Reflection by Transparent Bodies.

275. We have just seen that glass, notwithstanding its transparency, reflects light enough to form an image. The same is the case with other transparent bodies, of which water forms a conspicuous example.

Fig. 161.

Fig. 161 represents the phenomenon of reflection from the surface of still water. It shows how the reflected rays produce images of objects above the water, which are symmetrically disposed with respect to the surface of the water. The case is entirely the same as though the images had been formed by a horizontal looking-glass.

Curved Mirrors.

276. A Curved Mirror is one in which the reflecting surface is curved. The most important class of curved mirrors, is that in which the reflecting surface is a portion

(**275.**) *Do transparent bodies reflect light? Explain the reflection from water.* (**276.**) What is a Curved Mirror?

of a sphere. When the reflection takes place from the hollow or concave side, the mirror is called *concave;* when the reflection takes place from the outer or convex side, the mirror is called *convex.*

Concave Mirrors.

277. A Concave Mirror is one in which the reflection takes place from the concave side of a curved surface.

We shall consider the case in which the reflecting surface is a portion of the surface of a sphere cut off by a plane.

The following definitions apply equally to concave and convex mirrors:

The middle point of the mirror is called its *vertex.* The centre of the sphere, of which the mirror forms a part, is called the *optical centre.* The indefinite straight line through the optical centre and the vertex, is called the *principal axis*, or sometimes simply *the axis.* Any plane section through the axis is called *a principal section.*

Thus, MN, Fig. 162, represents a principal section of a concave mirror, A is its vertex, C its optical centre, and AX is its principal axis.

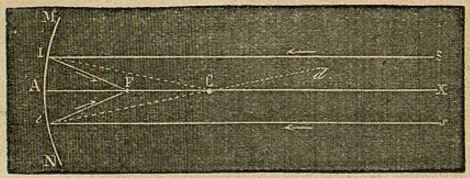


Fig. 162.

It is to be observed, that in practice the surface of a curved mirror is only a very small part of the surface of the sphere of which it forms a part.

Concave? Convex? (**277.**) What is a Concave Mirror? What is the vertex? The optical centre? The principal axis? A principal section? Illustrate.

Principal Focus of a Concave Mirror.

278. A Focus is a point in which deviated rays meet. When these rays are parallel to the axis, the focus is called the *Principal Focus.*

In Fig. 162, *SI* and *si*, are two rays parallel to the axis. *CI* and *Ci* are normals at the points of incidence, *I* and *i*. *IF* and *iF* are reflected rays, making the angles of reflection equal to the angles of incidence. When the mirror is small, compared with the whole sphere, all other rays parallel to the axis are reflected to the same point, *F*. Hence, from the definition, *F* is the principal focus. It can be shown that the principal focus is on the axis, and midway between the vertex and optical centre. We shall always designate the principal focus by the letter *F*.

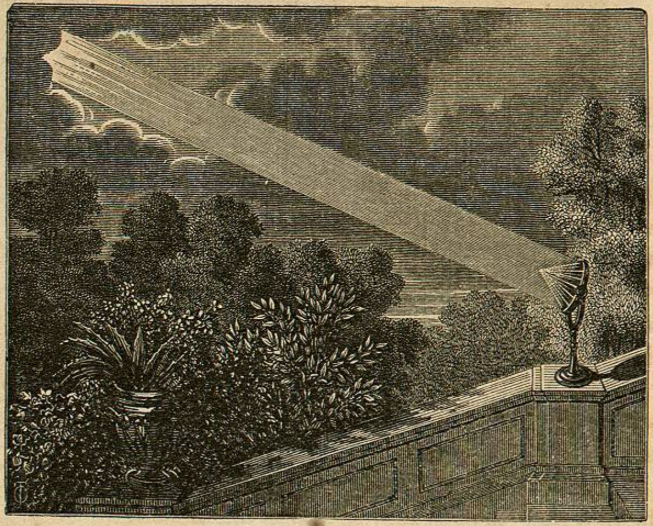


Fig. 163.

(**278.**) What is a Focus? The Principal Focus? Illustrate.

