1.9 REFERENCES

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5.10 THIN-LENS COMBINATION AS A THICK LENS

A combination of two or more thin lenses may also be referred to as a thick lens because the optical properties of a set of coaxially mounted lenses can be conveniently treated in terms of only two focal points and two principal points. If the object space and image space have the same refractive index (and this is nearly always the case), the nodal points and planes coincide with the principal points and planes.

A combination of two thin lenses with focal lengths of 8.0 and 9.0 cm, respectively, is shown in Fig. 5L. By the oblique-ray method the focal points F and F'' and the principal points H and H'' have been determined graphically. In doing so the refraction at each lens was considered in the same way as the refraction at the individual surfaces of the thick lens of Fig. 5G. There is a strong resemblance between these two diagrams; i.e., for a thin lens we assume that all the deviation occurs at one plane, just as for a single surface. This assumption is justified only when the separation of the principal planes of the lens can be neglected. The definition of a thin lens is just a statement of this fact: *a thin lens is one in which the two principal planes and the optical center coincide at the geometrical center of the lens.* The locations of the centers of the two lenses in this example are labeled A_1 and A_2 in Fig. 5L.

A diagram for a combination of a positive and a negative lens is given in Fig. 5M. The construction lines are not shown, but the graphical procedure used in determining the paths of the two rays is the same as that shown in Fig. 5L. Note here that the final principal points H and H'' lie outside the interlens space but that the focal lengths f and f'' measured from these points are as usual equal. The lower ray, although shown traveling from left to right, is graphically constructed by drawing it from right to left.

The positions of the cardinal points of a combination of two thin lenses in air can be calculated by means of the thick-lens formulas given in Sec. 5.6. As used for thin lenses in place of individual refracting surfaces, A_1 and A_2 become the two lens centers, while f_1, f_2 and P_1, P_2 become their separate focal lengths and powers, respectively. The latter are given by

$$P_1 = \frac{n_1 - n}{r_1} + \frac{n' - n_1}{r_1'} = \frac{n}{f_1} \qquad P_2 = \frac{n_2 - n'}{r_2} + \frac{n'' - n_2}{r_2'} = \frac{n'}{f_2'} \tag{5t}$$

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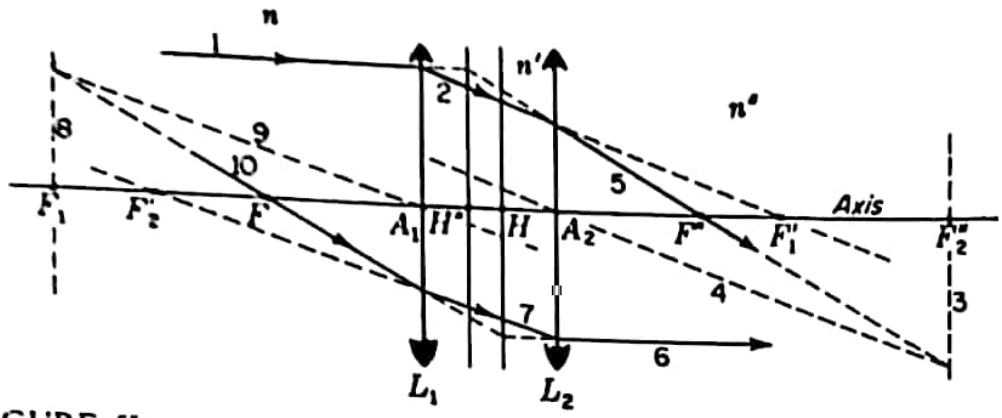

FIGURE 5L
Focal points and principal points of a system involving two thin lenses.

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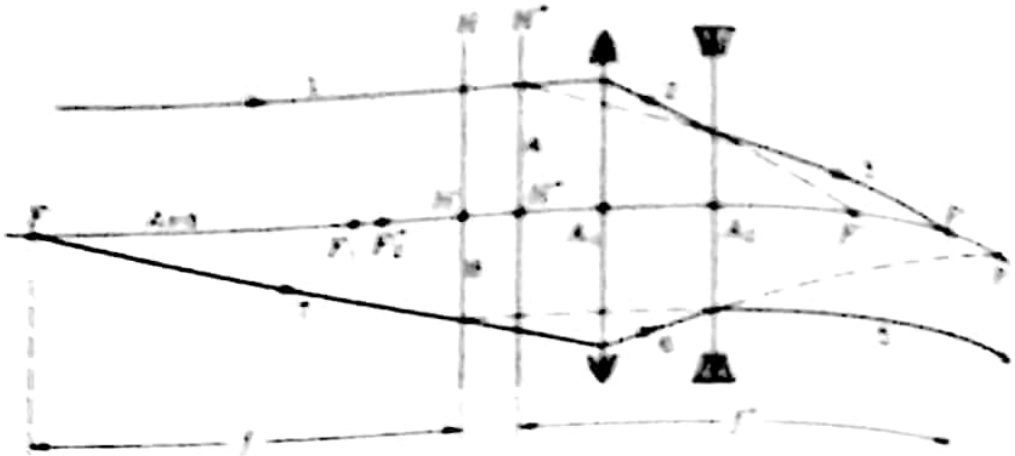

FIGURE 5M
The oblique-ray method applied to positive and negative thin lenses in succession.

where r_1 and r_1' are the radii of the first lens of index n_1 and r_2 and r_2' are the radii of the second lens of index n_2. The surrounding media have indices n_0 and n_2' (see Fig. 5L). The other formulas, Eqs. (5g) to (5k), remain unchanged.

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5.11 THICK-LENS COMBINATIONS

The problem of calculating the positions of the cardinal points of a thick lens consisting of a combination of several component lenses of appreciable thickness is one of considerable difficulty, but one which can be solved by use of the principles already given. In a combination of two lenses such as that in Fig. 5L, if the individual lenses cannot be considered as thin, each must be represented by a pair of principal planes. There are thus two pairs of principal points, H_1 and H_1' for the first lens and H_2' and H_2'' for the second, and the problem is to combine these to find a single pair H and H'' for the combination and to determine the focal lengths. By carrying out a construction similar to Fig. 5G for each lens separately, it is possible to locate the principal points and focal points of each. Then the construction of Fig. 5L can be accomplished, taking account of the unit magnification between principal planes.

Formulas can be given for the analytical solution of this problem, but because of their complexity they will not be given here.* Instead, we shall describe a method of determining the positions of the cardinal points of any thick lens by direct experiment.

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