



The Importance of Three-Dimensionality

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A polished diamond owes its beauty to many interrelated factors. As we have seen in the previous articles, several interdependent relationships affect light's behavior in a polished diamond, and thus can affect that diamond's appearance. The properties that we discussed in the articles on diamond optics “Diamond Optics Part 1; Part 2; and Part 3” help us predict some of these appearance aspects

(e.g., brilliance or fire); however, we also need to consider a fashioned round brilliant cut (RBC) diamond as an object that has three dimensions – height, width, and depth.

A number of previous models of diamond appearance have assumed that simplifying the problem of light interaction with diamond by using a two-dimensional model will give sufficiently accurate results. With the advent of computer models, we have found this two-dimensional approach to be inadequate.

Executive Summary:

- Diamonds are three-dimensional objects. Any attempt to understand how light behaves in a diamond needs to take all three dimensions into account.
- The traditional two-dimensional diamond profile is not a sufficient representation of a round brilliant cut (RBC) diamond, because two-dimensional light paths through a diamond are very rare, and every facet interaction has the potential to change the plane within which the light ray travels.
- A two-dimensional face-up view of a diamond is also not complete, since it does not capture all of the light paths that exit the crown of the diamond and so contribute to that diamond's appearance.

HISTORICAL APPROACHES

Diamonds are three-dimensional objects. Although this statement seems obvious, many historical studies of diamond appearance neglected this fact. This includes Tolkowsky's well-known 1919 book, *Diamond Design*. Early diamond theorists were limited in their ability to carry out complex mathematical calculations. Lacking

computers and electronic calculators, these individuals faced difficult and time-consuming calculations whenever they attempted to trace the paths of light within a diamond. Therefore they used a two-dimensional slice through the diamond's bezel facets and pavilion mains in order to make those calculations more manageable (figure 1). That is, even though these individuals regularly worked with diamonds and realized that they were three-dimensional objects, they had to do their best with the tools available at that time.

It is true that a symmetrical RBC diamond has eight-fold symmetry and that the same proportion profile is repeated eight times (figure 2, left). However, the complete repeating unit in this symmetry is a *wedge* of the diamond shape (somewhat similar to a slice of a pie; figure 2, right and bottom), not a two-dimensional plane. Because this wedge has a multitude of different facet angles and angular relationships – which often cause the light ray to travel through various planes of incidence – a two-dimensional plane is not adequate to model even this small section.

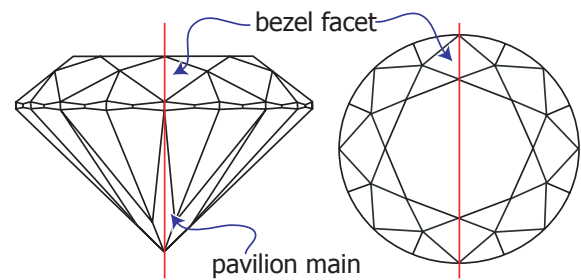


Figure 1. The traditional two-dimensional diamond profile consists of a plane that runs through the bezel facets and pavilion mains.

