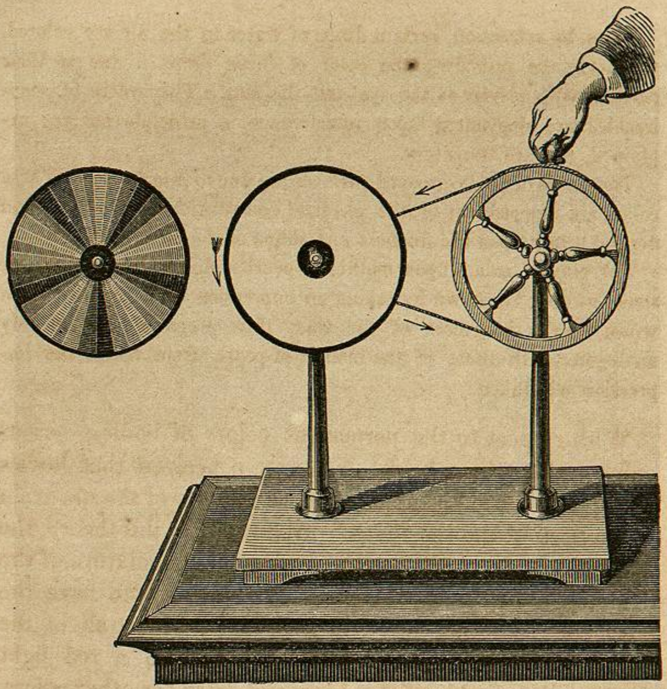

Fig. 207. Fig. 208.

that lasts for an appreciable length of time. In the experiment, the rotation is so rapid that the impressions from all of the colors coexist at the same instant, and the effect is the same as though the colors were mixed.

That the impression produced by light lasts for an appreciable length of time, may be shown by whirling a lighted stick round in a circle; it will present the appearance of a continuous circle of fire.

Color of Opaque Bodies.

309. The color of a body may be *temporary* or *permanent.* Temporary colors arise from some modification of light, of a transient character.

How does it appear that the impression of color lasts for a short time? How may it be shown? (**309.**) From what does the color of a body arise?

Thus, by refraction, certain drops of water in the air are colored, producing the rainbow; the color of these drops is due to their position with respect to the eye and the sun. The colors of soap-bubbles are dependent upon interference, a principle not yet explained, and are transitory.

The colors of finely-grooved surfaces are due to interference. These colors are independent of the physical constitution of the body, and depend solely upon the fineness and shape of the grooves.

The play of colors upon mother-of-pearl is due to fine grooves or striæ, as may be shown by taking an impression of a piece of it in white wax; the colors of the wax, thus prepared, are entirely analogous with those of the mother-of-pearl, from which the impression was taken.

With respect to the permanent colors of bodies, various opinions have been held. NEWTON conceived that bodies had the power of absorbing some of the rays of the spectrum and reflecting the remainder. According to this theory, the color of a body would be that arising from a mixture of the reflected rays. Thus, vermilion was supposed to have the power of reflecting the red rays only, whilst all of the others were absorbed. All bodies placed in a red light appear red, in a blue light, blue, and so on for other colors.

ARAGO was of the opinion that the colors of bodies arose from light admitted into the body and then emitted again, undergoing certain modifications. Color would, according to this theory, depend upon the molecular condition of the body. According to this view, color is a modification of light, entirely analogous to that modification of sound which we call the *tone.*

ARAGO'S theory was based upon a difference of property between reflected and refracted light. On examining the colors of opaque bodies, he found that the light agreed with that which had been refracted, rather than with that which had been reflected.

Explain temporary colors in case of rain-drops. Of grooved surfaces. Of mother-of-pearl. What is NEWTON'S theory of colors of bodies? What is ARAGO'S theory? *On what was* ARAGO'S *theory based?*

Colors of Transparent Bodies.

310. All transparent bodies absorb more or less of the light which enters them, and if sufficiently thick, must appear colored. Their color is due to that part of the light which is transmitted.

