the water at a, is refracted from the perpendicular, and the eye referring the object in the direction of the refracted ray, it appears thrown up.

One effect of refraction is to make ponds and rivers appear shallower than they really are, and many accidents have resulted from the illusion.

If a stick be partially plunged into water, the portion immersed will be thrown up by refraction, and the stick will appear bent, as shown in Fig. 176.

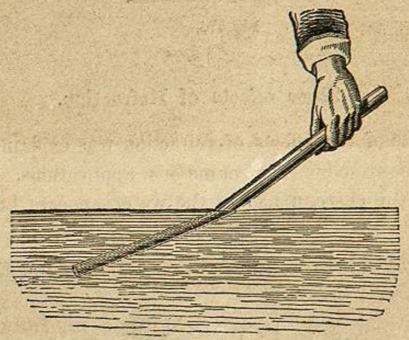

Fig. 176.

Refraction has the effect to make the heavenly bodies appear higher than they are, and thereby causes them to rise earlier and set later than they would do were there no atmosphere.

The manner in which refraction acts to increase the length of the days is shown by Fig. 177. In that figure, our globe is represented surrounded by the atmosphere. A represents the position of an observer, and AH is the horizon. A ray of light coming from the sun at S, whilst still below the horizon, falls upon the upper surface of the atmosphere, and is refracted more and more as it penetrates the air, and finally reaches the eye at A. The observer referring the sun to the direction in which the ray enters the eye, it appears really to be above the horizon when it is actually below it. In like man-

Explain the phenomenon. What effect has refraction on the apparent depth of ponds? Why? Explain the bent appearance of a stick in water. Effect on the heavenly bodies? How does refraction serve to increase the length of daylight?

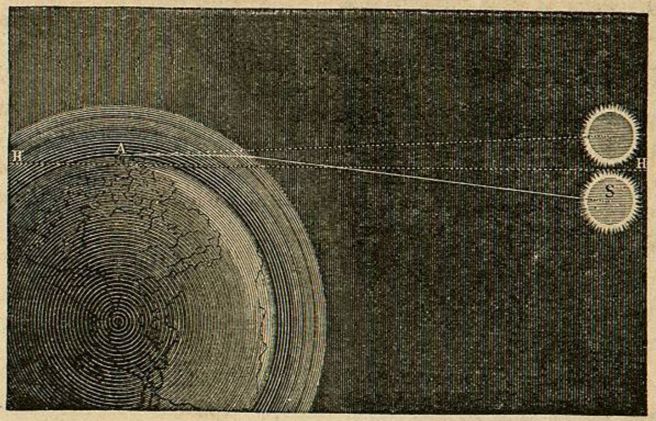

Fig. 177.

ner, at sunset, the sun seems to be above the horizon when in reality it is below it.

Total Reflection.

290. When light passes from one medium to a more refractive one, it will always be refracted, but not so when it passes into a less refractive medium, as when it passes from water or glass into air. In this case there is a limit to the angle of incidence, beyond which refraction can not take place.

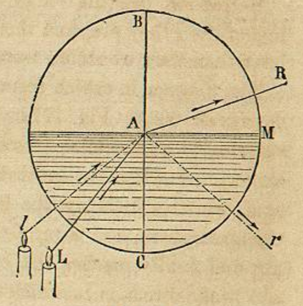

Fig. 178.

To illustrate this, let BMC, Fig. 178, represent a hollow globe half full of water. A ray of light coming from L to A, being normal to the surface of the globe, experiences no refraction there, but on reaching A, if the angle of incidence,

(**290.**) Explain the phenomenon of total reflection.

LAC, is small enough, it will be refracted from the normal, *BA*, and pass out into the air in some direction, *AR*. If, now, the angle of incidence exceeds 41°, as is the case with the ray, *lA*, it can no longer pass the surface, *AM*, but is reflected in the direction, *Ar*, making the angle *lAc*, equal to the angle, *CAr*.

