With respect to the size of the image in this case, it may be either greater or smaller than the object. When the object is farther from the lens than twice the principal focal distance, the image is smaller than the object; when the object is at twice the focal distance, the image is of the same size as the object; when the distance is less than twice the principal focal distance, and greater than the principal focal distance, the image is greater than the object.

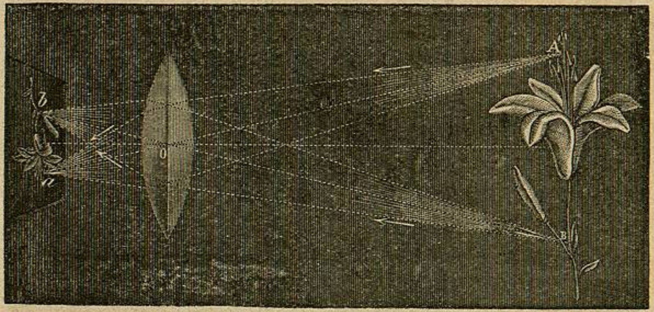

Fig. 194.

These principles may be shown experimentally as follows:

Let a convex lens be placed in a dark room, and suppose its principal focal distance to have been determined by means of a beam of solar rays. Let a candle be placed in front of the lens, and a screen behind it to receive its image, as shown in Fig. 195.

When the distance of the candle from the lens is more than twice the principal focal distance, its image will be less than the object; and the more remote the candle, the less will be its image.

If the candle be moved towards the lens, its image will grow larger, until, at twice the principal focal distance, the size of the image and object will be equal.

If the candle be moved still nearer, the size of the image will be

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How does the size of the image compare with that of the object in different cases? *Explain in detail the method of illustrating the foregoing principles by experiment.*

increased, that is, it will become greater than the object, as is shown in Fig. 196.

If the distance of the object does not become smaller than the principal focal distance, the image will be inverted, as is shown in Figs. 195 and 196.

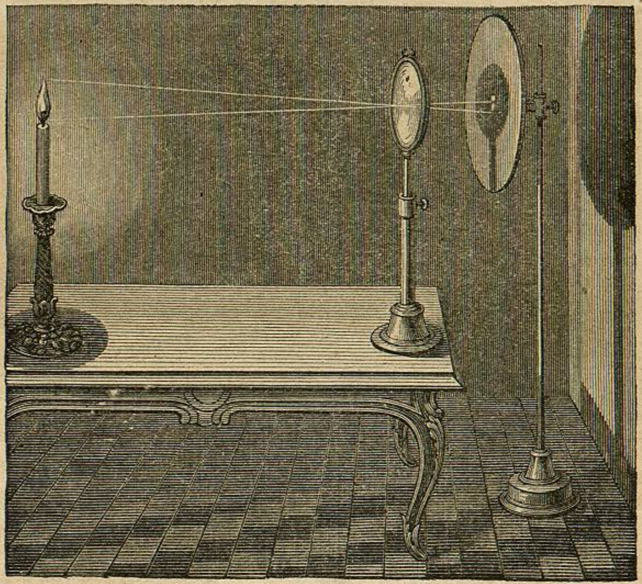

Fig. 195.

If the object approach still nearer the lens, that is, if its distance becomes less than the principal focal distance, the image will increase, it will become erect, and furthermore it will be virtual. The course of the rays in this case is shown in Fig. 197. Here, *ab* is the object, and *AB* is its image, which can only be seen by looking through the lens.

In this case the lens becomes what is called a *single microscope.*

When the object is at the principal focal distance from the lens, the image is infinite; that is, it disappears.

What is a single microscope? Illustrate.

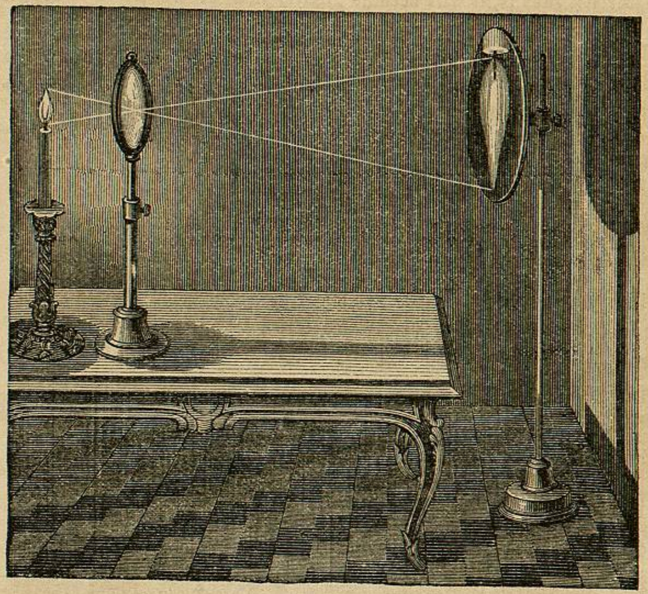

Fig. 196.

