these different media as to be sent obliquely upward to the eye. The low warm layer of air acts like a totally reflecting mirror, and inverted images are dimly seen amid the bright light along the horizon.

Fig. 160.

Mirage.

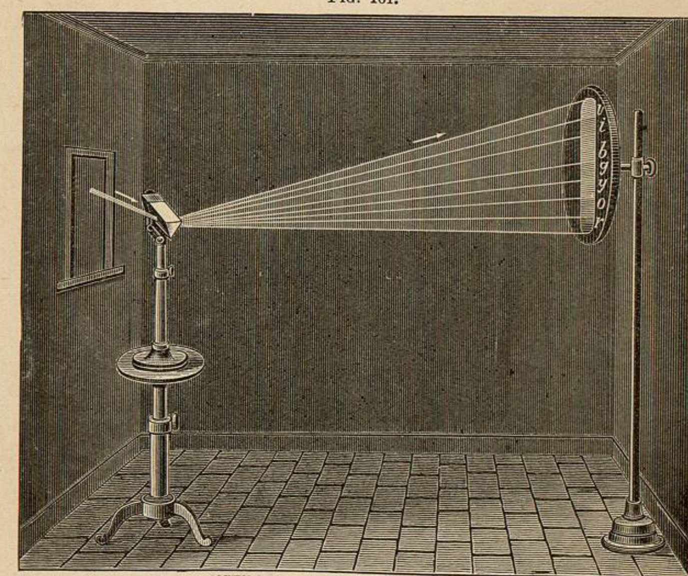
In Fig. 160, rays of light from a clump of trees are refracted more and more until finally they are bent upward from a layer at *a*, and enter the eye of the Arab as if they came from the surface of a quiet lake.

IV. COMPOSITION OF LIGHT.

1. The Prismatic Spectrum.—When a sunbeam is received through a narrow slit and transmitted through a prism, properly placed, the ray is not only bent from its course, but is also spread out into a band of rainbow colors—the solar spectrum. This includes a multitude of tints grading imperceptibly

from one to another. The most prominent are *violet, indigo, blue, green, yellow, orange, red.** If we receive the spectrum on a concave mirror or pass it through a convex lens appropriately adjusted in position, these colors may be recombined so as to form a white band. We therefore conclude that

Fig. 161.



The Prismatic Spectrum.

white light is made up of these many tints. Because each has its own separate index of refraction (see p. 204, foot-note) when passing through the same prism, this refracts them unequally. The deviation of the violet is the greatest, and that of the red is the least, for the visible rays of the spectrum.

* Notice that the initial letters spell the mnemonic word, *Vib-gy-or.*

2. Solar Energy.—What we receive from the sun is called Solar Energy. It reaches us in tiny waves, the longest of which are so minute that 8,000 of them in succession would be required to cover an inch. The shortest that have been measured are about a tenth as long, or $\frac{1}{80000}$ of an inch. The longer ones are manifested largely as heat; some of the intermediate ones as light, and the shortest as chemical energy, giving vigor to the growing plant and disturbing the arrangement of molecules on the photographer's sensitive plate. All these waves come mixed together in the sunbeam. The prism changes their direction, but not in proportion to wave-lengths. It crowds together some and separates others unequally. The prismatic spectrum includes the invisible heat and chemical rays, as well as the visible light waves.

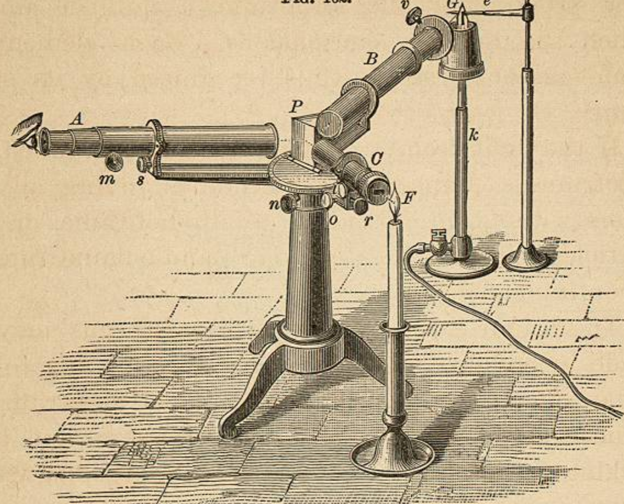
3. The Normal Spectrum.—By using a diffraction grating instead of a prism, a spectrum is obtained in which the deviation is proportional to wave-length. In such a spectrum it is found that rays of all colors may be manifested as heat, light, or chemical energy, according to the means used to reveal the presence of the solar energy. To the human eye some of them are imperceptible, yet these have been photographed and the dark parts explored by the aid of instruments far more sensitive than our nerves. They all convey heat; only those whose wave-length is between $\frac{1}{60000}$ and $\frac{1}{40000}$ of an inch affect the eye with the sensation of light. Of these the shortest are manifested as violet, the longest as

