II. REFLECTION OF LIGHT.

1. Definition.—Light falling on a surface is divided into two portions. One enters the body; the other is reflected * according to the familiar law of Motion and of Sound: The angle of incidence is equal to that of reflection.

2. Action of Rough and Polished Surfaces.—When the surface is rough, the numerous little elevations scatter the reflected rays in every direction, forming *diffused* light. Such a body can be seen from any point. When the surface is polished, the rays are uniformly reflected in particular directions, and may bring to us the images of other objects. We thus see non-luminous objects by irregularly-reflected (diffused) light, and images of objects by regularly-reflected light. †

3. Mirrors.—All highly-reflecting surfaces are mirrors. These are of three kinds—*plane*, *concave*, and *convex*. The first has a flat surface; the second, one

pose the waves are vibrating E. and W., others N. and S., and others toward all other possible points of the compass in succession.

* The amount of light reflected varies with the angle at which light falls. Thus, if we look at the images of objects in still water, we notice that those near us are not so distinct as those on the opposite bank. The rays from the latter striking the water more obliquely, are more perfectly reflected to the eye.—Fill any dark-colored pail with water tinted with bluing or red ink. The color will be quite invisible to a spectator at a little distance. Now insert in the water a plate. This will reflect the transmitted light and reveal the hue of the water.

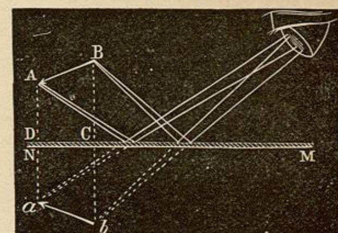
† The most perfectly polished substance, however, diffuses some light—enough to enable us to trace its surface; were it not so, we should not be aware of its existence. The deception of a large plate-glass mirror is often nearly complete; but dust or vapor, increasing the irregular reflection, will bring its surface to view.

like the inner surface of a hollow globe; the third, like part of its outer surface. The general principle of mirrors is that *the image is seen in the direction of the reflected ray as it enters the eye.*

(1.) Plane Mirrors.—Rays of light retain their relative direction after reflection from a plane surface.* While standing before a plane mirror, one sees his image erect and of the same size as himself. It is, however, reversed right and left.

Why the image is as far behind the mirror as the object is in front. Let *AB* be an arrow held in front of the mirror *MN*. Rays of light from the point *A* striking upon the mirror at *C*, are reflected, and enter the eye as if they came from *a*. Rays from *B* seem to come from *b*.

Fig. 139.



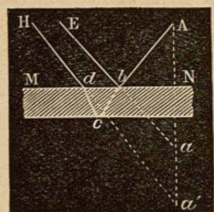
Since the image is seen in the direction of the reflected rays, it appears at *ab*, a point which can easily be proved to be as far behind *MN* as the arrow is in front of it. Such an image is called a

* The perpendiculars are not given in the figures of the book, as *the pupil at recitation should draw all the cuts on the blackboard, erect the perpendiculars, and demonstrate the location of the reflected ray.* It will aid in drawing the perpendicular to a convex or concave surface, to remember that it is a radius of the sphere of which the mirror forms a part. A book held in various positions before a looking-glass illustrates the action of plane mirrors. A beam of light admitted into a dark room and reflected from a mirror will show that the angles of incidence and reflection are in the same plane. Many of the grotesque effects of concave and convex mirrors may be seen on the inner and outer surfaces of a bright spoon, call-bell, or metal cup (see "Mayer & Barnard's Light" for inexpensive experiments).

virtual one, as it has no real existence apart from the observer's eye.

Why we can see several images of an object in a mirror. Metallic mirrors form only a single image. If, however, we look obliquely at the image of a candle in a looking-glass, we shall see several images, the first feeble, the next bright, and the others diminishing in intensity. The ray from A is in part reflected to the eye from the glass at b, and gives rise to the image a; the remainder passes on and is reflected from the metallic surface at c, and coming to the eye forms a second image a'. The ray cd, when leaving the glass at d, loses a part, which is reflected back to form a third image. This ray in turn is divided to form a fourth, and so on.

