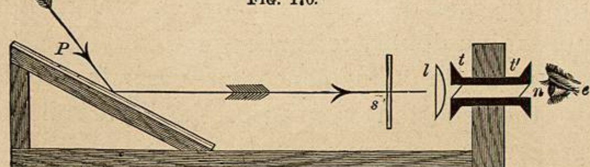
transmit the extraordinary ray and quench the ordinary ray. It is called a Nicol's prism. Whatever is used for examining the light after it has been polarized is called an analyzer. The Nicol's prism makes the best analyzer also. An instrument that includes both polarizer and analyzer is called a polariscope. A glass plate fixed at the proper angle makes an excellent polarizer, and a small Nicol's prism, or piece of tourmaline, for analyzer is enough for many beautiful experiments. Exquisite displays of complementary colors, due to interference of polarized beams in transmission, may be seen by examining thin pieces of crystallized gypsum, mica, horn, strained glass, etc., between polarizer and analyzer.* Polarized light affords a delicate means of examining the molecular structure of a body.

* A simple polariscope is shown in Fig. 170. Upon a wooden frame a plate of glass, *P*, blackened on the under side, is fixed so that light falling on it at the polarizing angle shall be reflected through the tube *tt'*. This contains a small Nicol's prism, *n*, for analyzer, and a lens, *l*, through which an object, *s*, may be examined with polarized light. The student who

Fig. 170.



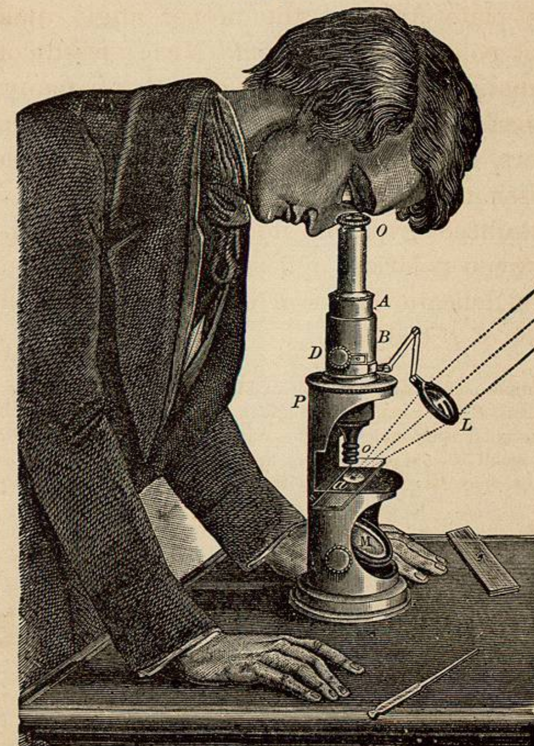
Polariscope.

makes one will find it a source of fascination and continued delight. He will find useful information very clearly expressed in the "Scientific American Supplement" for Nov. 20, 1886, p. 9072; also, a full and admirable explanation of these beautiful experiments in "Light," by Lewis Wright, published by Macmillan & Co., London.

V. OPTICAL INSTRUMENTS.

1. Microscopes (*to see small things*) are of two kinds, *simple* and *compound*. The former consists of one or more convex lenses through which the object

Fig. 171.

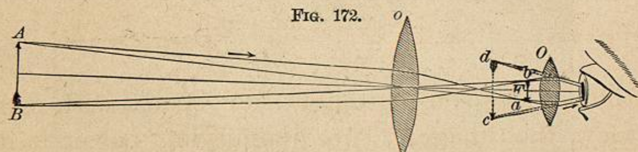


The Microscope.

is seen directly; the latter contains a simple magnifier for viewing the image of an object produced by a second lens. Fig. 171 represents a compound microscope. At M is a mirror which reflects the rays of light through the object a. The object-lens (objective), o, forms, in the tube above, a magnified, inverted image of the object. The eye-lens, O (ocular), magnifies this image. The magnifying power of the instrument is nearly equal to the product of that of the two lenses. If a microscope increases the apparent diameter of an object 100 times, it is said to have a power of 100 diameters, the surface being magnified $100^2 = 10{,}000$ times. The eye-piece may be only a single lens, and is really a simple microscope. The object-lens often consists of several lenses, and each one of a combination of convex crown glass and concave flint glass (p. 219) to prevent aberration.