The phenomena just described may be observed by looking through a convex lens at the letters on a printed page. When the letters are at a short distance from the lens, they are magnified and erect;

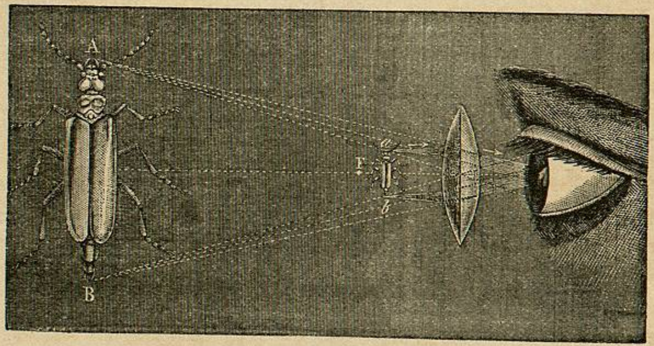

Fig. 197.

on removing the lens, they disappear at the principal focal distance, and finally reappear inverted and diminished in size.

Formation of Images by Concave Lenses.

302. Concave lenses being thinner in the middle than at the edges, have the effect to diverge parallel rays. If the rays are already divergent, these lenses make them still more so.

This is shown in Fig. 198, in which a pencil of rays, coming from the radiant, *L*, are made to diverge, as though they proceeded from a point, *l*, nearer the lens. This point, *l*, is the virtual focus, corresponding to the radiant, *L*. To an eye situated on the left of the lens, the light, *L*, appears to be situated at *l*.

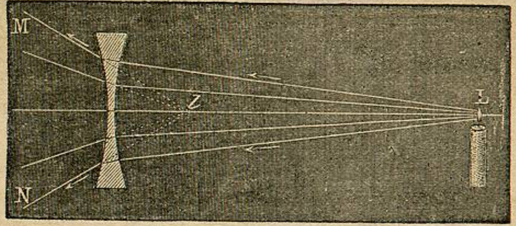

Fig. 198.

From what has been said, it is plain that the images formed by concave lenses are virtual. They are also erect, as in Fig. 198.

The course of the rays, in forming an image in the case of a concave lens, is shown in Fig. 199. In that figure, *AB* represents the object. A pencil of rays, coming from *A*, is deviated so as to appear to come from *a*, situated on a line drawn from *A* to the optical centre of the lens *O*. A pencil, coming from *B*, is deviated so as to appear to come from *b*,

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(**302**.) What is the effect of a divergent lens upon light? *Explain Fig.* 198. What kind of images are formed by concave lenses? Explain the course of the rays in a concave lens.

on the line *Bo*. Hence, *ab* is the image of the object *AB*,

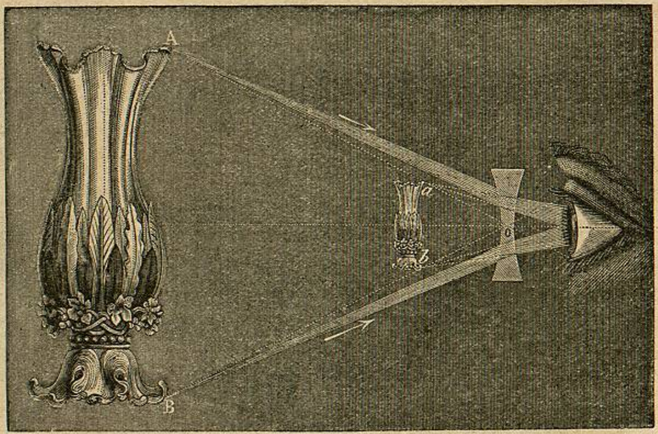

Fig. 199.

and is, as we see, smaller than the object, being nearer the optical centre, and furthermore it is erect.

