

We may produce white light by combining the seven primary colors in another way. Divide the surface of a circular card into seven parts proportioned to each other as the spaces which the different colors occupy in the spectrum, and paint them the corresponding shades. Then cause the card to revolve rapidly. No separate color will be visible, but the whole card will look white.

667. A prism decomposes white light into its seven component parts, because these parts are refracted differently, some more and some less. It will be observed that red, which occupies the lowest part of the spectrum, is turned from its course the least; orange, a little more; yellow, still more; then green; then blue; then indigo; while violet, which is at the top of the spectrum, is refracted the most. The colors, therefore, have different degrees of refrangibility. This fact was discovered by Sir Isaac Newton.

668. DIFFERENCE OF COLOR, EXPLAINED.—According to the Undulatory Theory, the color of light depends on the size of the minute waves that produce it. The undulations that excite in the eye the sensation of red light are each $\frac{1}{400000}$ of an inch in breadth; those that produce violet, $\frac{1}{600000}$; while the intermediate colors are produced by undulations varying between these limits.

669. Color is not a property inherent in bodies, but in the light that they reflect. A non-luminous body seems to be whatever color it reflects to the eye.

An object lying in green light, looks green; in red light, red, &c. This is because green or red is the only light that falls upon it, and therefore it can reflect no other to the eye. A body seen by ordinary light looks green, when it absorbs all or most of the other colors of the spectrum, and reflects or transmits green alone. It looks red when it absorbs the other colors, and reflects or transmits red, &c. It looks white, when it does not decompose the light that falls on it, but reflects all the colors combined. It looks black, when it absorbs nearly all the light that falls on it, and does not reflect any particular color in preference to the rest.

670. What colors a substance absorbs and what it reflects, depends chiefly on its structure. The particles of some bodies are so arranged as to have a peculiar affinity for certain colors; these they absorb, reflecting the rest.

of this? How may we re-unite the seven primary colors? What other mode is there of doing this? 667. To what is it owing that a prism decomposes white light into its seven component parts? By whom was this fact discovered? 668. According to the Undulatory Theory, on what does the color of light depend? What is the difference in the undulations that respectively produce red and violet light? 669. In what is the property of color inherent? Why does an object lying in green light look green? When does an object seen by ordinary light look green? When does it look white? When, black? 670. What is it that determines what colors a

Changes of color are caused by changes of structure. We may show this by an experiment with a substance called iodide of mercury. This mineral is a bright scarlet; when heated and allowed to cool undisturbed, it becomes yellow; but, the moment the surface is scratched, the particles rearrange themselves, and the color turns back to scarlet. Here the same particles undergo a marked change of color by simply being made to assume a different arrangement.

671. COMPLEMENTARY COLORS.—Any two colors are said to be Complementary, when, if combined in due proportion, they will produce white. Those colors are complementary to each other which are distant half the length of the spectrum; as,

Red and green,	Orange and blue,
Yellow and violet,	White and black.

It is a curious fact that if we look intently at a bright object of any given color and then close our eyes, we shall still see it, but tinged with the complementary color. After gazing a few moments at a bright fire, everything we look at seems to have a greenish hue. If we place a red wafer on a piece of white paper and look at it intently, we shall soon see a circle of light green playing around it. A blue wafer will have a similar circle of orange, and a yellow wafer one of a violet tinge.

672. A color appears to the best advantage, when placed beside its complementary color.

Thus red is set off by green; blue, by orange, &c. A pale face appears paler still when a black dress is worn. On white paper, black ink is plainer and pleasanter to the eye than ink of any other color. In arranging bouquets, and selecting different articles of dress that are to be worn together, the effect of each individual color is heightened by bringing it in immediate contrast with its complementary color.

673. PROPERTIES OF THE SPECTRUM.—Every ray of ordinary sun-light appears to have three distinct properties:—1. Brightness. 2. Heat. 3. Power of producing chemical effects. This last property is called Actinism.

