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DYNAMICS OF REFLECTION OF LIGHT ON CONVEX SURFACE WITH SPECIAL REFERENCE TO OPTICAL SPECIFICATIONS

Dr. MD ASIF ALI
University Department of Physics, L.N. Mithila University, Darbhanga-846004, Bihar

Abstract

Reflection of light occurs when the waves encounter a surface or other boundary that does not absorb the energy of the radiation and bounces the waves away from the surface. The simplest example of visible light reflection is the surface of a smooth pool of water, where incident light is reflected in an orderly manner to produce a clear image of the scenery surrounding the pool which disrupt the reflection by scattering the reflected light rays in all directions. Laser damage threshold indicates the maximum amount of laser power per area that a surface can withstand before it is damaged. Values are provided for pulsed lasers and continuous wave (CW) lasers. Laser damage threshold is a very important material specification for mirrors since they are used in conjunction with laser products more than any other optic; however, any laser-grade optic will provide a threshold. For example, consider a Ti: Sapphire Laser Mirror with damage threshold ratings of 0.5 J/cm^2 @ 150 femto second pulses and 100kW/cm^2 CW. This means that the mirror can withstand energy densities of 0.5J per square centimeter from a high repetition femto second pulsed laser or 100kW per square centimeter from a high power CW laser. If the laser is concentrated on a smaller region, then the proper consideration must be taken to ensure the overall threshold does not exceed the specified values. Though a host of additional manufacturing, surface, and material specifications exist, understanding the most common optical specifications can greatly alleviate confusion. Lenses, mirrors, windows, filters, polarizers, prisms, beam splitters, gratings, and fiber optics share a variety of attributes, therefore, knobjectedge of how they relate to each other and can affect overall system performance helps to choose the best components for integration into optics, imaging, or photonics applications.

Key Words: Dynamics, Reflection, Light, Convex Surface, Optical Specifications.

Introduction: The incoming light wave is referred to as an incident wave, and the wave that is bounced away from the surface is termed the reflected wave. Visible white light that is directed onto the surface of a mirror at an angle (incident) is reflected back into space by the mirror surface at another angle (reflected) that is equal to the incident angle (Moffatt, 2009). Thus, the angle of incidence is equal to the angle of reflection for visible light as well as for all other wavelengths of the electromagnetic radiation spectrum. This concept is often termed as **Law of Reflection (**Heyman and Felsen, 2003**)**. It is important to note that the light is not separated into its component colors because it is not being "bent" or refracted, and all wavelengths are being reflected at equal angles. The best surfaces for reflecting light are very smooth, such as a glass mirror or polished metal, although almost all surfaces will reflect light to some degree (Heyman and Felsen, 2011). The amount of light reflected by an object, and how it is reflected, is highly dependent upon the degree of smoothness or texture of the surface. When surface imperfections are smaller than the wavelength of the incident light (as in the case of a mirror), virtually all of the light is reflected equally (Heyman and Felsen, 2007). However, in the real world most objects have convoluted surfaces that exhibit a diffuse reflection, with the incident light being reflected in all directions. Many of the objects that we casually view every day (people, cars, houses, animals, trees, etc.) do not themselves emit visible light but reflect incident natural sunlight and artificial light. For instance, an apple appears a shiny red color because it has a relatively smooth surface that reflects red light and absorbs other non-red (such as green, blue, and yellow) wavelengths of light. The reflection of light can be roughly categorized into two types of reflection:

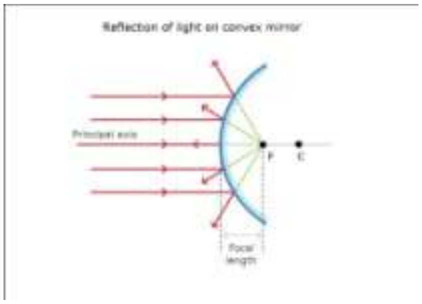
- **Specular reflection** is defined as light reflected from a smooth surface at a definite angle. whereas,
- **Diffuse reflection** is produced by rough surfaces that tend to reflect light in all directions.

There are far more occurrences of diffuse reflection than specular reflection in our everyday environment.

