2.5 RAY TRACING AND IMAGE FORMATION IN THIN LENSES

For thin lenses there are three special rays whose refractive behavior can be easily followed in a diagram. Two of these rays emerge from the definitions of F_1 and F_2, and the third ray is the undeviated ray, also called the **chief ray**, through the center of the lens as illustrated in Fig. 2.22.

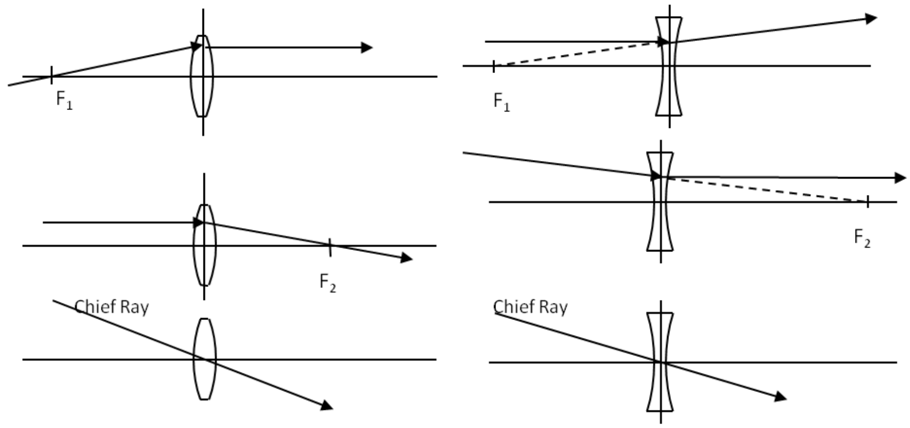

Figure 2.22: Three special rays for thin convex and concave lenses.

The image of a point on a given object in front of a lens is determined by drawing two of these special rays emanating from the point under consideration, and then noting what happens as they emerge on the other side of the lens. If the outgoing rays pass though a point, then a real image forms there, else if they diverge then the emerging rays are extended backwards to form a virtual image at the crossing point. We now illustrate the ray tracing method by examples.

2.5.1 Real Image by a Convex Lens

As usual we start with drawing the lens, the center plane of the lens, and the symmetry axis. Then we position the foci F_1 and F_2 symmetrically about the lens, and place the object at the object distance from the center plane of the lens. It is a good idea to keep the height of the object smaller then the height of the lens. It is also best to draw the object from the axis rather than straddling the axis. Label appropriate points of the object. In our example only the ends points O and P need labeling. We will work out the image of point P and by symmetry the image point of O will be on the axis in the plane containing the image point of P. Sometimes, it is a good idea to

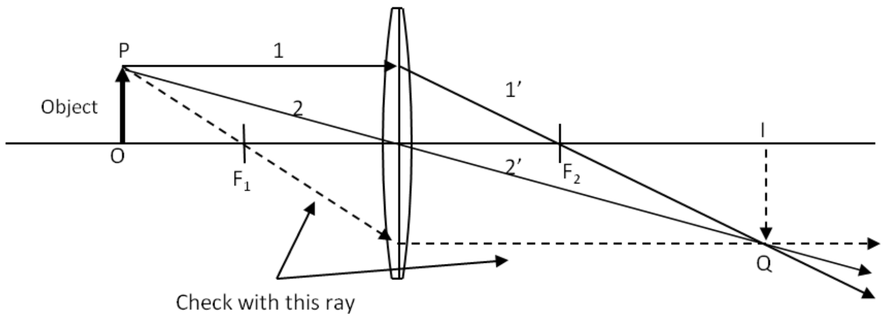

Figure 2.23: Real image formation in a convex lens by ray tracing.

draw the third special ray just to check the accuracy of the drawing. The drawing of the image formation is shown in Fig. 2.23.

The real image is not observable unless we place a screen at the site of the image. If you directly look at point Q in space you would not see anything even though the image is formed there; the rays from P that go through the lens just intersect at Q and continue on. Since in the given example, the rays emerging from the lens are converging towards Q, after intersecting at Q, they diverge away from each other.

2.5.2 Virtual Image by a Convex Lens

Once again, we follow the process outlined in the last sseubction, and draw two rays from an off-axis point of the object (see Fig. 2.24). Because the image is enlarged, during drawing you may have to extend the center line of the lens to accommodate the drawing e.g. point X in the ray labeled PXY. Note also that the ray PX does not pass through F_1 but is in the direction from F_1 when it strikes the center plane of the converging lens. This is one of the special rays discussed previously and it is equivalent to the ray that has passed through F_1 in the PX direction, and therefore, the outgoing ray XY will emerge parallel to the optical axis.

Here we get a virtual image which is larger than the object. This is the principle behind a magnifying glass. Whenever an object is placed within a focal length of a converging lens we always obtain an enlarged virtual image. To observe the virtual image you would look "through" the lens. Placing a screen at Q would not show any image there since rays after going through the lens do not come back to Q.

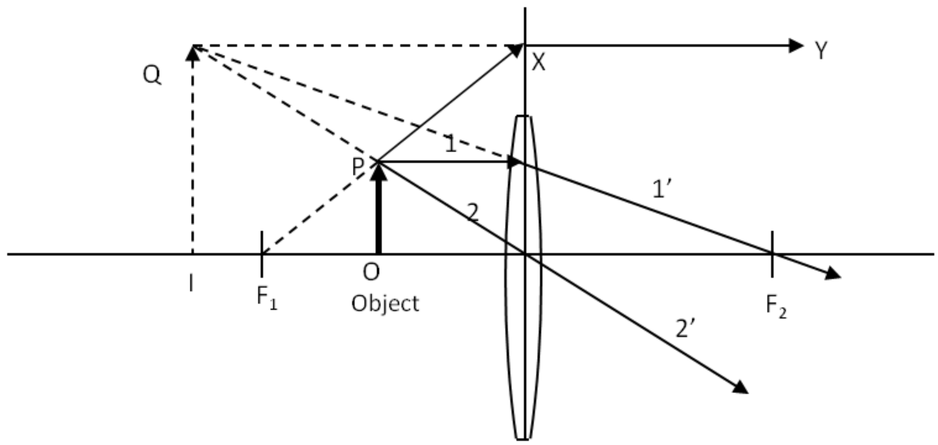

Figure 2.24: Virtual image formation by a convex lens.