This kind of reflection at the surface which separates two media, is called *internal reflection*, or *total reflection*. It is called total reflection because the light is all reflected, which is not the case under any other circumstances of reflection, no matter how nicely the reflecting surface may be polished.

It is in consequence of total reflection that we are unable to see the bottom of a pond of water when we look at it very obliquely, because the rays coming from the bottom towards the eye do not pass out into the air, but are internally reflected.

Mirage.

291. Mirage is an atmospheric phenomenon due to refraction and total reflection. In its simplest form, it consists of what sailors term looming; that is, by the effect of extraordinary refraction, objects on the shores of lakes and seas are thrown up higher than they naturally appear.

It is a matter of record that on one occasion the French coast for several leagues in extent was visible at Hastings, in England, though fifty miles distant. Looming takes place most frequently in very hot or very cold countries, and in those regions where the sea and land are pretty equally divided. It is due to different portions of the atmosphere becoming unequally heated.

Sometimes bodies are seen thrown up and inverted; this is due to extraordinary refraction and total reflection, some stratum of air acting as a reflector to the oblique rays thrown upon it. In this way inverted images of ships have been seen in the air, when the ships themselves were so far below the horizon as to be invisible.

Why can we not see the bottom of a pond when looking very obliquely? (**291.**) What is Mirage? *Explain looming. Explain inversion of objects.*

Sometimes a layer of atmosphere next the earth becomes a reflector, and in that case portions of the earth appear to the traveller like lakes and ponds; such appearances are frequent in desert countries when the heat is intense. To heighten the illusion, trees are often seen reflected from the surfaces of these apparent ponds. An example of this kind is shown in Fig. 179. The rays coming from the top

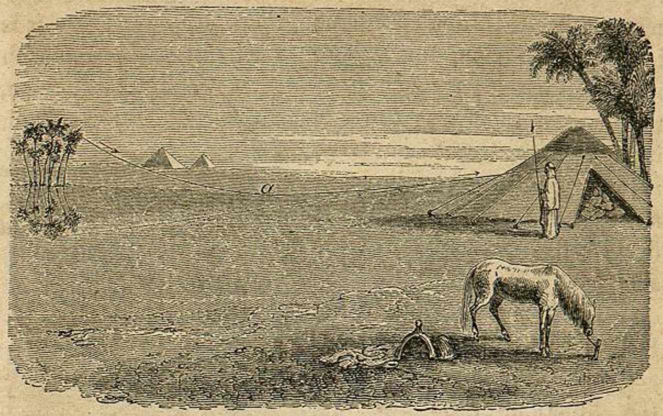

Fig. 179.

of the tree on the left of the picture, are totally reflected at *a*, from a layer of the atmosphere, and reach the eye of the observer at the tent. The observer refers the position of the tree top backwards along the direction of the dotted line, which causes the tree to appear inverted. In this case both the tree and its image are seen.

Now if we suppose both to be thrown up by extraordinary refraction, we shall have a phenomenon not unfrequently noticed, in which the object is seen elevated in the air, accompanied by an inverted image.

Many other curious phenomena are classed under the head of mirage, which we have not space to describe.

Explain the appearance of ponds and lakes in the desert. Explain the appearance of an object and an inverted image both thrown up.

Media with parallel Faces.

292. When a ray of light, *Lm*, Fig. 180, falls upon a medium bounded by plane faces, as a plate of glass, for example, it is refracted towards the normal and passes through the plate in some direction, *mn;* here it is refracted as much from the normal as it was towards it in the first instance, and the ray emerges in the direction *no*, parallel to *Lm*. The two refractions do not change the direction of the ray, but simply shift it slightly to one side or the other. Hence, in looking through a window, we do not see the direction of objects changed by the intervening glass.

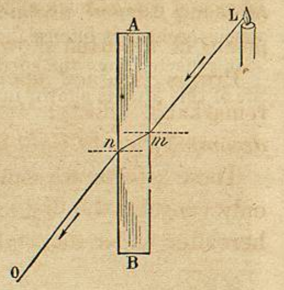

Fig. 180.

