establishing spatial relations, their basic functioning still rests on comparison of stimuli from neighbouring cells, which was fundamental to motion detection. When observing a static scene, the eyes perform small repetitive motions called saccades that move edges past receptors. If an image is stabilized on the retina, it soon darkens and disappears, since a motion detector responds only to motion. The same thing happens if the eye is exposed to a neutral, featureless scene, the Ganzfeld. Faint stars soon disappear when stared at, but return as soon as the image moves on the retina. Blood vessels in front of the retina surely cast shadows upon it, but these shadows are never seen. Any constant stimulus is ignored. The eye bears very little resemblance to a camera, except for its power to focus an image on the retina, and none whatsoever after this. Even a digital camera records point-by-point, which the eye does not do. The eye is not a pixel device, though location is very important.

Eyes are the portals through which electromagnetic radiation from our environment enters the visual system, exciting a flood of information from the distorted, two-dimensional image cast upon the sensitive cells of the retina. Most of vision takes place in the brain, and this begins in the retina, where the signals from neighbouring receivers are compared and a coded message dispatched on the optic nerves to the occipital cortex, behind the ears, where the information is formatted and made available to the processing activities of the brain. The eye is essentially a motion detector, its original purpose when eyes began to evolve from light-sensitive pits in the pre-Cambrian. The compound eye of the flying insect is an extremely sensitive motion detector, and well-suited to its purpose, since only moving things were of any interest. Even here, additional advantage was gained from the ability to receive light, the colours of a flower and the polarization of sunlight proving useful in certain cases. Arthropods, cephalopods, and chordates independently evolved eyes that made images, as the ability to identify objects and understand spatial relations proved valuable. The variety of these evolutionary inventions shows the great advantage of having a visual spatial sense. The most extraordinary eyes are those of the copepod Copilia, which physically scans an image projected by a lens with its light-sensitive organ, or the pinhole pupil of Nautilus.

The coded signals sent to the brain down the optic nerves are used to recognize objects, and recognition is necessary, indeed fundamental, for sight. This depends on past experience and learning, so sight is not an instinctive sense. The potential of the system, and its general characteristics are innate, of course, but the complete sense must be developed by experience. This is very easy in the young individual, and is done by comparing the information from other senses, mainly touch and smell, with the corresponding visual perceptions. Even in adults, the sense is not unalterable. An experimenter who wore glasses that inverted his retinal images so they were right-side up instead of the usual upside-down, gradually found that things started to look normal after a while. It is important to realize that vision is principally a function of processing in the brain, and that images and pixels play a very small role. Many objects are recognized from borders, at which changes occur, and the rest is inferred. The orientation of lines, and the directions of movement, are the major sources of information, and are specially coded. Visual sense is a property of consciousness, and is deeply involved in the functioning of the brain.

Structure and Functioning of the Human Eye

The retina is the light-sensitive part of the eye. There are two systems of receptors in the retina, the rods and the cones. In fact, the retina is actually a dual organ, a rod network and a cone network. Birds and reptiles have only cones, and some nocturnal animals only rods. The rods are sensitive to weak light, inoperative in strong light, and have maximum sensitivity at about 507 nm. The cones are sensitive to strong light, insensitive to weak light, and have a maximum sensitivity at 555 nm. Rod vision is called scotopic (dark-seeing) and cone vision is called photopic (light-seeing). Rods are located in all parts of the retina, and are very sensitive to motion, but give no colour discrimination. Cones are located most densely in a small area called the fovea, a shallow pit 1.5 mm in diameter, to the temporal side of the optic nerve. Their density decreases as one recedes from the fovea. The fovea has no blood vessels. All acute and colour vision is due to the cones. The fovea is surrounded by a pigmented area called the macula lutea, the yellow spot, 2-3 mm in diameter, containing the yellow dye xanthophyll, which absorbs light of wavelengths shorter than 500 nm. This spot cannot be seen in an ophthalmoscope against the living red choroid behind it in normal circumstances. Nerves from the rest of the retina go around it, as do larger blood vessels. It is richly equipped with ganglion cells, which indicates it is a site of signal processing. It plays an important but not clearly understood role in vision.