2. Telescopes (*to see afar off*) are of two kinds, *reflecting* and *refracting*. The former contains a large metallic mirror (speculum) which reflects the rays of light to a focus. The observer stands at the side and examines the image with an eye-piece.*

Fig. 172.



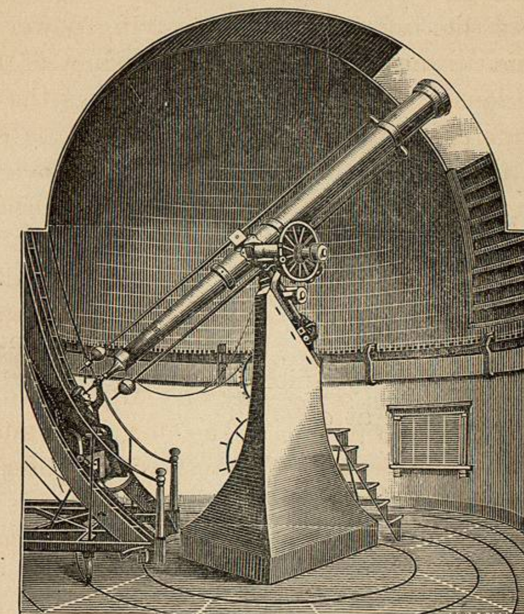
Formation of Image in the Telescope.

The Refracting Telescope contains an object-lens, o, which forms an inverted image, ab. This is viewed through the eye-piece, O, which produces a magnified

* The largest reflecting telescope is that of Lord Rosse (see Frontispiece to "Astronomy"). Its speculum is 6 ft. in diameter and gathers about 120,000 times as much light as would ordinarily enter the eye.

image, cd, of the first image, ab. The image cd is as much larger than ab as the focal distance of the object-glass exceeds that of the eye-glass. The larger

Fig. 173.



Cambridge Equatorial.

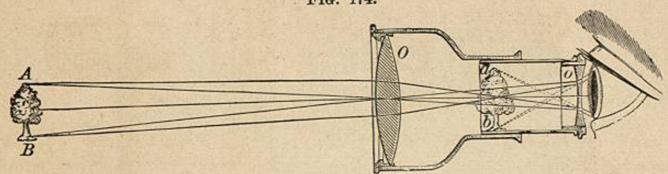
the object-lens the more light is collected with which to view the image. The magnifying power is due to the eye-piece.* The apparent inversion of the ob-

* The use of the telescope depends upon (1st) its light-collecting and (2d) its magnifying power. Thus Herschel, illustrating the former point, says that once he told the time of night from a clock on a steeple invisible on account of the darkness. It is noticeable that while in the compound microscope the image is as much larger than the object as the image is farther than the object from the object-glass, in the telescope the image is as much smaller than the object as it is nearer than the object to the object-glass; while in both cases the image is examined with a magnifier. If

ject is of no importance for astronomical purposes. In terrestrial observations additional lenses are used to invert the image.

3. The Opera-glass contains an object-glass, *O*, and an eye-piece, *o*. The latter is a double-concave lens; this increases the visual angle by diverging

Fig. 174.



Formation of Image in Opera-glass.

the rays of light, which would otherwise come to a focus beyond the eye-piece. An erect and magnified image is seen at *ab*.