red; the intermediate tints have each its own wave-length.

4. Interruptions in the Spectrum. — When the spectrum of the sun, whether prismatic or normal, is carefully examined, it is found that there are numerous breaks in both the visible and invisible parts. Numerous black lines, parallel to the slit that transmits the light, may be detected in the visible part. The more prominent of these have been named. Thus, the *A*, *B*, and *C* lines are in the red; the *D* line in the yellow; the *E* line in the green; the *F* line in the blue; the *G* and *H* lines in the violet. The interruptions in the invisible portion are far broader, becoming bands rather than narrow lines.

5. The Spectroscope.—Any instrument for examining the spectrum is a spectroscope. The simplest is the single prism or diffraction grating. But in connection with either of these it is better to use telescopes. From the source of light, *G*, Fig. 162, the rays pass through an adjustable slit and are made parallel by the lens in the tube *B* before passing through the prism, *P*. The spectrum is seen through the telescope *A*. The tube, *C*, has at one end a scale on glass through which passes the light from a candle or coal-gas jet at *F*. This is reflected from the surface of the prism into the telescope *A*, where an image of the scale is seen alongside of the spectrum. Each part of the spectrum can thus be distinguished by its own scale number. Instead of a single prism, often a train of prisms is used, thus widening the spectrum and diminishing its brightness.*

FIG. 162.



The Spectroscope.

6. Three Kinds of Spectra.—If in the spectroscope we examine the light of a glowing thin *gas or vapor*, its spectrum is seen to consist of one or more bright lines only. Thus burning sodium gives

* On the uses of the spectroscope, examine "New Astronomy," p. 258, and "Popular Chemistry," p. 147. In the former, opposite p. 258, is a colored illustration of the spectra.—The dark lines which cross the solar spectrum are known as *Fraunhofer's lines*, being so named in honor of the physicist who first carefully studied and mapped them. The spectroscope affords an unrivaled mode of analysis. No chemical test is so delicate. Strike together two books near the light at the slit of the spectroscope, and the dust blown into the flame will contain enough sodium (the basis of common salt) to cause the yellow *D* lines—its test—to flash out distinctly. A very effective spectroscope may be contrived thus: Cut a slit not over $\frac{1}{20}$ inch wide and 2 inches long in a piece of tin-foil, and gum it on a pane of glass. Hold this before a flame and look at it through a prism.

a pair of brilliant yellow lines close together; zinc vapor, a number of lines among which the blue are very prominent; and strontium, a number among which the red are conspicuous. Each element, if made gaseous, can be thus recognized by its spectrum.

If the light from a glowing solid be examined, its spectrum is found to be continuous, giving all the colors without interruption. White-hot lime, or the particles of carbon in a common candle-flame, furnish a continuous spectrum.

The bright lines given by a glowing gas may be made to broaden into bands, and these finally to become joined into a nearly continuous spectrum by subjecting the gas to very great pressure, and thus making it very dense. There is no sharp distinction between line spectra and continuous spectra.

The interrupted spectrum is that given by the sun and stars. It may be produced to a limited extent by interposing a glowing vapor, like that of sodium, between the spectroscope and a white-hot solid, like lime. It is believed that the body of the sun and of each of the stars is made up of very dense glowing matter, which is surrounded by less hot vapors. These absorb some of the light from within, and thus produce the interruptions observed in the spectra of the sun and stars. Moreover, it has been proved that each gas or vapor absorbs the same waves as those given out by itself in glowing. By comparing the bright lines of a known gas or vapor with the dark lines in the sun or star spectrum, it becomes possible to determine whether this vapor exists in the atmosphere of the sun or star.