Light is electromagnetic radiation to which eyes respond. In light of a single wavelength, or spectrally pure light, the extreme range is from 380 nm to 740 nm. The sensitivity of the eye falls off at the ends of this range, so that 400 nm to 700 nm is a good approximation. Infrared radiation cannot enter the eye, and only warms its surface. Long-wave ultraviolet radiation causes fluorescence in the eye (especially in the visual purple), and the fluorescent radiation can be seen. Short-wave ultraviolet again cannot penetrate, but irritates the conjunctiva. Ultraviolet is damaging to the eye, causing irreversible changes. The dark-adapted eye is also sensitive to X-rays, which are not refracted by the eye and pass freely through it. This appears to be a direct sensitivity, since there is little fluorescence, and the stimulus can be moved around on the retina. Gamma rays can also be perceived, but this is again due to fluorescence, so a diffuse glow results. Do not try this at home!

The size of the pupil changes with different levels of brightness, expanding in dim light, and contracting in bright light, or when an object is held close. This change, over a range from 4 mm to about 8 mm, changes the retinal illumination of an extended object only by a factor of 16, far smaller than the actual dynamic brightness range of the eye of perhaps a factor of one million. A more plausible reason for the change in pupil size is to restrict the entering rays to the centre of the aperture when the illumination is sufficient, reducing aberrations and increasing the depth of field, while allowing the full aperture to be used in dim light. The rim of the lens, where the muscles are attached, is particulary irregular, and may exhibit diffraction at its radial fibres, so it is used only when necessary. Light entering near the edge of the pupil is less effective per unit area in producing retinal illumination than light passing through the centre of the pupil, a fact which could simply follow from optical principles, although there appears to be some controversy. This is known as the Stiles-Crawford effect. The slit pupil of the cat can be

closed more completely in bright light than can a round pupil. The spacing of the rods in the fovea is roughly equal to the size of the diffraction pattern produced by the aperture of the pupil when contracted for vision in bright light. Given either the diameter of the pupil or the spacing of the rods, the eye is proportioned so that it could not be more acute, taking diffraction into consideration.

To the nasal side of the fovea is the blind spot, or papilla, where the optic nerve enters the eye, and where there can, therefore, be no receptors. This area is simply ignored by the eye and filled in with the neighbouring field, so that it does not disturb vision. The blind spots in the two eyes do not overlap, of course. It can occasionally be seen as a dark spot when the eye is first opened. At a distance of 7 ft, the blind spot is about 8 inches across, so it is not negligible, and may cause something not to be seen. To demonstrate it, draw two small spots on a card about 60 mm apart. Close the left eye, and fixate the left-hand spot with the right eye. When the card is at the proper distance from the eye, the right-hand spot will disappear. The retinal blood supply enters through the centre of the optic nerve.

The eye is almost a sphere, of 12 mm radius, consisting of three layers. The sclera is the tough white outer hide of the eye, merging into the cornea at the boundary called the limbus. The choroid is a dark absorbing layer, richly supplied with blood vessels. Cats have a reflecting layer of unpigmented fibrous tissue, the tapetum on the choroid. The sensitive cells of the retina are transparent cylinders of higher index of refraction than their surroundings, so they guide the light by total internal reflection. A tapetum causes light to pass through them twice, increasing the sensitivity of the eye to weak light. It also causes the pupil to become luminous, returning light in the direction it arrived, a well-known feature of cat's eyes. The choroid is continuous with the iris, which forms the pupil of the eye, and has radial and circumferential muscles to control its size. The ciliary body contains muscles to control the lens, to which it is connected by fibres called the zonule. The innermost layer comprises the retina and the lens. The ora serrata is the edge of the retina. The insertions of the six extrinsic muscles that move the eye are not shown in the diagram. The very sensitive conjunctiva lines the inner side of the eyelid, and covers the exposed front of the eye, including the cornea.