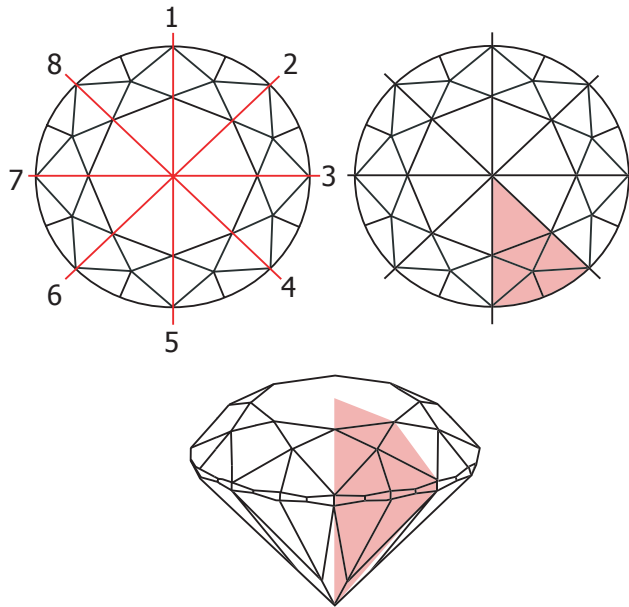


Figure 2. An RBC diamond has eight-fold symmetry (note that planes 5-8 in the above image are also planes 1-4), and the repeating unit is a wedge with various facets and angles (right and bottom).

INSIDE THE DIAMOND

Let's begin by examining the standard two-dimensional diamond profile that has been traditionally used for ray tracing, and then comparing it to a more accurate three-dimensional model. The standard diamond profile is a two-dimensional plane that slices through the bezel facets and pavilion mains. Although the angles covered in this plane are repeated eight times in an RBC diamond, this plane does not contain examples of all the angular relationships in that diamond. A large portion of surface area – up to 50% or more, depending on the lengths of the upper and lower girdle facets—consists of facets that are not included in these planes (figure 3). However, it is not merely a matter of missing surface area, but also of unaccounted-for angular relationships, that makes the two-dimensional diamond model inaccurate for understanding light paths. If we take the standard two-dimensional profile and rotate it around its central axis (i.e., the line that runs through the culet and the center of the table facet) to create a three-dimensional shape, we do not end up with a true RBC diamond (figure 4). Instead, the

resulting shape consists of two smooth cones, connected at their bases (i.e., the girdle), with one of the cones being truncated to form a flat surface (i.e., the table). This shape does not take into account the faceted surface of an RBC diamond (figure 5). Therefore, it is an inaccurate portrayal of an RBC diamond.

One reason we must consider each individual facet surface is that every interaction with a facet surface affects a light ray's path as it travels through

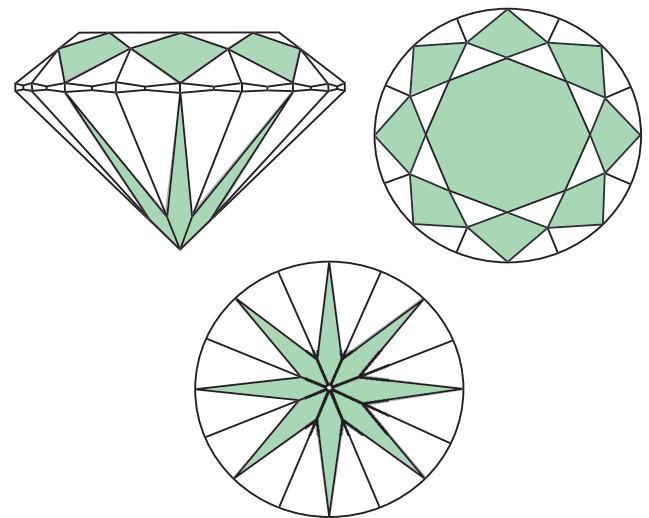


Figure 3. Up to 50% of a diamond's surface (those areas shown in white) are not included in the standard two-dimensional profile plane.

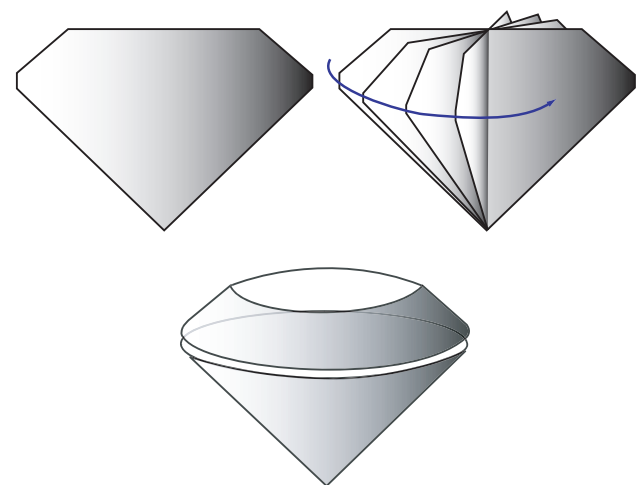


Figure 4. Rotating a two-dimensional diamond profile produces a smooth shaped (non-faceted) figure.