674. The chemical effects of sun-light are shown in various ways. Phosphorus and nitrate of silver undergo a marked change when exposed to the

substance absorbs, and what it reflects? By what are changes of color caused? Prove this with an experiment. 671. When are two colors said to be Complementary? Name four pairs of complementary colors. What curious fact is stated with respect to complementary colors? Give examples. 672. When does a color appear to the best advantage? Give examples. 673. How many distinct properties has every ray of ordinary sun-light? Name them. 674. Instance some of the chemical

solar rays. Daguerreotypes and photographs are taken by means of the action of light on sensitive chemical preparations. Almost all the colored vegetable juices, when exposed to sun-light, undergo a change of hue. Hydrogen and chlorine, which may be mixed without danger in the dark, combine with a loud explosion in the light. Light, also, is essential to the chemical changes which result in the healthy growth of plants. Hence plants kept in a dark room become pale and sickly. A similar effect is produced on persons kept away from the light of the sun.

675. Ordinary sun-light combines these three properties, but the seven colors into which it is decomposed by the prism do not possess them alike. Brightness belongs particularly to yellow; heat, to red; actinism, to violet and indigo.

An object that is bright yellow makes a more vivid impression on the eye than one of any other color. Hence soldiers dressed in yellow are more distinct objects of aim to an enemy and more apt to be shot than those dressed in dark green or gray.

The red portion of the spectrum has the most heat. This is shown by placing the bulb of a thermometer successively in each of the colors of the spectrum. It will be most affected by the red, but will show a still higher temperature, if brought a short distance below the red end of the spectrum, where no light falls at all. This shows that the heat of a solar ray is refracted as well as its light, but in a less degree.

Actinism is strongest in violet and indigo rays. If a seed be placed under a dark blue glass, so that all the light that strikes it will be tinged with that color, it will germinate in one-fourth of the time that it usually takes. Placed under a red glass, it will hardly germinate at all, because red, although it contains more heat than the other colors, has little or no actinism.

676. DARK LINES IN THE SPECTRUM.—If the solar spectrum be viewed through a telescope, a great number of dark lines, parallel to each other but differing in breadth, will be seen crossing its surface. Seven of these are particularly distinct, but with a powerful telescope as many as 2,000 have been counted.

The position of these lines is always the same in the solar spectrum; but, when a ray of star-light is decomposed, their number and arrangement

effects of sun-light. 675. Do the seven primary colors possess these three properties in equal degrees? To which does brightness particularly belong? To which, heat? To which, actinism? What follows from the peculiar brightness of yellow? How is it proved that the red portion of the spectrum has the most heat? How does the refraction of solar heat compare with that of solar light? Prove this. How may it be shown that actinism is strongest in violet and indigo rays? 676. Describe the dark lines in the spectrum. What is said of the lines found in spectra produced from star-

are different, nor do they correspond in spectra formed by rays from different stars. When rays produced by electricity or combustion are decomposed with the prism, bright lines are found crossing the spectrum instead of dark ones.

677. DISPERSION OF LIGHT.—By the Dispersion of light is meant the formation of a spectrum from a single ray. Spectra formed by different refractive media are of different lengths. Thus flint-glass forms a spectrum about twice as long as crown-glass forms, and four times as long as water. Flint-glass is therefore said to have twice the dispersive power of crown-glass, and four times that of water.

678. ACHROMATIC LENSES.—Lenses, like prisms, refract light, and produce spectra. Rays passing through a convex lens, therefore, instead of coming to a focus at a single point, are more or less dispersed, and form colored fringes about the focus. This defect is called Chromatic Aberration. It was long a serious drawback in the use of optical instruments; but the difficulty is now remedied by combining two lenses of such different materials that the dispersive power of the one may nullify that of the other. Lenses combined on this principle are called Achromatic Lenses.

Achromatic means colorless, and the lenses are so called because they do not fringe their images with the colors of the spectrum. A double convex lens of crown glass may be united with a plano-concave lens of flint glass. The latter corrects the chromatic aberration of the former, without entirely nullifying its converging effect.

679. THE RAINBOW.—The Rainbow is an arch composed of the seven primary colors, which is visible in the sky when the sun shines during a shower. It appears in the opposite quarter to the sun,—in the west in the morning, and the east in the afternoon.