Materials and Methods: In computer graphics, ray tracing is very simple and powerful method to present physical phenomena especially light-related things such as reflection and refraction since it traces the ray from the eye to the light source. It is time-consuming to render the target object considering reflection and refraction (Überall, et.al, 2016). If the object distorted by reflection and refraction is previously obtained, it is very fast to generate the result image since all we have to do is to render the distorted object without considering reflection and refraction (Kim and Burnside,2016).

In the proposed method, firstly, a virtual object, which is constructed with vertices translated from original ones by considering reflection and refraction, is generated. Then, the image with reflection is generated by rendering the virtual object (Ma and Ciric, 2001). In the analysis, total reflection and attenuation of light power are also considered. At last, the proposed method is applied to two types of transparent objects: concave and convex surfaces and the comparison between the simulation results and the real photos are performed to demonstrate that the generated images are the same as the real ones (Wait and Conda, 2009).

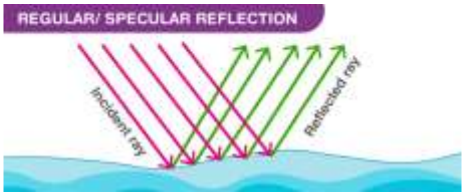
Results and Discussion: The reflection patterns obtained from both concave and convex mirrors. The concave mirror has a reflection surface that curves inward, resembling a portion of the interior of a sphere (Naishadham and Yao, 2013). When light rays that are parallel to the principal or optical axis reflect from the surface of a concave mirror (in this case, light rays from the object's feet), they converge on the focal point (red dot) in front of the mirror. The distance from the reflecting surface to the focal point is known as the mirror's focal length. The size of the image depends upon the distance of the object from the mirror and its position with respect to the mirror surface (Pathak, 2008). In this case, the object is placed away from the center of curvature and the reflected image is upside down and positioned between the mirror's center of curvature and its focal point.



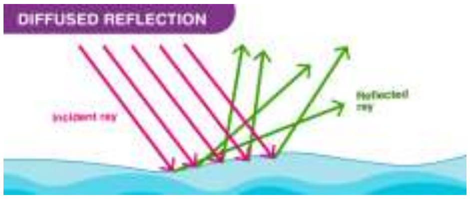
Dynamics of Reflection of Light: Different types of reflection of light are briefly discussed below:

- Regular reflection (is also known as specular reflection).
- Diffused reflection
- Multiple reflection

Regular/ Specular Reflection: It refers to a clear and sharp reflection, like the ones you get in a mirror. A mirror is made of glass which is coated with a uniform layer of a highly reflective material such as powder (Pathak, 2012). There is not much variation in the angles of reflections between various points. This means that the haziness and the blurring are almost entirely eliminated.



Diffused Reflection: Reflective surface other than mirrors, in general, has a very rough finish. This may be due to wear and tear such as scratches and dents or dirt on the surface. Sometimes even the material of which the surface is made of matters. All this leads to a loss of both the brightness and the quality of the reflection (Schafer, 2008). In the case of such rough surfaces, the angle of reflection when compared between points is completely haphazard. For rough surfaces, the rays incident at slightly different points on the surface is reflected in completely different directions. This type of reflection is called diffused reflection and is what enables us to see non-shiny objects.



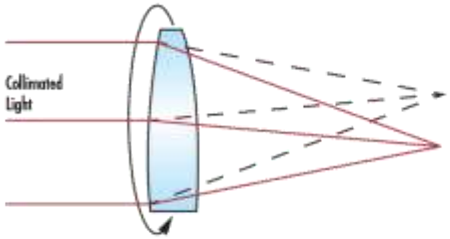
Multiple Reflection: A single image is formed when an object is placed in front of a mirror. What happens if we use two mirrors? This multiple reflection is possible until the intensity of light becomes low until the point that we cannot see. This means that we can have almost infinite multiple reflections (Schafer and Kouyoumhian, 2015). When the mirrors become parallel to each other, the number of images becomes infinite . This effect can be easily observed when your barber uses another smaller mirror to show you the back of your head. When this happens, not only do you see the back of your head, you also see innumerable images of yourself. The variation of the number of images of an object placed between two mirrors with the angle between the mirrors can be described by a simple formula:

$$\text{Number of images} = \frac{360}{\text{angle beween mirrors}} - 1$$

Optical Specifications: There are so many optical specification which are detailed below:

Diameter Tolerance: The diameter tolerance of a circular optical component provides the acceptable range of values for the diameter. Although diameter tolerance does not have any effect on the optical performance of the optic itself, it is a very important mechanical tolerance that must be considered if the optic is going to be mounted in any type of holder (Mori and Marzano, 2014). For instance, if the diameter of an optical lens deviates from its nominal value it is possible that the mechanical axis can be displaced from the optical axis in a mounted assembly, thus causing decenter. Typical manufacturing tolerances for diameter are:

+0.00/-0.10 mm for typical quality, +0.00/-0.050 mm for precision quality and +0.000/-0.010 mm for high quality.