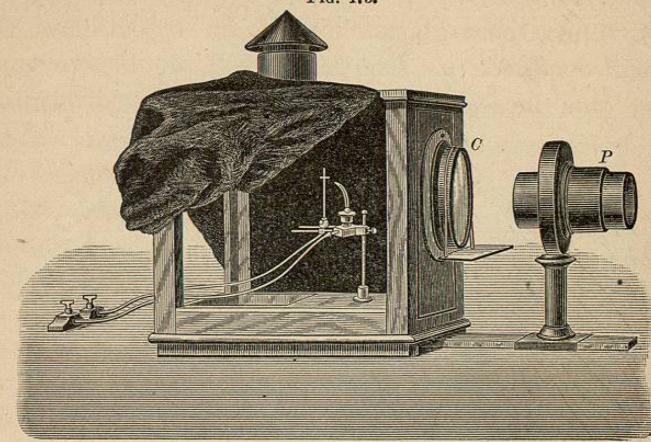
4. The Projecting Lantern consists of a system of lenses attached to a dark box, within which is a powerful source of illumination such as the electric light or lime light. Sometimes an oil-lamp is used. From the white-hot source the light is converged by the condensing lens, *C*, Fig. 175, so as to send through the projecting lens, *P*, as much of it as possible. A picture on glass is placed in front of the

a power of 1,000 be used in looking at the sun, we shall evidently see the sun as if it were only 93,000 miles away, or less than one half the distance of the moon. The same power used upon the moon would bring that body apparently to within 240 miles of us.

The National Observatory telescope at Washington has an object-glass 26 inches in diameter, and of excellent defining power. The Lick telescope, erected in 1887 upon Mt. Hamilton, in California, has an object-glass just one yard in diameter. Its light-collecting power is estimated to be about 30,000 times that of the unaided eye.

condenser, and is thus strongly illuminated. An image of it, greatly enlarged, is formed by the pro-

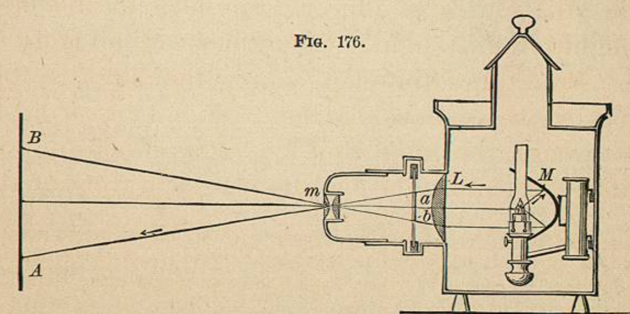
Fig. 175.



Projecting Lantern for the Lime Light.

jecting lens and focalized on a distant white screen in a dark room. *Dissolving views* are produced by

Fig. 176.

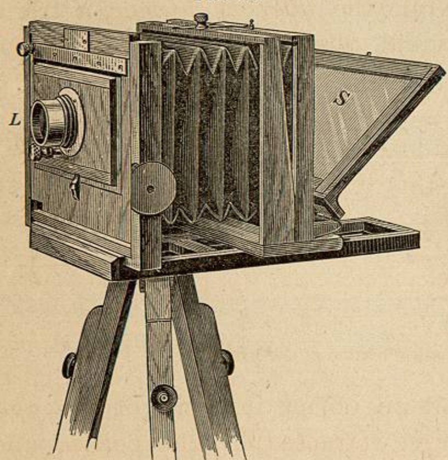


Projecting Lantern for the Oil Light.

using two lanterns together. While one view is on the screen, another is projected upon it. The light is then cut off from the first lantern so as to leave only the second view. Fig. 176 is an outline of one form of oil-lantern. The reflector, *M*, helps to illuminate the transparent picture, *ab*, in front of the condenser.

5. The Camera, used by photographers, contains a double-convex lens, *L*, which throws an inverted image of the object upon a removable ground-glass screen, *S*. When the focus has been obtained, the screen is removed and a slide, containing a sensitive film, is inserted in its place. ("Chemistry," p. 171.)

Fig. 177.

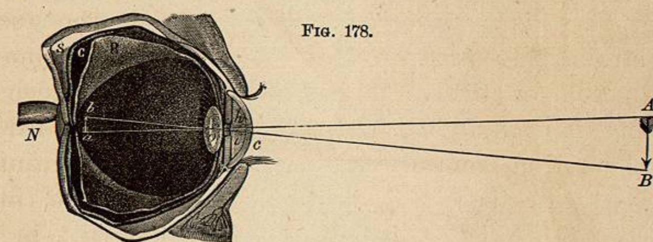


Photographer's Camera.