Burning-glasses.

303. Rays of heat are subject to the same laws of reflection and refraction as rays of light. When a beam of solar light falls upon a convex lens, there is not only a concentration of light at the focus, but of heat also.

The heat concentrated is so great as to inflame combustible bodies, such as paper, cloth, wood, and the like. In the case of large lenses, the heat becomes sufficiently powerful to fuse metals. This property of lenses has been used to procure fire; the lens in this case is called *a burning-glass.* Lenses carelessly exposed may sometimes cause dangerous results, by setting fire to inflammable materials. This effect may result from spherical vessels of glass filled with water, which possess all the properties of lenses.

Do concave lenses magnify or diminish objects? (**303.**) How are rays of heat affected by lenses? *What is a burning-glass? Explain its action.*

A curious application of this principle is shown in Fig. 200. A lens is arranged with its axis in the meridian, so that its principal focus shall fall upon the vent of a small cannon When the sun crosses the meridian, the rays are concentrated upon the vent, and if the gun has been loaded and primed beforehand, it will be discharged at midday.

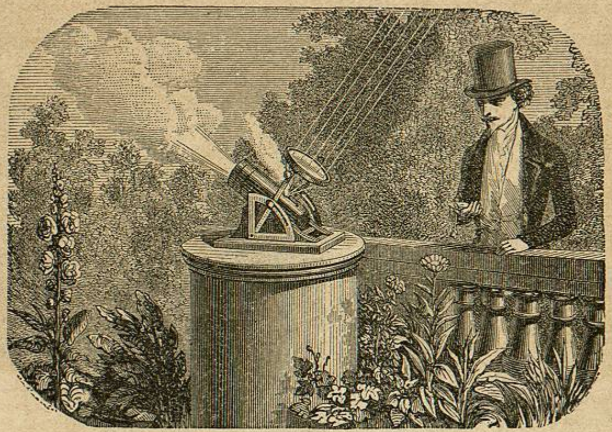

Fig. 200.

Light-houses.

304. Light-houses are towers, erected along the coast, upon the tops of which are lanterns. These lanterns are lighted at night as guides to mariners.

One of the most famous light-houses of antiquity was that on the little Island of *Pharos*, near Alexandria, in Egypt. From the location of this light-house the French derive the name *pharo*, which they apply to all light-houses. In former times light-houses were illuminated by fires built with wood, coal, or some bituminous substances.

Explain Fig. 200. (**304.**) What is a light-house? *Give an account of the ancient light-houses.*

These methods of illumination were afterwards replaced by oil lamps placed in the foci of concave reflectors, which served to concentrate the rays, and thus to heighten their illuminating effect. But the reflectors, being made of metal, were soon tarnished, and the light afforded became feeble.

In 1822, **Fresnel**, already distinguished by his discoveries in optics, and by his researches on the wave theory of light, invented a new system of illumination, which is now being adopted in all civilized countri

Fig. 201.

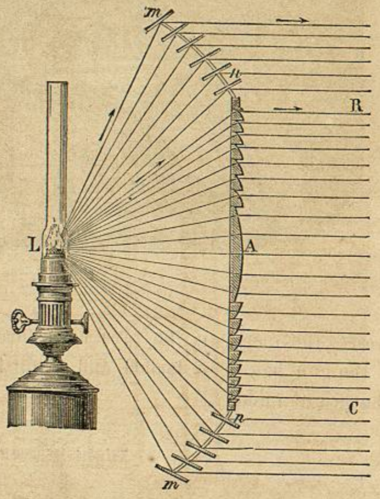

Fig. 202.

Abandoning the reflectors, which became tarnished by the influence of sea fogs, he substituted for them plano-convex lenses, in the principal foci of which he placed powerful lamps with four concentric wicks, each of which, for the quantity of oil consumed, and the amount of light given out, was found to be equivalent to seventeen carcel-lamps. The difficulty of constructing large plano-convex lenses, together with their great absorption of light, led finally to the adoption of a particular system of lenses, known as *échelon lenses*.

These lenses will be understood by examining Figs. 201 and 202;

Explain the principle of reflectors. What modification did **Fresnel** introduce? *Explain the échelon lens.*

Fig. 201 shows a front view, and Fig. 202 a section or profile of an échelon lens.