The visual system is tolerant of errors in the retinal image, correcting them where possible. The eye has considerable spherical and chromatic aberration, so the image produced on the retina is very poor. The mental image is much sharper, refined by the visual system. The acute vision at the fovea is used to correct the mental image, when the focus is proper. Poor focus, however, makes edges indistinct, and since the system depends on edges, the result is discomfort and lack of sharpness in perception. The most common reason for poor focus is incorrect curvature of the cornea, where the majority of the focussing power of the eye resides (because of the large change in index of refraction at this surface). If the cornea is too steeply curved, which is quite common, distant objects are focussed short of the retina, and myopia is the result. Hypermetropia is the opposite case. An eye with neither is called emmetropic. Lack of sphericity of the cornea causes astigmatism, in which no stigmatic (point) focus exists. These errors of refraction may have other causes, as discussed in Helmholtz (Ref. 1). Young found that his marked astigmatism was not due to corneal curvature, for example. The lens becomes rigid with age, so that the ciliary muscles can no longer give it the curvature

required to focus on close objects, a property called accommodation, and presbyopia is the result. All such errors of refraction can be corrected by external lenses, and an approximate correction is usually quite satisfactory. Because of chromatic aberration (the indexes of refraction vary with wavelength) blue and red are normally less well-focused than greenish-yellow. Visual perception contains little hint of this chromatic aberration, another proof that perception is subjective.

The pupil of another person's eye appears black to the observer. We have noticed that cat's eyes, and those of dogs and horses, reflect light that enters them back in the same direction because of the tapetum. In flash snapshots, the pupil often shows a fuzzy redness, caused by light entering the eye through the choroid and its blood vessels, then being scattered out the pupil. It is practically impossible to observe the back of the eye, as for medical purposes, by looking in the pupil, for three reasons. First, illumination of the retina is difficult, since it must enter via the pupil, and the light is not regularly scattered, but preferentially normal to the retina. Second, the eye is a refracting instrument, and the image of the retina produced by light going the reverse direction may not be in a suitable place for observation, and moves around as the subject's eye accommodates. Thirdly, the field of view limited by the iris is very restricted when the observer's eye is far enough away to see the retina clearly. These difficulties are overcome by the ophthalmoscope, invented by Helmholtz. The retina is illuminated by a light to the side, reflected into the pupil by a mirror with a small hole through it for viewing. The observer's eye can be brought close to the pupil by using a lens to place the image at a suitable distance for viewing. There are many possible arrangements, which have resulted in the design of small, portable instruments. A minimum ophthalmoscope can be assembled from a penlight held beside the observer's eye to illuminate the subject's pupil, and a converging lens for observation. The retina is still not easy to observe, since it is a thin transparent layer seen against the dark red choroid. It is possible to examine one's own retina by using a mirror (plane or convex) with a tiny hole in the centre. Hold the hole before the pupil and look at a source of light that is not too bright. The field of view is small, but may be moved about by moving the eye.

Properly focussed eyes can resolve two sources separated by about 6' of arc in everyday life. Exceptionally good observers can resolve down to about 4' or 3', but this is not common, and depends on the object viewed. The absolute limit of acuity, under laboratory conditions with fine gratings, seems to be between 1' and 2'. The Snellen chart for assessing visual acuity uses small characters (often E's or other hook-shaped patterns in various orientations) that subtend 5' at specified distances, and the width of whose lines are 1/5 the size of the pattern. The chart contains lines of patterns that subtend 5' at, say, 10 ft, 20 ft, 30 ft and 40 ft. If the chart is placed 20 ft from an observer, and the line subtending 5' at 20' can be resolved, the visual acuity is called 20/20. If the line subtending 5' at 40' can be resolved, the visual acuity is now 20/40, and so on.