6. The Eye is a unique optical instrument resembling a camera. The outer membrane is termed the *sclerotic* coat, *S* (Fig. 178). It is tough, white, opaque, and firm. A little portion in front, called the *cornea*, *c*, is more convex and perfectly transparent. The middle or *choroid* coat, *C*, is soft and delicate, like velvet. It lines the inner part of the eye and is covered with a black pigment. Over it the optic nerve, which enters at the rear, expands

in a net-work of delicate fibers termed the *retina*, the seat of vision. Back of the cornea is a colored curtain, *hi*, the *iris* (rainbow), in which is a round hole called the *pupil*. The *crystalline lens*, *o*, is a double-convex lens, composed of concentric layers somewhat like an onion, weighing about four grains and transparent as glass. Between the cornea and the crystalline lens is a limpid fluid termed the *aqueous humor;* while the *vitreous humor*, a transparent, jelly-like liquid, fills the space back of the crystalline lens.

Fig. 178.



Vertical Section of the Eye.

Let *AB* represent an object in front of the eye. Rays of light are first refracted by the cornea and aqueous humor, next by the crystalline lens, and last by the vitreous humor, forming on the retina an image, *ab*,* which is real, inverted, and smaller than the object. To render vision distinct, the rays must

* The diameter of the eye is less than an inch; yet, as we look over an extended landscape, every feature, with all its variety of shade and color, is repeated in miniature on the retina. Millions upon millions of ether waves, converging from every direction, break on that tiny beach, while we, oblivious to the marvelous nature of the act, think only of the beauty of the revelation. Yet in it the physicist sees a new illustration of the simplicity and perfection of the laws and methods of the Divine Workman, and a continued reminder of His forethought and skill.

be accurately focused on the retina. If we gaze steadily at an object near by, and at the same time regard a distant object in the same direction, we find our vision of this blurred. If now we gaze at the more distant object, our vision of the nearer one becomes blurred. The eye thus has the power of adapting itself to the varying distances of objects. This is done by a change in the convexity of the front surface of the crystalline lens under the action of the ciliary muscle which surrounds it at its edges. When clear vision can not be had of distant objects, the person is *near-sighted*. When the ciliary muscle is strained to produce clear vision of objects less than ten or twelve inches distant, the person, if young, is *over-sighted*. In the first case, the distance of the retina from the crystalline lens is too great to permit of distinct focalization; in the second case, this distance is too small. The remedy for near-sightedness is to wear concave glasses, selected by a competent oculist. Rays from distant objects are thus made to diverge before entering the eye, as if they had come from very near objects. For over-sightedness, the remedy is properly selected convex glasses.* As old age approaches, the crystalline lens

* There are other defects for which the aid of the oculist should be sought. If glasses are needed, they should never be selected except after examination by a thoroughly competent person. If not properly adapted, they may do much more harm than good. No eye is optically perfect, and but few are free from defects that may be detected on examination. That glasses are more used now than during the previous generations is due not so much to increase of habits injurious to vision as to the better knowledge of the eye and the better opportunities for every person to find out his own defects.

becomes less elastic so that the eye loses the power of accommodation to near objects. Convex glasses become necessary for reading, while the vision of distant objects may remain perfect.

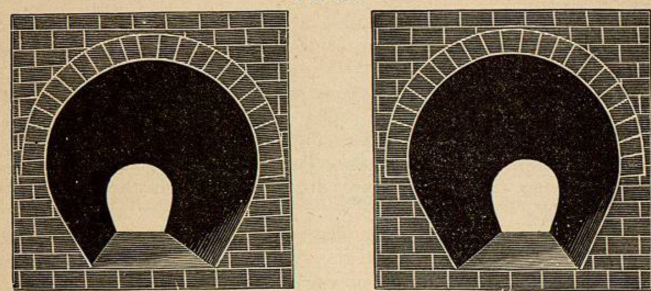
The retina retains an impression for a brief time after the object has been removed, usually a fraction of a second, which varies according to the brightness.* This explains why a lighted coal, rapidly moved in the dark, appears as a line of light. Many of the most brilliant effects from fire-works depend on this property of the retina. The *Zoetrope* is an instrument by which a succession of pictures of the same object in different phases of motion are made to pass rapidly before the eye. The persistence of the successive sensations causes an apparent blending, so that the illusion is that of an object actually in motion.