Prisms.

293. A Prism is a refractive medium bounded by plane faces intersecting each other.

Fig. 181 represents a prism mounted for optical experiments. It consists of a piece of glass with three plane faces,

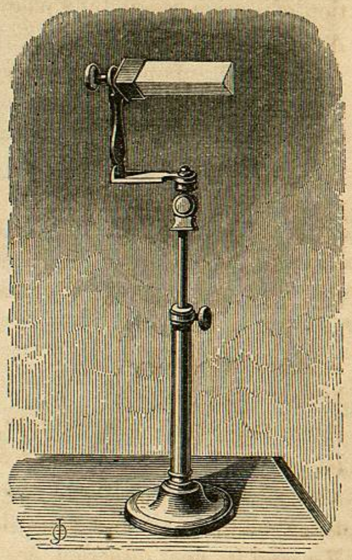
Fig. 181.

(**292.**) Is a ray of light bent from its course in passing through a medium with parallel faces? Explain the phenomenon. (**293.**) What is a Prism? Explain it.

meeting in parallel lines called *edges*. It is placed on a stand so that it can be elevated or depressed, and it also is capable of being turned around an axis parallel to the edges, by means of a button shown on the left.

Prisms produce upon light which traverses them, two remarkable effects: 1st, *a considerable deviation;* 2d, *a decomposition of light* into several different kinds.

These effects are simultaneous, but we shall at present only consider the first one, leaving the second to be studied hereafter under the name of *dispersion*.

Course of Luminous Rays in a Prism.

294. In order to follow the course of a ray of light in passing through a prism, let *nmo*, Fig. 182, represent a section of a prism made by a plane perpendicular to the edges. A ray of light, *La*, falling upon the face, *nm*, is refracted towards the normal, and passes through the prism in the direction, *ab;* here it falls upon the second face, *mo*, and is again refracted, but this time from the normal, and emerging into the air, takes the direction, *bc*. An eye situated at *c*, refers the object, *L*, backwards along the ray, *cb*, so that it appears to be situated at *r*. The total deviation is the angle between its original direction, *La*, and its final direction, *cr*.

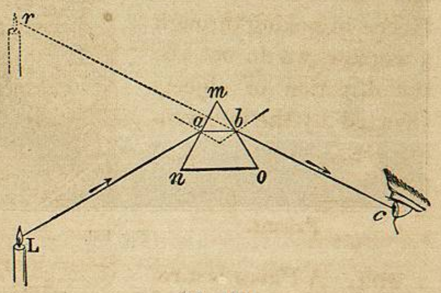

Fig. 182.

We see from the figure that the ray is bent from the

What effect has a prism on light? (**294.**) Explain the course of a ray through a prism.

edge in which the refracting faces meet, that is, it is bent towards the thick part of the prism; this deviation has the effect to make the object appear as though thrown towards that edge. The angle, *nmo*, is called the refracting angle of the prism.

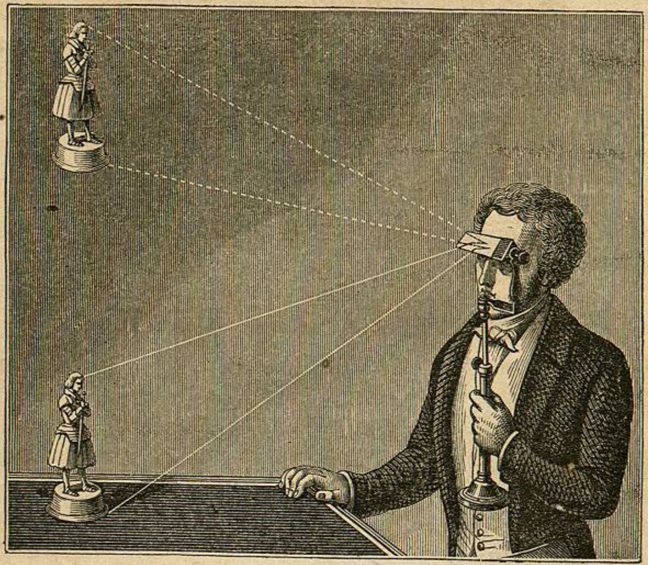

Fig. 183.