Center Thickness Tolerance: The center thickness of an optical component, most notably a lens, is the material thickness of the component measured at the center (Lee, et.al, 2003). Typical manufacturing tolerances for center thickness are: +/-0.20 mm for typical quality, +/-0.050 mm for precision quality, and +/-0.010 mm for high quality.

Radius of Curvature: The radius of curvature is defined as the distance between an optical component's vertex and the center of curvature (Weston, 2009). It can be positive, zero, or negative depending on whether the surface is convex, plano, or concave, respectfully. Manufacturing tolerances for radius of curvature are typically +/-0.5, but can be as low as +/-0.1% in precision applications or +/-0.01% for extremely high quality needs.

Centering: Centering, also known by centration or decenter, of a lens is specified in terms of beam deviation δ (Equation 1).

$$\delta = \frac{\Delta}{f} \qquad (1)$$

Once beam deviation is known, wedge angle W can be calculated by a simple relation (Eq 2).

$$W = \frac{\delta}{(n-1)} \qquad (2)$$

The amount of decenter in a lens is the physical displacement of the mechanical axis from the optical axis. The mechanical axis of a lens is simply the geometric axis of the lens and is defined by its outer cylinder (Chen, 2004). Collimated light directed along this axis of rotation is sent through the lens and comes to a focus at the rear focal plane. As the lens is rotated by rotating the cup, any decenter in the lens will cause the focusing beam to diverge and trace out a circle of radius Δ at the rear focal plane.

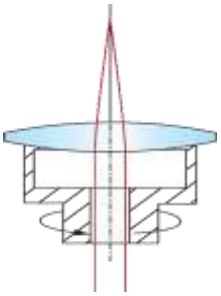
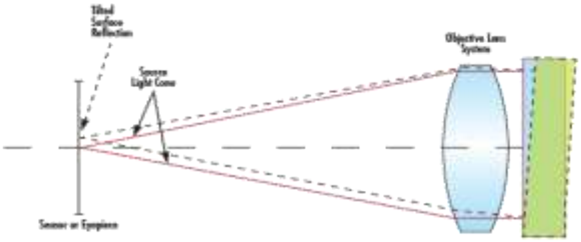


Figure 2: Test for Centration

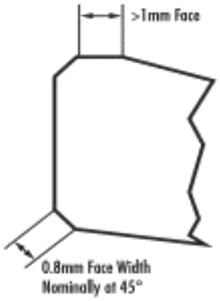
where *W* is the wedge angle, often reported as arcminutes, and n is the index of refraction.

Parallelism: Parallelism describes how parallel two surfaces are with respect to each other. It is useful in specifying components such as windows and polarizers where parallel surfaces are ideal for system performance because they minimize distortion that can otherwise degrade image or light quality. Typical tolerances range from 5 arcminutes down to a few arcseconds.

Angle Tolerance: In components such as prisms and beam splitters, the angles between surfaces are critical to the performance of the optic. This verifies that the collimated beam is hitting the surface at exactly normal incidence. The difference in angle between the two measured positions is used to calculate the tolerance between the two optical surfaces. Angle tolerance can be held to tolerances of a few arcminutes all the way down to a few arc seconds.

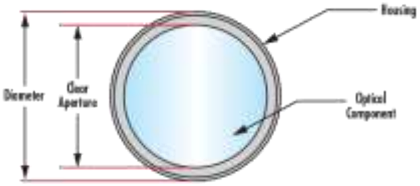


Bevel: Glass corners can be very fragile, therefore, it is important to protect them when handling or mounting a component. The most common way of protecting these corners is to bevel the edges. Bevels serve as protective chamfers and prevent edge chips. They are defined by their face width and angle.



It is important to note that for small radii of curvature, for example, lenses where the diameter is ≥ 0.85 x radius of curvature, no bevel is needed due to the large angle between the surface and edge of the lens.