7. Binocular Vision.—In looking with both eyes at an object that is not very distant, we obtain a much better idea of its position and form, or its "depth in space," than when a single eye is employed. The two retinal images differ slightly because the two eyes are different in direction from the object, and hence to a slight extent we see around the object on two sides. The illusion of depth in space is well brought out by means of Fig. 179. The tunnel, *A*, appears as if viewed by the left eye alone; *B*, as if

* When one is riding slowly on the cars and looking at the landscape between the upright fence-boards, he catches only glimpses of the view; but *when moving rapidly, these snatches will combine to form a perfect landscape*, which has, however, a grayish tint, owing to the decreased amount of light reflected to the eye.

by the right eye alone. Bring the page close up to the face, so that one picture is immediately in front of each eye. The two images at once seem combined into a single blurred image. Now withdraw the page a few inches;* the haziness gives place to distinct-

Fig. 179.



A B

A Stereograph which may be Viewed without a Stereoscope.

ness and the tunnel appears startlingly deep, as if it were a hole through the book. While still gazing into its depths two more tunnels may be indirectly seen, one on each side of it; but the illusion of depth in them is far less clear. Each is seen by but a single eye, while the middle one is a binocular perception.

The *Stereoscope* is an instrument intended to aid in attaining binocular vision of a pair of properly prepared pictures, which together compose the stereograph. With a little practice like that just described, any one may become independent of the stereoscope.

* In performing this experiment, it is very important to avoid crossing the eyes. Perfect relaxation of the muscles of the eyeballs will make it very easy. Imagine yourself to be looking *through* the page at the opening of a *distant* tunnel, and keep the muscles relaxed.

For further discussion of the Stereoscope, consult an article on this subject in the "Popular Science Monthly" for May and June, 1882.

PRACTICAL QUESTIONS.

1. Why is the secondary bow fainter than the primary? Why are the colors reversed?
2. Why can we not see around the corner of a house, or through a bent tube?
3. What color would a painter use if he wished to represent an opening into a dark cellar?
4. Is white a color? Is black?
5. By holding an object nearer a light, will it increase or diminish the size of the shadow?
6. What must be the size of a glass in order to reflect a full-length image of a person? *Ans.* Half the person's height.
7. Where should we look for a rainbow in the morning?
8. Can two spectators see the same bow?
9. Why, when the drops of water are falling through the air, does the rainbow appear stationary?
10. Why can a cat see in the night better than a human being?
11. Why can not an owl see distinctly in daylight?
12. Why are we blinded when we pass quickly from a dark into a lighted room?
13. If the light of the sun upon a distant planet is $\frac{1}{100}$ of that which we receive, how does its distance from the sun compare with ours?
14. If, when I sit six feet from a candle, I receive a certain amount of light, how much shall I diminish it if I move back six feet farther?
15. Why do drops of rain, in falling, appear like liquid threads?
16. Why does a towel turn darker when wet?
17. Does color exist in the object, or in the mind of the observer?
18. Why is lather opaque, while air and a solution of soap are each transparent?
19. Why does it whiten molasses candy to "pull it"?
20. Why does plastering become lighter in color as it dries?
21. Why does the photographer use a lamp with a chimney of red glass in the "dark room"?
22. Is the common division of colors into "cold" and "warm" verified in philosophy?
23. Why is the image on the camera, Fig. 177, inverted?
24. Why is the second image seen in a mirror, Fig. 140, brighter than the first?
25. Why does a blow on the head make one "see stars"? *Ans.* The blow excites the optic nerve, and so produces the sensation of light.
26. What is the principle of the kaleidoscope? (If you can not discover this, consult Deschanel's "Natural Philosophy," pp. 886-891.)
27. Which can be seen at the greater distance—gray or yellow?
28. When a star is near the horizon, does it seem higher or lower than its true place?

