Lecture 7

A telephoto lens is a long focal-length lens, providing magnification at the expense of subject area. The telephoto lens avoids a correspondingly “long” camera by using a positive lens, separated from a second negative lens of shorter focal length, such that the combination remains positive.

Also important to the operation of the camera is the size of its aperture, which admits light to the film. In most cameras, the aperture is variable and is coordinated with the exposure time (shutter speed) to determine the total exposure of the film to light from the scene. The light power incident at the image plane (irradiance E_e in watts per square meter) depends directly on (1) the area of the aperture and inversely on (2) the size of the image. If, as in Figure (2-3) , the aperture is circular with diameter D and the energy of the light is assumed to be distributed uniformly over a corresponding image circle of diameter d, then

$$E_e \propto \frac{area\ of\ aperture}{area\ of\ image} = \frac{D^2}{d^2} \quad \text{………. (2-1)}$$

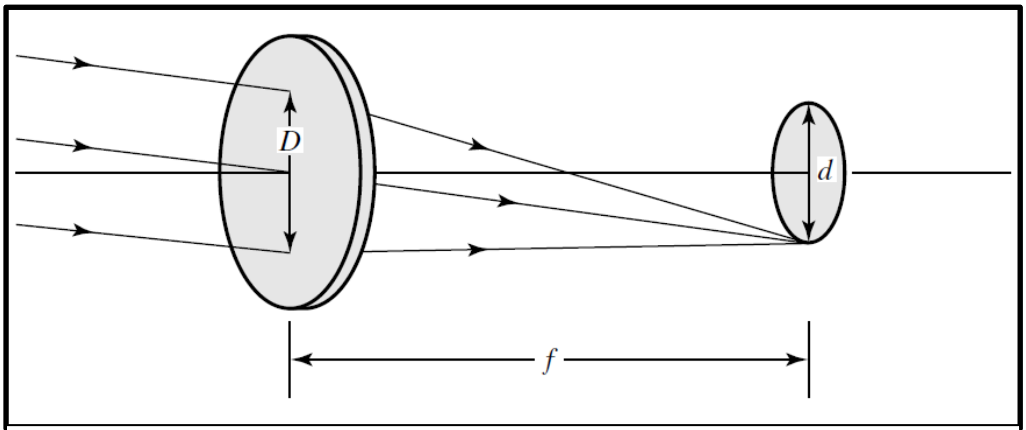

Figure (2-3) Illumination of image. The aperture (not shown) determines the useful diameter D of the lens.

The image size, as in Figure (2-3), is proportional to the focal length of the lens, so we can write:

$$E_e \propto \left(\frac{D}{d}\right)^2 \quad \text{……….. (2-2)}$$

The quantity f/D is the relative aperture of the lens (also called f-number or f/stop), which we symbolize by the letter A,

$$A \equiv \frac{f}{D} \quad \text{………….. (2-3)}$$

For example, a lens of 4-cm focal length that is stopped down to an aperture of 0.5 cm has a relative aperture of $\mathrm{A} = 4/0.5 = 8$.

Another important property of the camera that needs to be well defined is the depth of field. To define this quantity precisely, we

utilize Figure (2-4), which shows an axial object point O at distance s_o from a lens being imaged at $\grave{O}$ a distance s'_o on the other side. All objects in the object plane are precisely focused in the image plane, disregarding the usual lens aberrations. Objects closer to (s_1) and farther from (s_1) the lens, however, send bundles of rays that focus farther $(s'_o + x)$ from and closer $(s'_o - x)$ to the image plane, respectively. Thus, a flat film, situated at distance from the lens, intercepts circles of confusion corresponding to such object points. If the diameters of these circles are small enough, the resultant image is still acceptable. Suppose the largest acceptable diameter is d, as shown, such that all images within a distance x of the precise image are suitably “in focus.” The depth of field is then said to be the interval MN in object space conjugate to the interval $M'N'$ as shown.

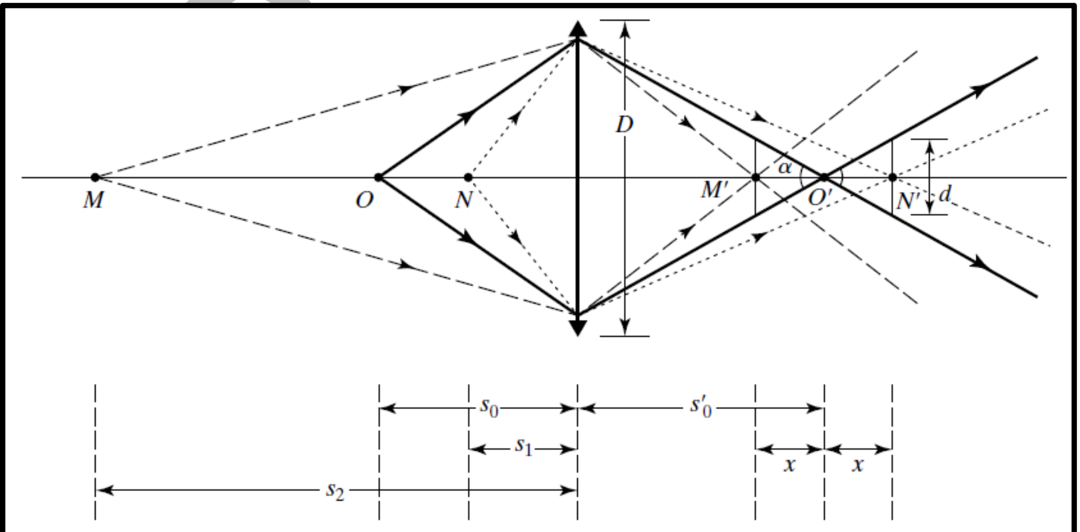

Figure (2-4) Construction illustrating depth of field.

The near-point and far-point distances, s_1 and s_2 of the depth of field (MN) can be determined once the allowable blurring

parameter d is chosen and the lens is specified by focal length and relative aperture. The s_1 and s_2 can be calculated from:

$$s_1 = \frac{s_o f(f+Ad)}{f^2+Ads_o} \quad \text{............ (2-4)}$$

$$s_2 = \frac{s_o f(f-Ad)}{f^2-Ads_o} \quad \text{............ (2-5)}$$

The depth of field, $MN = s_2 - s_1$ can be expressed as:

$$depth\ of\ field = \frac{2Ads_o\,(s_o-f)f^2}{f^4-A^2d^2s_o^2} \quad \text{............ (2-6)}$$

Example

A 5 cm focal length lens with an $f/16$ aperture is used to image an object 275 cm away. The blurring diameter in the image is chosen to be $d = 0.04$ mm. Determine the location of the near point, far point, and the depth of field.