Fig. 183 shows the displacement of an object, caused by viewing an object through a prism. If the prism is vertical, the displacement is towards the right or left, according to the position of the refracting angle.

Lenses.

295. A Lens is a refracting medium, bounded by curved surfaces, or by one curved and one plane surface.

Which way is the ray bent? Explain Fig. 183. (**295.**) What is a Lens?

Lenses are usually made of glass, and are bounded by spherical surfaces, or by one spherical and one plane surface. The surfaces are made spherical, because they are more easily wrought by the glass grinder.

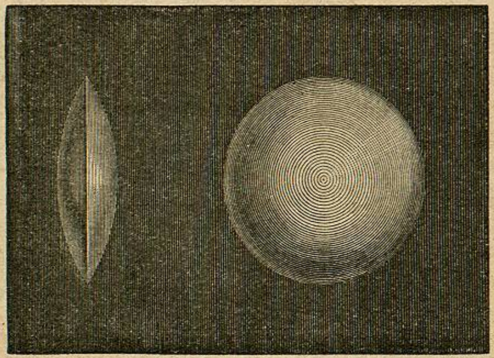

Fig. 184. Fig. 185.

Fig. 184 represents a side view, and Fig. 185 represents a front view of a lens, bounded by two spherical surfaces.

Classification of Lenses.

296. Lenses are divided into six classes, according to the nature and position of the bounding surfaces, sections of which are shown in Figs. 186 and 187.

The first three, represented in Fig. 186, are thicker in the middle than at their edges. These *converge* or collect rays of light, and are called *convergent lenses.*

The last three are thinner in the middle than at their edges. These *diverge* or scatter rays of light, and are called *divergent lenses.*

Of what are lenses made? (**296.**) How many kinds of lenses are there? What are convergent lenses? Divergent lenses?

These different lenses are named and described in the following definitions:

1. The *double convex* lens, *M*, bounded by two convex surfaces.

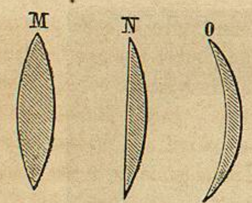

Fig. 186.

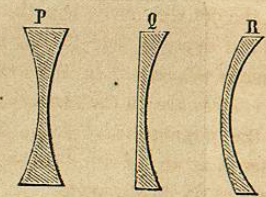

Fig. 187.

2. The *plano-convex* lens, *N*, bounded by one convex and one plane surface.

3. The *meniscus*, *O*, bounded by one concave and one convex surface, the concave surface being the *least* curved.

4. The *double concave* lens, *P*, bounded by two concave surfaces.

5. The *plano-concave* lens, *Q*, bounded by one concave and one plane surface.

6. The *concavo-convex* lens, *R*, bounded by one concave and one convex surface, the concave surface being the *most* curved.

In studying the effect of these lenses, it will be sufficient to consider the *double convex* and the *double concave* lenses as specimens of the classes to which they belong, the former representing the *convergent*, and the latter the *divergent* classes.

Name and describe the six kinds of lenses separately. What two are taken as specimens?

Definitions of Terms.

297. The centres of the bounding surfaces of a lens are called *Centres of Curvature;* thus, in Fig. 188, *c*, and *C*, are centres of curvature.

In the double convex lens the centre of curvature of each surface is on the opposite side of the lens; in the double concave lens the reverse is the case. In the meniscus and the concavo-convex lens, both centres are on the same side of the lens. In the plano-convex and the plano-concave lens, the centre of curvature of the plane surface is at an infinite distance, and in a perpendicular to the plane surface at its middle point.

