centre of the lens, and is the point from which all measurements are made. It is usually said that this optical centre is a point through which a ray passing does not undergo any deviation from its original course. This is only true when the lens is very thin indeed. In a single lens this point can be found graphically when the radius of the spherical surfaces is known. Take a meniscus lens, for instance, and draw a section.

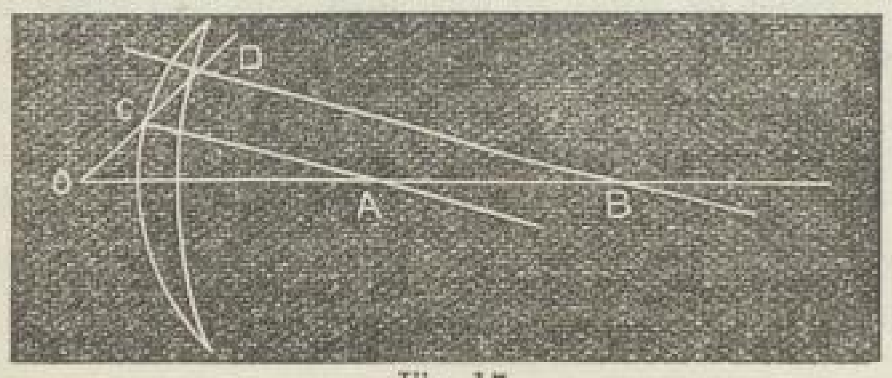

Fig. 17.

Let A be the centre of one spherical surface (fig. 17), and B of the other. B A O is called the *principal axis* of the lens. Through A, draw a line, A C, making a moderate angle with the axis A B, cutting the spherical surface of which A is the centre in C, and draw B D parallel to this line, cutting the other spherical surface in D. Join D C, and prolong it till it meets the principal axis in O; then O is the optical centre of the lens. [It will be seen that any ray which is refracted along C D will be refracted at D parallel to the direction it enters at C, since the normals to the two surfaces are parallel.] In the case of a bi-convex lens, it will be seen that D C would intersect the principal axis, A B, in the lens. The same rule applies to the bi-concave and convexo-concave lenses. When a lens is plano-convex, or plano-concave, the optical centre is situated at the intersection of the spherical surface with the principal axis, A B.

A straight line which passes through the optical centre of a lens, and striking the lens, is called a *secondary axis*.

The Focal Length of Lenses.—The focus of a lens has already been defined; but we require to know more about the alterations in it. For instance, it will be found that the focus of a *distant* point in a landscape is at a different distance from a lens than that of a near object. Suppose we examine the first case. Here the rays of light, coming from a distant point, which strike the lens, are virtually parallel to one another, and there is no alteration to be made whether we focus a distant mountain, the moon, or the sun—there is always the same distance of the focussing screen from the lens, and the screen is, in this case, at the *principal focus* of the lens. Take another object close to the lens, and it will be found that the screen has to be pulled back from the lens very considerably. Make an experiment in regard to this: use only the central portion of the lens, screening off the margin with black paper. The reason of doing this we shall see shortly. Let the object be a candle-flame, and find the exact position of the sharp image. Now replace the candle-flame by the screen, and the screen by the candle-flame. The image of the flame will be found to be still in focus, though most likely of a different size. Thus A being the focus of B, if the candle be placed at B the focus of B will be at A. A and B are said to be *conjugate foci*, and A C and B C conjugate focal lengths. Now, in the case of *parallel* rays, in fig. 18,

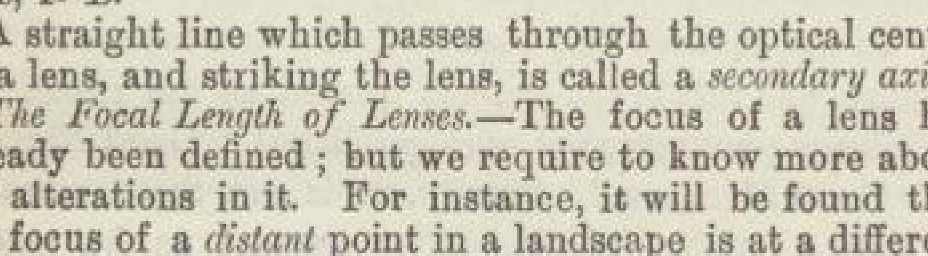

Fig. 18.

it is evident that A must be very far off; and the further A is removed, the nearer, up to a certain limit, B will approach to L, and this limit, beyond which B cannot approach, is the principal focus of the particular lens.* As a rule, in landscape photography, the focussing screen is very close to this principal focal distance, since the objects to be photographed generally lie at some distance from the lens. In portrait photography this is not the case. When once this principal focus is found, all other distances can be calculated.