Fig. 163 shows the manner of determining the principal focus by experiment, making use of a beam of light coming from the sun. In this form the concave reflector may be used to collect the rays for the purpose of developing a great amount of heat.

Conjugate Foci.

279. If the rays of light emanate from some point of the axis not infinitely distant from the mirror, they will be brought to a focus at some point of the axis, generally

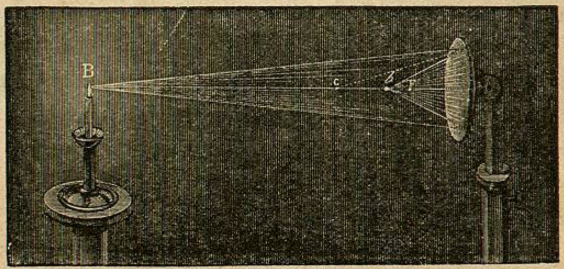


Fig. 164.

different from *F*. Thus, in Fig. 164, the pencil of rays, coming from the point *B*, are brought to a focus at *b*, between *F* and *C*. Had the rays emanated from *b*, they would have been brought to a focus at *B*. These points are so related as to receive the name of *conjugate foci.* Hence we have the following definition :

Conjugate Foci are any two points so related that a pencil of light, emanating from either one, is brought to a focus at the other.

That one from which the light actually proceeds is called the *radiant ;* thus, in Fig. 164, *B* is the radiant.

Explain the manner of determining the principal focus by experiment.
(**279.**) What are Conjugate Foci? The radiant?

The following are some properties of conjugate foci of concave mirrors:

If the radiant is on the axis and at an infinite distance from the mirror, the rays will be parallel, and the corresponding focus is at *F*, the principal focus. (See Fig. 162.)

If the radiant approaches the mirror, the focus recedes from it.

If the radiant is beyond the optical centre, *C*, the focus is between *F* and *C*.

If the radiant is at *C*, the focus is at *C* also.

If the radiant is between *C* and *F*, the focus is beyond *C*, in the direction *CX*.

If the radiant is at *F*, the focus is at an infinite distance, that is, the reflected rays are parallel.

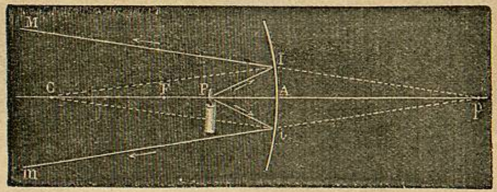


Fig. 165.

If the radiant is between *F* and *A*, as shown in Fig. 165, the rays are reflected so as to diverge, and on being produced backwards, meet at *p*. In this case the focus is behind the mirror, and is said to be *virtual* (Art. 273).

If the radiant is not on the axis, the pencil of rays is oblique, but it is still brought to a focus, and if not far distant from the axis, the radiant and focus enjoy properties entirely analogous to those just explained.

If the radiant is at an infinite distance, where is the conjugate focus? If the radiant approaches the mirror, how does the focus move? Where do they meet? If the radiant is at the principal focus, where is the conjugate focus? When is the focus virtual? Explain the law of an oblique pencil of rays.

Formation of Images by Concave Reflectors.

280. If an object be placed in front of a concave mirror, a pencil of rays will proceed from each point of the object, and after reflection will be brought to a focus either real or virtual. The collection of foci thus formed, make up an *image of the object.*

Real Images.

281. If the object is further from the mirror than the principal focus, the image will be inverted, and real.

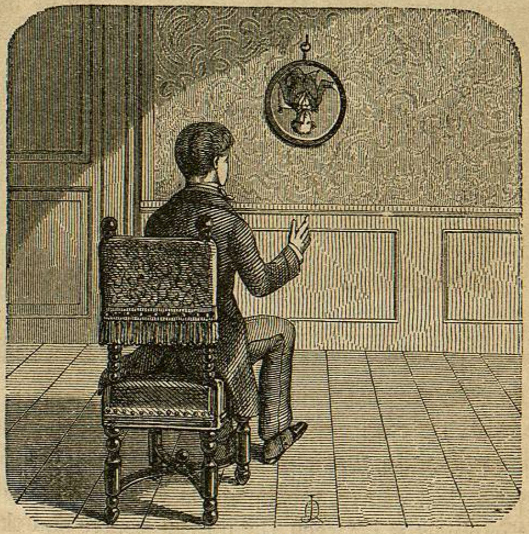


Fig. 166.