A lens of this kind consists of a plano-convex lens, *A*, about a foot in diameter, around which are disposed several annular lenses, which are also plano-convex, and whose curvature is so calculated that each one shall have the same principal focus as the central lens, *A*.

A lamp, *L*, being placed at the principal focus of this refracting system, as shown in Fig. 202, the light emanating from it is refracted into an immense beam, *RC*, of parallel rays.

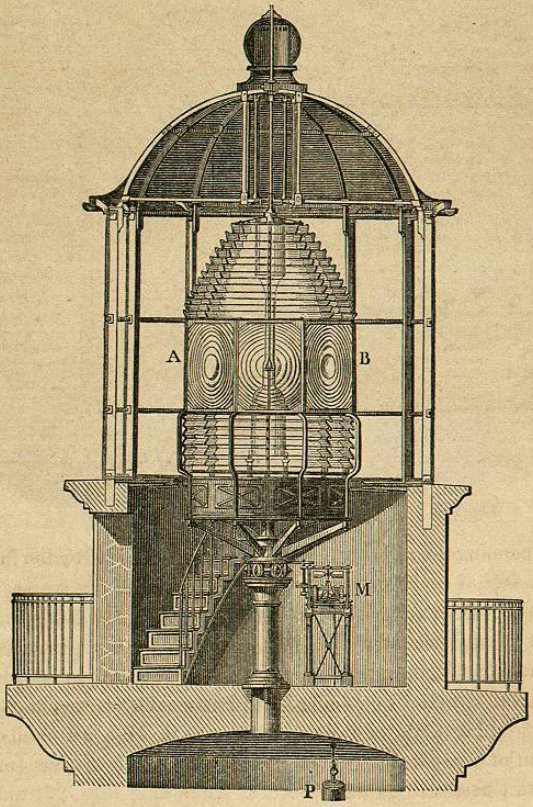

Fig. 203.

Explain the reflectors used by **Fresnel**.

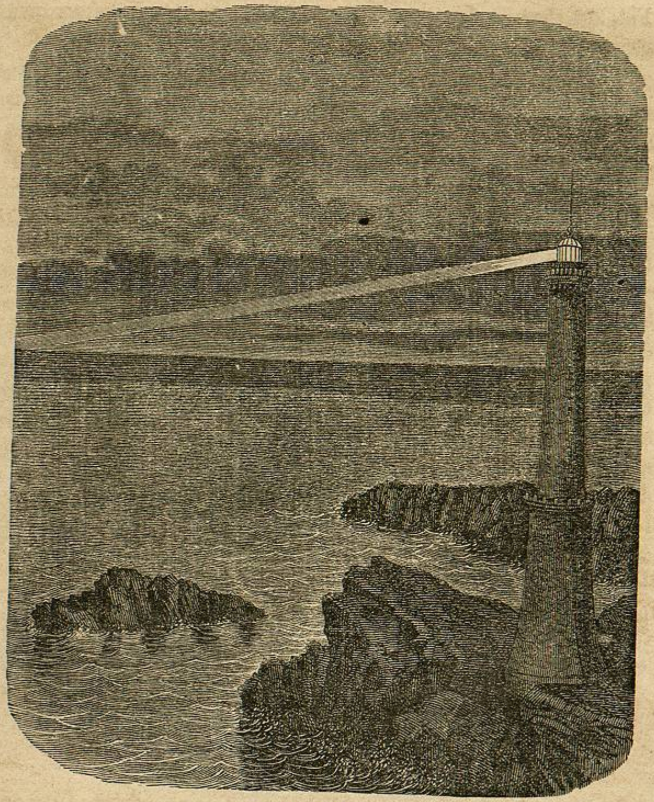

Fig. 204.

Besides this refracting system, several ranges of reflectors, *mn*, are so disposed as to reflect such light as would otherwise be lost, to increase the beam of light formed by refraction.

By this double combination, an immense beam of light is afforded, which renders the light visible for fifteen or twenty leagues; but this beam is only visible in a single direction. To remedy this defect, FRESNEL united eight systems similar to that just described, which combination presents the appearance of a pyramid of glass, nine or ten feet in height.

Fig. 203 represents a section of the lantern of a light-house of the

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How far is a FRESNEL *light visible?*

first order, which was actually constructed by M. SAUTTER, and exhibited at the great "Universal Exposition" of France, in 1855.

