TECHNICAL SERIES: LENSES - PART 2

Concepts in Light and Optics

Now that we've covered the basic type of lens configurations and how, by design, lenses either converge (focus) or diverge light, we can begin to explore the various characteristics that define their physical shape.

Overall, there are many parameters that govern the performance of a lens. As previously discussed, it is the specific optical properties of a given material, namely its refractive index and dispersion, that influence light's behavior when passing between mediums. Opticians build upon these carefully controlled properties by generating highly precise curvature (radii) across the surface of their lenses. By combining this curvature in relation to a material's refractive index, a lens can be made to focus or disperse light in a controlled and quantifiable manner. In the following article we will describe in greater detail the basic physical parameters and terminology used to characterize the shape of a lens. For simplicity, we will first start with lenses having regular, spherical surfaces generated on round substrates. Aspheric contours and cylindrical designs using rectangular substrate configurations will be covered in later articles.

Focal Length

Specifically relating to a single lens of negligible center thickness, for positive lenses (plano-convex, biconvex, and positive meniscus) the focal length is the physical distance from the center of the lens to the point where all light rays are brought to focus. Conversely, for negative lenses (plano-concave, biconcave, negative meniscus), the focal length is the point out ahead of the lens from where all the light rays theoretically diverge.

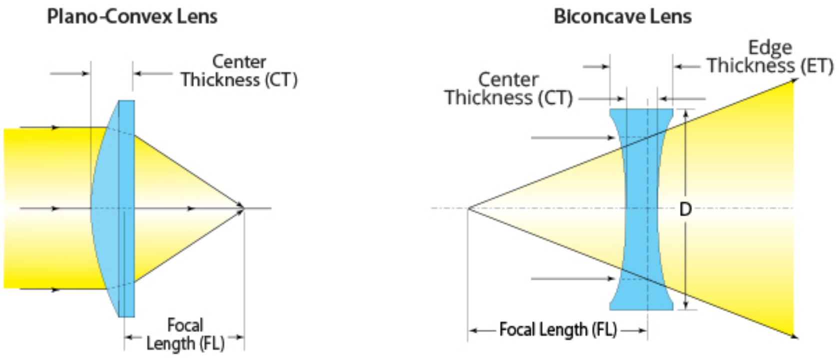

Figure 1

General lens convention has the front side of the lens as the side from which the light is incident, meaning the side where the light enters the lens. As such, positive lenses can be thought of as having their focal point downstream once the light passes through the lens (positive focal length) while negative lenses have their theoretical focal point upstream from the lens (negative focal length).

Optical designers also distinguish between long and short focal lengths by describing the amount of optical power of their lenses. Short focal lengths, those which bend light more quickly and therefore achieve focus in a shorter distance from the center of the lens are said to have greater optical power, while those which focus light more slowly are described as having less optical power.

A simple way to calculate focal length for thin lenses is given by the Thin Lens Approximation of the Lens-Maker's Formula. ***Please note, this formula is only valid for lenses whose thickness is small when compared to the calculated focal length.***

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Where:

f = focal length
n = refractive index of lens material
r1 = radius of curvature for surface closest to incident light
r2 = radius of curvature for surface furthest away from incident light

Radius of Curvature

Since the focal length of a lens is directly related to its refractive index, as well as, the curvature of its surface (or surfaces), it is important to understand exactly how this shape is physically characterized in terms of radius of curvature. To define radius of curvature, we must first start with the concept of a circle. We know that every point along the edge of a circle is equidistant from the center, i.e. the same distance, and this is called a circle's radius. For example, if a circle has a radius of 25.4 mm, regardless of which direction you place a straight line beginning at the center and extending to the edge, the distance will always be 25.4 mm. By doubling the radius, we can derive the longest distance between two opposite points along a circle's edge, a distance otherwise known as the diameter. Now, to conceptualize a radius of curvature on a lens, imagine a plano optic with a diameter of 20 mm. We can picture this optic in two ways, either from the top or viewed from the side, edge-on.

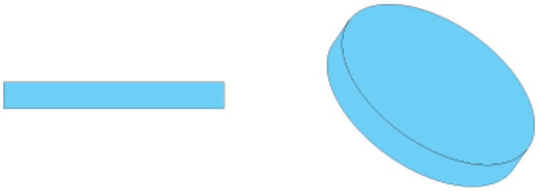

Figure 2

If we take the above edge-on view and then superimpose it into a circle with a radius of 25.4 mm, locating it where two points on the edge of the circle are 20 mm apart, you will see that the circle forms a theoretical curved surface that travels from one side of the optic to the other.

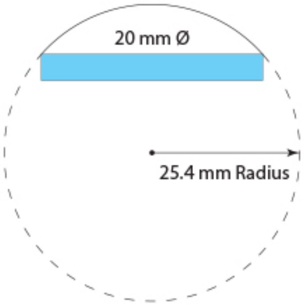

Figure 3

In figure 3, you can see the drawing represents a plano-convex lens with a radius of curvature of 25.4 mm. But what happens to this same profile of curvature if we apply successively longer radii to the 20 mm diameter plano-convex lens? You will see in the below diagrams that as the radius of curvature becomes greater, the curvature of the lens becomes more and more shallow.