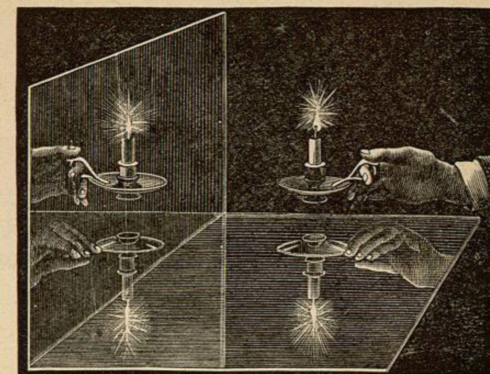
FIG. 140.



If two mirrors are arranged as in Fig. 141, three images of a candle may be seen. (Let the pupil trace the formation of each by the diagram of Fig. 142.) To vary the experiment, hold the mirrors together like the covers of a book placed on end, and put the candle between them on the table, opening and shutting the mirror-cover so as to vary the angle; or hold the mirrors parallel to each other with the light between them. When the mirrors are inclined at 90°, three images are formed; at 60°, five images; and at 45°, seven images. As the angle increases, the number diminishes. The images are upon the circumference of a circle whose center

is on a line in which the reflecting surfaces would intersect if produced. Where the mirrors are parallel the

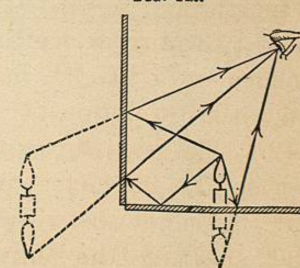
FIG. 141.



Multiple Reflection.

images are in a straight line. They become dimmer as they recede, light being lost at each reflection.—The *Kaleidoscope* contains three mirrors set at an angle of 60°. Small bits of colored glass at one end reflect to the eye at the other multiple images which change in varying patterns as the tube is revolved.

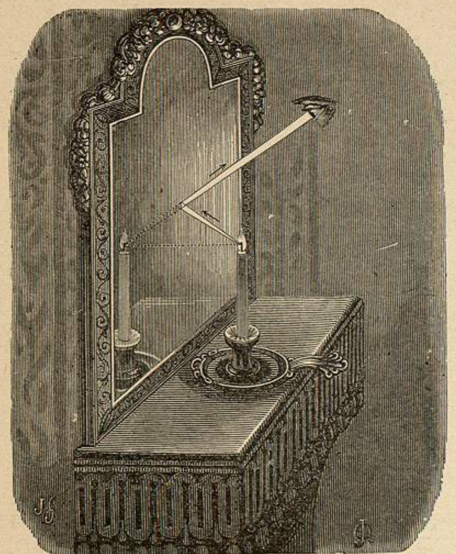
FIG. 142.



Images seen in water are symmetrical, but inverted. The reason of this can be understood by holding an object in front of a horizontal looking-glass and noticing the angle at which the rays must strike the surface in order to be reflected to the eye.

When the moon is high in the heavens, we see the image in the water at only one spot, while the rest of the surface appears dark. The light falls upon all parts, but each ray is reflected from only one point at the proper angle to reach the eye. Each observer sees the image at a different place. When the surface of the water is ruffled, a tremulous line of light is reflected from the side of each tiny wave that is turned toward us. As every little billow rises, it flashes a gleam of light to our eyes, and then sinking, comes up beyond, to reflect another ray.

Fig. 143.

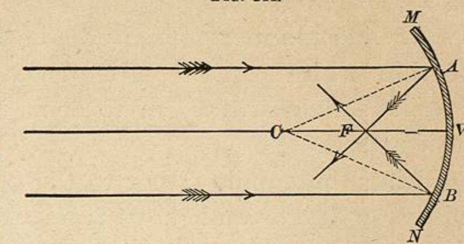


Reflection of Light.