If, for example, all of the solar rays except the red ones are absorbed by a medium, it will appear red by transmitted light. Water when seen in masses by transmitted light, appears of a greenish hue. Air appears blue; hence the color of the sky. As we ascend, the mass above us becomes smaller and loses its blue tint. It is probable that the bluish tint of the heavens is also in a measure due to reflection from the aerial molecules. At sunrise and sunset, the rays of the sun have to traverse a great body of the atmosphere, which absorbs most of the rays except the red ones. Hence it is, that the sun appears red at sunrise and sunset.

Complementary Colors.

311. NEWTON calls two colors *complementary*, when by their mixture they produce white.

If all the rays of the spectrum except the red ones be recomposed by a convex lens, a bluish-green color will result; hence, red and green are complementary. In like manner, it may be shown that blue and orange are complementary, as are also violet and yellow.

Accidental Images.—Accidental Fringes.

312. A curious effect of color upon the eye is manifest in the production of what are called accidental images.

If a wafer upon a black ground be viewed intently for some time, until the nerve of the eye becomes fatigued, and the eye be then directed to a sheet of white paper, an image of the wafer will be seen upon the paper, whose color is complementary to that of the

(**310.**) To what is the color of transparent bodies due? *Illustrate by examples.* (**311.**) What are complementary colors? What is the complement of red? Of green? Of blue? Of orange? (**312.**) *What is an accidental image? Illustrate. What is the cause of accidental images?*

wafer. Thus, if the wafer is red, the image will be green; if the wafer is orange, the image will be blue, and so on. These images are called *accidental*.

If the setting sun, which is red, be viewed for some time, and then the eyes be directed to a white wall, a green image of the sun will be seen, which will last for some instants, when a red image will appear; a second green image succeeds it, and so on till the effect entirely ceases.

If we look for some time at a colored object on a white ground, we shall finally observe the object surrounded by a fringe, whose color is complementary to that of the body; thus, if a red wafer be placed upon a sheet of white paper, the fringe will be green. Such fringes are called *accidental*.

Many phenomena are explained by the principle of accidental images.

Shadows cast upon a wall by the rising or setting sun, are tinged green, the tint of the sun being red at that time.

If we examine several pieces of cloth of the same color, the eye becomes wearied, and in consequence of the accidental complementary color being formed, the last pieces examined appear of a different shade from those first viewed.

When colored figures are stamped on a colored ground, the tint of the figures is changed by the accidental or complementary color of the ground.

When figures are stamped on a ground whose color is complementary to that of the figures, they render each other more brilliant. When the figures are of the same color as the ground, but of a different shade, the colors render each other less brilliant.

These facts have an application in the selection of colors used in calico printing, stamping woolen goods, wall papers, in carpet weaving, and in a great multitude of the arts.

For further details on the law of contrasts and combinations of colors, the reader is referred to a work entitled, "*Contrast of Colors*," by M. CHEVREUIL, director of the manufactory of Gobelin tapestry near Paris.

Explain the images of the sun. Why are shadows at sunset tinged green? Explain the effect of looking at different colored cloths. What is the effect of stamping colors on complementary grounds? On different shades of the same color? Applications.

The Rainbow.

313. The RAINBOW is a brilliantly colored arc, seen after a shower opposite the sun.

The colors being disposed in the same order as in the solar spectrum, it indicates that the rainbow is due to refraction. Such is shown to be the case. Fig. 209 indicates the course of the rays in the formation of a rainbow. The rays of light coming from the sun, *S*, fall upon the spherical rain drops, enter them, undergoing refraction, are

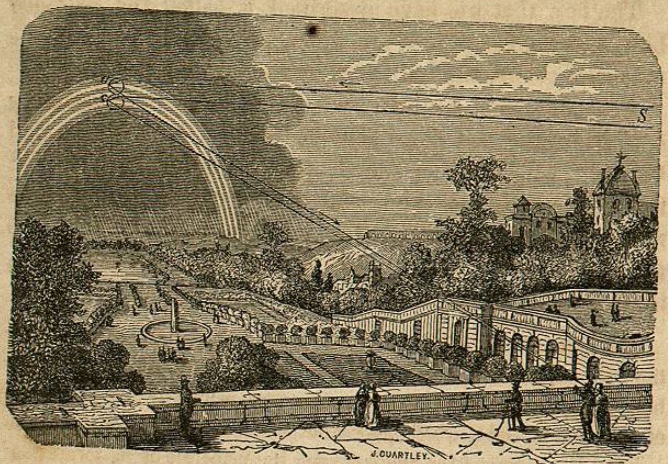

Fig. 209.

internally reflected, and then emerge, undergoing a second refraction. The result is that the emergent light is resolved into the seven prismatic colors, which, reaching the eye from different drops, give rise to the colors that are observed.