The eye as an optical mechanism is reducible to a single lens and therefore the image focused upon the retina is inverted. However, there is no way for the observer to be conscious of this and therefore the inverted image causes no difficulty in seeing. The

images of objects in the right half of the field of view are focused upon the left half of the retina. Similarly, the left half of the field of view corresponds to the right half of the retina; the upper half of the former to the lower half of the latter; and so on. When a ray of light from an object strikes the retina the impression is referred back along the ray-line into the original place in space. This is interestingly demonstrated in a simple manner. Punch a pin-hole in a card and hold it about four inches from the eye and at the same time hold a pin-head as close to the cornea as possible. The background for the pin-hole should be the sky or other bright surface. After a brief trial an inverted image of the pin-head is seen in the hole. Punch several holes in the card and in each will be seen an inverted image of the pin-head.

The explanation of the foregoing is not difficult. The pin-head is so close to the eye that the image cannot be focused upon the retina; however, it is in a very favorable position to cast a shadow upon the retina, the light-source being the pin-hole with a bright background. Light streaming through the pin-hole into the eye casts an erect shadow of the pin-head upon the retina, and this erect image is projected into space and inverted in the process by the effect of the lens. The latter is not operative during the casting of the shadow because the pin-head is too close to the lens, as already stated. It is further proved to be outward projection of the retinal image (the shadow) because by multiplying the number of pin-holes (the light-sources) there are also a corresponding number of shadows.

The foregoing not only illustrates the inversion of the image but again emphasizes the fact that we do not see retinal images. Even the "stars" which we see on pressing the eye-lid or on receiving a blow on the eye are projected into space. The "motes" which we see in the visual field while gazing at the sky are defects in the eye-media, and these images are projected into space. We do not see anything in the eye. The retinal image impresses the retina in some definite manner and the impression is carried to the brain by the optic nerve. The intellect then refers or projects this impression outward into space as an external image. The latter would be a facsimile of the physical object if there were no optical illusions but the fact that there are optical illusions indicates that errors are introduced somewhere along the path from and to the object.

It is interesting to speculate whether the first visual impression of a new-born babe is "projected out-ward" or is perceived as in the eye. It is equally futile to conjecture in this manner because there is no indication that the time will come when the baby can answer us immediately upon experiencing its first visual impression. The period of infancy increases with progress up the scale of animal life and this lengthening is doubtless responsible and perhaps necessary for the development of highly specialized sense-organs. Incidentally, suppose a blind person to be absolutely uneducated by transferred experience and that he suddenly became a normal adult and able to see. What would he say about his first visual impression? Apparently such a subject is unobtainable. The nearest that such a case had been approached is the case of a person born blind, whose sight has been restored. This person has acquired much experience with the external world through other senses. It has been recorded that such a person, after sight was restored, appeared to think that external objects "touched" the eyes. Only through visual experience is this error in judgment rectified.

Man studies his kind too much apart from other animals and perhaps either underestimates or overestimates the amount of inherited, innate, instinctive qualities. A

new-born chick in a few minutes will walk straight to an object and seize it. Apparently this implies perception of distance and direction and a coordination of muscles for walking and moving the eyes. It appears reasonable to conclude that a certain amount of the wealth of capacities possessed by the individual is partly inherited, and in man the acquired predominates. But all capacities are acquired, for even the inherited was acquired in ancestral experience. Even instinct (whatever that may be) must involve inherited experience. These glimpses of the depths to which one must dig if he is to unearth the complete explanations of visual perception - and consequently of optical illusions - indicate the futility of treating the theories in the available space without encroaching unduly upon the aims of this volume.

Certain defects of the optical system of the eye must contribute toward causing optical illusions. Any perfect lens of homogeneous material has at least two defects, known as spherical and chromatic aberration. The former manifests itself by the bending of straight lines and is usually demonstrated by forming an image of an object such as a wire mesh or checker-board; the outer lines of the image are found to be very much bent. This defect in the eye-lens is somewhat counteracted by a variable optical density, increasing from the outer to the central portion. This results in an increase in refractive-index as the center of the lens is approached and tends to diminish its spherical aberration. The eye commonly possesses abnormalities such as astigmatism and eccentricity of the optical elements. All these contribute toward the creation of optical illusions.