(2.) A Concave Mirror tends to collect the rays of light to a focus. In Fig. 144, *C* is the *center of curvature*, *i.e.*, the center of the hollow sphere of which the mirror is a part; *V* is the *vertex*, or middle of the mirror; *F* is the *principal focus;* it is half-way between *C* and *V*. Any ray which passes through *C* is an *axis;* it is called the *principal* axis

if it pass also through *V*, otherwise it is a *secondary* axis. All axial rays are reflected back upon their own paths. All rays parallel to the principal axis cross at the principal focus after reflection, and conversely all rays which pass through the principal focus will be reflected parallel to the principal axis.* An image is *real* if the rays after reflection cross before reaching the eye; it will appear to be at the crossing point. Otherwise, the image is *virtual*.

Fig. 144.



Parallel Rays Reflected to the Focus.

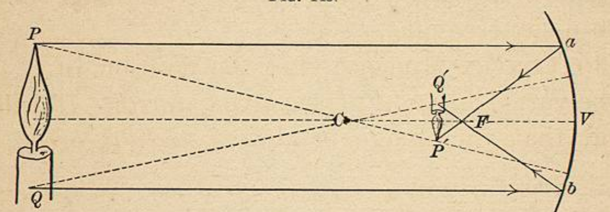
Images formed by Concave Mirrors.—In a dark room place a candle (*PQ*, Fig. 145) in front of a concave mirror at some distance beyond its center of curvature. A *small inverted image* of it will appear to be suspended in mid-air near its focus. It is easy to determine the position of this image. From *P* draw an axial ray through *C*; it will be reflected back on its own path, hence the image of *P* must be

* These statements are approximately true only for mirrors of slight curvature, where the angle *MCN*, or *angular aperture*, does not exceed 8° or 10°. When greater, the rays reflected near the edge of the mirror meet the *principal axis VC*, nearer the mirror than *F*. This is called the *aberration* of the mirror. The reflected rays will then cross at points in a curved surface called a *caustic*. A section of such a curve can be seen when the light of a candle is reflected from the inside of a cup partly full of milk. All of these phenomena can be proved mathematically to be necessary consequences of the one law, that the angles of incidence and reflection are equal.

on this line. From P draw also a ray, Pa, parallel to the principal axis; after reflection it will pass through the focus, F, and cross the secondary axis at P', which is hence the position of the image of P. In like manner we may determine Q'. If a piece of thin white paper or roughened glass be put at $P'Q'$, the light will seem to come from it since the rays cross here.

Bring the candle closer to the mirror. The image will grow larger and move from F toward C. When the candle reaches C, the image will fall upon it and

Fig. 145.



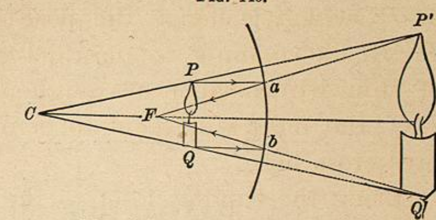
Inverted Real Image of a Candle.

just cover it. When it reaches $P'Q'$, the image will have receded to PQ, and in every case *the ratio of the lengths of candle and image will be the same as the ratio of their distances from C.* P and P' are called *conjugate points;* for they are so related together that an object placed at one of them will be imaged at the other.

If the candle be brought to F, the image will have grown still larger and more distant till it has vanished. When brought within F, the image suddenly appears as if it were *behind* the mirror, *large*

and erect. Let the student trace the rays, as shown in Fig. 146, and satisfy himself that they can never cross after reflection. The image is hence *virtual;* it can not be caught on a screen; but its apparent length is as much *greater* than that of the candle as its apparent distance from C is greater. Moreover, it appears erect, and not inverted like the real image of the more distant candle.