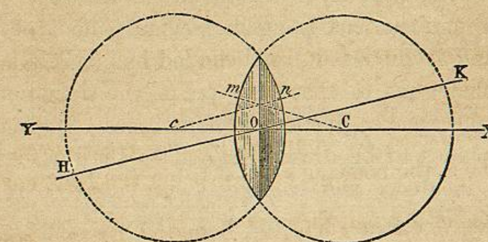

Fig. 188.

The straight line through the centres of curvature is called the *axis* of the lens; thus, in Fig. 188, *XY* is the axis.

It is demonstrated in higher optics, that there is always one point on the axis of a lens, such that the rays of light passing through it, are not deviated by the lens. This point is called the *optical centre*, and is of much use in the construction of images.

In practice it is usual to make the surfaces which bound double convex and double concave lenses, equally curved.

(**297.**) What are the Centres of Curvature of a lens? *Where are they in the double convex lens? Double concave? Meniscus? Plano-concave and plano-convex?* What is the axis? What is the optical centre? Its use? In practice, how are the curvatures of the surfaces?

When this is the case, as we shall suppose in what follows, the optical centre is on the axis, and midway between the two surfaces of the lens; thus, in Fig. 188, *O* is the optical centre, and any ray, *HK*, passing through it, is not deviated by the lens.

To find a normal at any point of the surface of a lens, we draw a line from that point to the corresponding centre of curvature; thus, *mC* and *nc*, are normals at the points *m* and *n*.

Action of Convex Lenses on Light.

298. When a ray of light falls upon one surface of a double convex lens, it is refracted towards the normal, passes through the lens, is again incident upon the second surface, and is refracted from the normal. This action is entirely analogous to that of a prism, the deviation being towards the thicker portion in both cases. In fact, if we suppose planes to be drawn tangent to the surfaces at the points of incidence and emergence, they may be regarded as the faces of a prism through which the ray passes.

Principal Focus.

299. If a beam of light, parallel to the axis, falls upon a lens, it will be collected by refraction in a single point. This

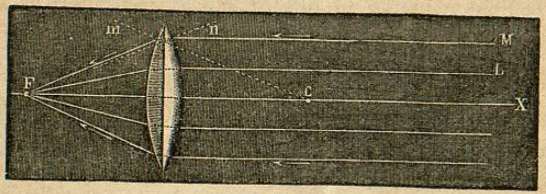

Fig. 189.

Where is the optical centre in this case? How do you find a normal? (**298.**) Explain the action of a convex lens on light. (**299.**) What is the principal focus?

point is called the *principal focus*, and its distance from the lens is called the *principal focal distance.*

The course of the rays is indicated in Fig. 189, in which the rays parallel to *CX*, are brought to a focus at *F*. Here, *F* is the principal focus.

It is to be observed that the rays will not be accurately brought to a focus, except in the case in which the surface of the lens is small, when compared with that of the whole sphere of which it forms part. This scattering of the rays from a focus is called *spherical aberration.* It is remedied in practice by covering up a part of the surface on which light falls, by a paper cover with an *aperture* in its centre.

Had the rays fallen upon the other side of the lens, they would have been brought to a focus as far to the right of the lens, as *F* is to the left of it.

Conjugate Foci.

300. Conjugate Foci are any two points so situated on the axis of a lens, that a pencil of light coming from one is brought to a focus at the other. That from which the light actually comes is called the *radiant.*

In Fig. 191, a pencil of rays, coming from *L*, is brought to a focus at *l*, had the light come from *l*, it would have been brought to a focus at *L*; *L* and *l* are conjugate foci, and in the case figured, *L* is the radiant.

When the radiant is at an infinite distance, the rays are parallel, and the corresponding focus is at *F*; this is the *principal focus.* As we have already seen, there are two such foci, one on each side of the lens. It will be sufficient for our purpose to suppose the light to come from the right, in which case the principal focus is on the left, at *F*.