White light consists of rays of light of various colors and these are separated by means of a prism because the refractive-index of the prism differs for lights of different color or wave-length. This causes the blue rays, for example, to be bent more than the red rays when traversing a prism. It is in this manner that the spectrum of light may be obtained. A lens may be considered to be a prism of revolution and it thus becomes evident that the blue rays will be brought to a focus at a lesser distance than the red rays; that is, the former are bent more from their original path than the latter. This defect of lenses is known as chromatic aberration and is quite obvious in the eye. It may be demonstrated by any simple lens, for the image of the sun, for example, will appear to have a colored fringe. A purple filter which transmits only the violet and red rays is useful for this demonstration. By looking at a lamp-filament or candle-flame some distance away the object will appear to have a violet halo, but the color of the fringe will vary with accommodation. On looking through a pin-hole at the edge of an object silhouetted against the bright sky the edge will appear red if the light from the pin-hole enters the pupil near its periphery. This optical defect of the eye makes objects appear more sharply defined when viewed in monochromatic light. In fact, this is quite obvious when using yellow glasses. The defect is also demonstrated by viewing a line-spectrum focused on a ground glass. The blue and red lines cannot be seen distinctly at the same distance. The blue lines can be focused at a much less distance than the red lines. Chromatic aberration can account for such an optical illusion as the familiar "advancing" and "retiring" colors and doubtless it plays a part in many optical illusions.

The structure of the retina plays a very important part in vision and accounts for various optical illusions and many interesting visual phenomena. The optic nerve spreads out to form the retina which constitutes the inner portion of the spherical shell of the eye with the exception of the front part.

Referring again to, the outer coating of the shell is called the sclerotic. This consists of dense fibrous tissue known as the "white of the eye." Inside this coating is a layer of black pigment cells termed the choroid. Next is the bacillary layer which lines about five-sixths of the interior surface of the eye. This is formed by closely packed "rods" and "cones," which play a dominant role in the visual process. A light-sensitive liquid (visual purple) and cellular and fibrous layers complete the retinal structure.

The place where the optic nerve enters the eyeball and begins to spread out is blind. Objects whose images fall on this spot are invisible. This blind-spot is not particularly of interest here, but it may be of interest to note its effect. This is easily done by closing one eye and looking directly at one of two small black circles about two inches apart on white paper at a distance of about a foot from the eye. By moving the objects about until the image of the circle not directly looked at falls upon the blind-spot, this circle will disappear. A three-foot circle at a distance of 36 feet will completely disappear if its image falls directly upon the blind-spot. At a distance of 42 inches the invisible area is about 12 inches from the point of sight and about 3 to 4 inches in diameter. At 300 feet the area is about 8 feet in diameter. The actual size of the retinal blind-spot is about 0.05 inch in diameter or nearly 5 degrees. Binocular vision overcomes any annoyance due to the blind-spots because they do not overlap in the visual field. A one-eyed person is really totally blind for this portion of the retina or of the visual field.

The bacillary layer consists of so-called rods and cones. Only the rods function under very low intensities of illumination of the order of moonlight. The cones are sensitive to color and function only at intensities greater than what may be termed twilight intensities. These elements are very small but the fact that they appear to be connecting links between the retinal image and visual perception, acuity or discrimination of fine detail is limited inasmuch as the elements are of finite dimensions. The smallest image which will produce a visual impression is the size of the end of a cone. The smallest distance between two points which is visible at five inches is about 0.001 inch. Two cones must be stimulated in such a case. Fine lines may appear crooked because of the irregular disposition of these elemental light-sensitive points. This apparent crookedness of lines is an illusion which is directly due to the limitations of retinal elements of finite size.