The ray which enters the drop, *a*, for example, after emergence sends to the eye a red ray, whilst that which enters the drop *c*, sends to the eye a violet-colored ray;

(**313.**) What is a Rainbow? To what is the bow due? Explain the course of the rays, Fig. 209.

intermediate drops send intermediate colors. Each drop sends a different color to the eye.

Analysis shows that it is only at certain angles that the refracted rays emerge with sufficient intensity to affect the eye with colors. Hence it is, that the colored drops are arranged symmetrically about a line drawn through the sun and the eye of the observer. The centre of the bow is in this line; hence, as the sun declines towards the horizon, the bow rises, and at sunset it becomes a semicircle. In looking down into spray with the back turned towards the sun, a complete circular bow may be seen.

The bow that we have described is called the *primary* bow, and the colors in it are arranged in the order of the prismatic colors, the red being on the outside.

Another bow is generally seen, concentric with the primary *bow*, which is called the *secondary* bow. This bow is formed by light which enters the drops being refracted, is then twice internally reflected, and then emerges, being again refracted. The result of this deviation is a bow similar to the first, but having its colors arranged in a reverse order, the red being on the inside.

The inversion of colors arises from the additional reflection that the light experiences. It is observed that the colors of the secondary bow are not so brilliant as in the primary, which is due to the loss of a portion of light, which passes out of the drop at each incidence.

From the nature of the rainbow, and the principle of its formation, it is plain that every observer sees a different bow.

Chromatic Aberration.

314. The light which falls on a lens is decomposed into colored rays of different degrees of refrangibility. These

How is the bow formed? Where is its centre? Why does the bow enlarge as the sun declines? How may a complete circular bow be seen? What is a primary bow? A secondary bow? How is it formed? *Why are the colors in the secondary bow reversed in order? How do the colors in the two bows compare in brilliancy? Does each observer see the same bow? Why not?* (**314.**) What is chromatic aberration?

rays are brought to different foci along the axis, giving rise to a multitude of partial images of different colors, which by superposition produce a single image slightly indistinct, and fringed with all the colors of the spectrum. This scattering of the colored rays to different foci, is called *chromatic aberration.*

Fig. 210 shows the phenomenon of chromatic aberration. The red rays being less deviated than the others, are brought to a focus beyond them at *r*, whilst the violet rays being less refrangible than the others, are brought to a focus within them at *v*. Between *v* and *r*, the intermediate colors are also brought to foci.

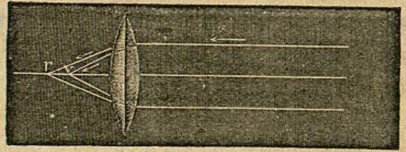
Fig. 210.

Achromatic Combinations.

315. An Achromatic Combination consists of two or more lenses of different kinds of glass, so constructed as to neutralize the effect of dispersion.

The combination usually consists of two lenses: a convex lens made of crown-glass, and a concave lens made of flint-glass, as shown in Fig. 211. Flint-glass disperses light more than crown glass. The combination, having its thickest part at the middle, is convergent. The dispersion of the rays by one of the lenses is exactly neutralized by a dispersion of them in an opposite way, so that the image is nearly colorless.


Fig. 211.

Such combinations of lenses are called *achromatic*, and are the ones used in the construction of telescopes.

Illustrate. (**315.**) What is an Achromatic Combination? Illustrate. What lenses are usually combined? Explain their action.

V.—THEORY AND CONSTRUCTION OF OPTICAL INSTRUMENTS.

Optical Instruments.