When the sun is in the horizon, the rainbow is a circle; but the lower part of it is intercepted by the earth's surface, and therefore we do not gen-

light? In spectra produced from the light of electricity or combustion? 677. What is meant by the Dispersion of light? When are different media said to differ in dispersive power? 678. What is Chromatic Aberration? How is it corrected? What does *achromatic* mean? Why are achromatic lenses so called? How may an achromatic lens be formed? 679. What is the Rainbow? Where is it seen? What is the

erally see more than a semi-circle. From the mast-head of a vessel or the top of a mountain, more than a semi-circle is visible.

680. The rainbow is caused by the refraction and reflection of the sun's rays by drops of falling rain. Each drop operates like a prism, decomposing the light that strikes it. The observer's eye is so placed as to receive but one of the colors from one drop, but from other drops it receives the other colors, and thus has an arched spectrum formed complete. As no two persons occupy exactly the same spot, no two can see exactly the same bow.

681. Sometimes two distinct bows are visible, one within the other. The inner one, which is called the Primary Bow, is the brighter of the two. The outer one is called the Secondary Bow; the rays that form it undergo one more reflection within the drop than those that form the primary bow, and are therefore fainter. In the primary bow, the arrangement of the colors is the same as in the solar spectrum; in the secondary bow, this order is reversed.

682. Whenever the air is filled with drops, and the sun shines on them at a certain angle, rainbows are formed, which are visible to an observer in a proper position. Hence they are often seen in the spray of water-falls and fountains.

683. Bows are sometimes similarly formed by moon-light, but they are faint and rarely seen. When so formed, they are called Lunar Rainbows.

684. HALOES.—Haloes are luminous or colored circles seen around the sun and moon under certain conditions of the atmosphere. They are more frequently seen around the moon, because the sun's light is so intense that they are lost in its superior brightness. Haloes arise from the refraction and dispersion of light by small crystals of ice floating in the higher regions of the atmosphere.

Vision.

685. THE EYE.—The eye is the organ with which we see. Nothing more strikingly displays the wisdom of the

form of the rainbow? 680. Explain the principle on which the rainbow is formed. 681. When two bows are formed, what is each called, and which is the brighter? In what order are the colors arranged in the rainbow? 682. By what besides rain may bows be produced? 683. What are Lunar Rainbows? What is said of them? 684. What are Haloes? Where are they most frequently seen? How are haloes pro-

Creator than the nice adaptation of this wonderful instrument to the purposes for which it is designed.

686. *Parts of the Eye.*—The human eye is a spheroid, about an inch in diameter, resting in a cavity below the forehead, capable of being moved upward, downward, or sidewise, by muscles attached to it behind. It consists of ten parts:—

- | | |
|--------------------------|------------------------|
| 1. The Cornea. | 6. The Vitreous Humor. |
| 2. The Iris. | 7. The Ret'i-na. |
| 3. The Pupil. | 8. The Choroid Coat. |
| 4. The Aqueous Humor. | 9. The Sclerotic Coat. |
| 5. The Crystalline Lens. | 10. The Optic Nerve. |

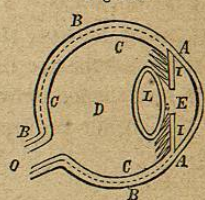
687. When we look at an eye as set in the head (see Figure 253), we see but three of these parts: the Cornea (*g*); the Iris (*i*); and the Pupil (*b*).

Fig. 253.



The Cornea is a transparent coat, covering the whole front of the eye, and more convex than the rest of the ball. The Iris is the circular membrane in the middle of the cornea, according to the color of which we say that the eye is blue or black, hazel or gray. The Pupil is a circular opening in the iris, through which light passes into the interior of the eye. Fig. 254 represents a section of the eye. AAA is the cornea. II is the iris, and the opening in the centre is the pupil. In the following description reference is made to this Figure.

Fig. 254.



On passing through the cornea, a ray of light enters the narrow apartment E, between the cornea on one side and the iris and crystalline lens on the other. This is filled with a transparent liquid resembling water, and called the Aqueous Humor. Traversing this, the ray next enters a transparent body, L, called from its shape the Crystalline Lens. Behind this is the Vitreous Humor, D, a trans-

duced? 685. What is the eye? 686. Describe the eye. Of how many parts does it consist? Name them. 687. Which of these parts do we see when we look at an eye as set in the head? What is the Cornea? What is the Iris? What is the Pupil? With the aid of Fig. 254, name and describe the various parts of the eye. By what is

parent fluid which fills the greater part of the globe of the eye. This humor is enclosed within the Retina, C C C, a delicate fibrous membrane resembling net-work, formed by the expansion of the optic nerve, on which every image seen by the eye is formed. The Optic Nerve, O, passes through the back of the eye to the brain, and conveys to that organ the impressions made on the retina.