The distribution of rods and cones over the retina is very important. In the fovea centralis - the point of the retina on the optical axis of the eye - is a slight depression much thinner than the remainder of the retina and this is inhabited chiefly by cones. It is this spot which provides visual acuteness. It is easily demonstrated that fine detail cannot be seen well defined outside this central portion of the visual field. When we desire to see an object distinctly we habitually turn the head so that the image of the object falls upon the fovea of each eye. Helmholtz has compared the foveal and lateral images with a finished drawing and a rough sketch respectively.

The fovea also contains a yellow pigmentation which makes this area of the retina selective as to color-vision. On viewing certain colors a difference in color of this central portion of the field is often very evident. In the outlying regions of the retina, rods predominate and in the intermediate zone both rods and cones are found. Inasmuch as rods are not sensitive to color and cones do not function at low intensities of illumination it is obvious that visual impressions should vary, depending upon the area of the retina

stimulated. In fact, many interesting optical illusions are accounted for in this manner, some of which are discussed later.

It is well known that a faint star is seen best by averted vision. It may be quite invisible when the eye is directed toward it, that is, when its image falls upon the rod-free fovea. However, by averting the line of sight slightly, the image is caused to fall on a retinal area containing rods (sensitive to feeble light) and the star may be readily recognized. The fovea is the point of distinct focus. It is necessary for fixed thoughtful attention. It exists in the retina of man and of higher monkeys but it quickly disappears as we pass down the scale of animal life. It may be necessary for the safety of the lower animals that they see equally well over a large field; however, it appears advantageous that man give fixed and undivided attention to the object looked at. Man does not need to trust solely to his senses to protect himself from dangers. He uses his intellect to invent and to construct artificial defenses. Without the highly specialized fovea we might see equally well over the whole retina but could not look attentively at anything, and therefore could not observe thoughtfully.

When an image of a bright object exists upon the retina for a time there results a partial exhaustion or fatigue of the retinal processes with a result that an after-image is seen. This after-image may be bright for a time owing to the fact that it takes time for the retinal process to die out. Then there comes a reaction which is apparent when the eye is directed toward illuminated surfaces. The part of the retina which has been fatigued does not respond as fully as the fresher areas, with the result that the fatigued area contributes a darker area in the visual field. This is known as an after-image and there are many interesting variations.

The after-image usually undergoes a series of changes in color as well as in brightness as the retinal process readjusts itself. An after-image of a colored object may often appear of a color complementary to the color of the object. This is generally accounted for by fatigue of the retinal process. There are many conflicting theories of color-vision but they are not as conflicting in respect to the aspect of fatigue as in some other aspects. If the eye is directed toward a green surface for a time and then turned toward a white surface, the fatigue to green light diminishes the extent of response to the green rays in the light reflected by the white surface. The result is the perception of a certain area of the white surface (corresponding to the portion of the field fatigued by green light) as of a color equal to white minus some green - the result of which is pink or purple. This is easily understood by referring to the principles of color-mixture. When green, red and blue (or violet) are mixed in their proper proportions they will produce any tint or color, even white. Thus these may be considered to be the components of white light. Hence if the retina through fatigue is unable to respond fully to the green component, the result may be expressed mathematically as red plus blue plus reduced green, or synthetically a purplish white or pink. When fatigued to red light the after-image on a white surface is blue-green. When fatigued to blue light it is yellowish.

Further mixtures may be obtained by directing the after-image upon colored surfaces. In this manner many of the interesting visual phenomena and optical illusions associated with the viewing of colors are accounted for. The influence of a colored environment upon a colored object is really very great. This is known as simultaneous contrast. The influence of the immediately previous history of the retina upon the perception of colored surfaces is also very striking. This is called successive contrast. It is interesting

to note that an after-image produced by looking at a bright light-source, for example, is projected into space even with the eyes closed. It is instructive to study after-images and this may be done at any moment. On gazing at the sun for an instant and then looking away, an after-image is seen which passes in color from green, blue, purple, etc., and finally fades. For a time it is brighter than the background which may conveniently be the sky. On closing the eyes and placing the hands over them the background now is dark and the appearance of the after-image changes markedly. There are many kinds, effects, and variations of after-images, some of which are discussed in other chapters.