316. The properties of mirrors and lenses have led to the construction of a great variety of instruments, which by increasing the limits of vision, have opened to our senses two new worlds, that had else remained unknown to us, the one on account of its minuteness, and the other on account of its immensity.

Of the optical instruments, the most useful and interesting are *microscopes*, so called because used to investigate minute objects, and *telescopes*, so called because they are employed to examine distant objects.

Besides these a great variety of other instruments have been devised, such as the *magic lantern*, the *phantasmagoria*, the *solar microscope*, the *camera obscura*, and the *stereoscope.*

Telescopes.

317. A Telescope is an optical instrument for viewing objects at a distance.

Telescopes may be divided into two classes, *refracting* telescopes, and *reflecting* telescopes.

In the first class a lens, called the *object-lens*, is employed to form an image; in the second class a mirror or speculum is employed for the same purpose; in both the image formed is viewed by a lens, or combination of lenses, called the eye-piece. The manner of arranging these component parts, together with the nature of the auxiliary pieces employed, determines the particular kind of telescope.

(**316.**) What are some of the most useful optical instruments? Mention some other instruments. (**317.**) What is a Telescope? How many classes of telescopes are there? What is the difference between the two classes? What determines the kind of telescope?

A great variety of devices have been employed to obviate the defects of spherical and chromatic aberration, and at the same time to obtain a sufficiency of illumination to render vision distinct. Hence the variety of telescopes is very great. Only a few of the most important will be described in these pages.

The Galilean Telescope.

318. The GALILEAN TELESCOPE, named from its illustrious discoverer, GALILEO, consists essentially of a *convex object-glass*, which collects the rays from an object, and a *concave eye-piece*, by means of which the rays from each point of the object are rendered parallel, and capable of producing distinct vision.

Fig. 212 shows the course of the rays in the Galilean telescope. Pencils of rays from points of the object, *AB*, falling upon the object lens, *O*, are converged by it, and tend to form an image beyond the eye-piece, *o*. The concave eye-piece is placed so as to intercept the rays coming from

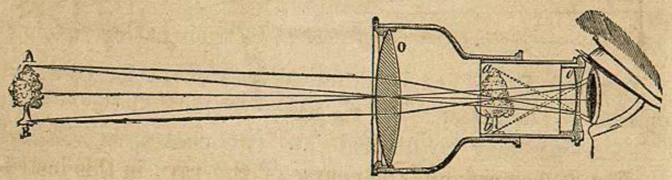

Fig. 212.

the object-glass, being at a distance from the image equal to its principal focal distance. In consequence of this arrangement, the pencil of light coming from *A*, is converged by the object-glass, and falling upon the eye-piece, is diverged and refracted so as to appear to the eye to come from *a*. In like manner the pencil from *B*, appears to the eye to come from *b*.

What are the special objects to be attained in making a telescope? (**318.**) What is a Galilean Telescope? Describe it. Explain the course of the rays in a Galilean telescope.

The image is erect and virtual, and because the visual angle under which the image is seen, is greater than that under which the object would be seen without the telescope, it appears magnified.

Opera-glasses are simply Galilean telescopes. They possess the advantage of showing objects in their proper position, of being short and portable, and of being well illuminated.

The Galilean telescope is not adapted to astronomical observation, because the image formed is virtual; nevertheless it was with such an instrument that GALILEO discovered the satellites of Jupiter.

The Astronomical Telescope.

319. The ASTRONOMICAL TELESCOPE consists essentially of two convex lenses, the one, *o*, being the object-lens, and the other, *O*, the eye-piece. The object-glass forms an inverted image of the object, which is viewed by the eye-piece.

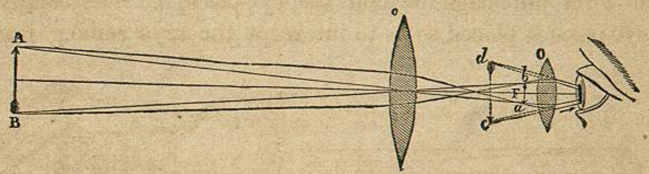

Fig. 213.