Principal focal distance? Explain the course of the rays. *What is spherical aberration? How remedied?* (**300.**) What are Conjugate Foci? What is the radiant? Illustrate. When the radiant is at an infinite distance, where is the conjugate focus?

When the radiant is anywhere on the axis at a greater distance than the principal focal distance, the corresponding focus will also be at a greater distance from the lens than the principal focal distance, as shown in Fig. 190.

Fig. 190.

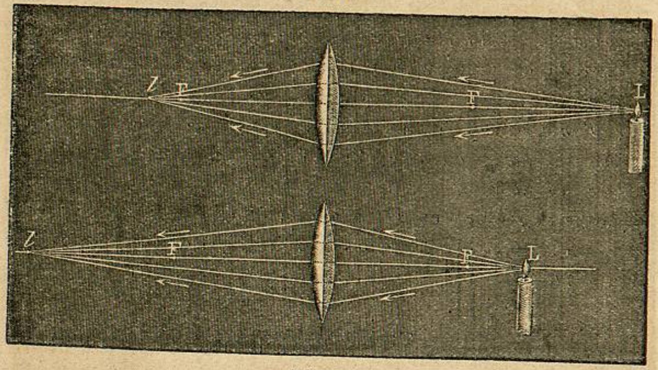

Fig. 191.

If the radiant approach the lens, the corresponding focus will recede from it, as is shown in Fig. 191.

If the radiant is at the principal focal distance, the refracted rays will be parallel, that is, the corresponding focus will be at an infinite distance, as is shown in the upper diagram of Fig. 193.

If the radiant is still nearer the lens, the rays will diverge after deviation, and will only meet the axis on being produced backwards, in which case the focus is *virtual*, as is shown in the lower diagram of Fig. 193. In this diagram *L* is the radiant, and *l* the virtual focus.

Thus far we have supposed the radiant to be situated on the principal axis; if it is on any line through the optical centre not much inclined to the axis, the corresponding

When the radiant is at a distance greater than the principal focal distance, where is the conjugate focus? When the radiant approaches the lens? When at the principal focus? If still nearer the lens? Suppose the radiant not on the axis?

focus will be on that line, and the laws which regulate the positions of conjugate foci, already considered, will be applicable.

These principles are of use in the discussion of images formed by lenses.

Fig. 192.

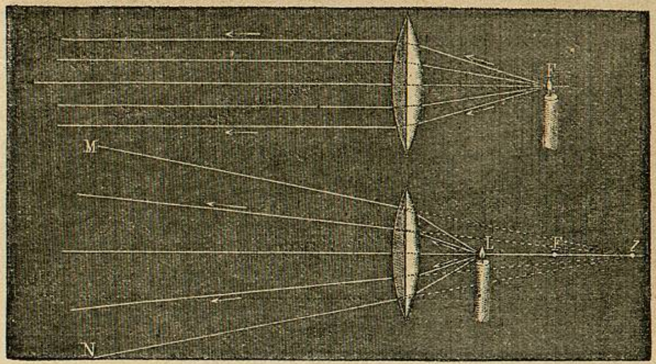

Fig. 193.

Formation of Images by Convex Lenses.

301. If an object be placed in front of a lens, each point of it may be regarded as a radiant sending out a pencil of rays. Each pencil is brought to a focus somewhere behind the lens. The assemblage of these foci makes up a picture of the object, which is called its *image*. When the object is at a greater distance from the lens than the principal focal distance, the image will be real and inverted. The course of the rays is shown in Fig. 194. The image is real, as may be shown by throwing it upon a screen; so long as the image is real, it is inverted, as may be seen by allowing it to fall upon a screen, or it may otherwise be shown from the fact that the axis of each pencil passes through the optical centre; hence the image of each point is on the opposite side of the axis from the point.

(**301.**) Explain the formation of an image by a lens.