Clear Aperture: Clear aperture is defined as the diameter or size of an optical component that must meet specifications. Outside of it, manufacturers do not guarantee the optic will adhere to the stated specifications. Due to manufacturing constraints, it is virtually impossible to produce a clear aperture exactly equal to the diameter, or the length by width, of an optic.



Surface Specifications: Some of the important surface specifications are detailed below:

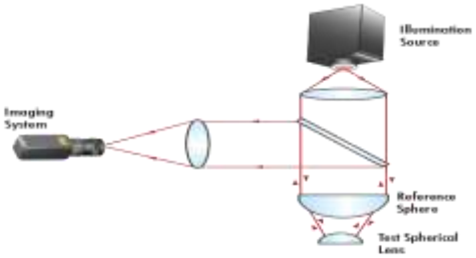
Surface Quality: The surface quality of an optical surface describes its cosmetic appearance and includes such defects as scratches and pits, or digs. However, certain surfaces, however, are more sensitive to these effects such as:

- Surfaces at image planes because these defects are in focus and
- Surfaces that see high power levels because these defects can cause increased absorption of energy and damage the optic.

The most common specification used for surface quality is the scratch-dig specification. The dig designation is calculated at the diameter of the dig in microns divided by 10. Scratch-dig specifications of 80-50 are typically considered standard quality, 60-40 precision quality, and 20-10 high precision quality.

Surface Flatness: Surface flatness is a type of surface accuracy specification that measures the deviation of a flat surface such as that of a mirror, window, prism, or plano-lens. The deviations in flatness are often measured in values of waves (λ), which are multiples of the wavelength of the testing source (Ruike, et.al, 2007). One fringe corresponds to ½ of a wave. 1λ flatness is considered typical grade, λ/4 flatness is considered precision grade, and λ/20 is considered high precision grade.

Power: Power, a type of surface accuracy specification, applies to curved optical surfaces, or surfaces with power. It is tested in a fashion similar to flatness, in that a curved surface is compared against a reference surface with a highly calibrated radius of curvature. A deviation from the reference piece will create a series of rings, known as Newton's Rings. The more rings present, the larger the deviation. The number of dark or light rings, not the sum of both light and dark, corresponds to twice the number of waves of error.



Power error is related to the error in the radius of curvature by the following equation where ΔR is the radius error, D is the lens diameter, R is the surface radius, and λ is the wavelength (typically 632.8nm):

$$\text{Power Error[waves or } \lambda] = \frac{\Delta RD2}{8R2\lambda}$$

Irregularity: **Irregularity:** Irregularity, a type of surface accuracy specification, describes how the shape of a surface deviates from the shape of a reference surface. When the power of a surface is more than 5 fringes, it is difficult to detect small irregularities of less than 1 fringe. Therefore it is common practice to specify surfaces with a ratio of power to irregularity of approximately 5:1.

Surface Finish: Surface finish, also known as surface roughness, measures small scale irregularities on a surface. They are usually an unfortunate by-product of the polishing process. Rough surfaces tend to wear faster than smooth surfaces and may not be suitable for some applications, especially those with lasers or intense heat, due to possible nucleation sites that can appear in small cracks or imperfections. Manufacturing tolerances for surface finish range from 50Å RMS for typical quality, 20Å RMS for precision quality, and 5Å RMS for high quality.

Conclusion: light behaves in some ways as a wave and in other ways as if it were composed of particles, several independent theories of light reflection have emerged. According to wave-based theories, the light waves spread out from the source in all directions, and upon striking a mirror, are reflected at an angle determined by the angle at which the light arrives. The reflection process inverts each wave back-to-front, which is why a reverse image is observed. The shape of light waves depends upon the size of the light source and how far the waves have traveled to reach the mirror. Wave fronts that originate from a source near the mirror will be highly curved, while those emitted by distant light sources will be almost linear, a factor that will affect the angle of reflection. The convex mirror has a reflecting surface that curves outward, resembling a portion of the exterior of a sphere. Light rays parallel to the optical axis are reflected from the surface in a direction that diverges from the focal point, which is behind the mirror. Images formed with convex mirrors are always right side up and reduced in size. These images are also termed virtual images, because they occur where reflected rays appear to diverge from a focal point behind the mirror.

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