Fig. 213 represents the course of the rays in this instrument. A pencil of rays coming from *A*, is converged by *o*, to a focus *a*, whilst a pencil from *B*, is brought to the focus *b*. In this manner the lens *o*, forms an image, *ab*, of an object, *AB*, which image is real and inverted. The eye-piece, *O*, is placed at a distance from *ab* equal to its principal focal distance. The pencil coming from the points, *a* and *b*, of the image, are refracted so as to appear to come from the points, *c* and *d*. The visual angle, that is, the

---

How is the image? Give an example of a Galilean telescope. Their advantages? Is the Galilean telescope adapted to astronomical purposes? (**319.**) What is the Astronomical Telescope? Explain the course of the rays in it.

angle formed by the extreme rays which enter the eye, is greater than it would be in viewing the object without the telescope, and consequently the object appears to be magnified.

In this, as in all other telescopes, the eye-piece is capable of being pushed in, or drawn out, to enable the observer to accommodate it to near as well as distant objects.

The object-glass is made as large as possible, and should be

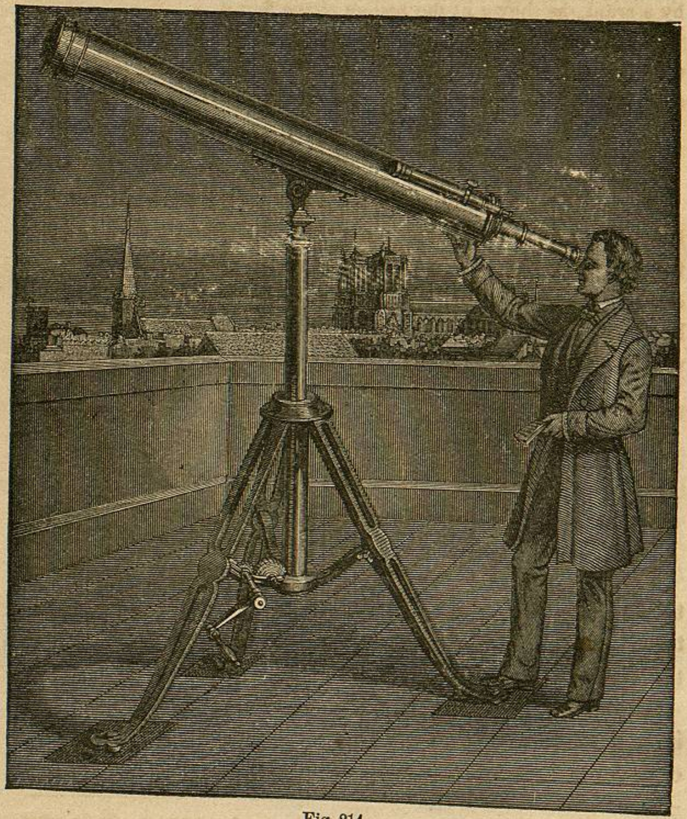

Fig. 214.

How is the eye-piece adjusted?

achromatic (Art. 315). The eye-glass is made quite convex, so as to magnify the image formed by the object-glass.

Fig. 214 represents an astronomical telescope mounted for use. It rests upon a cast-iron stand, with three feet, called a *tripod*. The tripod supports a vertical axis, capable of turning around in its supports; the telescope is attached to the top of this axis by a hinge joint. These arrangements enable the observer to direct the telescope to any point of the heavens. The telescope may be raised or depressed by means of a rack, worked by toothed wheels, set in motion by a crank, as shown at the bottom of the figure.

A smaller telescope with a larger field of view is attached to it, to aid the observer in fixing the instrument on any object. This telescope is called *the seeker*.

The Terrestrial Telescope.

320. The TERRESTRIAL TELESCOPE differs from the astronomical telescope, in having two additional lenses, which together constitute what is called an *erecting piece.* The object of the erecting piece is to invert the image formed by the object-lens, so that objects may appear erect when viewed through the telescope.

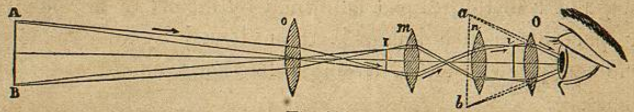

Fig. 215.