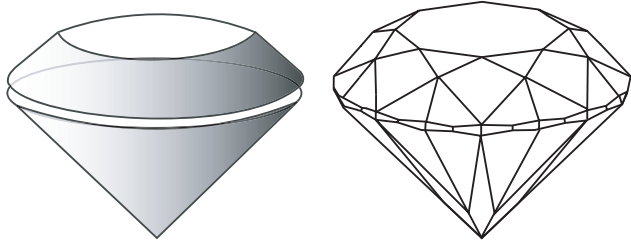


Figure 5. The smooth-surfaced shape produced by rotating a two-dimensional profile is not an accurate representation of an RBC diamond.

a diamond. Remember that the plane of incidence (which is determined by the normal of the surface and the striking light ray) determines the plane of the resulting ray. If the incident light ray and the normal of the surface that ray just struck is not in the same plane as the normal of the next surface¹, the resulting reflective or refractive ray *will be in a new plane of incidence* (figure 6).

Thus, three dimensions are needed to accurately model the light ray's path. For most light rays, the plane of incidence changes several times as the ray travels through an RBC diamond. This becomes increasingly true as the ray's path within the diamond becomes longer and thereby undergoes more facet interactions. Although ray paths with multiple facet interactions (i.e., four or more) have a higher likelihood of traveling through several different planes of incidence, even those paths with only two interactions can travel through multiple planes

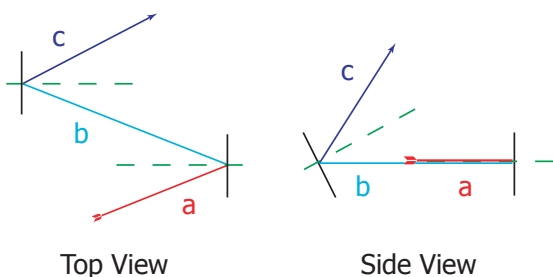


Figure 6. You could imagine that the ray path (shown in both top and side view above) is two-dimensional if you only consider one view at a time. But when you consider both views, the three-dimensional path of the light ray becomes apparent. In this case, segment "a" is not in the same plane as segment "c" because the surfaces are not parallel (as shown in the side view).

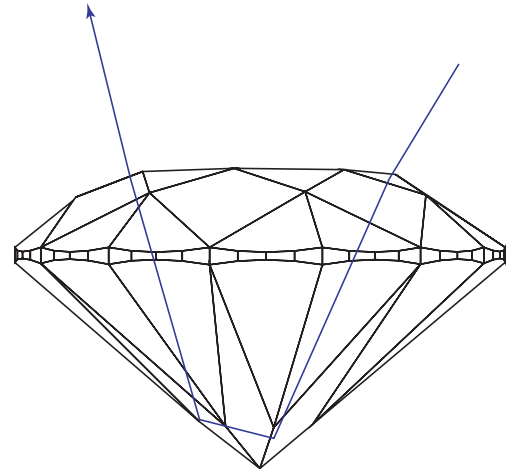


Figure 7. This "two-bounce profile shot" looks two-dimensional from a specific viewing angle.

(again, see figure 6). In addition, some light rays may travel through the diamond, have several facet interactions, and exit through the crown without ever having crossed a central plane in that diamond². It is important to recognize that these types of rays exist, because they might be completely missed if only the traditional two-dimensional diamond profile is considered.