Fig. 166 represents an inverted image formed by a concave reflector. That the image is real, may be shown by throwing it upon a screen or a sheet of paper.

(**280.**) How is an image of an object formed? (**281.**) When is the image real and inverted?

Fig. 167 shows the course of the rays in forming a real image by means of a concave mirror. In this case the image of a distant church is formed and thrown upon a sheet of paper; the image is a perfect picture, not only in outline but in color; its only defect is that it is inverted.

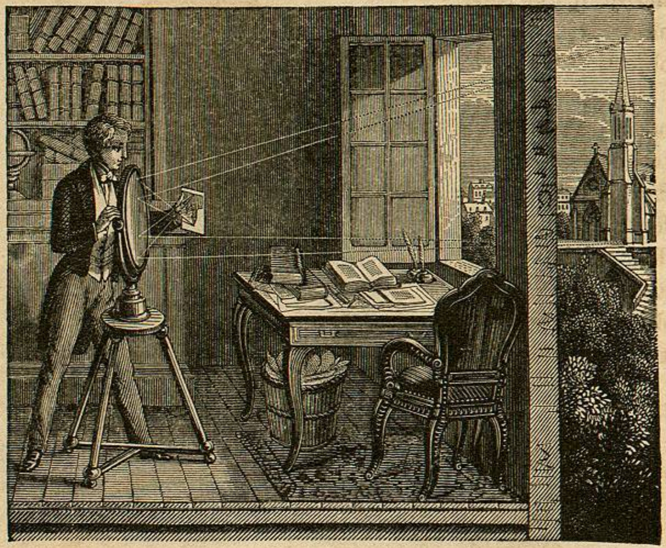


Fig. 167.

When the object is at a greater distance from the mirror than the optical centre, the image is less than the object; when the object is between the optical centre and the principal focus, the image is greater than the object. In this case the reflector may be used as a magnifier.

Explain the course of the rays in forming an image. When is the image smaller than the object? When larger?

Virtual Images.

282. When the object is between the principal focus and the mirror, the image is virtual and erect, as shown in Fig. 168. Furthermore, it is larger than the object, or magnified.

Fig. 168.

Fig. 169 shows the course of the rays in forming a virtual and erect image. The face is between the principal focus, *F*, and the mirror. The pencils of rays from *a* and *b* are reflected so as to diverge from the virtual foci, *A* and *B*. It is easily seen that the image is larger than the object.

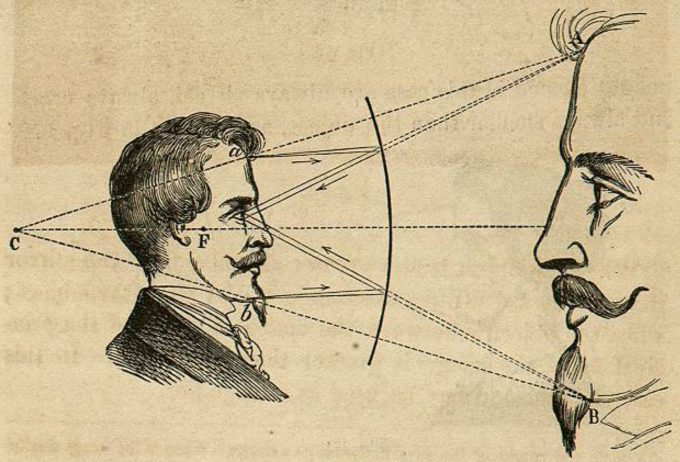


Fig. 169.

(**282.**) When is the image virtual? Explain the course of the rays in forming a virtual image.

Formation of Images by Convex Reflectors.

283. In convex reflectors the reflection takes place from the outer or convex surface.

From what has been said of concave mirrors, it will readily be seen how images are formed by convex reflectors. The

Fig. 170.

images formed in this case are always virtual, always erect, and always smaller than the object, as is shown in Fig. 170.