Fig. 215 shows the course of the rays in a terrestrial telescope. *AB* is the *object*, *o* is the *object-lens*, *m* and *n*, two convex lenses, constitute the erecting piece, and *O* is the *eye-piece*.

The erecting piece is so placed that the distance of the image, *I*, shall be at a distance from *m*, equal to its principal focal distance.

What is said of the object-glass and of the eye-piece? (**320.**) In what respect does the Terrestrial differ from the Astronomical Telescope? What is the object of the erecting piece?

A pencil of rays from A, falling upon the object-lens, is converged to a focus at the lower end of the image, I; the pencil proceeding from I, is converted into a beam by the lens, m, directed obliquely upwards, which beam is converged to a focus at i. In this manner an erect image, i, is formed, which is then viewed by the eye-piece, O. The eye-piece refracts the pencils coming from the image i, so as to make them appear to come from ab.

The angle, under which ab is seen, is the *visual angle*, and being greater than the angle under which AB would be seen without the telescope, the object is magnified.

The number of times which the visual angle of the image contains the visual angle of the object, is the *magnifying power* of the telescope.

The terrestrial telescope is used at sea and on land for viewing objects at a distance. It may, for convenience, be mounted in the same way as the astronomical telescope shown in Fig. 214.

Reflecting Telescopes.

321. A Reflecting Telescope is one in which the image of a distant object is formed by means of a reflector or speculum, which image is then viewed by an eye-piece. The eye-piece is either a single lens or a combination of lenses.

One of the first telescopes of this description was constructed by Newton, and this is the only one of the kind which we shall describe in detail.

Newtonian Telescope.

322. Fig. 216 shows a Newtonian Telescope, as constructed by M. Froment, of Paris, with improvements introduced by that distinguished physicist.

Describe the course of the rays in the terrestrial telescope. What is the magnifying power? *What is the use of the terrestrial telescope?* (**321.**) What is a reflecting telescope? (**322.**) Describe the Newtonian Telescope.

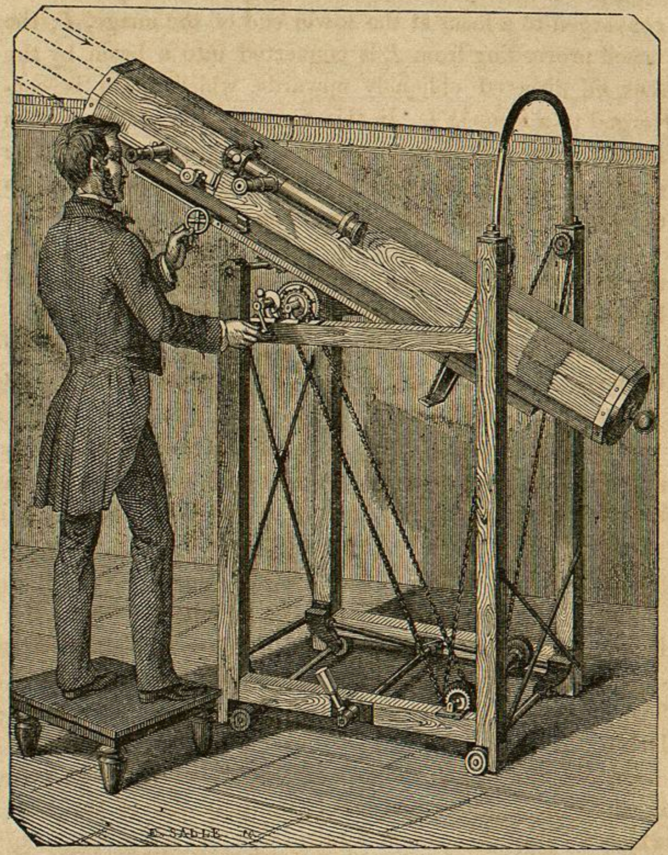

Fig. 216.

Fig. 217 shows the same telescope in section, and indicates the course of the rays of light.

M is a concave mirror placed at the bottom of a long tube. This reflector tends to form a small image of an object at the other end of the tube. But before the rays reach the image, they are intercepted by a prism of glass, mn, so arranged that the rays enter its first face without