Finally, even a light ray that interacts solely with two crown facets and two pavilion facets (the interaction often shown in standard diamond profile images) cannot always be represented within a single plane. This is because of the relationship of the relevant individual facet angles and their corresponding normals. As we have seen, each facet surface has the potential to change the ray's corresponding plane of incidence – *and often does*. A ray of this type (i.e., a ray that has four facet interactions, or two internal bounces) might appear two-dimensional from a certain viewing angle (figure 7). However, when viewed from other angles, the three-dimensional nature of this ray becomes obvious (figure 8).

Remember that this view is for a ray path with only two internal bounces. Light rays with more facet interactions would have increasingly more complex three-dimensional paths³.



VIEWING A DIAMOND FACE UP

There is another aspect of polished diamonds that is often considered only in two dimensions: their face-up appearance. Although experienced viewers “rock” diamonds when observing them, most commercial optical devices consider only the perpendicular face-up appearance of the diamond. This viewing angle, although important, does not convey the whole story. Just as a two-dimensional plane captures some, but not all, of a diamond’s information, a straight face-up view of the diamond neglects some of that diamond’s appearance.

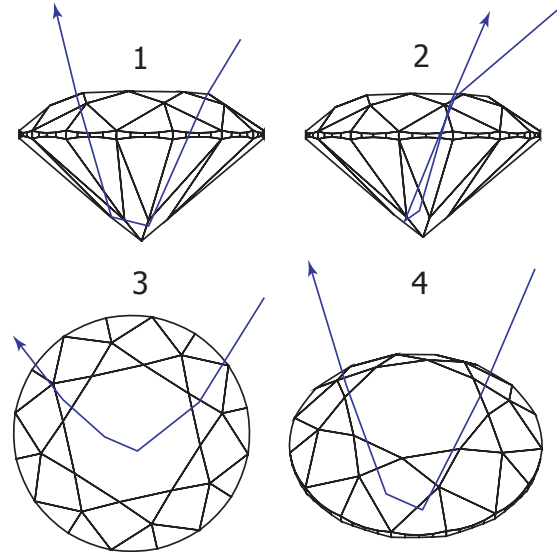
As we saw in “Diamond Optics Part 2,” many light paths leave the diamond at steep angles to the table. These rays would be “unseen” by a flat, two-dimensional, face-up observation, and would include some of the chromatic flares (fire) and white light (brightness) returned from a diamond. Although it is important to “weight” light return when measuring the performance of a diamond (i.e., give more value to those rays that are returned straight up from the crown, and presumably toward the observer), all of the other rays that exit the crown of a diamond should not be neglected.

SUMMARY

In the last four articles, we have reviewed foundational information about diamond optics. Three-dimensionality is as important to diamond optics as the laws of reflection and refraction, critical angles, the dispersion of different wavelengths, and polarization. All of these factors *work in an interrelated manner at all times* to bring about the appearance of an RBC diamond. Therefore, to accurately calculate the behavior of light in an RBC diamond, all of these optical properties must be tracked *for each light ray*, from its first facet interaction to its last.

We hope that you enjoyed this article, and invite any feedback or comments that you may have. You may contact us by e-mail at DiamondCut@gia.edu. ■

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Four Views of the Same Light Ray

Figure 8. This is the same diamond and ray path from the previous figure. Image 1 shows the original viewing angle. Image 2 rotates the diamond 90 degrees clockwise. Image 3 rotates the original image down 90 degrees to show the table-up appearance. And image 4 rotates the diamond down only 45 degrees. The three-dimensional path of this light ray is evident.

¹This situation (where facet normals are not in the same plane) is actually very common, even in a symmetrical RBC diamond. Four pairs of opposing facets usually have their normals in the same plane: opposite bezel facets, opposite star facets, opposite pavilion main facets, and table-culet. Most other facet pairs are generally not in the same plane; therefore, a ray that interacts with them would have a three-dimensional path.

²A central plane is a plane that slices through the center axis of the diamond (i.e., through the center of the table and the culet).

³In fact, the only light ray paths that can be captured in a two-dimensional model are those in which all of the relevant facet normals are in the same plane.