7. Color.—If a piece of pure red paper is put against the successive parts of the spectrum on a screen, it will look red only when in the red part, but dark gray or black in the other parts. It reflects red light and absorbs the other tints. Color is analogous to pitch, violet corresponding to the high and red to the low sounds in music. Intensity of color, as of sound, depends on the amplitude of the vibrations. When a body absorbs all the colors of the spectrum except blue, but reflects that to the eye, we call it a blue body; when it absorbs all but green, we call it a green body.* Red glass has the power of absorbing all except the red rays, which it transmits. When a substance *reflects* all the colors to the eye, it seems to us white. If it *absorbs* all the colors, it is black. Thus color is not an inherent property of objects.† In darkness all things are colorless.

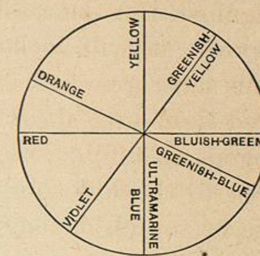
8. Complementary Colors.—Two colors, which by their mixture produce white light, are termed com-

* Some eyes are blind to certain colors, as some ears are deaf to certain sounds. "Color-blindness" generally exists as to red. Such a person can not by the color distinguish ripe cherries from green ones. Doubtless railway accidents have occurred through this inability to apprehend signals. Dr. Mitchell mentions a naval officer who chose a blue coat and red waistcoat, believing them of the same color; a tailor who mended a black silk waistcoat with a piece of crimson; and another who put a red collar on a blue coat. Dalton could see in the solar spectrum only two colors, blue and yellow, and having once dropped a piece of red sealing-wax in the grass, he could not distinguish it.

† Moisten a swab with alcohol saturated with common salt. On igniting this in a dark room, every object will take on a curious ghastly yellow hue from the burning sodium. The gay colors of flowers will instantly be quenched.

plementary to each other. Thus, if we sift the red rays out of a beam of light and bring the remainder to a focus, a bluish-green image will be formed.* In Fig. 163 the colors opposite each other are complementary. Place a red and a blue ribbon side by side. The former will take on a yellowish and the latter a greenish tint. Lay a piece of tissue paper upon black letters printed on brightly colored paper. The dark letters will appear of a color complementary to that of the background.†

Fig. 163.



Complementary Colors.

9. The Rainbow is formed by the *refraction* and *reflection* of the sunbeam in drops of falling water. The white light is thus decomposed into its simple colors. The inner arch is termed the primary bow; the outer or fainter arch, the secondary.

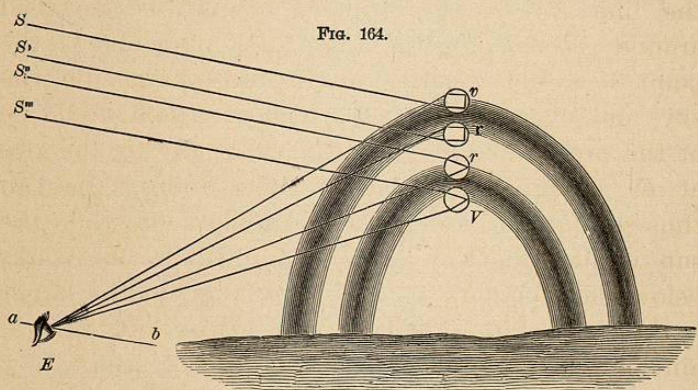
Primary Bow.—A ray of light, S'', enters, and is bent downward at the top of a falling drop, passes to the opposite side, is there reflected, then passing out of the lower side, is bent upward. By the refrac-

* Certain substances are able to split a ray of light into two colors, and are said to be *dichroic*. Gold-leaf reflects the yellow, transmits the green, and absorbs the rest.

† A color is heightened when placed near its complement. A red apple is the brighter for the contrast of the green leaf.—Observe a white cloud through a bit of red glass with one eye and through green glass with the other eye. After some moments, transfer both eyes to the red glass, opening and closing them alternately. The strengthening of the red color in the eye, fatigued by its complementary green, is very striking.—In examining ribbons of the same color, the eye becomes wearied and unable to detect the shade, because of the mingling of the complementary hue.

tion the ray of white light is decomposed, so that when it emerges it is spread out fan-like, as in the solar spectrum. Suppose that the eye of a spectator is in a proper position to receive the red ray, he can not receive any other color from the same drop, because the red is bent upward the least, and all the others will pass directly over his head. He sees the violet in a drop below. Intermediate drops furnish the other colors of the spectrum.