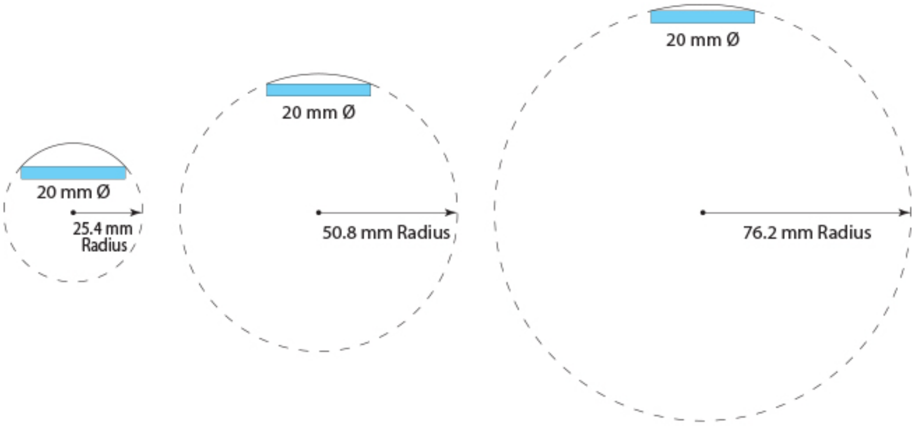

Figure 4

placed outside as demonstrated below (Figure 5). Just as with convex lenses, assuming the diameter of the lens remains constant, as the radius of curvature increases, the curvature of the lens become more and more shallow.

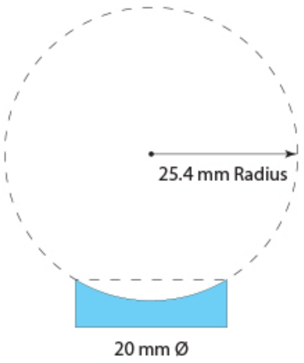

Figure 5

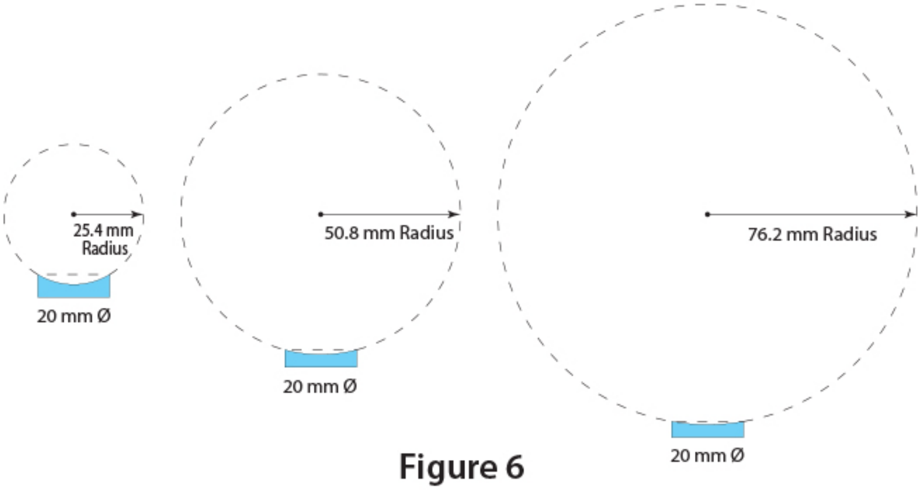

Figure 6

(***Note:*** *Often times there is a small flat on the edges of plano-concave optics or biconcave optics to avoid sharp edges, however, for consistency and simplicity of our examples we are leaving them off.*)

For both the novice and experienced optician alike, Esco offers a full portfolio of online tools as part of their Optical Design Work Center to calculate various aspects of lenses. You can easily find your radius of curvature by entering the desired material, focal length, substrate diameter and edge thickness, whether deriving one or two curved surfaces. The following links provide access to this resource.

Single Radius Calculator
http://calc.escooptics.com/lens?calc=lens-plano

Double Radius Calculator
http://calc.escooptics.com/lens?calc=lens-plano

Sagitta (Sag)

Radius of curvature is directly related to Sagitta, more commonly called Sag in the optical industry. In geometric terms, Sagitta represents the distance from the exact center of an arc to the center of its base. In optics, Sag applies to either the convex or concave curvature and represents the physical distance between the vertex (highest or lowest point) point along the curve and the center point of a line drawn perpendicular to the curve from one edge of the optic to the other. Figure 7 below offers a visual depiction of Sag.

