Modern Optical Engineering

The Design of Optical Systems

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And the final slope is found by Eq. 2.31a:

$$N'_2u'_2 = N'_1u'_1 - y_2(N'_2 - N_2)c_2$$

$$= -(N-1)y_1c_1 - y_1\left[1 - \frac{(N-1)}{N}tc_1\right](1-N)c_2$$

$$(1.0)u'_2 = u'_2 = -y_1(N-1)\left[c_1 - c_2 + tc_1c_2\frac{(N-1)}{N}\right]$$

Thus the power ϕ (or reciprocal focal length) of the element is expressed as

$$\phi = \frac{1}{f} = \frac{-u'_2}{y_1} = (N-1)\left[c_1 - c_2 + tc_1c_2\frac{(N-1)}{N}\right] \tag{2.36}$$

or, if we substitute $c = 1/R$,

$$\phi = \frac{1}{f} = (N-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{t(N-1)}{R_1R_2N}\right] \tag{2.36a}$$

The back focal length can be found by dividing y_2 by u'_2 to get

$$\text{bfl} = \frac{-y_2}{u'_2} = f - \frac{ft(N-1)}{NR_1} \tag{2.37}$$

The distance from the second surface to the second principal point is just the difference between the back focal length and the effective focal length (see Fig. 2.11); this is obviously the second term of Eq. 2.37.

The above procedure has located the second principal point and second focal point of the lens. The "first" points are found simply by substituting R_1 for R_2 and vice versa.

The focal points and principal points for several shapes of elements are diagramed in Fig. 2.12. Notice that the principal points of an equiconvex or equiconcave element are approximately evenly spaced within the element. In the plano forms, one principal point is at the curved surface, the other is about one-third of the way into the lens. In the meniscus forms shown, one of the principal points is completely outside the lens; in extreme meniscus shapes, both the principal points lie outside the lens and their order may be reversed from that shown. Note that the focal points of the negative elements are in reversed order compared to a positive element.

If the lens element is not immersed in air, we can derive a similar expression for it. Assuming that the object medium has an index of N_1, the lens index is N_2, and the image medium has an index of N_3,