29. Why can we not see a rainbow at midday?

30. What conclusion do we draw from the fact that moonlight shows the same dark lines as sunlight?

31. Why does the bottom of a boat seen under clear water appear flatter than it really is?

32. Of what shape does a round body appear in water?

33. Why is rough glass translucent while smooth glass is transparent?

34. Why can a carpenter, by looking along the edge of a board, tell whether it is straight?

35. Why can we not see out of the window after we have lighted the lamp in the evening?

36. Why does a ground-glass globe soften the light?

37. Why can we not see through ground-glass or painted windows?

38. Why does the moon's surface appear flat?

39. Why can we see farther with a telescope than with the naked eye?

40. Why is not snow transparent, like ice?

41. Are there rays in the sunbeam which we can not perceive with the eye?

42. Why, when we press the finger on one eyeball, do we see objects double?

43. Why does a distant light, in the night, seem like a star?

44. Why does a bright light, in the night, seem so much nearer than it is?

45. What color predominates in artificial lights? *Ans.* Yellow.

46. Why are we not sensible of darkness when we wink?

47. Under what condition do the eyes of a portrait seem to follow a spectator to all parts of a room?

48. Why do the two parallel tracks of a railroad appear to approach in the distance?

49. Why does a fog apparently magnify objects?

50. If you sit where you can not see another person's image, why can not that person see yours?

51. Why can we see the multiple images in a mirror better if we look into it very obliquely?

52. Why is an image seen in water inverted?

53. Why is the sun's light fainter at sunset than at midday?

54. Why can we not see the fence-posts when we are riding rapidly?

55. Ought a red flower to be placed in a bouquet close to an orange one? A pink or blue with a violet one?

56. Why are the clouds white while the clear sky is blue?

57. Why does skim-milk look blue and new milk white?

58. Why is not the image of the sun in water at midday so bright as near sunset?

59. Why is the rainbow always opposite the sun?

60. Hold a card with its edge close in front of your eye and look at a distant candle flame in a dark room. You will probably perceive either a reddish or a bluish fringe on one side. Explain.

SUMMARY.

Light comes from the sun and other self-luminous bodies. It is transmitted by means of vibrations in ether, in accordance with the laws of wave-motion. It is radiated equally in all directions, travels in straight lines, decreases as the square of the distance increases, and is propagated 186,000 miles per second. Light falling upon a body may be absorbed, transmitted, or reflected. If the surface be rough, the irregularly-reflected light enables us to see the body; if it be smooth and highly polished, the rays are reflected so as to form an image of the original object. Surfaces producing such images are termed mirrors—plane, concave, or convex. The image is seen in the direction from which the reflected ray enters the eye, and, in a plane mirror, as far behind the mirror as the object is in front. Multiple images are produced by repeated reflections, as in the kaleidoscope. A concave mirror, as generally used, collects the rays, and serves to produce either a magnified erect virtual image or a magnified or diminished inverted real image of an object. A convex mirror scatters the rays, and diminishes the apparent size of an object.

When a ray enters or leaves a transparent body obliquely, it is refracted; if passing into a rarer medium, it is bent away from the perpendicular erected at the point of incidence; if into a denser medium, it is bent toward this perpendicular. A lens is a transparent body with one or more curved surfaces, which are usually spherical, so as to refract the light either to a focus, or as if it had come from a focus. There are two classes—convex and concave. The former lens, as generally used, tends, like a concave mirror, to collect the rays of light; the latter, like a convex mirror, causes the rays of light to diverge. Mirage is an optical delusion caused by refraction of light in passing through air composed of strata of unequal density. Owing to the varying refrangibility of the different waves of the sunbeam, a prism can disperse them into a colored band called the solar spectrum. The spectrum shows white light to consist of many tints, and that the solar energy may produce luminous, heating, or chemical effects according to the nature of the body receiving it. By means of the spectroscope we can examine the spectrum of a flame, and find whether its light is due to the burning of a gas alone, or to the glowing of denser particles diffused in it. Each substance in the gaseous state gives a spectrum with its peculiar lines of color. A gas absorbs the same rays that it is capable of emitting; if, therefore, a burning gas or vapor is interposed between the eye and a glowing solid, the spectrum of the solid is interrupted by dark lines due to absorption by the vapor. A delicate mode of analysis is thus furnished, whereby the elements even of the distant stars can be detected. The rainbow is formed by the refraction and reflection of the sunbeam in rain-drops. Light, when reflected by or transmitted through bodies, is so modified, chiefly by absorption, as to produce the varied phenomena of color. Each color has its own wave-length, which is less than $\frac{1}{35000}$ inch. Different systems of light-waves, as of sound-waves, may be combined. But if any two coincide with similar phases they will strengthen each other; and if with opposite phases, weaken each other. Interference of light, as thus produced, causes the play of colors in the soap-bubble, mother-of-pearl, etc. Polarized light is that in which the molecular vibrations are made in the same plane. Many of the most beautiful color effects may be produced by polarization.