In order to illuminate all points of the horizon, the system is made to revolve on a vertical axis by clock-work. The clock-work is shown at *M* in the figure, and the weight at *P*. To prevent friction the system turns upon six wheels, or rollers, shown in the figure to the left of *M*.

In consequence of this rotation an observer at any point will see eight flashes of light during one revolution, which are followed by as many intervals of darkness, called *eclipses*. By suitably regulating the number of revolutions in any given time, different light-houses may be distinguished from each other.

Fig. 204 shows a complete light-house, and the manner in which it throws out a beam of light. The distance at which these lights may be seen depends upon the quality of the illuminating apparatus, and upon their altitude above the sea. They are usually built upon bluffs, or else the tower is sufficiently elevated to place the lantern from 150 to 200 feet above the level of the sea. The United States government is engaged, through its present efficient Light-house Board, in constructing a great number of light-houses on our coast, of the most approved description.

IV.—DECOMPOSITION OF LIGHT.—COLORS OF BODIES.

Solar Spectrum.

305. When a ray of solar light passes through a prism, it is not only deviated, but it is decomposed into several rays, which are scattered, or spread apart.

The property which a refractive medium possesses of decomposing and scattering solar light, is called its *dispersive power*, and the phenomenon is called *dispersion*.

The phenomenon of dispersion is shown in Fig. 205. A beam of light entering a hole in the shutter of a darkened

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How are all points of the horizon illuminated? What are flashes? Explain their production. Explain Fig. 204. (**305.**) How does a prism act to scatter rays? What is the dispersive power? Dispersion? Illustrate.

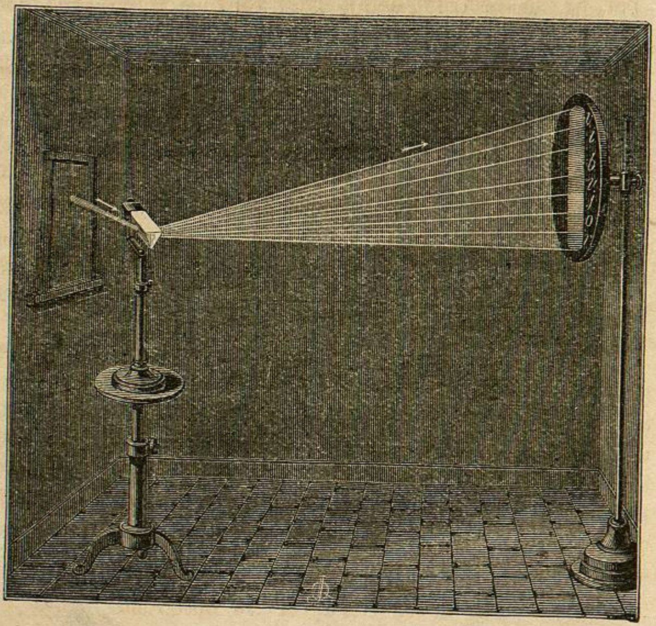

Fig. 205.

room falls upon a horizontal prism, having its refracting angle turned downwards. The whole beam is bent upwards, and at the same time is separated into seven distinctly colored beams, as may be seen by interposing a screen at the distance of several feet to receive them.

The elongated image formed upon the screen is called the *solar spectrum*, and counting from below upwards, the following is the order of the colors shown upon the screen: 1st, *red* at *r*; 2d, *orange* at *o*; 3d, *yellow* at *j*; 4th, *green* at *v*; 5th, *blue* at *b*; 6th, *indigo* at *i*; and 7th, *violet* at *v*. Besides the colored rays, it can be shown there is an invisible space below *r*, where the heat is greater than at any other

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What is the solar spectrum? Give the colors of the spectrum in their order. What are heat and actinic rays?

part of the spectrum, and a space above *v*, where the chemical effect is greater than at any other part of the spectrum. These invisible rays have been called *heat rays* and *actinic rays*.

In the figure, those rays which lie lowest are least refracted; thus heat rays are less refracted than red rays, red rays less than orange ones, and so on to the actinic rays, which are more refracted than any of the colored rays.

Colors in light correspond to pitch in sound. The red waves are the longest of the colored ones, and correspond to sounds of a low pitch; violet waves are the shortest, and correspond to sounds of a high pitch. The range of colors that are visible to the eye is much less than that of sounds that are audible to the ear.