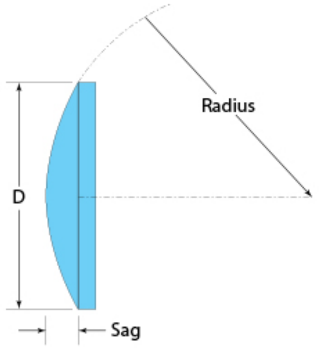

Figure 7

Sag is important because it provides the center location for the radius of curvature, thus allowing fabricators to correctly position the radius on the optic, as well as, establishing both the center and edge thickness of an optic. By knowing the radius of curvature, as well as, the diameter of an optic, the Sag can be calculated by the following formula.

$$\mathrm{SAG} = R - \sqrt{R^2 - \left(\frac{d}{2}\right)^2}$$

Where:

R = radius of curvature
d = diameter

While you can use the above equation to find the sag of your optic, we again encourage you to use Esco's Optical Design Work Center to easily derive this physical dimension. Simply enter the lens diameter and radius to find the sag of your optic. The following link take you directly to the online calculator

Sag Calculator
http://calc.escooptics.com/lens?calc=lens-sag

Center Thickness Verses Edge Thickness

From the examples shown so far, you've probably noticed that the thickness of a lens varies from the edge to the center of the optic. Obviously, this is a function of the radius of curvature and sag. Plano-convex, biconvex and positive meniscus lenses have greater thickness at their centers than at the edge. For plano-concave, biconcave and negative meniscus lenses, the center thickness is always thinner than the edge thickness. Optical designers generally specify both the edge and center thickness on their drawings, tolerancing one of these dimensions, while using the other as a reference dimension. It is important to note that without one of these dimensions, it is impossible to discern the final shape of the lens.

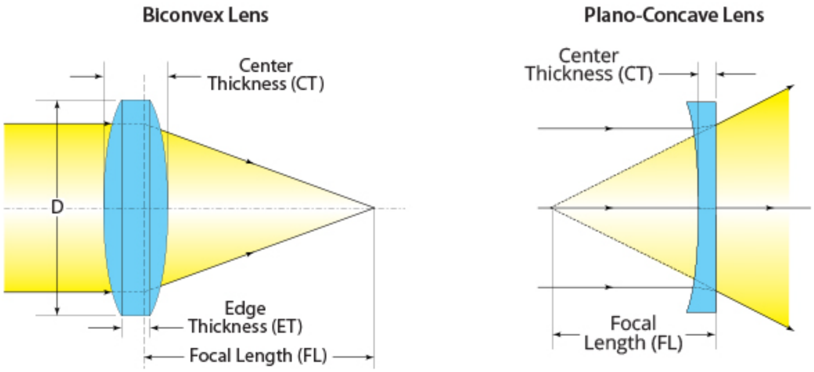

Figure 8

Wedge / Edge Thickness Variation (ETV)

Wedge, sometimes referred to as Edge Thickness Variation or ETV, is a straightforward concept to understand in terms of lens design and fabrication. Basically, this specification controls how parallel the two optical surfaces of a lens are to one another. Any variation from parallel may cause the transmitted light to deviate from its path and, since the goal is to focus or diverge light in a controlled manner, wedge therefore introduces unwanted deviation in the light path. Wedge can be specified in terms of angular deviation between the two transmitting surfaces or a physical tolerance on the edge thickness variation.

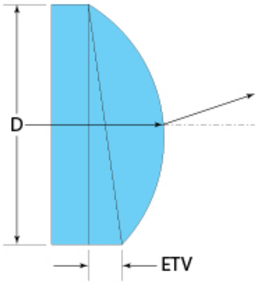

Figure 9

Esco's online calculator also allows for quick derivation of the wedge tolerance of your optic. Enter the material, diameter and edge thickness deviation to see the angular tolerance.

Wedge Calculator
http://calc.escooptics.com/lens?calc=lens-wedge

Centration

As the name implies, centration controls the location accuracy of the radius of curvature. A perfectly centered radius would precisely align the vertex (center) of its curvature to the outside diameter of the substrate. For example, a plano-convex lens with a diameter of 20 mm would have a perfectly centered radius if the vertex was linearly positioned exactly 10 mm from any point along the outside diameter. It therefore follows that optical fabricators must take into account both the X and Y axis when controlling centration as shown below.

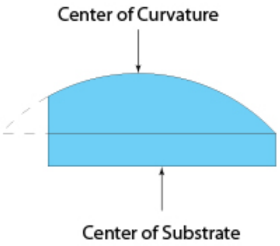

Figure 10

Summation

In this article we've covered the basic physical parameters of spherical lens configuration when using round substrates. By taking into account the focal length, radius of curvature, Sag, edge and/or center thickness, wedge and centration, optical fabricators have the information they need to define the shape and mechanical precision of their lenses.

We welcome the opportunity to discuss your individual stock and custom lens requirements and are available anytime to assist. We also encourage you to try Esco's online Optical Design Work Center using any of the above links or from the Esco homepage www.escooptics.com.

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Business Development
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