The principal optical instruments, including the eye, are adapted to produce and examine the image formed by a lens. In the projecting lantern and solar microscope, the image is thrown on a screen in a dark room. In the refracting telescope and the microscope, the image is formed in a tube by a lens at one end and looked at from behind by a lens at the other end. In the eye, which is a small camera-obscura, the image is formed on the retina, whence the sensation is carried by the optic nerve to the brain. The retinal sensation continues for a short time after the impression is made. Advantage is taken of this fact in the use of the zoetrope, by which a succession of images is made to appear in motion. Vision with two eyes is superior to that with a single eye, because we are thus enabled to form better ideas of depth in space, and hence of the distance and form of a body. The stereoscope is an instrument for studying the peculiarities of binocular vision.

HISTORICAL SKETCH.

THE ancients knew that light is propagated in straight lines. They discovered the laws of reflection, and one of the ancient fables is that Archimedes set fire to the Roman ships off Syracuse by means of concave mirrors. Euclid and Plato, however, thought that the ray of light proceeds from the eye to the object, an error that was long uncorrected. One thousand years did not bring much advancement in this department of knowledge. The Arabian philosopher, Alhazen, who lived in the eleventh century, discovered the apparent displacement of a body seen in water. The law of intensity of light was established by Kepler, and the first researches on the comparison of intensity from different sources were made by Maurolycus, Huygens, and Francis Marie. About 1608, the telescope was invented by the Dutch.* Jansen, Metius, and Lippersheim each claimed the honor, and the legend is that the discovery grew out of some children at play, accidentally arranging two watch-glasses so as apparently to magnify an object. In fact, however, the action of the convex lens was already known, the compound microscope had been invented by Jansen twenty years previously, and the simple microscope was known to the ancient Chaldeans. In 1621, Snell discovered the law of refraction. By its aid Descartes explained the rainbow. Half a century of waiting, and Newton published his investigations in the decomposition of light. He, however, believed in what is known as the "corpuscular theory." This holds that light consists of minute particles of matter radiated in straight lines from a luminous object, the ray being endued with alternate "fits" of easy reflection and easy transmission. In 1676, Roemer, by observing Jupiter's moons (p. 192), found out the velocity of light, which up to that time had been considered instantaneous. In 1665, Gri-

* "In 1609, the government of Venice made a considerable present to Signor Galileo, of Florence, Professor of Mathematics at Padua, and increased his annual stipend by 100 crowns, because, with diligent study, he found out a rule and measure by which it is possible to see places 30 miles distant as if they were near, and, on the other hand, near objects to appear much larger than they are before our eyes."—*From an old paper in the Library of Heidelberg University.*

maldi discovered the existence of fringes of light and shade when a beam is received through a narrow slit. Huygens soon afterward advanced the undulatory theory, which was originated independently about the same time by Hooke. This involved them in vigorous disputes with Newton, without the definite establishment of their theory. In 1802, Thomas Young revived the undulatory theory, accounting by it for all the phenomena of interference then known. In 1817, Fresnel extended the researches of Young, and Newton's corpuscular theory began to fall into discredit. The elementary phenomena of polarization were discovered by Malus in 1808, and this subject was afterward studied with great thoroughness by Fresnel, Arago, Biot, and Brewster.

VIII.

ON HEAT.

"THE combustion of a single pound of coal, supposing it to take place in a minute, is equivalent to the work of three hundred horses; and the force set free in the burning of 300 lbs. of coal is equivalent to the work of an able-bodied man for a life-time."