Between the seven colors above mentioned, there is every variety of shade, so that a colorless ray of light is not only resolved into seven separate rays, but it is actually resolved into an infinite number of rays. It will however, be found convenient to consider them in seven groups, as before stated.

Different media possess different dispersive powers.

The Seven Colors of the Spectrum.

306. If any one of the seven colored rays of the spectrum be allowed to pass through a hole in a screen and fall upon a second prism, it will be deviated as before, but no further dispersion will take place. This fact is expressed by saying that the colors of the spectrum are *simple colors*.

The lengths of the waves necessary to produce any color have been measured, and it is found that in order to produce the extreme red light the length of the wave must be 0.0000266th of an inch, and to produce the extreme violet, this length must be 0.0000167th of an inch. These facts indicate that in *red* light the number of vibrations in one second is 458 millions of millions, and in *violet* light the number of vibrations per second is 727 millions of millions.

Which are most, and which least refracted? What relation do colors bear to sound? Into how many actual rays is a ray of light divided? (**306.**) What are simple colors? Why so called? *How many vibrations per second in red light? In violet light?*

Heat Rays and Actinic Rays.

307. The seven rays enumerated differ in illuminating power, the middle rays being those which possess the greatest illuminating power. That is, the most powerfully illuminating rays lie midway between the heat rays and the actinic rays.

If a thermometer be held for a time in the different rays, beginning at the violet, it will show an increase of heat till it comes outside of the red rays, where it is greatest.

The actinic rays are those which produce chemical changes. If a strip of paper, prepared with nitrate of silver, be placed in the spectrum, it will be least changed in the red, and in passing towards the violet end, this change will increase till it becomes the greatest beyond the violet.

Recomposition of Light.

308. The seven colors produced by a prism may be reunited so as to produce white light.

1. If we decompose light by a prism, and then receive it upon a second prism exactly like it, having its refracting angle turned in an opposite direction, it will be recomposed, and emerge as white light.

This amounts to nothing more than passing light through a medium bounded by parallel plane faces.

2. If the light, after being decomposed, is received upon a double convex lens, it will be recomposed, and if a screen be held at the focus of the lens, an image will be formed entirely free from color.

The manner of performing this experiment is shown in Fig. 206.

(**307.**) Which are the most illuminating rays? How is their heating power? What are actinic rays? Which produce the greatest chemical effect? How shown? (**308.**) May the rays be reunited? First method? *To what is this equivalent?* Second method?

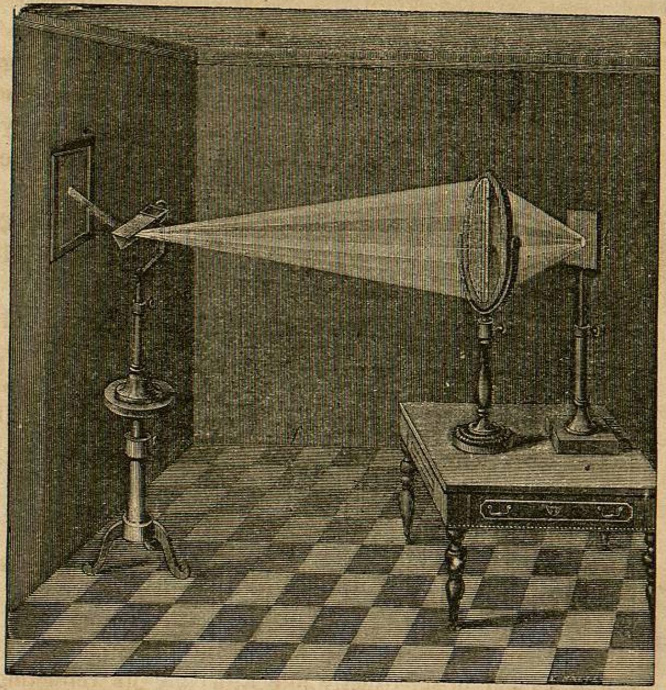

Fig. 206.

3. If the decomposed light be received upon a concave mirror, it will in like manner be recomposed and a colorless image produced.

4. If a circular disk of card-board be painted as shown in Fig. 207, in sectors, the colors being distributed according to intensity and tint, as in the spectrum, it will be found on rotating the disk rapidly by a piece of mechanism shown in Fig. 208, that the separate colors blend into a single one, which is a grayish white.

The color from any sector produces upon the eye an impression

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Third method? Fourth method?