To Determine Practically the Optical Centre and Principal Focus of a Lens.—There are several ways of proceeding. An easy plan is as follows:—Make two marks on a wall distant about ten times the approximate focal length of the lens, so that the middle point between them lies very nearly in the principal axis of the lens, and focus them sharply on the screen. Measure the distance of the screen from the focussed marks, and measure as accurately as possible the distance apart of the images of the two points (a photograph may be taken and the image taken from that).

Example.—The distance apart of two marks is 2 feet, and the distance of the screen from the scale 12 feet, and the distance apart of the images of the two marks is 3 inches: to find the optical centre of the lens.

Now by our definition of the optical centre, if a pinhole be placed there, we shall have the same sized image on the screen. If, therefore, we choose to draw the distances to scale, we shall easily find the optical centre. A simple rule is, however, as follows: Multiply the distance of the

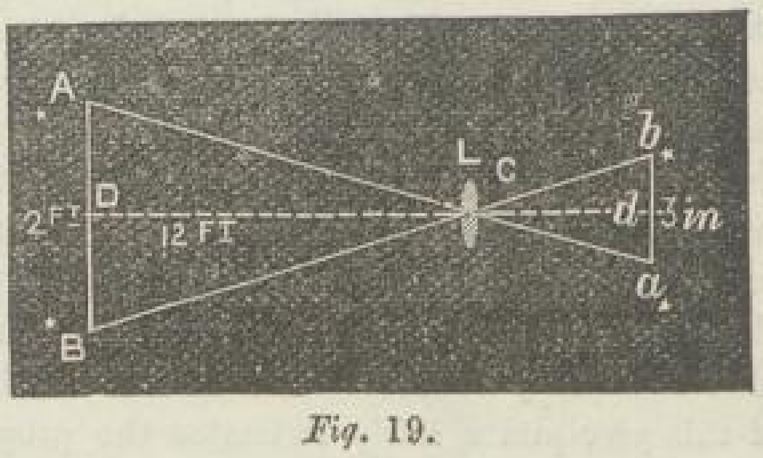

Fig. 19.

screen from the scale by the distance apart of the images, and divide this by the distance apart of the marks to which has been added the distance apart of the images; the result will be the distance of the optical centre from the screen. If it be a photographic lens which is used, the point on the principal axis can be indicated by a mark on the brass mount. In the example before us, the result is—

$$\frac{144 \text{ in.} \times 3 \text{ in.}}{27 \text{ in.}} = 16 \text{inches from the screen.}$$

This, however, does not give the equivalent focal length of the lens, though it can be calculated from it by a formula we shall give presently. The optical centre being obtained, a distant object should be focussed, and the distance of the screen from the optical centre will give the required equivalent focal length, which, in this case, would be $13\frac{5}{7}=13{\cdot}7$ inches. This mode of finding the optical centre and principal focus applies not only to single lenses, but to any combination (doublet, triplet, &c.). With such combinations the principal focal length is usually called *the equivalent focal length*. This is the same thing as saying that a combination of lenses will give an image at the focus or parallel rays, of the same size as would a pinhole placed at the same distance from the screen.

To find the size of the Images at Conjugate Foci.—Supposing we are making an enlargement, it is often useful to know at what distance we have to place the negative or other object in order with a lens of given focal length to obtain an image of a given size. A reference to fig. 19 will show that the size (in diameter) of the images is proportional to the distances of the lens from the object, D C, and the lens from the focussing screen (d c); but the distance, D C, regulates the distance of A C from the screen with any given lens. Now suppose the image of the object is to be (say) "n" times the size of the object,

* A common magnifying glass will answer every purpose.