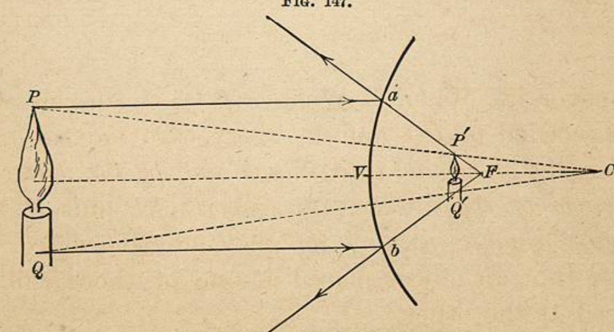
Fig. 146.



Virtual Image in a Concave Mirror.

(3.) Convex Mirrors.—Let the position of a candle be varied in front of a convex mirror. It will be found that the image is always *virtual*, *erect*, and

Fig. 147.



Virtual Image in a Convex Mirror.

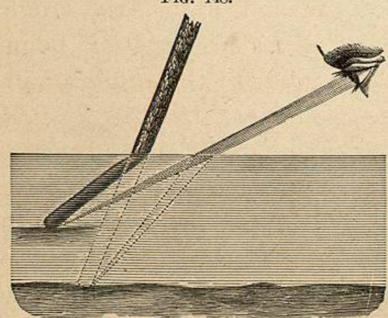
smaller than the candle. Parallel rays are made to *diverge* after reflection, as if they had come from a point within the sphere, half-way between its surface and center. The image of P is at the crossing point of the axial ray from P and the backward prolongation of the ray from P which was parallel before reflection. The student can easily trace the rays and determine the position of the image.

III. REFRACTION OF LIGHT.

1. Definition.—When a ray of light passes obliquely from one medium to another of different density, it is *refracted* or bent out of its course.—*Examples:* A spoon in clear tea appears bent.—An oar dipping in still water seems to break at the point where it enters the water.*—Put a cent in a bowl. Standing where you can not see the coin, let another

* In Fig. 148 is shown a stick sunk till the end is at the bottom of the water. Rays of light from this end are bent as they emerge from the liquid and reach the eye as if they had come from a point considerably higher. The entire bottom, therefore, seems lifted up. Hence, water is always deeper than it appears. Look obliquely into a pail of water, then place your finger on the outside where the bottom seems to be; you will be surprised to find the real bottom is several inches below.—Fill a glass dish with water, and, darkening the windows, let a sunbeam fall upon the surface. The ray will bend as it enters. Dust scattered through the air will make the beam distinct.

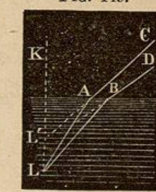
Fig. 148.



Apparent breaking of a Stick in Water.

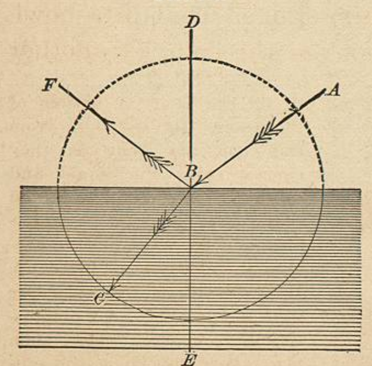
person pour water into the vessel, when the coin will be lifted into view. To understand the apparent change of position, remember that *the object is seen in the direction of the refracted ray as it enters the eye.* Let L, Fig. 149, be a body beneath the water. A ray, LA, coming to the surface, is bent away from the vertical, LK, and strikes the eye as if it came from L'. The object will therefore apparently be elevated above its true place.

Fig. 149.



2. Laws of Refraction.—From any point, A, Fig. 150, let a beam of light, AB, pass through air and meet a denser transparent medium at B, such as water or glass. At this point let a line, DE, be drawn perpendicular to the surface. Then some of the light will be reflected at B, the angle of reflection DBF being equal to the angle of incidence, DBA. A little of it will be absorbed and changed into heat. The rest will be transmitted, but its direction changed to BC. This apparent breaking of the ray is called *refraction*, and the angle EBC, which is less than DBA, is the *angle of refraction.* If the source of light were at C, its direction on emerging at B

Fig. 150.



Reflection and Refraction.