Fig. 164.



The Rainbow.

Secondary Bow.—A ray of light, *S*, strikes the bottom of a drop, *v*, is refracted upward, passes to the opposite side, where it is twice reflected, and thence passes out at the upper side of the drop. The violet ray being most refracted, is bent down to the eye of the spectator. Another drop, *r*, refracting another ray of light, is in the right position to send the red ray to the eye.

Why the Bow is Circular.—When the red ray of

the primary bow leaves the drop, it forms an angle with the sun's ray, $S''r$, of about 42°, and the violet forms with it one of 40°. These angles are constant. Let *ab* be a straight line drawn from the sun through the observer's eye. If produced, it would pass through the center of the circle of which the rainbow is an arc. This line is termed the *visual axis*. It is parallel to the rays of the sun; and when it is also parallel to the horizon, the rainbow is a semicircle. Suppose the line *EV* in the primary bow to be revolved around *Eb*, keeping the angle *bEV* unchanged; the point *V* would describe an arc of a circle on the sky, and every drop over which it passed would be at the proper angle to send a violet ray to the eye at *E*. Imagine the same with the drop *r*. We can thus see (*a*) the bow must be circular; (*b*) when the sun is high in the heavens, the whole bow sinks below the horizon; (*c*) the lower the sun the larger is the visible circumference; and (*d*) on lofty mountains a perfect circle may sometimes be seen.*

10. Chromatic Aberration of Lenses.—Since in passing through any medium, such as a lens, the violet rays are bent farther away from their first direction than the red rays, they will be brought to a focus nearer than that of the red rays. An image on a screen produced with a single lens is therefore fringed with a reddish or a bluish fringe according

* Halos, coronas, sun-dogs, circles about the moon, and the tinting at sunrise and sunset, are produced by the refraction and reflection of the sun's rays by the clouds. The phenomenon known as the "sun's drawing water," consists of the long shadows of broken clouds. Twilight and kindred topics are treated in Astronomy.

to the position of the screen. By combining two lenses properly, one made of crown glass and the other of flint glass, it is possible to correct much of this coloring, which is called chromatic aberration, and at the same time much of the spherical aberration.*

11. Interference of Light (*Newton's Rings*).—Let the convex side of a plano-convex lens be pressed down upon a plane of glass. The two surfaces will apparently touch at the center. If different circles be described around this point, at all parts of each circle the surfaces will be the same distance apart, and the larger the circle the greater the distance. Now let a beam of red light fall upon the flat surface. A black spot is seen at the center; around this a circle of red light, then a dark ring, then another circle of red light, and so alternating to the circumference. The distances between the surfaces of the glass, where the successive dark rings appear, are proportional to the numbers 0, 2, 4 . . . . , and the bright circles to 1, 3, 5 . . . . . This fact suggests the cause. There are two sets of waves, one reflected from the upper surface of the plane glass, and the other from the lower surface of the

FIG. 165.

Production of Newton's Rings.

* The crown-glass lens must be bi-convex and the flint-glass lens plano-concave or meniscus. Flint glass gives a spectrum nearly twice as wide as crown glass. The two lenses oppose each other in their action on light. They may be so adjusted that each tends almost completely to reverse the spectrum that the other would produce, and yet the excess of deviation produced by the crown glass may still be enough to bring the rays of this nearly white light to a focus.

convex glass. These alternately interfere, producing darkness, and combine, making an intenser color.* To determine the length of a wave of red light, we have only to measure the distance between the two glasses at the first ring.

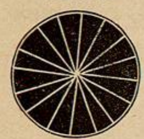
When beams of light of the various colors are used corresponding circles are obtained, having different diameters; red light gives the largest, and violet the smallest. We hence conclude that red waves are the longest, and violet the shortest. The minuteness of these waves passes comprehension. About 40,000 red waves, or 60,000 violet ones, are comprised within a single inch. Knowing the velocity of light, we can calculate how many of these tiny waves reach our eyes each second. When we look at a violet object, 757 million million of ether-waves break on the retina every moment!