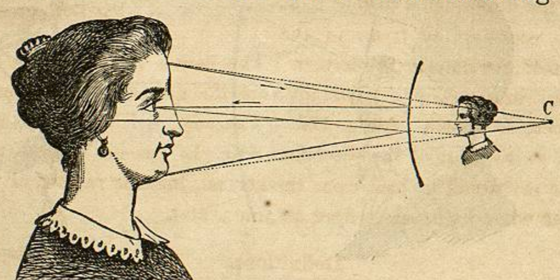


Fig. 171.

Fig. 171 shows the course of the rays in the formation of

(**283**) Do convex reflectors form erect or inverted images? Are they magnified or diminished? Explain the course of the rays in this reflector.

an image by means of a convex mirror. After what has been said in the preceding article, this figure needs no explanation.

III.—REFRACTION OF LIGHT.—LENSES.

Refraction.

284. Refraction is the deviation or bending which a ray of light undergoes in passing from one medium into another.

When a luminous ray falls obliquely upon the surface which separates two transparent media, it is divided into three parts, as has been stated (Art. 266). The first part is diffusely reflected, the second is regularly reflected, and the third part enters the second medium, changing its direction.

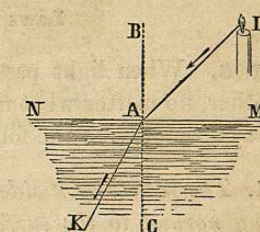


Fig. 172.

The cause of this change of direction is a change in the elasticity and density of the ether in passing from one medium into the other, which causes a change in the velocity of the ray. Thus the density and elasticity of ether in water are different from what they are in the atmosphere, so that light travels considerably faster in the latter medium than in the former. This causes the ray, on passing from air into water to bend towards the normal at the point of incidence, as shown in Fig. 172. The ray, *LA*, is bent from its course so as to take the direction *AK*. In passing from water to air, the ray would be bent from the normal, just the reverse of what happens when light passes from air into water.

Definitions.

285. The ray before refraction is called the *incident ray ;* thus, *LA* (Fig. 172), is an incident ray.

(**284.**) What is Refraction? *What is the cause of refraction? Which way is the ray bent?* (**285.**) What is the incident ray? Illustrate.

The point at which the ray is deviated or bent, is called *the point of incidence;* thus, A is a point of incidence.

The ray after deviation is called *the refracted ray;* thus, AK is a refracted ray.

The angle which the incident ray makes with the normal at the point of incidence is called *the angle of incidence*, and the plane of this angle is *the plane of incidence.* Thus, LAB is an angle of incidence, and the plane, LAB, is the plane of incidence.

The angle which the refracted ray makes with the normal at the point of incidence is called *the angle of refraction*, and the plane of this angle is *the plane of refraction;* thus, the angle KAC is an angle of refraction, and the plane of this angle is a plane of refraction.

Laws of Refraction.

286. When light passes from any given medium into another, no matter what may be the angle of incidence, it always conforms to the following laws:

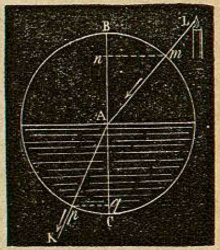
1. *The planes of incidence and refraction coincide, both being normal to the surface separating the media, at the point of incidence.*

2. *The sine of the angle of incidence is equal to the sine of the angle of refraction multiplied by a constant quantity.*

The constant quantity referred to varies with the media, but is the same for any given medium. It is called the *index of refraction.*

What is the point of incidence? Illustrate. The refracted ray? Illustrate. The angle and plane of incidence? Illustrate. The angle and plane of refraction? Illustrate. (**286.**) What is the first law of refraction? The second law? What is the index of refraction?

The second law may be illustrated by the figure in the margin. Let A be the point of incidence on a surface separating air from water. With A as a centre, describe a circle, $BmCp$. Let LA be an incident ray, and AK the refracted ray. Draw mn and pq perpendicular to the normal, BC. Then will these lines be the sines of the angles of incidence and refraction, and we shall have in the particular case of air and water, mn equal to pq multiplied by $1\frac{1}{3}$, whatever may be the inclination of LK. Here $1\frac{1}{3}$ is the index of refraction. For air and glass the index of refraction is $1\frac{1}{2}$.