The retina is surrounded by another coat called the Choroid, represented in the Figure by a dotted line. The choroid coat is lined on its inner surface with black coloring matter, to prevent any reflection of light from the interior of the eye. Outside of all is the Sclerotic Coat, B B B, a strong membrane, to which the muscles that move the eye are attached. It envelopes the whole ball except the portion in front covered by the cornea, which fits into it just as the crystal of a watch fits into the case.

688. *Uses of the Different Parts.*—The outer coats of the eye protect the delicate parts within. The cornea reflects some of the light that falls on it, and this gives the eye its brilliancy. It transmits the greater part, however, and unites with the aqueous humor, the crystalline lens, and the vitreous humor, in bringing the incident rays to a focus and forming an image on the retina.

The iris intuitively regulates the supply of light admitted into the eye, contracting and thus enlarging the pupil in a faint light, expanding and thus diminishing it in a strong one. These changes are not instantly made. Hence, when we pass from a bright light into a room partially darkened, we can hardly discern anything till the pupil enlarges, so that more rays are admitted. When we go from a dark room into a bright light, the eye is pained, because the pupil, which had expanded to the utmost to accommodate itself to the faint light, does not immediately contract, and more light is admitted than the sensitive membrane can endure.

The pupils of cats, tigers, and animals generally that prowl at night for prey, are capable of being expanded to such a degree as to admit one hundred times as much light as when they are most contracted. They can therefore see as well by night as by day. The owl's pupil is exceedingly large;

the retina surrounded? With what is the choroid coat lined? What is outside of all? What are attached to the sclerotic coat? 688. What is the use of the outer coats of the eye? Of the cornea? Which parts unite with the cornea in bringing incident rays to a focus? What is the use of the iris? Give some familiar proofs that the iris accommodates itself to the intensity of the light. What is said of the pupil

in the day-time, even when contracted to the utmost, it admits so much light that the bird is nearly blinded, and has to remain stupidly on its roost.

689. *DEFECTS OF VISION.*—In a perfect eye, the rays that enter are brought to a focus on the retina, and an image is there formed. If the rays are not brought to a focus by the time they reach the retina, or come to a focus before reaching it, no impression is made on the optic nerve or communicated to the brain, and consequently no image is seen.

Hence arise two defects of vision. When the cornea is too convex, distant objects form images in front of the retina, and are not seen; only such objects as are very near the eye are visible, and hence persons with this defect of vision are called *near-sighted*. When, on the contrary, the cornea is not convex enough, the rays are not brought to a focus by the time they reach the retina, and no image is seen. The eyes of old people generally labor under this defect, in consequence of the waste of a portion of the vitreous and the aqueous humor, so that the crystalline lens and the cornea fall in. This falling in is just what the near-sighted person needs; accordingly it is often found that those who are near-sighted in youth see perfectly well when they grow old.

690. The two defects of vision mentioned above are remedied by the use of spectacles, which consist of lenses of different shapes placed in frames before the eyes. A near-sighted person uses glasses just concave enough to nullify the too great convexity of his eye. An old person uses glasses with sufficient convexity to make up the deficiency of his eye in that respect.

691. Spectacles were first used about the end of the thirteenth century. It is supposed that the world is indebted to Roger Bacon for their invention. Before that time all near-sighted and most aged persons had to remain in a state of comparative blindness.

692. Though all other parts of the eye be perfect, if the optic nerve does not perform its functions, blindness is the result. Images are formed on the retina, but there is no communication with the brain, and no impression

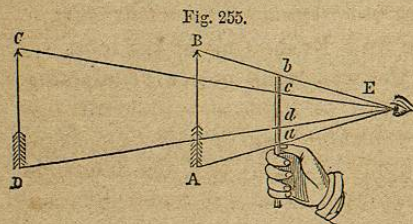
of beasts that prowl at night? What is said of the owl's pupil? 689. Where are images formed in a perfect eye? What will prevent an image from being seen? Describe the two defects of vision arising from images' not being formed on the retina. 690. How are these two defects of vision remedied? What sort of glasses does a near-sighted person use? An old person? 691. When were spectacles first used? By whom are they supposed to have been invented? 692. If the optic nerve does not

is produced. For amaurosis, or paralysis of the optic nerve, there is no remedy.