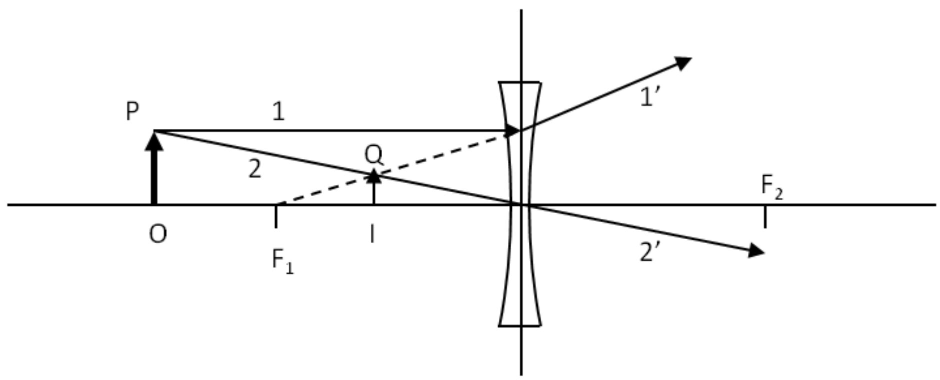

Figure 2.25: Image formation by a concave lens by ray tracing.

The extended rays that meet at Q are only mathematical devices to locate Q graphically.

2.5.3 Virtual Image by a Diverging Lens

In this case we always get a virtual image no matter where the object is placed. The procedure for drawing rays is the same as outlined above for the converging lens. We illustrate the drawing in Fig. 2.25.

2.5.4 Oblique Parallel Rays and Focal Plane

We have seen above that rays that are parallel to the optical axis are focused on the focal point of a converging lens. In the case of a

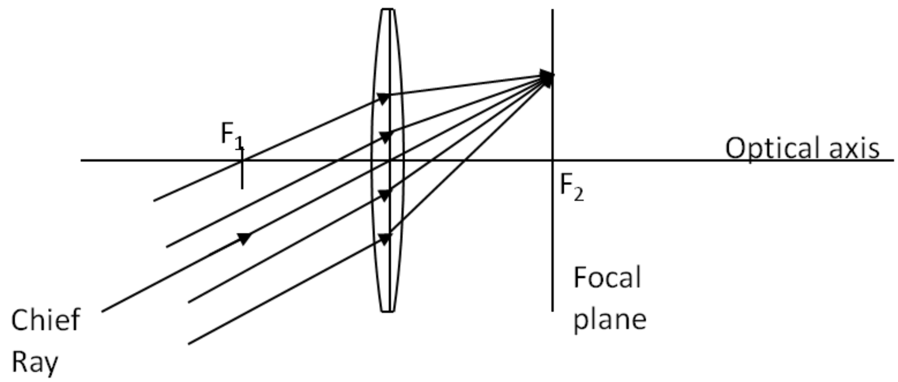

Figure 2.26: Oblique rays focus on a point in focal plane.

diverging lens, they come out in a direction such that they appear to be coming from the focal point. What happens to the rays that are themselves parallel but they are not parallel to the optical axis? In the case of converging lens, these rays do not converge on the focal point. Instead they come together on another point in a plane called the focal plane containing the focal point and which is perpendicular to the optical axis. The parallel rays focus where the chief ray through the center of the lens crosses the focal plane as shown in Fig. 2.26.

2.5.5 Ray Tracing in a Two Lens System

Ray tracing in two or more lens system is done by working with one lens at a time. First we find the image by the first lens alone. This image serves as the object for the next lens and so forth regardless of whether the image is real or virtual. You have to keep track of foci of different lenses. You need to introduce clear notation so that you don't get confused which focus is for which lens. I will draw one example case just to give you an idea. In Fig. 2.27 I have used a two index subscript, the first one is the focus number and the second refers to the lens; for instance, F_{12} is the first focus of lens 2.

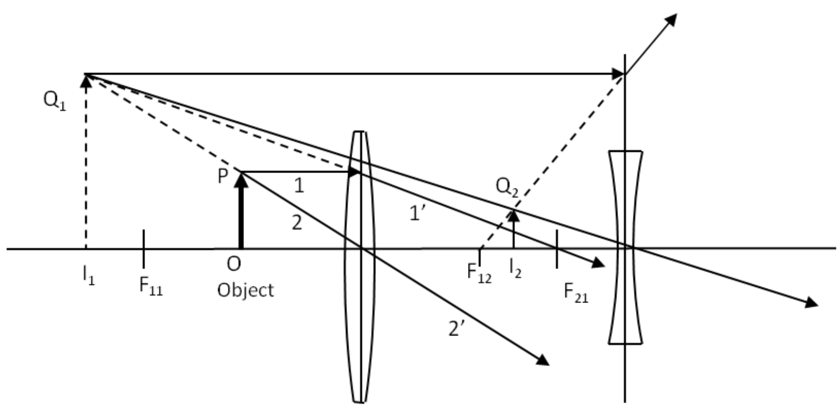

Figure 2.27: Ray tracing in a two-lens optical system.