Refractive power of Bodies.

287. Different bodies possess different refractive powers. NEWTON observed that, as a general rule, the refractive power was greatest for combustible bodies, or bodies containing combustible elements, such as alcohol, ether, oils, &c., which contain both hydrogen and carbon. He found that the diamond was more highly refractive than any other body, and hence inferred that it was a combustible body, an inference that has since been confirmed. It is to its high refractive power that the diamond owes its brilliancy as a jewel. Gases are not so highly refractive as liquids, but their refractive power may be increased by compression, which augments their density.

Experimental proofs of Refraction.

288. If a beam of light be introduced through a hole in a shutter of a dark room, and allowed to fall upon the surface of water in a glass vessel, as shown in Fig. 173, the bending of the beam as it enters the water may be seen by

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How may the second law be illustrated? (**287.**) *Do all bodies refract equally? Explain* NEWTON'S *views?* (**288.**) Explain the method of proving refraction experimentally?

the eye. The course of the ray in the air may be rendered more apparent by filling the air with fine dust or smoke, as, for example, the smoke from gunpowder.

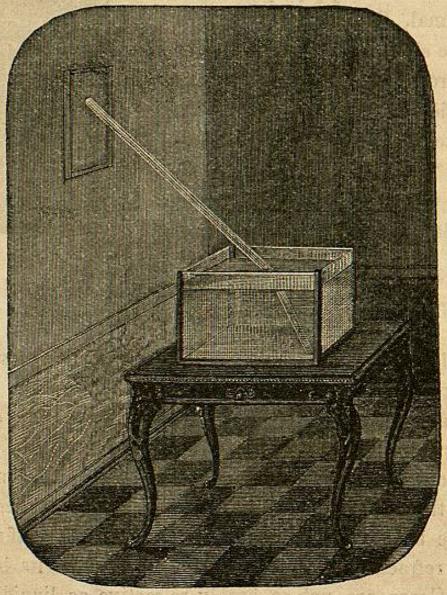

Fig. 173.

Let a piece of money be placed at the bottom of an empty vessel, and then take a position such that the coin shall just be hidden by the wall of the vessel. Whilst in this position, if water be poured into the vessel, the rays from the coin will be refracted so as to render it visible. The effect of refraction in this and similar cases, is to make the bottom of the vessel appear higher than it is in reality, as shown in Fig. 174.

Explain a second method?

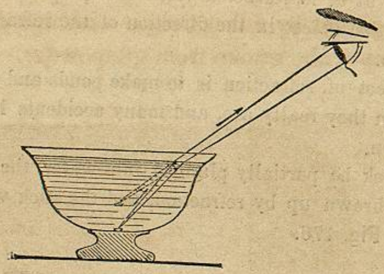

Fig. 174.

Some effects of Refraction.

289. One of the effects of refraction was explained in the last article. The principle has numerous applications. To a person standing on the shore, a fish in the water appears higher than his

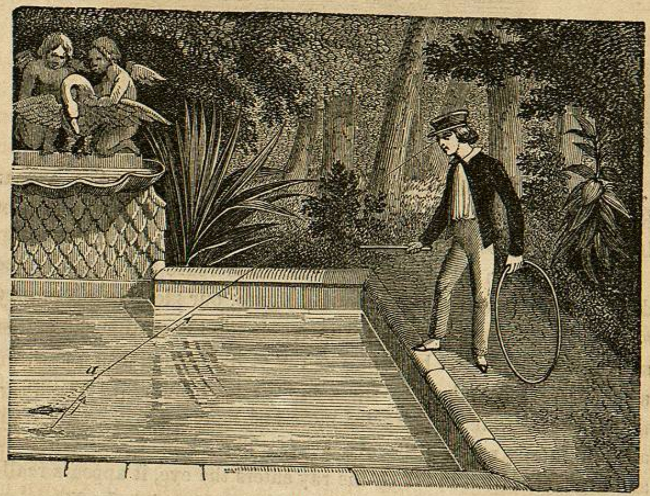

Fig. 175.

real position, as is shown in Fig. 175. The ray, in emerging from

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(**289.**) *Why does a fish seem higher in the water than he really is?*