693. IMAGES FORMED ON THE RETINA.—Images are formed on the retina, just as in a dark room, by light admitted through an aperture (see Fig. 235). In the latter case, as we have already seen, the image is inverted, and it follows that images formed on the retina must be inverted also. Why then do we see them in their natural position? This question it is hard to answer. The explanation commonly given is this:—That we see all things inverted, and have always done so; but, inasmuch as we know by experience that they are erect, the mind of itself, insensibly to us, corrects the delusion that the inversion would otherwise produce. We have no means of comparison; we see nothing erect, to serve as a standard and prove the general inversion.

694. Another question is sometimes asked:—Since we have two eyes, and two images are formed, one on each retina, why do we not see two images of every object? The answer is, because both eyes are inclined to any given object at nearly the same angle. The images produced on the retinas are very nearly the same. The impressions transmitted to the brain by the two branches of the optic nerve are identical and simultaneous, and but one perception is the result. If we press on one of our eyes, so as to incline it towards an object at a different angle from the other, we see two images. Drunken men often see double, because they lose control of the muscles of the eye, and do not direct both eyes towards a given object at the same angle.

695. VISUAL ANGLE.—The visual angle is the angle formed by two lines drawn from the eye to the extremities of a given object.



In Fig. 255, the visual angle of the arrow BA is BEA; that of the arrow CD is CED.

A given object

perform its functions, what is the consequence? 693. What kind of an image is formed on the retina, and why? Since an inverted image is formed on the retina, why do we see objects in an erect position? 694. Since we have two eyes, why do we not see two images of every object? How may we make two images visible? Why do drunken men often see double? 695. What is the Visual Angle? Show the

looks large or small, according to the visual angle that it forms. Two equal arrows held up before the eye at different distances, as in Fig. 255, form different visual angles, and therefore seem to be of different size. If we measure their apparent lengths with an interposed rod, we shall find the nearer one to measure the distance ab , the farther one only about half as much, cd . A small object placed near the eye may form as great a visual angle as a very large distant object, and may therefore entirely hide the latter when interposed between it and the eye.

Accordingly, the nearer an object is brought to the eye, the larger it appears to be, and the farther it is removed the smaller it looks. When the visual angle is less than $\frac{1}{300}$ of a degree, an object becomes invisible. A bird flying from us grows smaller and smaller, till its visual angle diminishes so that it can no longer be seen, and we say that *it has gone out of sight*.

696. In the case of familiar objects, experience prevents us from being misled by their apparent size. Insensibly to ourselves, we make allowance for their distance, of which we judge by the distinctness of their outline and by intervening objects. A man at work on a lofty steeple may not look more than two feet high, yet we are in no danger of mistaking him for a dwarf. A distant tree seems to be no higher than a bush; but, if we see a horse feeding beneath it, we intuitively compare the two, and arrive at a correct idea of the tree's size.

A white object can be distinguished at a greater distance than one of any other color, and is visible twice as far when the sun shines directly on it as when simply illumined by ordinary light. An object is brought out most distinctly by a back-ground which contrasts strikingly with it in color. Dark-colored eyes, for the most part, see farther than light ones; and those who are in the habit of looking at remote objects, like sailors, can discern minute bodies at distances which render them invisible to ordinary sight.

697. ADAPTATION OF THE EYE.—One of the most remarkable properties of the eye is its power of adapting itself to different intensities of light and different distances. The pupil, by expanding and contracting, regulates in a measure the supply of light; still, the difference of intensity in the light admitted to the eye under different

visual angles of the arrows in Fig. 255. On what does the apparent size of an object depend? Illustrate this with the Figure. When does an object become invisible? When is a bird said to go *out of sight*? 696. In the case of familiar objects, what prevents us from being misled as to their size? Give some familiar examples. What color must an object be, to be distinguished at the greatest distance? How is an object most distinctly brought out? What is said of dark-colored eyes? 697. What is