12. Polarization of Light.—(1.) DEFINITION.—If we could look at the end of a ray of light coming to-

* The play of colors in mother-of-pearl is due to the interference of light in its thin overlapping plates.—In a similar manner the plumage of certain birds reflects changeable hues.—A metallic surface ruled with fine parallel lines not more than $\frac{1}{2000}$ of an inch apart, gleams with brilliant colors.—Thin cracks in plates of glass or quartz, mica when two layers are slightly separated, even the scum floating in stagnant water, breaks up the white light of the sunbeam and reflects the varying tints of the rainbow.—The rich coloring of a soap-bubble is caused by the interference of the rays reflected from the upper and lower surfaces of the bubble.—DIFFRACTION is interference produced by a beam of light passing along the edge of an opaque body or through a small opening, or reflected by a surface ruled with fine lines.—*Examples:* Place the blades of two knives closely together and hold them up to the sky; waving lines of interference will shade the open space.—Look at the sky through the meshes of a veil, or at a lamp-light through a bird-feather or a fine slit in a card, and delicate colors like those of the prism will appear.

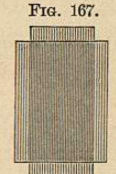
ward us, as we can at the end of a rod, we should see the molecules of ether vibrating across the direction of the ray in all possible planes, as shown in Fig. 166. There are certain conditions under which reflected or refracted light may be made to vibrate in but a single plane. It is then called polarized light.

Fig. 166.



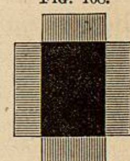
The crystal *tourmaline* has this power upon transmitted light. If two thin plates of this be cut parallel to the axis of the crystal and light be passed perpendicularly through them, when one is placed parallel to the other, as in Fig. 167, some of it will be absorbed, but what passes through vibrates only in a plane the same as that of the axis. This is proved by crossing them, as in Fig. 168; at once the light is quenched. What passed through the first plate had been polarized, and was stopped by the second plate when crossed. If they be placed with axes oblique to each other, part of the polarized light is transmitted and part quenched.

Fig. 167.



Tourmalines Parallel.

Fig. 168.

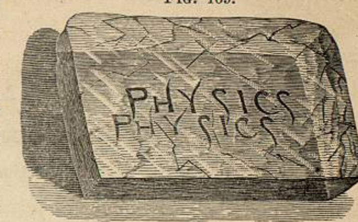


Tourmalines Crossed.

(2.) Double Refraction.—In tourmaline and many other crystals the ether is unequally elastic in two directions at right angles to each other. The light is hence divided into two parts which pass through with unequal velocities. If transmitted across the axis of the crystal, these parts are separated so that two beams become perceptible. Iceland spar shows

this remarkably well. An object viewed through it appears double. If the crystal be placed over a dot and turned around, two dots will be seen; one appears a little nearer than the other and revolves around it, or a word will appear double if viewed in like manner. (Fig. 169.) If now a plate of tourmaline be put between the eye and the rotating crystal of spar, the dots will alternately disappear. This shows that the two beams were polarized at right angles to each other. One of them is called the *ordinary* and the other the extraordinary ray. Tourmaline is a doubly refracting crystal in which the extraordinary ray is absorbed unless the plate be exceedingly thin.

Fig. 169.



Double Refraction.

(3.) Polarization by Reflection.—When light falls upon a surface of glass at such an angle that the reflected and refracted beams are at right angles to each other, each of these is polarized, just as in passing through a doubly-refracting crystal. This special polarizing angle of incidence for glass is about 56°. Many other substances polarize the light reflected at the proper angle from them.*

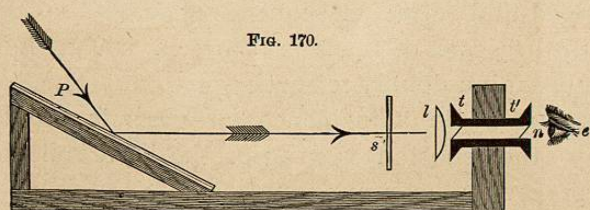
(4.) The Polariscope.—The best polarizer is a crystal of Iceland spar specially arranged so as to

* If a tourmaline is rotated before the eye while looking obliquely at the surface of a varnished table, or leather-seated chair, the reflected light will be found to be polarized.

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 mi-