As the intensity of illumination of a landscape, for example, decreases toward twilight, the retina diminishes in sensibility to the rays of longer wave-lengths such as yellow, orange, and red. Therefore, it becomes relatively more sensitive to the rays of shorter wave-length such as green, blue, and violet. The effects of this Purkinje phenomenon (named after the discoverer) may be added to the class of optical illusions treated in this book. It is interesting to note in this connection that moonlight is represented on some paintings and especially on the stage as greenish blue in color, notwithstanding that physical measurements show it to be approximately the color of sunlight. In fact, it is sunlight reflected by dead, frigid, and practically colorless matter.

Some optical illusions may be directly traced to the structure of the eye under unusual lighting conditions. For example, in a dark room hold a lamp obliquely outward but near one eye (the other being closed and shielded) and forward sufficiently for the retina to be strongly illuminated. Move the lamp gently while gazing at a plain dark surface such as the wall. Finally the visual field appears dark, due to the intense illumination of the retina and there will appear, apparently projected upon the wall, an image resembling a branching leafless tree. These are really shadows of the blood vessels in the retina. The experiment is more successful if an image of a bright light-source is focused on the sclerotic near the cornea. If this image of the light-source is moved, the tree-like image seen in the visual field will also move.

The rate of growth and decay of various color-sensations varies considerably. By taking advantage of this fact many optical illusions can be produced. In fact, the careful observer will encounter many optical illusions which may be readily accounted for in this manner.

It may be said that in general the eyes are never at rest. Involuntary eye-movements are taking place all the time, at least during consciousness. Some have given this restlessness a major part in the process of vision but aside from the correctness of theories involving eye-movements, it is a fact that they are responsible for certain optical illusions. On a star-lit night if one lies down and looks up at a star the latter will be seen to appear to be swimming about more or less jerkily. On viewing a rapidly revolving wheel of an automobile as it proceeds down the street, occasionally it will be seen to cease revolving momentarily. These apparently are accounted for by involuntary eye-movements which take place regardless of the effort made to fixate vision.

If the eyelids are almost closed, streamers appear to radiate in various directions from a light-source. Movements of the eyelids when nearly closed sometimes cause objects to appear to move. These may be accounted for perhaps by the distortion of the moist film which covers the cornea. The foregoing are only a few of the many visual phenomena

due largely to the structure of the eye. The effects of these and many others enter into optical illusions, as will be seen here and there throughout the chapters which follow

Examples of Visual illusions

Are these ink blobs or something more?
Click on the picture for more information

Can you see gray spots in between the black squares?
You see gray spots because your eyes see the black squares but can't make the adjustment to seeing the white lines quick enough. The result is gray, a mixture of black and white.

Which square is the front of the cube

Do you see the tower on the right side or is the tower on the left side, upside down?
The left tower is pretty easy to see but for those who can not see the right tower here's how.
Treat the bottom square on the right as you would on the left.

Do you see stairs going up or see stairs upside down.
You can probably see the stairs going up but the stairs going down are harder to see. To see the stairs upside down look at the wall behind the stairs and you should seethe stairs upside down. Click the picture if you still can't see the stairs upside down

Do you see a vase or two people kissing?
To see the vase focus on the black part.
To see the people kissing focus on the white part.
Can you see them?

If you move your head back and forth the circle seems to turn.

Ambiguous illusions

Is this a man playing a saxaphone or a ladies face?
If you can't see the ladies face treat the man's chin as one eye and the blotch floating in the air as the other eye. Treat the end of the saxaphone as her chin and the mans body as the shadow at the side of her face. For those of you who can't see the man paying the sax here's how. Treat the woman's chin as the end of the of sax and the woman's left eye as the man's chin. The shaded part of the woman's face is the man's body. Do you see both of them?

Impossible illusions

Here are a few.

How many legs does this elephant have? Where are they?

Conclusion: