COLOR GRADING "D-TO-Z" DIAMONDS AT THE GIA LABORATORY

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Since its introduction in the early 1950s, GIA's D-to-Z scale has been used to color grade the overwhelming majority of colorless to light yellow gem-quality polished diamonds on which laboratory reports have been issued. While the use of these letter designations for diamond color grades is now virtually universal in the gem and jewelry industry, the use of GIA color grading standards and procedures is not. This article discusses the history and ongoing development of this grading system, and explains how the GIA Laboratory applies it. Important aspects of this system include a specific color grading methodology for judging the absence of color in diamonds, a standard illumination and viewing environment, and the use of color reference diamonds ("master stones") for the visual comparison of color.

Historically, the evaluation of most gem diamonds focused on the absence of color (Feuchtwanger, 1867; figure 1). Today, this lack of color is expressed virtually worldwide in a grading system introduced by GIA more than 50 years ago that ranges from D (colorless) to Z (light yellow). With the acceptance of this system, color grade has become a critical component in the valuation of diamonds, leading to historic highs at the top end of the scale. In May 2008, the diamond in figure 2 (a 16.04 ct round brilliant that GIA graded D color, VVS2 [potentially Flawless]) sold at Christie's Hong Kong for a record US$208,500 per carat for a colorless diamond. At the same auction, a 101.27 ct shield-shaped diamond sold for $61,500 per carat, a vivid reminder of the impact of even minor differences in grade; it was F color, VVS1. At auction, and throughout the marketplace, differences between adjacent color grades can result in substantial differences in asking price. For example, on December 5, 2008, the *Rapaport Diamond Report* noted an approximately 32% (and *Idex* about 33%) difference between D and E color for a one carat Internally Flawless round-brilliant diamond. Important price distinctions based on color are not limited to high-end colors and clarities. On the same date, the difference between G and H color for a one carat round-brilliant diamond of VS1 clarity was about 16% in both *Idex* and *Rapaport*.

As part of its educational program, GIA has taught the basics of color grading D-to-Z diamonds since the early 1950s. And in the more than five decades since the GIA Laboratory issued its first diamond grading report in 1955 (Shuster, 2003), it has issued reports for millions of diamonds using the D-to-Z system. Throughout this period, GIA has experienced increased demand for its diamond grading services over a growing range of diamond sizes, cutting styles, and color appearances. This has required a continual evolution in the equipment and methods used in the GIA Laboratory, while maintaining the integrity of the grading system itself. At the core of the system's development has been an ongoing assessment of how best to observe a diamond in order to describe its color consistently. At times, the resulting adjustments have appeared to conflict with earlier statements.

This article reviews the history of the system's

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Figure 1. Although historically absence of color has been important in selecting diamonds for jewelry, only with the global acceptance of GIA's D-to-Z color grading system has the industry been able to refine that selection to tight tolerances. This contemporary brooch is one example, with all the diamonds in the D-E-F range. Prior to the broad acceptance of the system, as with the 1955 necklace, pieces typically had a greater color range. The brooch, courtesy of Harry Winston Inc., is 21.93 carats total weight. The necklace is about 24 carats total; gift of Harriet B. Coccomo, GIA Collection no. 14188. Photo by Robert Weldon.

development to help clarify the various modifications that have taken place over the years in the color grading equipment and practices used at the GIA Laboratory. We then describe how D-to-Z diamonds are currently graded in the lab, that is, the procedures that have resulted from these years of evolution and refinement. Last, we discuss special considerations in D-to-Z color grading, such as the grading of brown and gray diamonds, the selection process for master color comparison diamonds ("master stones"), and the impact of adopting advanced instrumentation.

BACKGROUND

While there has been evaluation of diamond color (or absence of color) throughout history, the systems and methods used for this purpose were not clearly defined, standardized, or consistently applied before the 1950s. In the late 19th century, color was considered a diamond's most important value factor, but the naming conventions in use at the time placed color in a variety of categories that were general at best. For example, the color appearance of gem diamonds was often described using metaphoric terms (e.g., "River" or "Water" for the most colorless diamonds), or by association with a geographic location from which similarly colored diamonds were commonly seen (e.g., "Wesselton" and "Top Wesselton" for near-colorless diamonds traditionally associated with the Wesselton mine, "Cape" for pale yellow diamonds from the Cape of Good Hope region, and "Jager" for colorless diamonds with strong fluorescence such as those typically recovered from the "Jagersfontein" mine in South Africa (Shipley, 1950b; Liddicoat, 1993). In the case of *blue white*, abuse of the term eventually prompted action by the U.S. Federal Trade Commission to ban its misuse in diamond marketing (Shipley, 1938).

Recognizing the importance of objective, consistent color communication, GIA—in conjunction with the American Gem Society (AGS)—began work on color grading standards in the 1930s ("Diamond grading instrument . . . ," 1934), and by 1941 had developed a color scale for evaluating diamonds (see following section; Barton, 1941; Shipley and Liddicoat, 1941; AGS, 1955; Shuster, 2003). The development of this "color yardstick," as it was then described, evolved over the next decade and became the basis for what is known today as the D-to-Z color grading scale.

While color grading was introduced in the early 1940s for AGS members, the general trade was not familiar with the GIA/AGS standard. Richard Liddicoat, who became the executive director of GIA in 1952, created a full diamond grading system that he taught for the first time in 1953 to jewelers in classes around the United States (Shuster, 2003). Soon, other GIA instructors such as Bert Krashes and G. Robert Crowningshield became part of the traveling team that taught this new grading system, which greatly expanded interest in—and use of—this approach.

Figure 2. This 16.04 ct D-color, VVS2 (potentially Flawless) round brilliant set an auction record for per-carat price for a colorless diamond when it sold for US$208,500 per carat in May 2008. Courtesy of Christie's.

Attracted by the system's ability to generate a diamond's market value based on the new quality grades and other concepts regarding diamond proportions and appearance (Gilbertson, 2007), jewelers flocked to GIA to get a better understanding of diamond valuation. GIA's new system launched the scale of "D to Z" for color grading. Regarding the unusual starting point (the letter *D*), Richard Liddicoat (Liddicoat, n.d.; *Gem Talk*, 1981) stated the choice was made to differentiate the GIA system from other less clearly defined ones that used designations such as "A," "AA," or metaphoric terms like those noted above.

As jewelers went home to grade their own diamonds, they started to question some of their decisions and sent the diamonds to GIA for checking by their instructors. Over time, this informal practice led to GIA's diamond grading laboratory service, with the first formal reports issued in 1955.

For more than 50 years, this grading system has been taught by GIA Education and used in the GIA Laboratory. The combination of understandable letter designations for color grades, the availability of a standardized grading environment and sets of diamonds as color references, and GIA's ability to teach the basics of this system to others provided a new level of stability and confidence in diamond commerce. In the decades since its introduction, the D-to-Z nomenclature has been adopted virtually worldwide for the sale, purchase, and evaluation of polished diamonds. Consequently, other grading laboratories also use this nomenclature, sometimes in combination with their own. While most claim to use the GIA system, however, it is not likely that it is applied as it is at the GIA Laboratory. *Using the same color grading terms does not constitute adhering to the conditions or methodology of the GIA system*. The reasons for this should be evident by the end of this article.

The Origin of GIA's Viewing and Comparator Standards. In 17th century India, Tavernier (1676) noted, diamonds were color "graded" at night by lamplight. By the 19th century, however, daylight was the worldwide standard in which gemstones were observed to discern their color (Chester, 1910; Cattelle, 1911; Wade, 1915, 1916; Ferguson, 1927). Unfortunately, the characteristics of daylight vary (throughout the day, in different locations around the globe, and at different times of the year), and these differences in light quality can significantly affect the color appearance of gemstones (Cattelle, 1911; Wade, 1915; Sersen and Hopkins, 1989).

The historical methods used to observe and compare diamond color were just as variable as the type of illumination itself. Observers held diamonds in the palms of their hands or between their fingers, typically examining them against a range of different backgrounds (Tavernier, 1676; Mawe, 1823; Feuchtwanger, 1867; Morton, 1878; Wodiska, 1886; "On diamonds," 1902; Wade, 1916). For most of history, of course, diamonds were so rare that very fine color distinctions among them were not needed, so the trade could function using such simple evaluation techniques.

With the discovery of large deposits in southern Africa in the late 19th century, more diamonds entered the marketplace than ever before. This influx generated a greater desire (more specifically, a commercial need) for finer color distinctions. By the early 20th century, certain minimal standards for color grading had evolved, as summarized from Wade (1916):

1. Use "good north light unobstructed by buildings or other objects. There must not be any coloured surface nearby to reflect tinted light, as a false estimate might easily result."
2. Color grade diamonds only between 10 a.m. and 2 p.m.
3. Do not use artificial light.
4. Always use the same location for color grading.

Figure 3. The GIA Colorimeter, introduced in 1941, was developed to select master stones by visually comparing a diamond to a repeatable standard called the "color yardstick" (inset, top)—a graduated wedge of glass that transitioned from colorless to yellow. When a diamond being graded matched a section of the wedge in the colorimeter, the corresponding Roman numeral expressed the grade. Lighting, viewing geometry, and the comparison standards were all controlled with this box. Although modified over time, these three factors continue to be at the heart of consistent color grading. Photos by Robert Weldon.

5. Use comparison diamonds.
6. Dim the "fire" (i.e., dispersion) of the diamond, perhaps by breathing on the stone.
7. View the stone on edge as well as face-up (face-up only can yield a false color).
8. Use magnification (aplanatic triplet lens).

Even with these standards, color grading among dealers and retailers was inconsistent; the result in the trade was chaos. Cattelle (1911, p. 134) noted that "Color in diamonds is the opportunity of many dealers, and the despair of others, for it is very deceptive."

By the mid-20th century, advances in lighting technology and vision science paralleled the jewelry industry's increasing desire for improvements in diamond color analysis. GIA began one of the earliest efforts to address this desire in the mid-1930s ("Diamond-grading instrument . . . ," 1934; AGS Research Service, 1936), which culminated in a 1941 article by GIA founder Robert Shipley and Richard Liddicoat. Among their concerns was the need for a grading scale with uniform comparators (i.e., color references) that could be used throughout the industry.

Although jewelers commonly kept a few reference diamonds to use for color comparison, there was no standard for such comparators, so the color grade given to a diamond by one jeweler could easily differ from the grade assigned to it by another. Moreover, different jewelers used different sources of light, both artificial and natural, which further complicated their interactions with one another. To address this situation, Shipley and Liddicoat's 1941 article announced the development of: (1) a visual color comparison instrument (the GIA Colorimeter), (2) a color scale (the "color yardstick") that represented grade categories, (3) a standardized light source and viewing environment for use by jewelers (the Diamolite), and (4) a service to grade "reference" or "master" diamonds for AGS jewelers to use as comparators.

The GIA Colorimeter and Color Yardstick. Notes and drawings from Shipley in the 1940s indicate that the GIA Colorimeter was adapted from the Duboscq Colorimeter made by Bausch & Lomb, which was widely used in the medical field up to the early 1960s (Warner, 2006). Shipley and Liddicoat's colorimeter (figure 3) consisted of a small box with an indirect light source and a split-image magnifier that allowed a grader to compare a diamond placed in a tray to a movable, transparent glass wedge that varied (and was graduated into ranges) from colorless at the thin end to yellow at the thick end (Shipley and Liddicoat, 1941). This first system had 13 grade ranges: The glass wedge had markings for seven categories, which were labeled "0" followed by Roman numerals "I" to "VI," with these latter six further separated by half-division marks (see figure 3, inset). These 13 grades equated to the D-to-P range in GIA's later system.

With this colorimeter, the color determination was made by visual comparison, with the diamond placed in three different positions (table-up, girdle-up, culet-up), and 10 observations in each position. The results obtained for each position were then averaged to reach the overall color grade. It is interesting to note that this early form of color grading at GIA was done with magnification (about 4×) and through the comparison of the diamond to a flat transparent wedge of graduated colored glass rather than other diamonds. The box in which the diamond was viewed against the glass wedge housed a light source for observing the diamond and eliminated influences from outside lighting. The light source used was a blue-coated incandescent bulb that was intended to mimic the color appearance of daylight.

When Shipley's son, Robert Shipley Jr., felt the colorimeter was ready to use for color grading, he wrote to his father in a letter dated April 2, 1941: "I have run thirty reading checks on four stones on which Dick [Liddicoat] has made thirty reading averages. Neither of us had any reference to the others (sic) work, and in no case were we off more than .125 of a division!" Nevertheless, to the best of our knowledge, the GIA Colorimeter was never manufactured commercially (apparently only two were made) or used for any purpose other than the grading of AGS master stones by GIA staff.

The GIA Diamolite. While the GIA Colorimeter allowed for the visual comparison of a diamond to a color standard to develop sets of master stones, jewelers still needed a standard viewing environment when comparing other diamonds to these masters. Although some jewelers had stores situated such that they could effectively use north daylight, many did not, so they used whatever light source they had available. Up to this point, artificial light had proved problematic because it was not close enough in color appearance to natural north daylight (the accepted trade standard). And, again, "north daylight" varied depending on the time of year, time of day, weather, and geographic location; the color of the diamond was also influenced by colors in the viewing area. Ultimately, the Diamolite was the first step toward providing a solution to this problem (figure 4).

From the development of their colorimeter, GIA researchers knew that controlling the light source would be critical, but they also realized that an environment to compare diamonds to one another would have different requirements from that of the colorimeter. Shipley Sr. had been working on this issue ("Diamond-grading instrument . . . ," 1934), but it was Shipley Jr. who carried it to its next step. He and others at GIA examined every new light source on the market; they tried argon bulbs (AGS Research Service, 1936) and filtered incandescent bulbs, as well as the relatively new fluorescent lamps ("Instrument research . . . ," 1937). Even though GIA was selling the "Da-Grade" fluorescent light source, made by General Electric (GE), for use in displaying diamonds ("At last . . . ," 1938), they

Figure 4. The GIA Diamolite was introduced to AGS members in 1941 and, for the first time, offered jewelers a controlled lighting and viewing environment for comparing "master" diamonds to other diamonds. The Diamolite measured 13¾ in. high × 12 in. wide × 6 in. deep (34.4 × 30 × 15 cm) and housed an incandescent bulb with a blue filter (inset) designed to make the light output better simulate daylight. Photos by Robert Weldon.

realized an observer could not use it to distinguish fine nuances of faint yellow color, so the search continued for a better light source for grading.

Shipley Jr. also looked to other industries in which fine color distinctions were critical and found a filtered incandescent light source used as a standard for oil colorimetry and cotton grading. The Shipleys and Liddicoat worked with the color technology company Macbeth (Shuster, 2003) to counterbalance the overabundance of the long rays (i.e., "redder" light) of this tungsten bulb with a special blue filter (figure 4, inset). This adjusted the color temperature (i.e., appearance) of the light output to be closer to that of daylight.

Shipley Jr. also recognized that color grading needed an enclosed viewing environment: "Preliminary research shows that the greatest single handicap in accurate color grading is the difficulty of securing a light absolutely free from colored reflections from adjacent objects" (AGS Research Service, 1936, p. 77). The following excerpt from an article about changes to the *Gemology* textbook ("A note on diamonds," 1938, p. 174) expresses GIA observations at the time on the effect of external lighting on diamond color appearance and defines "body color" for the trade:

> The color of a diamond, as it is seen by the eye, may be affected (1) by the comparative amount of the various spectrum colors which it disperses, and (2) by the color of the light reflected from sky, walls, ceiling or other objects. Upon examination by transmitted light against a white, neutral gray, or black background, the true color of the diamond itself is observable, and the resulting appearance is known as the *body color*. However, if colored reflections fall upon those surfaces of the diamond which are toward the eye, the true body color may not be observable. (If colored reflections fall upon a white background against which the diamond is being examined, they will also affect the body color.)

Some in the trade already understood this effect of the lighting environment. By the late 1800s, diamond dealers were very aware of how the surrounding environment affected the appearance of color in a diamond. In the New York jewelry district on Maiden Lane, neighboring buildings were painted yellow—and these faced the windows from which dealers judged color in the north daylight. The dealers pooled their funds and offered to repaint the offending buildings. *Jewelers' Circular* reported: "Several [dealers] stated that it is impossible to sell diamonds in their offices, and unless the colors of [buildings] No. 5 and 7 are changed, they will be forced to vacate their offices" ("Dealers object . . . ," 1894, p. 16).

GIA researchers ultimately determined that a box made of translucent white matte paper, open on one side for observation, furnished a much more satisfactory environment for judging color (AGS Research Service, 1936). Not only was the direction of the light that fell on the diamond controlled, but the light was also diffused, which subdued surface reflections from facets that might obscure the bodycolor. In 1941, the Institute introduced a commercial version, the GIA Diamolite, for use in color grading (again, see figure 4; Shipley and Liddicoat, 1941). The accompanying brochure stated that this viewing box (small enough for the display counter in a retail store) allowed a jeweler to observe diamonds under a standardized light source in any physical location at any time of the day or night.

Grading Master Stones. Now that it had a light source and an environment in which to visually compare diamond color, as well as an instrument that related the color to an established scale, in the early 1940s GIA began to collect diamonds graded with the colorimeter to use as its own "master" comparators.

After leadership review, the AGS membership voted in 1941 to recommend the use of the GIA Colorimeter for master stones, the scale as the standard for color distinctions in diamonds, the GIA Diamolite, and the new grading service for master stones (see, e.g., Shipley and Liddicoat, 1941). For the AGS master stones, two of the averaged colorimeter grades were reported to the AGS member jeweler—for the table-up and girdle-up positions. The "0–VI" numerical scale of the colorimeter was promoted as the color grade nomenclature to be used for diamonds (Shipley and Liddicoat, 1941) and was strictly for AGS members. Consequently, when GIA chose to develop a diamond grading system available to everyone, it had to use new terms. The choice for color grading colorless to near-colorless diamonds, as previously noted, was the letter grade scale beginning with D.

GIA had offered other technical services, such as pearl identification, to the trade since the 1930s, but the master diamonds service (started in 1941) was the first one related to diamond grading. In fact, this service preceded the 1949 creation of the laboratory as its own division within GIA.

The 1950s to '80s: The Continued Evolution of Lighting and Viewing Environments. The last known mention of the name *Diamolite* was in the January 1950 issue of *Jeweler's Circular Keystone* (*JCK*) magazine. *Gems & Gemology* first cited the new name, *DiamondLite*, in 1949 (Schlossmacher, 1949). This change in name accompanied an updated filter from Macbeth that was still used with an incandescent bulb (Shipley, 1950a). We do not know if the physical proportions of the viewing environment changed at that time.

This period saw the continuation of GIA's investigation into alternative light sources for the assessment of diamonds. By the 1950s, Liddicoat and his contemporaries had apparently developed a comfort level with the fluorescent lamps available at that time. GIA began teaching that jewelers could use a modified fluorescent lamp for color grading when they didn't have access to a (still incandescent bulb) DiamondLite: "a reasonable substitute may be secured by adapting a simple fluorescent tube desk lamp . . . lined with flat-white paper . . . enclosed on the back and two sides so as to exclude as nearly as possible all reflections from surroundings" (Shipley, 1955, p. 5). A sheet of white tissue paper between the fluorescent tubes and the diamond further diffused the light.

Depending on the evenness, thickness, and type of phosphor coating, however, the early generations of fluorescent lamps had considerable variation in the wavelengths and intensities of their light output. This included an inconsistent—and, at times, relatively high—amount of ultraviolet (UV) emission, in contrast to the extremely low UV content in incandescent bulbs commonly used at that time. Realizing that some fluorescent diamonds appeared different when observed under lights with UV content (fluorescent lamps as well as the former Diamolite with its UV source, added in 1947, turned on), GIA made a number of statements related to this with each accompanying modification. In 1955 course material, GIA advised that "This factor should not cause too much difficulty, however, since only a very small percentage of stones fluoresce strongly enough to modify the body color under this light source" (Shipley, 1955, p. 5). Nevertheless, contemporary course materials advocated the grading properties of the (low-UV) incandescent bulb grading light, even to the disavowal of the historical standard, (relatively higher UV) daylight. GIA Assignment 2-31 (Shipley, 1957, p. 8) stated that "Fluorescent stones should be graded at their poorer color [as seen] in artificial light devoid of ultraviolet radiation [i.e., the incandescent bulb of the DiamondLite], rather than at their daylight grade [i.e., the grade they would receive if viewed against a comparison stone in daylight]."

In the mid-1960s, GIA introduced the GIA Diamond Color Grader tray to their Mark IV gemological microscope, which allowed color grading under the overhead diffused fluorescent source attached to the microscope. However, Gem Instruments advised that "Highly fluorescent stones cannot be graded in the GIA Color Grader" (GIA, 1966), due to the proximity of the diamond to the lamps.

In 1974, Ken Moore (director of Gem Instruments Corp.) introduced a DiamondLite (figure 5) that used 6-watt fluorescent lamps made by Verilux, with a new coating that minimized UV emission as compared to similar lamps and especially as compared to earlier fluorescent lamps. GIA often promoted the minimized UV emission in these lamps. For example, in 1979 course materials, GIA described these new lamps as "practically devoid of ultraviolet waves" (GIA, 1979, p. 9). Later course material (GIA, 1995, p. 9) claimed that "Filtered, cool white balanced fluorescent light is best: unlike sunlight, it is nearly free of ultraviolet." As frequent as such statements were, it is important to remember that no fluorescent lamp is truly "UV free."

Figure 5. This version of GIA's early fluorescent viewing environment, the DiamondLite, was introduced in 1974 and used Verilux 6-watt lamps. It measured 9 in. high, 13 in. wide, and 8 in. deep (22.5 × 32.5 × 20 cm). Photo by Robert Weldon.

From the 1990s to the Present: Lighting and Viewing Refinements. Research in the 1990s and the first decade of the new millennium led to refinements in the equipment and processes used to color grade diamonds that are reflected in the grading methods in place today.

Light Source Testing. Since at least the 1970s, millions of diamonds have been graded using fluorescent lighting, at GIA and throughout the industry. It has become the standard in the diamond industry. To ensure consistency in GIA's grading, proposed changes in lighting must be thoroughly tested to balance the potential benefits to the grading methodology against the very real damage that would be caused if subsequent color grades were inconsistent with earlier ones. (The success the laboratory has had in this regard can be tracked in very real terms through its update service. Today we occasionally see diamonds graded in the 1970s that have been submitted for updated grading reports; after they have undergone a full grading process using contemporary equipment and procedures, the vast majority are returned with the same grade determinations.) With that as a guideline, GIA began researching options for fluorescent "daylight equivalent" lighting. In part, this research was driven by the fact that the Verilux 6-watt lamps used in the DiamondLite were no longer readily available, and other manufacturers' lamps of the same size did not consistently meet GIA lighting standards.

Researchers compiled a list of factors to be considered in selecting an alternative lamp: worldwide availability, suitable illumination levels, uniform distribution across the work area, a spectrum that mimics International Commission on Illumination (known as CIE) D55-to-D65 specifications, a color temperature in the 5500–6500 K range, and a color rendering index of at least 90 (for details, see box A). Data collection began in January 1998, with 40 different lamps from various manufacturers. The 6-watt Verilux lamp used in the DiamondLite at that time was included for comparison. For each manufacturer, four different sizes of fluorescent lamps were tested: 4 watt (134 mm/5–6 in.), 6 watt (210 mm/8–9 in.), 15 watt (435 mm/17–18 in.), and 18/20 watt (590 mm/23–24 in.). Spectra were collected when the lamps were first turned on and after "burn in" times of 50, 100, 500, 1,000, and 2,000 hours, so that the evolution of each spectrum could be analyzed (see, e.g., figure 6). Data were collected using a Photo Research PR-704 Spectrascan spectroradiometer, an Ocean Optics SD2000 spectrometer, and a Gossen Mavolux digital lightmeter.

In late 1998, GIA researchers did additional testing on three of these lamps: an 18-watt Osram Biolux, a 20-watt Verilux, and a 20-watt Macbeth. For comparative visual observations, choices were narrowed to the Verilux and Macbeth lamps. The former was selected because researchers felt that continuity with the Verilux lamp characteristics was important, and the latter was chosen because GIA had been using the Macbeth lamp successfully to color grade colored diamonds for a number of years. After weighing all the factors and completing data analysis, GIA decided that the Verilux lamp was the best lighting source for the purpose of color grading D-to-Z diamonds.

Viewing Environment. The decision to use the longer (23–24 in.) 20-watt lamps required the design of a new and much larger viewing environment to house them. From its research on color grading colored diamonds (see, e.g., King et al., 1994), GIA recognized that a larger viewing box would also better shield the observer from distracting visual clutter in the surrounding environment, give a larger neutral background for the field of vision, and be more comfortable for the observer. These factors contributed

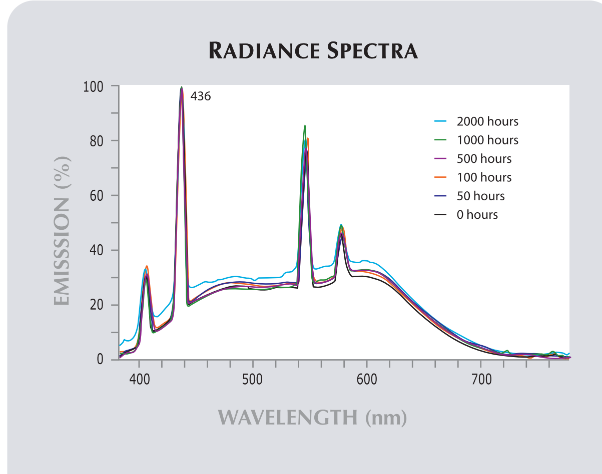

Figure 6. In characterizing light sources, it is important to know the consistency of their properties over time. To accomplish this, the lights are left on for extended periods and a number of radiance spectra are taken at specified times; in this case after 50, 100, 500, 1,000, and 2,000 hours. The plot shows the captured radiance spectra of the Verilux 6-watt fluorescent lamp (used for comparison with potential new selections) normalized for the 436 nm peak at 100%. The minor deviations seen here are typical and do not result in noticeable differences in performance for color grading.

to our decision to make the height of the box 18.5 in. (47 cm), which is similar to the Judge II used for colored diamonds (20 in.; illustrated in King et al., 1994, p. 230). Recognizing that the depth of environments used for D-to-Z color grading had traditionally been shallow (approximately 8 in. in the DiamondLite to 6 in. in the Diamolite), we decided to make the prototype viewing box 6 in. (15.24 cm) deep. As mentioned above, the width was determined by the length of the two lamps being used. In practice, we found that the wider environment was better for handling the diamonds. To improve the consistency and life cycle of the lamps, we successfully experimented with electronic high-frequency ballasts. Although the walls of the DiamondLite were coated dull white, GIA staff members had found that medium to light gray walls reduced eye fatigue (at the same time, various standards organizations also recommended a neutral gray surround for color grading environments; ASTM, 2003; ISO, 2005).

Subtle modifications were made to the design of the box over the next five years, as a prototype was formalized for use in the laboratory in the early 2000s. At the same time, we also developed a product for commercial release, a viewing environment that incorporates two 15-watt Verilux lamps into a slightly smaller (more retailer friendly) box, which is market-

Box A: Characteristics of the Standardized Fluorescent Light Source GIA Uses for D-to-Z Color Grading

Proper illumination is critical when performing tasks requiring subtle color comparisons, as is the case with color grading D-to-Z diamonds. There must be enough light to view the subtle differences, but not so much that color perception is affected by surface glare or that the light causes eye fatigue. We have found the acceptable range for light output to be between 2000 and 4500 lux. The light output needs to be stable (which is accomplished with an efficient, high-frequency ballast) so there is no variation in intensity (e.g., flickering), and it should be consistent across the entire viewing surface. It should take very little time for the lamps to become stable once they are turned on. The light emitted also must be diffuse, since point or spot lighting can cause bright surface reflections, more obvious dispersion, and strong contrasts in polished diamonds.

There are a number of characteristics of daylight that are valued in diamond color grading and were considered in choosing the standard light. These include, for example, daylight's overall spectrum, its color appearance in the northern hemisphere, and its ability to render colors. While the full emission spectrum should be considered when choosing lamps, it is also important to note the output in the areas that can affect the predominant task at hand, in this case the grading of colorless to light yellow diamonds. In particular, there must be enough output in the blue region of the spectrum, as it is the absorption area of wavelengths in this region that allows yellow diamonds to be perceived at optimum visual acuity. Fluorescent lamps have "spikes" in their emission spectra (see again figures 6 and 8): narrow ranges of wavelengths that have much greater intensity. The positions of these spikes and their potential effect on color grading were important to our choice of a light source. In addition, the spectrum of a lamp used for color grading should not emit short- and mid-wave UV, as these emissions can be harmful to the eyes of the observer over extended periods of time. However, the lamp should emit long-wave UV, which is an important characteristic of daylight. The CIE standards for D55 to D65 light also specify a UV component.

Regarding the UV component, we have learned that for some fluorescent diamonds the distance between the lamps and the grading tray can influence the final color grade. For consistency, we use a distance of 8–10 in. (20–25 cm) between the lamps and the diamond. Bringing a fluorescent diamond closer to the lamps may result in a stronger fluorescence impact. For instance, a yellow diamond with strong blue fluorescence could appear less yellow (i.e., to have a higher color grade) as it gets closer to the lamps. Moving the same diamond more than 10 in. from the lamps will have the opposite effect; that is, the color will appear more yellow (a lower color grade).

The relative amount of UV versus visible light

ed for both D-to-Z color grading and round-brilliant-cut evaluation as the GIA DiamondDock (figure 7). It is also used in the laboratory.

With each modification to the viewing environment, experienced color grading staff in the New

Figure 7. This viewing box, the DiamondDock, provides a good surround for making visual comparisons of diamonds, both for color grading D-to-Z stones and observing round brilliant cuts. When the raised platform is inserted in the box as seen here, a viewing tray of master diamonds is at the appropriate height for color grading. When the platform is removed (and the auxiliary LED lights turned on), cut can be observed with the diamonds placed in a tray on the base of the unit. The box measures about 18 in. high × 21 in. wide × 6½ in. deep (45 × 52.5 × 16.25 cm). Photo by Robert Weldon.

emission in the spectrum remains the same regardless of the distance to the light source. However, if the stone is observed close to the light source, the blue fluorescence emission in diamond may become more obvious than its absorption of yellow.

The "correlated color temperature" (CCT; or just "color temperature") is another important aspect of a light source. This term is used to describe the overall color of "white" light sources, and the "temperature" is most commonly expressed in units of kelvin (K). Incandescent lighting has color temperatures around 2000–3000 K and is generally referred to as being "warm" light. Common fluorescent lighting in general, with a CCT of 4500 K or higher, is considered "cool." The use of *warm* and *cool* with regard to lights refers to the color appearance of the light; the temperature designations could lead one to think the reverse. To simulate north daylight, a light source should be much "cooler" or "whiter" and have a color temperature in the 5500–6500 K range.

Lighting manufacturers often refer to the light's color rendering index (CRI) as an important criterion as well. In general, CRI is a quantitative measure of a specific light source's ability to reproduce colors faithfully in comparison with an ideal or natural light source (CIE and IEC, 1987). On a scale of 0 to 100, lights with 90 or higher are generally preferred for tasks requiring color differentiation.

When choosing a lamp, GIA uses the CRI and the color temperature of the light source in conjunction with both its complete spectrum and the specific regions that can affect D-to-Z color grading.

In researching practical solutions for the laboratory and the trade, GIA requires that the lamp be energy efficient, widely available in the marketplace, and reasonably priced. (Information on lighting criteria and explanations of these and other terms used regarding lighting can be found on many lighting websites. One example is www.lightsearch.com/resources/lightguides/colormetrics.html.)

In summary, the basic technical specifications for the lighting used for D-to-Z color grading at GIA are:

- Stable, fluorescent lamps 17 in. (43 cm) or longer
- An intensity of light in the range of 2000–4500 lux at the surface of the grading tray
- An 8-to-10 in. distance between the lamps and the grading tray
- A color spectrum close to CIE D55–D65
- A color temperature between 5500 K and 6500 K
- A color rendering index of 90 or above
- A high-frequency (>20,000 Hz) electronic ballast
- A light ballast with efficiency (power factor) above 0.5 (50%)
- No noticeable output in the short- or medium-wave UV range (or a filter available to eliminate UV in this range)
- An emission for long-wave UV (between 315 and 400 nm, close to the reference spectrum of D55–D65)

York and Carlsbad laboratories independently color graded the same diamonds in the DiamondLite and the two new viewing environments to verify the consistency of grading results. Our findings showed that overall results were within tolerances recorded in the history of GIA's D-to-Z color grading. Spectral analysis of the three lamps showed consistency as well (figure 8).

THE UV CONTENT IN LIGHT SOURCES USED FOR D-TO-Z COLOR GRADING

The potential effect of lighting on diamond fluorescence (and therefore color appearance) has long been a subject of discussion, although the UV component in a light source only impacts color appearance in some obviously fluorescent diamonds. In the 1930s and before, there was general agreement that diamonds should be observed in north daylight, which contains UV. Yet the first widely accepted standard viewing environment, the Diamolite, contained a filtered incandescent bulb, which had low UV content compared to daylight. As noted earlier, fluorescent lamps of that era were neither stable enough nor consistent enough to meet the requirements of diamond color grading.

During the 1940s, the appearance of a highly fluorescent diamond in daylight was considered a positive attribute. Recognizing the inherent limitations of the Diamolite's incandescent bulb in this regard, GIA introduced a stand-alone long-wave ultraviolet light source in 1945 (Shannon, 1945) and in 1946 updated the Diamolite by adding a UV source. When used alone, this UV lamp revealed the presence and strength of fluorescence in a diamond and, when used in conjunction with the filtered tungsten lamp of the Diamolite, created a condition that was felt to better simulate daylight and "show the

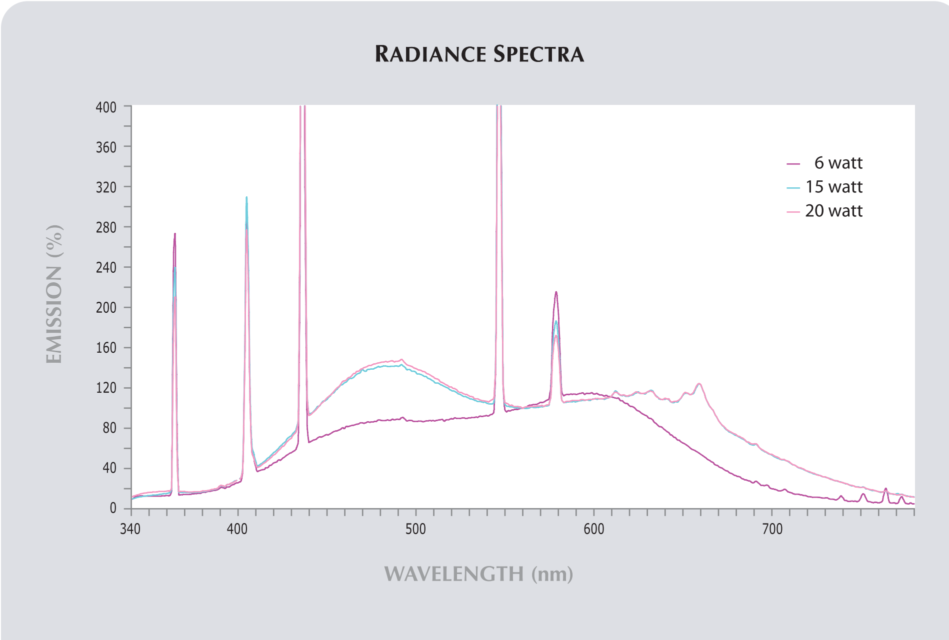

Figure 8. The 15- and 20-watt Verilux lamps chosen for the new viewing environments produce results that are within tolerance for color grading and compatible with the 6-watt lamps used in the past. Here, the UV region shows good agreement between the three lamps. Note that the 15- and 20-watt lamps have a phosphor layer that results in an additional emission in the red region between 620 and 700 nm that does not have a noticeable influence on D-to-Z color grading. Spectra normalized at 560 nm.

diamond off under the most attractive and favorable conditions" (Collison, 1947, p. 431).

As noted earlier, GIA continued to experiment with different lighting sources throughout the 1950s and '60s, and began moving toward the use of fluorescent lamps, both in conjunction with the incandescent bulb of the DiamondLite and separately in the overhead light source of their microscopes.

Eventually, the use of different phosphors, phosphor layer thicknesses, and new ignition technologies reduced the amount of UV emitted by fluorescent lamps. Research that GIA began in the early 1970s revealed that the lower UV content helped reduce the extreme appearance differences in diamonds that had been encountered with earlier lamps. To market the new DiamondLite, with its 6-watt Verilux lamps, some GIA literature implied that little to no UV content was preferable for D-to-Z color grading. Actually, the low UV content of these lamps was preferable to the UV content of earlier fluorescent lamps, which was higher or inconsistent. Indeed, the lamps chosen in the '70s had a small, but not negligible, UV component. And we continue to see this UV component in lamps chosen since then.

We recognize, however, that language used and certain statements made by GIA in the past several decades have led to confusion about the presence and, therefore, perceived desirability of the UV component in lighting used for D-to-Z diamond color grading. As mentioned above, course materials from the late 1970s to mid '90s described the lamps as "practically devoid" or "nearly free" of UV (GIA, 1979, p. 8; 1995). Even in the GIA Laboratory, an internal manual published in 1989 (p. IH-1) noted "Use a cool white, filtered, *ultraviolet free* fluorescent light [in the lab, the DiamondLite] in an area of consistent, subdued light."

"Filtered" referred (incorrectly) to the coatings used on the lamps to control output *across the spectrum*; this could be confused with using a filter to block UV. Again, these fluorescent lamps were not UV free.

In the late 1990s, referring to lamps with essentially the same UV content as their predecessor, laboratory staff spoke of the appropriateness of that UV component. As one of the authors [JMK] commented in an interview (Roskin, 1998, p. 149), "Yes, you can create an environment devoid of UV but it's a false situation . . . . It may sound like the ideal, but it steps outside the practical world. It's not relevant because it doesn't really exist anywhere. We try to be sensitive to the practical gemological issues." Tom Moses corroborated this position at GIA by stating, "we found that the Verilux bulbs used in GIA's diamond-grading units, standard cool-white fluorescent light bulbs, and northern hemisphere daylight (even filtered through a glass window) all have a certain amount of UV radiation. Hence the Verilux sources are similar—in terms of UV exposure—to grading environments throughout the world" (Moses, 1998, p. 21). The light source GIA uses for color grading has continued to be discussed in the trade (Tashey, 2000, 2001; Haske, 2002; Cowing, 2008).

The fact is that since the 1974 implementation of new coatings on fluorescent lamps, GIA has promoted using a daylight-equivalent fluorescent lamp with a non-negligible amount of emitted UV. GIA will continue to study the subject as new lighting technology and research become available, with the goal of maintaining existing color grading standards. In fact, one of the authors (RG) was recently informed by CIE (Peter Hanselaer, pers. comm., 2008) that the UV content of the proposed new reference illuminant for "Indoor Daylight" (e.g., ID65) that CIE is working on will define the daylight specifications indoors under standardized conditions regarding glass thickness and absorption of the windows and standard angles of incidence of the light. This "Indoor" reference illuminant will have a noticeably reduced UV content compared to the regular CIE Daylight standard D65 because of the typical absorption of glass in the UV region, so its resulting spectrum will be even closer to the Verilux lamps GIA is using in the lab.

THE GIA D-TO-Z COLOR GRADING SYSTEM

The equipment and methods used today at GIA to color grade D-to-Z diamonds have come from the experience gained through the observation of millions of diamonds, as well as from continuous research into advances in lighting technology and vision science. *Even though there have been modifications, such as changes to the viewing environment, it is important to recognize that the GIA standard—the spacing of the key historical grade markers—has remained unchanged since the system's inception more than 65 years ago.*

D-to-Z color grading is based on the observations of a trained observer, who compares a diamond to color master stones of known position on the grading scale (see box B for a discussion of the selection and care of master stones for clients and the laboratory). To achieve repeatable results, graders use a standard light source and a controlled viewing environment. Also important are the proper maintenance of equipment and consistency in the set-up of references, viewing geometry, and methodology. In addition, the observer must have been tested and shown to have normal color vision.

Screening, Training, and Monitoring of GIA Color Graders. Controlling all the conditions would be of little value without the proper screening and training of staff. At GIA, eligible staff members must pass tests such as the Dvorine Color Test, the Matchpoint Metameric Color Rule Test, and the Farnsworth-Munsell 100 Hue Test to ensure that they have normal color vision, discrimination, and acuity. Other tests are designed to gauge visual and verbal understanding of the color grading process.

Training sessions with experienced graders allow those staff members who are accepted as new color graders to gain first-hand knowledge over a period of weeks. All staff members are routinely monitored through the data collection of "blind" observations on control stones as well, to help insure color grading consistency.

To control for potential perception differences from individual to individual, GIA's grading process requires a minimum of two or three random, independent opinions (depending on the size of the stone). A consensus is required before a color grade is finalized. For larger or potentially D-color stones, the laboratory's computer operating system identifies the need for the most experienced graders. Last, to avoid the potential of reduced accuracy due to eye fatigue, color grading sessions are limited to approximately one hour, at which point a minimum break of one hour must be taken.

Routine Calibration and Maintenance. Since the viewing environment (e.g., the DiamondDock) is the neutral surround for the observer's field of vision, its care and cleaning is the first priority before grading even begins. If it is soiled it can distract the observer just as objects in the field of vision would. In the laboratory, the viewing environments are cleaned with a mild soap and soft cloth every week. Prior to placing new lamps in a unit, we capture their spectra with an Ocean Optics spectrometer equipped with an integrating sphere to make sure they are within tolerances. The light output at the surface of observation is checked monthly using a Gossen Mavolux Digital 5032B lux meter. Our testing has shown that the average life of a lamp is around 5,000 hours; from our experience, the "useful" life of the lamp for color grading purposes is half that, 2,500 hours. To avoid any deterioration in the illumination, we replace the lamps even sooner, at approximately 1,800 hours, unless some problem is noted earlier (i.e., discoloration at the ends of the lamps or a prominent drop in the lux meter readings). In the color grading area of the laboratory, ambient lighting is also controlled. Overall, the lighting is subdued, with no influence from natural daylight.

Again, see box B for the routine cleaning and care of master stones.

Box B: Selection and Care of Master Stones at the GIA Laboratory

Since the advent of its first colorimeter in 1941, GIA has received requests from members of the trade to evaluate diamonds that would serve as master comparators for color grading (figure B-1). This service continues to this day, although the selection process is accomplished through visual comparison supported by instrumentation, not a colorimeter.

Acceptance of one stone as a master is sufficient to start a set for a client and the issuance of a GIA Master Color Comparison Report. This report contains basic identifying information on the diamonds selected as masters and can be expanded with new master stone selections over time. There are several criteria for the selection of diamonds for a master set. These include cut, size, inclusions, fluorescence, and color. In creating a set of diamond color masters, the laboratory's overriding goal is to reduce as many visual variables as possible for the greatest consistency in all but color from one master stone to the next. Therefore, GIA will only grade round brilliant diamonds for masters. Besides being the most common cut, the round brilliant yields the most consistent color appearance (and shape) of any cut. In addition, master stones must meet good proportion standards.

Members of the trade decide the best size for the diamonds in their set of master stones, based on their typical stock (understanding that GIA will not grade diamonds under 0.25 ct for master stones). If, for example, a manufacturer or jeweler typically works with half-carat diamonds, the master stones should also be approximately half a carat. Over the years, we have found that sets larger than one carat are not necessary, as masters in the one-carat range can accommodate comparisons to larger diamonds. At the laboratory, we have compared masters of this size to diamonds 50 ct and more. When such diamonds have been observed on more than one occasion, we have come to the same color grading results. Within a given set (up to about one carat), master stones should not vary more than 10 points from one another. There can be no eye-visible inclusions, and they cannot exhibit "off-colors" such as having a subtle brown or gray cast.

Fluorescence is also an important consideration. For the E-to-J range, GIA only accepts diamonds as masters that have no observable (reported as "none") fluorescence. For K and lower, a "faint" fluorescence reaction is acceptable. While a more strongly fluorescent diamond might be used as a master if strict laboratory conditions were always to be used (i.e., standardized methodology, lighting, and environment), GIA has no way of determining whether client master stones will be used in these conditions. With regard to the acceptance of faint fluorescence for masters K and lower, our experience has shown that, as the amount of color increases, the impact of faint fluorescence on color appearance is less noticeable. Also, we have found that diamonds in the lower color grades commonly fluoresce, so it would be difficult to locate stones with no fluorescence in this color range.

A diamond selected as a master stone is not necessarily an exact duplicate of the GIA master of the same color grade designation. A diamond is an acceptable master when it falls in the range of repeatable visual tolerance as established by the laboratory over the years. Consequently, a diamond may be acceptable as a master if it is very close to the GIA master, but is very slightly to the higher or lower side. Our research has shown that skilled graders reach a point of visual tolerance (i.e., the range of repeatability) for D-to-Z color discrimination at slightly less than one-fifth of a grade at best. While this fraction may appear large, it is important to remember that even between whole grades the differences are extremely subtle. For example, it is common for untrained observers to see no dif-

Locations of Master Stones in the Grade Ranges. Every individual grade designation on the D-to-Z scale is actually a range of colors within that grade. *The GIA master stones are located at the highest boundary of each grade range* (figure 9), that is, at that end of their respective grade range that has the least color. Therefore, a diamond with less color than the G master stone (but not less than the F) would receive a grade of F. If the diamond appears to have the same amount of color as the G master, it would receive a grade of G. When a diamond has slightly more color than the G master stone but less than the H master stone, it will be called a G color. Any diamond, no matter how colorless in appearance, receives a D grade if it appears to have less color than the E master stone. Thus, no D master stone is necessary.

Set-Up of References in the Viewing Environment. At the laboratory, a "working master set" of the 10 master stones needed to grade the most commonly submitted diamonds, D through M range, is typical-

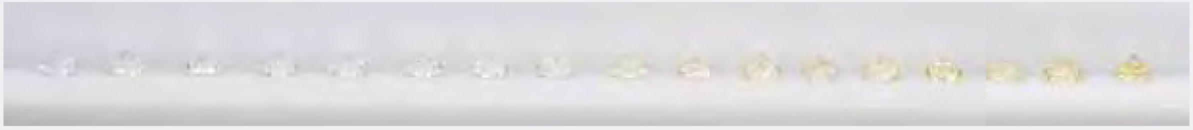

Figure B-1. For almost 70 years, GIA has been building diamond "master sets" as comparators for use in color grading. Since the mid-1950s, such sets have been at the core of the GIA diamond grading system for colorless to light yellow diamonds. The diamonds in the set above range from E to Z. There is no D master; a D-color diamond is one that has less color than the E master. Photo by Robert Weldon.

ference between two or three adjacent masters (e.g., the E, F, and G masters or the I and J masters). To overcome this challenge, GIA has multiple graders independently grade diamonds submitted for master stone reports (as is the practice for regular grading, too) and uses instrumentation for support. In assembling a new master set, our goal is to create a group of stones that meet this visual tolerance. Such subtle appearance differences relative to a GIA master have not been found to adversely affect the use of sets within the laboratory or by our clients.

Note that there may be differences in the color grade indicated on a GIA Diamond Grading Report and a Master Color Comparison Report; that is, if the diamond was within visual tolerance to the slightly higher side, it could receive a different grade than its master designation. For example, a diamond accepted as an L on a Master Color Comparison Report might be perceived during random grading to be slightly to the high side in the visual tolerance range of a GIA master. In that case, the diamond could be graded K on a Diamond Grading Report (see, e.g., figure B-2).

As a final note, master stones require special care and maintenance. It is particularly important to clean them regularly. The GIA Laboratory routinely boils master stones in sulfuric acid every two to four weeks, depending on the frequency with which they are used, to minimize the potential influence of foreign surface material. Boiling is an especially critical part of master stone maintenance for diamonds with bruted girdles. When outside sources have returned sets for us to review or supplement, the laboratory has seen up to four grade shifts in appearance for diamonds with bruted girdles that have not been boiled for some time.

Constant handling of diamonds can result in minor damage, so this must also be monitored. If a master stone has noticeable chips or is badly worn, its color appearance may be affected. The laboratory uses rubber-tipped tweezers to greatly reduce the risk of damage (these tweezers also reduce the accumulation of surface material mentioned above).

Figure B-2. Master stones are always at the high side of the grade range. The shaded area here indicates the visual tolerance range surrounding a master diamond designated as L on a GIA Master Color Comparison Report. The vertical line represents the location of an ideal L master diamond. If the stone is randomly graded toward the high end of the tolerance range, it could receive a K on a GIA Diamond Grading Report.

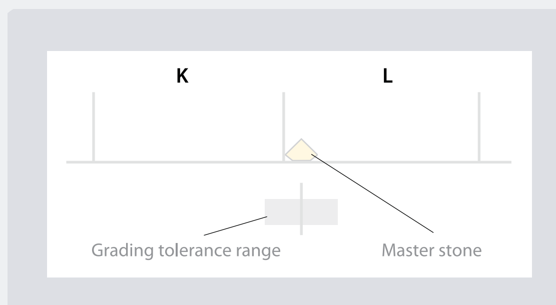

Figure 9. GIA master stones are located at the highest point in their respective grade range. A diamond equal to the G master is graded a G. If it has slightly less color, it would receive a grade of F. A diamond with more color than the G master and less than the H master would receive a G grade. A diamond with less color than the E master is graded a D. A diamond with more color than the Y–Z master is graded face-up as a fancy color.

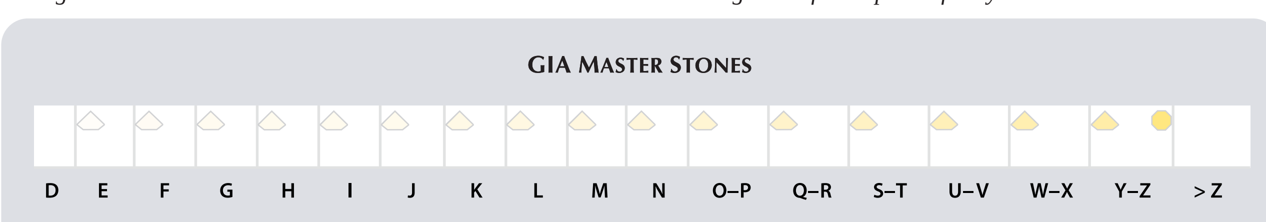

Figure 10. To speed production and facilitate comparison, all the E-to-N masters are kept in the grading tray throughout a grading session. They are spaced far enough apart to allow focused observations and the efficient movement of the diamond between masters. The tray is white, since that is the traditional background color used at GIA and throughout the trade. From our experience, a white background is best for making comparisons of pale colors. Photo by Robert Weldon.

ly kept in the viewing box in a 12 in. (30 cm) long V-shaped nonfluorescent white plastic tray (figure 10), with the E master on the left. The portion of the tray on which the diamonds sit is 1 in. (25 mm) wide and the backing is ¾ in. (19 mm) high. This size creates a consistent background for the diamonds. The length of the tray allows enough room between diamonds for the grader to handle them, as well as to focus on color comparisons between specific pairs of diamonds. With this arrangement, a grader can efficiently move through the grading process with an assigned quantity of diamonds without the added time of taking out and replacing the master stones.

While many diamond dealers and manufacturers take out only one or two reference diamonds at a time to compare to a diamond of unknown color, such a procedure is impractical for the production needs of a grading laboratory. It also may require that the observer rely on color memory in the decision making process. Studies have shown that color memory is not reliable for subtle color comparisons (Epps and Kaya, 2004), and having several master stones in the viewing environment at all times eliminates this problem.

Viewing Geometry. The visual complexity and often extremely subtle color of a polished diamond can make the grading of color very challenging. Therefore, the primary observation direction for color grading a diamond in the D-to-Z range is through the pavilion facets, with the diamond in the table-down position in order to reduce the complex, mosaic-like appearance seen face-up. The grader sits with his or her eyes approximately 12–15 in. (30.5–38 cm) from the diamond, closely adhering to a standard “0/45” geometry between the observer, the light source, and the diamond’s pavilion facets (figure 11). The tray holding the diamonds is positioned 8 in. (20 cm) beneath the fixed light source.

Figure 11. A standard “0/45” viewing geometry is used when color grading D-to-Z diamonds. The light source is above the tray at approximately “0” degrees, and the diamond is observed from a position approximately 12–15 in. (30–37.5 cm) away at an angle about 45° from the stone.

Figure 12. When grading D-to-Z diamonds, the observer rocks the tray over a small range in order to view the stone from nearly perpendicular to the pavilion facets to near-perpendicular to the girdle. This is necessary to avoid distracting reflections during color grading.

Figure 13. Fancy-shape diamonds have long played an important role in diamond jewelry. The color grading of fancy shapes is challenging due to the variations in proportions. GIA uses a standard viewing position for all fancy shapes to average the appearances encountered. The necklace consists of 44.06 carats of F-to-H oval diamonds; the J-color emerald-cut diamonds in the cuff links weigh 3.04 and 3.01 ct. Courtesy of Louis Glick & Co; photo by Harold & Erica Van Pelt.

During examination, the tray, while remaining on the upper shelf base of the viewing box, is rocked slightly—such that the line of sight varies from approximately perpendicular to the pavilion facets to near-perpendicular to the girdle (figure 12).

The visual comparison of round-brilliant diamonds to round-brilliant master stones eliminates one significant variable: shape. The situation is more complicated, however, when color grading fancy-shape diamonds (figure 13). Most fancy shapes can display up to three distinct amounts of color depending on their orientation in the table-down observation position. We have found that the most representative set-up for color grading fancy shapes is to orient them with their long and short axes at approximately 45° to the observer (figure 14). In this position, the outline of the fancy shape most closely resembles that of the round brilliant (i.e., reduces shape comparison differences) and functions as the best visual "average" for the amount of color observed. It exhibits neither the most intense color appearance nor the "washed out" areas.

From our experience, it is difficult to distinguish subtle differences between the colors of two diamonds that are touching one another. Therefore, we place a diamond close to (no more than ⅕ in. or 5 mm) but not touching a master stone when making color observations. The diamond being graded should also be placed in the same line as the master stones, not in front of or behind them, so that they are all the same distance from the observer. Fancy-shape stones also should not be so close that their

Figure 14. When grading fancy shapes, the average appearance is best represented by placing the fancy shape with its long axis approximately 45° to the observer. This series of photos for a 1.20 ct emerald cut next to a GIA master stone illustrate why this "middle" position is used. On the far left, the emerald cut is positioned so the observer views the long side—its weakest color appearance. The photo on the far right illustrates the appearance seen when the grader looks through the end of the fancy cut, where the color appears strongest. The angled position used at the laboratory, which averages the color, is seen in the center. Other fancy shapes also best simulate the outline of the round when set in this position. Photos by Robert Weldon.

Figure 15. A fancy shape positioned with its long axis at 45° may visually overlap a master stone if placed too close to it (left), as seen with this 2 ct marquise. The fancy shape should be placed near the master stone, but without any overlap (right). Photo by Robert Weldon.

angled position causes them to overlap the master stone along the observer's line of sight (figure 15).

It is important to acknowledge that some years ago (in particular the 1970s and '80s), laboratory staff experimented with placing diamonds in different positions and at different distances from the light source in the color-assessment process (K. Hurwit, pers. comm., 2007). Whether the diamond was a round brilliant or a fancy shape, there were times when observations were made through the crown with the diamond face-up and through the pavilion with the diamond on its side, *in addition to* the primary direction: through the pavilion with the diamond table-down. In each of these positions, observations of color appearance were made through a wide range of viewing angles. Mentally averaging the appearances encountered through the combination of directions was used in an effort to ascertain differences between the subtle colors of a diamond and a master stone. Ultimately, it was determined that using multiple positions further complicates decision making and the repeatability of the color determination.

For consistent results across many observers and locations, the laboratory restricts the positions in which diamonds are observed. For round brilliant cuts in the D-to-Z range, color is graded table-down only. Because fancy shapes toward the lower end of the D-to-Z scale typically appear to have more face-up color than their round-brilliant counterparts, at or below Q a combination of table-down and face-up is used to balance the grade and acknowledge the more noticeable face-up color. At Z, face-up color determines whether a diamond is a fancy color.

Just as the diamond being graded and the master stone were put in a number of different positions in the past, the viewing conditions have varied, too. In the 1970s and 1980s, the color tray that fit over the well of the microscope for use with the microscope's overhead light was recommended to members of the trade who did not have a DiamondLite. Occasionally, staff members also used it for color grading. During that same period, GIA's Gem Instruments division added a small recessed opening at the top front of the DiamondLite. When the cover to this opening was raised, a "color grader" tray could be placed in the opening (which was in front of the lamps). With this configuration, the light from the lamps was filtered through the plastic tray, thus minimizing the diamond's internal and surface reflections. Trade members and staff in the laboratory occasionally used this upper recessed tray area to observe color, similar to the way some diamantaires breathe on a diamond to "fog it" to minimize reflections.

The only location currently used for color grading at the GIA Laboratory is a V-shaped tray on the upper shelf in the viewing box (again, see figure 11). We do not alter the appearance of the diamond by filtering the light or breathing on the stone. All observations are made without magnification.

Determining the Diamond's Color Grade. GIA grades the overall color appearance of a diamond. Attention is not focused on specific areas, such as the center of the pavilion of a round brilliant or the long flat side of an emerald cut. By observing the overall appearance, the grader mentally blends all the visual sensations of the diamond.

Instead of trying to *match* the color of a diamond with a reference color, the GIA system involves placing or *bracketing* the color between pairs of master stones, which for most observers is an easier task. In general, the grading process is one of progressively narrowing the range until the diamond fits within a single grade (i.e., more color than the master stone on the left, and less color than the master stone on the right).

After the diamond to be graded has been wiped clean with a lint-free cloth, it is initially placed at one end (far left—the colorless end—by laboratory convention) of the tray on which the master stones are set in the viewing box. Using a pair of rubber-tipped tweezers, the grader moves the diamond along the set of master stones until it appears to be one to two grades past the estimated color grade. It will, at this location, appear to have noticeably less color than the master stone to its left. The grader then moves the diamond back by placing it consistently to the right side of each master for comparison. When the diamond being graded appears to have less or the same amount of color as one master stone, and more color than the next master stone to its left, it has arrived at a single color grade range. Its grade is associated with the least colored of the two diamonds, since each master stone represents the highest (least colored) boundary marker in the range.

Some color grades in the D-to-Z scale may not appear to be different at first glance (for example, D, E, and F diamonds all appear virtually colorless). Therefore, it can be challenging for a grader to clearly place the diamond being graded between two master stones through the bracketing process (it may be located much closer to one of the masters). In this situation, it is common to identify the closest master stone, and then determine to which side of that master the diamond being graded should be placed. In making this determination, the grader places the diamond in one of two grade ranges that are separated by a master stone and then observes the diamond on each side of that master. This will result in one of a number of appearance relationships, the five most common of which are described in table 1 along with the corresponding grading decisions.

Master Eye Effect. The procedures detailed in table 1 were instituted to compensate for the phenomenon known as "master eye effect" (highlighted row in table 1) and the very subtle visual deviations in color assessment it may cause. The effect is described as follows: When two diamonds are very similar in color appearance, the amount of color appears to reverse as the position of the diamonds is switched from left to right and right to left (Liddicoat, 1993). Much has been written about the dominance of one eye over the other in human binocular vision (see, e.g., Kromeier et al., 2006). What has long been described as the "master eye effect" in color grading is related to some degree to the difference in perception between the left and right eye. It is likely there are also psychological influences, such as the starting point used by a grader.

The effect of the master eye can be compounded in color grading by the production requirement of having a set of master stones in the field of vision when grading. The overall appearance of this set is that of a color gradation. If the master stones that form the color gradation are too close together, this can affect the grader's perception of appearance relationships. To confirm this phenomenon, in the late 1990s we created a gradation of light-toned yellow color chips (simulating the D-to-Z range), and placed the chips in the viewing environment with one of them being a duplicate. Graders found that the undisclosed duplicate appeared to have less color than its twin when placed to the side of its twin next to chips with increasing color, and more when placed to the side of chips with lessening color (figure 16).

This tendency held true whether the gradation was arranged so the chips with less color were to the left or right of the observer. Recognizing this effect further strengthened the laboratory's desire to

TABLE 1. Grading decisions for the five most common diamond vs. master stone appearance relationships.

Appearance of diamond as compared to closest master stone			Grading decision
Left side of master stone		Right side of master stone	
Slightly more color than master stone	→	AND noticeably less color than master stone	Receives higher grade than master stone
Same amount of color as master stone	→	AND less color than master stone	
Slightly more color than master stone	→	AND slightly (and to the same degree) less color than master stone	Receives same grade as master stone
Same or slightly more color than master stone	→	AND same or slightly less color than master stone	
Noticeably more color than master stone	→	AND slightly less color than master stone	

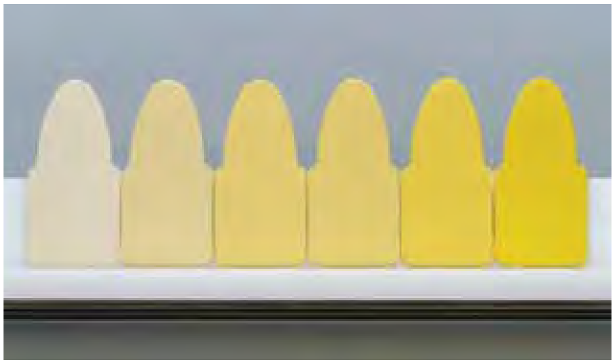

Figure 16. To better understand the effect of surrounding colors in making comparisons, color experiments were performed using standard color chips. In this photo, the third and fourth chips from the left are the same color. Graders found that the undisclosed duplicate appeared to have less color when placed to the side of its twin with increasing color and more when placed to the side with lessening color. This effect can be minimized in the grading process by spacing the color comparators farther apart on a long viewing tray. Photo by Jian Xin Liao.

transition to a longer viewing tray. Graders can now create much wider spacing between master stones to minimize the impact of the color gradation.

Additional Considerations for Color Grading. *Color Grading Diamonds that Differ Significantly in Size from the Master Stones.* Overcoming the visual effect of size differences between the diamond being graded and the master stone is an additional challenge even for the most experienced grader (figure 17). To aid in making this determination, graders observe an overall blend of color, similar to that previously described for colored diamonds (King et al., 2005), rather than select visual details. Through experience, the grader also learns how to gaze simultaneously at both the master and the diamond being graded. In so doing, the blend of color in each diamond is easier to relate regardless of size.

Figure 17. When grading diamonds significantly larger or smaller than those in the master set, the observer must look at the overall blend of color rather than the details. Here, a 10+ ct round brilliant is positioned next to an 0.70 ct J master. The best comparison process in this situation is for the experienced grader to observe the overall blend of the two diamonds simultaneously, rather than switching between the two diamonds, so that subtle color differences stand out. Photo by Robert Weldon.

Color Grading Fluorescent Diamonds. While some obviously fluorescent diamonds can appear different under differing conditions (Moses et al., 1997), our goal is to report the colors of all D-to-Z diamonds under one standard set of conditions. Therefore, fluorescent diamonds are graded using the same viewing environment and geometry as for other diamonds in the D-to-Z color range. In fact, all diamonds are color graded before they are checked for fluorescence strength, as we have noted that occasionally the color appearance of a diamond will change temporarily when exposed to UV radiation. As a result, color graders do not know the degree of fluorescence in a diamond before they assess its color.

Color Grading Diamonds with Eye-Visible Clarity Characteristics. While not common, the laboratory occasionally encounters diamonds with large, extensive, and/or colored inclusions that affect or obscure the bodycolor when observed under normal color grading conditions. In these instances, the color grade includes the effect of the inclusions. Noticeable inclusions become blended into the overall appearance such that, for example, dense areas of dark inclusions result in the diamond having a gray appearance (figure 18, left). If inclusions are restricted to a small area, their effect is limited (figure 18, right), because the diamond can usually be positioned so as to minimize the visual impact of the inclusions for grading purposes.

There are also times when the lab encounters diamonds with stains in fractures. If the stain is so prominent that it affects overall appearance, the lab will not grade the diamond because all or a portion of the stain might be removed by boiling in sulfuric acid, a procedure commonly used to alter the appearance of diamonds with surface-reaching fractures. Such a diamond will be graded only after the client has boiled it and the stain has been removed, as that is considered its permanent state.

Diamonds with dense clouds of tiny particles or whitish graining may appear translucent in the color grading process. If the transparency is greatly

Figure 18. When the grader observes the overall blend of color, the extensive inclusions in the diamond on the far left will become part of the observation and ultimately affect the final grade. When the included area is very limited, as in the diamond in the center, the stone is positioned (far right) to minimize the visual impact of the inclusions on the final grade. Photos by Jian Xin Liao.

affected, the diamond is graded as a colored diamond and described as Fancy white. At the laboratory, a master diamond is used for this comparison, but a simple method to help understand the approximate color-grade boundary is as follows: If the transparency is so affected that a grader cannot readily observe the pavilion facets through the table of the diamond using a 10× loupe under standard conditions, it is too translucent to grade on the D-to-Z scale and should be described as Fancy white. If it is not too translucent, it follows standard D-to-Z color grading procedures (figure 19). The movement of translucent diamonds off the D-to-Z scale is similar to the movement of light yellow diamonds past Z: In both cases, it is the degree of color, or translucency, seen table-up that determines whether the diamond enters the Fancy range. A translucent D-to-Z diamond may receive virtually any color grade.

Grading Mounted Diamonds. Prior to the 1980s, the laboratory graded mounted D-to-Z diamonds, reporting the grade in a two- to three-grade range. Over time, the laboratory decided to discontinue this practice and issue reports only on unmounted diamonds. Currently, we examine mounted diamonds solely as part of a "confirmation process"—that is, to confirm it is the same diamond as one described on an existing report—within the laboratory's Verification Service. Because the subtle color appearance of D-to-Z diamonds makes consistent color grading in mountings very challenging (since they can be affected by the color of the surrounding metal), the lab uses grade *ranges* (e.g., H to J) in these instances. For the Verification Service, the range is described only on "in-house" documents as part of the identification process required to match a diamond to a GIA report.

Color Grading Brown or Gray Diamonds in the D-to-Z System. From its inception, the D-to-Z system included near-colorless to light brown diamonds. Prior to and throughout the 1980s, the use of yellow master stones for brown diamond comparisons was a common procedure. At that time, the brown diamonds typically submitted for grading reports were in the E-to-J range. While there is a noticeable difference in hue, brown diamonds in this range share tone and saturation qualities with their yellow counterparts (for a discussion on the three attributes of color—hue,

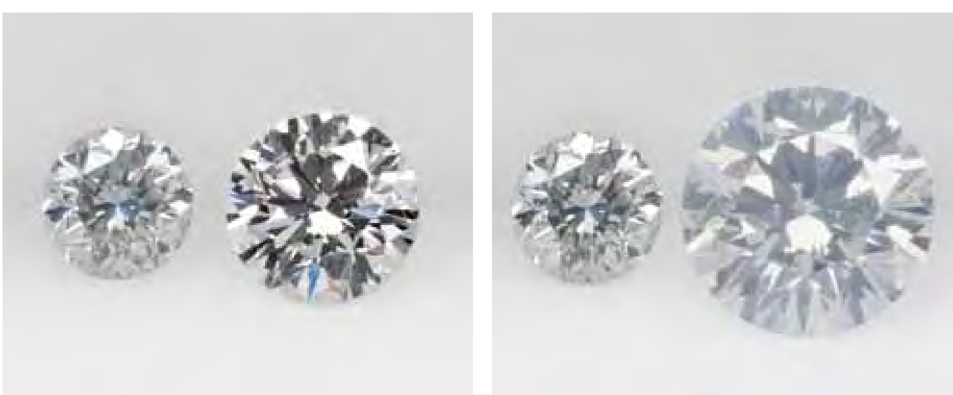

Figure 19. The smaller diamond appears obviously translucent next to the J master stone (left), but it is less translucent than the boundary Fancy white master (right). Therefore, it would be graded (table-down) on the D-to-Z scale. Photos by Robert Weldon.

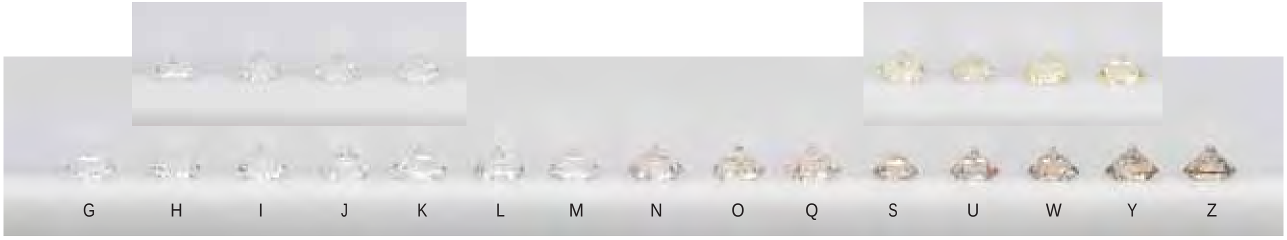

Figure 20. Historically, brown diamonds submitted to the lab for grading were most often located in the higher color grade range, similar to yellow masters (inset above left) in tone and saturation. In recent decades, the lab has seen greater numbers of darker brown diamonds. As a result, toward the lower end of the D-to-Z scale, graders noticed significant differences in color attributes between yellow (inset above right) and brown diamonds. To maintain consistency in the grading of these diamonds, GIA developed this master set of browns, which begins at G. Photos by Robert Weldon.

tone, and saturation—see King et al., 1994). This made the visual comparison to yellow masters compatible for brown diamonds in these letter grades.

With the influx of stones from Australia's Argyle mine since the mid-1980s, there has been greater industry awareness and marketing of brown diamonds (Richardson, 1991). As a result, more brown diamonds have been submitted to the GIA Laboratory, not only in the near-colorless region but throughout the color grade scale. Accordingly, the laboratory created a master set of brown diamonds (figure 20). As these stones become darker, the differences in hue, tone, and saturation are more pronounced. This contributed early on to the laboratory's decision to begin associating a word description with the letter grades of brown diamonds beginning at K (figure 21). Today, *a letter grade plus word descriptions* of "Faint brown," "Very Light brown," and "Light brown" are used for the grade ranges of K–M, N–R, and S–Z, respectively.

The color transition between brown and yellow diamonds is continuous, and the laboratory occasionally encounters diamonds with color appearances that are "in-between" the two different colors of the master sets (e.g., yellow-brown). It is important to choose the appropriate set of masters (i.e., yellow or brown) for the comparison process. This is usually accomplished by comparing the diamond being graded to both sets and selecting the one closest in appearance.

We recognize that others in the industry do not have D-to-Z scale brown master sets (and grading brown master stones is not a service the GIA Laboratory currently offers). Assessing the color of brown diamonds using only yellow master stones can be challenging. When doing so, the observer must remember to assess the overall depth of color—the combined effect of tone (lightness to darkness) and saturation (strength or weakness) of a color (King et al., 1994). Some observers try to grade just as they would yellow diamonds, and only look for saturation differences (the "amount" of yellow), which can result in an incorrectly high determination compared to laboratory grading. If yellow master stones are the only ones available, the observer should assess the overall depth of color and equate it to the overall depth of the yellow master stone.

The reporting approach for gray diamonds is similar to—but not the same as—that used for browns. In the colorless to near-colorless range (E to J), they are graded using the D-to-Z scale letter grades. Beginning at K, though, gray diamonds receive *a word description only* of "Faint," "Very Light," or "Light" gray for the same letter grade ranges as for brown diamonds (King et al., 1994). Although gray diamonds are reported with only word terms in this range, historically they have not been considered a "fancy" color until they reach a description of "Fancy Light" (as with yellows and browns).

Color Grading at the Lower End of the D-to-Z Range. Color grading at the lower end of the scale (below N or O) can present special challenges for graders. As the color becomes more noticeable, so do the differences between color attributes. In determining the relationship of a diamond to a master stone, an observer must contend with subtle differences in tone (lightness or darkness) and hue (as opposed to the predominance of saturation in the decision making for other areas of the scale).

The difficulty in making grade distinctions between single color grades in this range limits the usefulness of all the individual color grades in the O-to-Z range. More important, we have found that such fine distinctions are not in demand among the laboratory's clients; nor are they significantly useful to the trade for valuing these diamonds. We have informed clients that reporting color grades in this portion of the grading scale by using *grade ranges* is the best solution. The master stone locations used for laboratory reporting, are O, Q, S, U, W, Y, and the Z/Fancy Light boundary. Therefore, GIA grading reports will note a color as "S–T range" or "Y–Z range," for example.

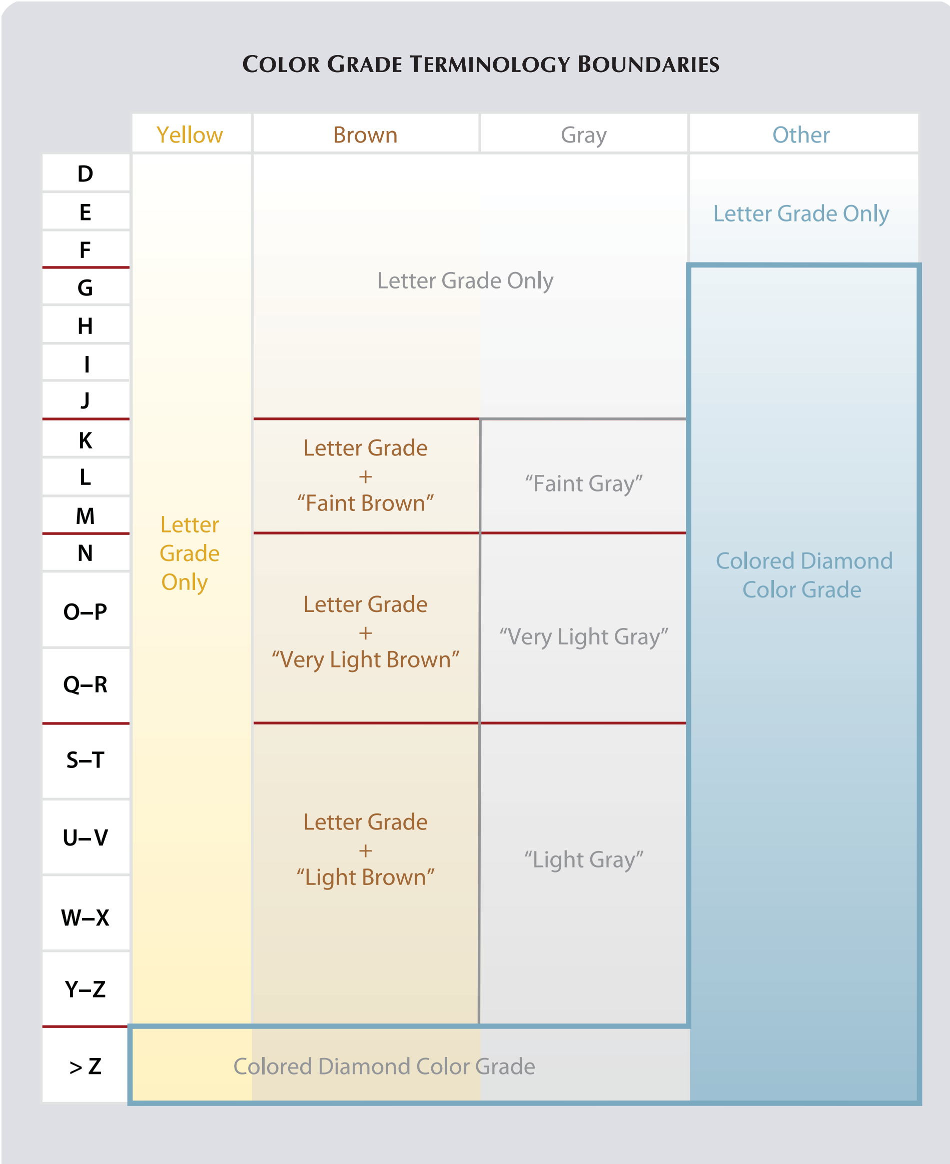

Figure 21. Shown here are the various boundaries at which colors transition off the D-to-Z scale, as well as terminology associated with the scale. After K, reports note a word description and letter grade for brown diamonds and a word description only for grays. Yellow, brown, and gray diamonds transition to the colored diamond color grading terminology after Z; all other colors transition at G.

As mentioned previously, round brilliants are graded table-down up to Z on the color grading scale, but face-up observation increases in importance when we are grading fancy shapes. From our experience, the majority of yellow fancy shapes graded Q or lower table-down appear to be one or more grades lower than this when observed face-up (figure 22). Historically, this led us to assign a final grade that averaged the two appearances when both diamonds fall on the D-to-Z scale. At the transition boundary between the D-to-Z scale and fancy colors, face-up appearance becomes the single factor that determines the color grade; that is, a diamond that has a stronger face-up color appearance than the Z/Fancy Light boundary master stone is considered a fancy color regardless of the color observed table-down. (For a detailed discussion of the transition of yellow diamonds from the D-to-Z scale to the terminology for colored diamonds, see King et al., 2005.)

Over a period of months in the late 1990s, the laboratory researched ways to increase consistency of grading yellow fancy shapes in this part of the scale while acknowledging the relationship of the two observation positions. Working from the known face-up location of the Z/Fancy Light boundary, staff members made table-down and face-up comparisons for hundreds of fancy-shape yellow diamonds. These data were used to establish the relationship between the two observation positions. At that point, the laboratory selected a series of fancy-shape diamonds (figure 23) that would represent the face-up fancy shape boundary for the reported Light yellow grade

Figure 22. All the diamonds in these pieces are in the light yellow (S-to-Z) color range. At this end of the scale, face-up color becomes more noticeable, and can be used to good effect for yellow stones when mounted in yellow metal. The pear shapes in the earrings weigh a total of 53.92 ct, the diamonds in the bracelet total 42.16 carats, and the "starburst" cut in the ring weighs 8.92 ct. Courtesy of Louis Glick & Co.; photo by Robert Weldon.

ranges (S-T, U-V, W-X, and Y-Z). These diamonds supplement the round-brilliant masters, help expedite the grading process, and enhance consistency.

Transitioning from the D-to-Z Scale to Fancy Color Grades for Colors other than Yellow, Brown, and Gray. The occurrence of subtle colors other than yellow, brown, or gray is so rare that the presence of even slight tints is acknowledged in their color grading. When colors such as blue, pink, or green are equivalent to G or lower (i.e., the amount of color has moved out of the colorless range and into the near-colorless range), colored diamond color grading terminology is applied to describe that diamond (e.g., Faint pink or Faint blue [figure 24]). Figure 21 notes the location, in relation to the D-to-Z scale, where alternative terminology is applied for these colors as well as for brown and gray.

D-TO-Z INSTRUMENTAL COLOR MEASUREMENT

Colorimetry was introduced into gemology in England in the 1930s ("Measurement . . . ," 1933; "The standardization of colour," 1933), but it was restricted to use with colored stones. Diamonds, with their often-subtle color differences, were more challenging. Robert Shipley Sr. envisioned the use of instruments for the color measurement of diamonds (Shipley, 1940) and, as mentioned earlier, introduced a visually comparative colorimeter in 1941. It was soon in full use at GIA for the grading of master stones. However, as Shipley Sr. recalled later (Shipley, 1958, p. 136), he was concerned because "the facets of the diamond were still pronounced, with the color varying over the observed portion of the stone. In other words, the facets being observed broke the color into a mosaic of varying intensities and this mixed pattern made it quite difficult to match the other half of the field [the portion of the wedge being viewed] with the diamond, since there was no single block of color to match against."

In 1949, GIA instructor Joe Phillips developed an electronic colorimeter that employed a selenium photoelectric cell. Because it measured the relative transmission of yellow and blue light by a diamond, it was referred to as a distimulus (i.e., two stimuli) colorimeter. It was fairly effective but too expensive to produce commercially, and Phillips failed to resolve a number of other problems. While it was eventually abandoned, its design became the starting point for a small colorimeter developed by Robert Shipley Jr. several years later (see, e.g., GIA, 1962).

Shipley Jr. demonstrated his colorimeter at the 1956 AGS Conclave. Designed for use by AGS members in their stores, the new distimulus colorimeter had several limitations: It did not accurately grade stones with a greenish or brownish cast or those that were poorly cut. Large diamonds (over 5 ct) were also problematic ("Operating and maintenance instructions . . . ," n.d.; Sloan, 1956; GIA, 1962), as were highly fluorescent diamonds, since this instrument used an incandescent bulb with virtually no UV component. Even so, this electronic colorimeter was soon in use. Shipley Jr.'s colorimeter expanded the AGS color scale from VI to X and encompassed 11 AGS grades (AGS, 1965); however, it was not used for GIA grades (even though the 11 grades spanned the full 23-color D-to-Z color grading scale). The GIA Laboratory only used the electronic colorimeter to grade masters for AGS members (who used a 0 to 10 scale, not D to Z) and to check the calibration of colorimeters being supplied to AGS members by GIA.

By 1975, the costs and difficulties of repairing Shipley's colorimeters rendered them obsolete. Given the limitations of the instrument, GIA concluded it was not a suitable foundation for further developments in this area. Others in the industry did pursue such instrumentation, and Eickhorst patented a device using more advanced technology in 1974 (Eickhorst and Lenzen, 1974).

Over the course of the next 30 years, GIA researchers evaluated a number of color-measurement devices already in the marketplace that had been developed for various applications, including gemstones. They tested several colorimeters and spectrometers extensively and, for reasons such as lack of reproducibility or efficiency, concluded that none served the laboratory's purpose. In 1997, GIA made the decision to use its laboratory and research resources to develop a color measurement device of its own design for internal use. It sought a device that would mimic the visual D-to-Z color grading methodology as closely as possible.

Work started on this project in March 1998. In early 1999, the first instrument was constructed and put into use in the laboratory. For approximately one year, measurement data were collected in tandem with the visual grading results on thousands of diamonds. The statistical analysis of these data showed a good correlation between instrumental and visual color grades, and minor modifications to the device and measurement protocols continued to bring results even closer together. In addition, modulating the UV content in the light source allowed the laboratory to obtain reliable color measurement results for diamonds with obvious fluorescence that were very similar to those obtained with visual color grading. By mid-2000, the color grading accuracy of the device was similar to that of the laboratory graders, but with higher repeatability. Around this time, the laboratory began to use several of these devices to support the graders' opinions. This "instrument" opinion was not influential in the grading decision, but it helped support the visual grade determination and avoid errors. The process was started with stones below 2 ct and eventually expanded to larger sizes.

This approach was followed for the next year until the device's ability to perform accurate color grading had been validated. In 2001, following its application in the grading of tens of thousands of diamonds, we integrated the device as a "valid" opinion in the grading process, with visual agreement by one or more graders required to finalize the color grade of a particular diamond. Since then, the vast majority of diamonds passing through the laboratory have been graded by combining visual observation with instrumental color measurement. Note that this instrument is for the laboratory's internal use and is not available commercially.

Figure 23. The use of face-up masters in the light yellow grade range acknowledges the role of face-up color in grading fancy-shape diamonds at the lower end of the D-to-Z scale and enhances grading consistency. These represent, from left to right, S, U, W, Y, and the boundary between Z and Fancy Light yellow. Photo by Jian Xin Liao.

SUMMARY AND CONCLUSIONS

Over the course of more than half a century, the D-to-Z diamond color grading system has become a critical component in the valuation of gem diamonds worldwide (figure 25). At the close of the background section, we noted that "*using the same color grading terms does not constitute adhering to the conditions or methodology of the GIA system*." We trust it is now clear that there is much more involved than the D-to-Z scale alone. The GIA system requires the use of standardized viewing conditions, calibrated references, and consistent

Figure 24. Colors other than yellow, brown, or gray are so rare that even subtle amounts are acknowledged. When a diamond has the same amount as— or more color than—the G master (i.e., moves out of the colorless to the near-colorless range) and shows a hue such as pink, blue, or green, it will be graded as a colored diamond—such as the Faint blue pear shape shown here between the F and G (yellow) masters. It appears to have more color than the G, to its right, so it would be graded on the colored diamond scale. Photo by Robert Weldon.

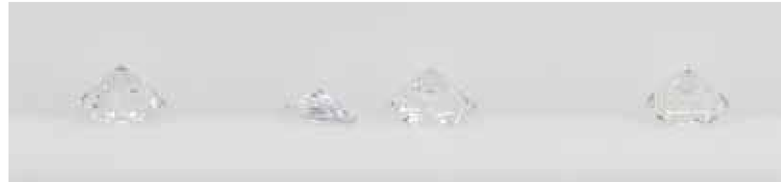

Figure 25. Color is so critical in the valuation of diamonds that diamond manufacturers must estimate the resulting color from the rough when calculating for the best yield. The octahedron pictured at top weighs 15.98 ct, while the macle weighs 22.33 ct. The faceted diamonds, ranging in color from D (the round on the left) to K (the oval), all weigh between 3.00 and 3.50 ct. Photo by Robert Weldon.

procedures to achieve sound, repeatable results. And it recognizes the importance of having standard policies and procedures not only for the majority of cases that are encountered but also for those seen less frequently. Special approaches must be taken when the diamond being graded is significantly different from the master stones used in the laboratory. Larger diamonds, fancy shapes, those with a hue other than yellow, heavily included diamonds, and borderline fancy-color stones all require specific protocols to ensure the highest level of consistency and accuracy in the color grading process.

Technologies have evolved and will continue to evolve, so it is important to stay abreast of changes that may prove helpful in establishing color grades based on the original historic choice of those grade ranges. Some of the important advances have been the move from incandescent to fluorescent lighting in the viewing environment, the development of a viewing environment that maximizes the efficiency of the observer, and refinements in the system to accommodate increasing numbers of diamonds at the lower end of the scale. As it entered the 21st century, GIA developed color grading instrumentation to support the visual grading process.

Although daylight is the historical and universal standard for diamond observation, in reality no artificial light duplicates natural "daylight," which itself changes with time and location. Nevertheless, we believe that a standard light source for diamond color grading should have key characteristics of daylight, including a UV component.

For GIA, any future updates in its diamond grading system must show a high correlation to past results in order to have merit. Nevertheless, we recognize that lighting technology and the understanding of human perception are constantly evolving, and believe that research is critical to maintaining the fundamental integrity of the system.

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REFERENCES

AGS Research Service (1936) Notes on diamond grading. *Gems & Gemology*, Vol. 2, No. 4, pp. 77–78.

American Gem Society [AGS] (1955) *Diamonds*. Los Angeles, CA.

——— (1965) Diamond grading examination. Assignment 11 in *Selling and Merchandising*, AGS course materials, Los Angeles, CA.

American Society for Testing and Materials [ASTM] (2003) Standard practice for visual appraisal of colors and color differences of diffusely-illuminated opaque materials. ASTM D1729-96, www.astm.org/standards/D1729.htm.

A note on diamonds (1938) *Gems & Gemology*, Vol. 2, No. 10, p. 174.

Approximate high asking price indications (1995) *Rapaport Diamond Report*, Vol. 31, No. 22, insert.

At last–A recommended diamond display lamp–A daylight model (1938) *Guilds*, Winter 1938–1939, p. 9.

Barton W. (1941) New devices grade gems. *Los Angeles Times*, June 29, p. A-8.

Cattelle W. (1911) *The Diamond*. J. B. Lippincott, Philadelphia, PA.

Chester C. (1910) *The Science of Diamond*. Chester & Bergman, Chicago.

Christie's (2008) *Jewels: The Hong Kong Sale*. Auction catalog, December 2, Hong Kong.

Collison W. (1947) The new standard Diamolite. *Gems & Gemology*, Vol. 10, No. 7, p. 431.

Cowing M. (2008) A place for CZ masters in diamond colour grading. *Journal of Gemmology*, Vol. 31, No. 3–4 [in press].

Dealers object to their diamonds having a jaundiced look (1894) *Jeweler's Circular*, March 7, p. 16.

Diamond-grading instrument developed by GIA (1934) *Gems & Gemology*, Vol. 1, No. 4, AGS Campaign Supplement, p. 20.

Eickhorst M., Lenzen G. (1974) *Method and Apparatus for Determining the Color of Cut Diamonds*. U.S. Patent 3,794,424, issued February 26.

Epps H.H., Kaya N. (2004) Color matching from memory. In J. J. Caivano, Ed., *AIC 2004 Color and Paints*, Interim Meeting of the International Color Association, Porto Alegre, Brazil, November 3–5, pp. 18–21.

Ferguson J. (1927) *Diamonds and Other Gems*. Publ. by the author, Los Angeles.

Feuchtwanger L. (1867) *A Popular Treatise on Gems*, 3rd ed. Publ. by the author, New York.

Gem talk (1981) *Jewelers' Circular Keystone*, September 1981, pp. 226–228.

Gemological Institute of America [GIA] (1962) A system for diamond color grading. Assignment 19 in *Diamonds*, GIA course materials, Los Angeles.

——— (1966) Diamond-grading, appraising and merchandising instruments. Assignment 35 in *Diamonds*, GIA course materials, Los Angeles.

——— (1979) The art and science of color grading. Assignment 19 in *Diamonds*, GIA course materials, Santa Monica, CA.

——— (1995) Grading color. Chapter 10 in *Diamond Grading*, GIA course materials, Santa Monica, CA.

Gilbertson A. (2007) *American Cut—The First 100 Years*. Gemological Institute of America, Carlsbad, CA.

Haske M. (2002) GIA GTL's color grading of fluorescent diamonds. www.adamasgem.org/giafluor.html [accessed December 14, 2007].

Instrument research at laboratory continues (1937) *Guilds*, Spring and Summer, p. 2.

International Commission on Illumination [CIE], International Electrotechnical Commission [IEC] (1987) *International Lighting Vocabulary*, 4th ed. Vienna, Austria.

International Organization for Standardization [ISO] (2005) Viewing conditions: Graphic technology and photography. ISO 3664:2000, www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=9117.

King J.M., Moses T.M., Shigley J.E., Liu Y. (1994) Color grading of colored diamonds in the GIA Gem Trade Laboratory. *Gems & Gemology*, Vol. 30, No. 4, pp. 220–242.

King J.M., Shigley J.E., Gelb T.H., Guhin S.S., Hall M., Wang W. (2005) Characterization and grading of natural-color yellow diamonds. *Gems & Gemology*, Vol. 41, No. 2, pp. 88–115.

Kromeier M., Heinrich S.P., Bach M., Kommerell G. (2006) Ocular prevalence and steroacuity. *Ophthalmic and Physiological Optics*, Vol. 26, No. 1, pp. 50–56.

Liddicoat R.T. (no date) Untitled presentation manuscript. Richard T. Liddicoat Library and Information Center, Carlsbad, CA.

——— (1993) *The GIA Diamond Dictionary*, 3rd ed. Gemological Institute of America, Santa Monica, CA.

Mawe J. (1823) *A Treatise on Diamonds and Precious Stones*. Longman, Hurst, Rees, Orme, and Brown, London.

Measurement of the colours of precious stones by means of the Guild Trichromatic Colorimeter (1933) *The Gemmologist*, Vol. 3, No. 26, pp. 39–44.

Morton I. (1878) To South Africa for diamonds. *Scribner's*, Vol. 16, No. 4, pp. 662–675.

Moses T.M. (1998) Letters: How GIA color-grades diamonds. *JCK*, Vol. 169, No. 12, pp. 21–22.

Moses T.M., Reinitz I.M., Johnson M.L., King J.M., Shigley J.E. (1997) A contribution to understanding the effect of blue fluorescence on the appearance of diamonds. *Gems & Gemology*, Vol. 33, No. 4, pp. 244–259.

On diamonds (1902) *The Connoisseur*, Vol. 4, September–December, pp. 248–252.

Operating and maintenance instructions, American Gem Society electronic colorimeter (no date) Richard T. Liddicoat Library and Information Center, Carlsbad, CA.

Richardson M. (1991) Australian miners peddle a browner shade of sparkle. *International Herald Tribune*, December 23, www.iht.com/articles/1991/12/23/shin.php.

Roskin G. (1998) What GIA's fluorescence study ignored. *JCK*, Vol. 169, No. 9, p. 149.

Schlossmacher K. (1949) The precise determination of the colors of gems, transl. by E. Kraus. *Gems & Gemology*, Vol. 6, No. 7, pp. 212–215.

Sersen W.J., Hopkins C. (1989) Buying and selling gemstones: What light is best? *Gemological Digest*, Vol. 2, No. 4, pp. 13–23.

Shannon J. (1945) The GIA fluorescent unit. *Gems & Gemology*, Vol. 5, No. 3, pp. 254–256.

Shipley R.M. (1938) New trade practice rules. *Gems & Gemology*, Vol. 2, No. 9, pp. 149–152.

——— (1940) Color grades of diamonds. Section 32 in *Diamonds*, GIA course materials, Gemological Institute of America, Los Angeles.

——— (1950a) A review of the diamond sections of the preceding courses. Assignment 201-2-4 in *Diamonds*, GIA course materials, Gemological Institute of America, Los Angeles.

——— (1950b) The color of diamonds. Assignment 226 in *Diamonds*, GIA course materials, Gemological Institute of America, Los Angeles.

——— (1955) Diamond-grading instruments. Assignment 2-37 in *Diamonds*, GIA course materials, Gemological Institute of America, Los Angeles.

——— (1957) Final application of color, imperfection, proportion & finish grades to price. Assignment 2-31 in *Diamonds*, GIA course materials, Gemological Institute of America, Los Angeles.

——— (1969?) Letter to Richard Liddicoat, June 10. Richard T. Liddicoat Library and Information Center, Carlsbad, CA.

Shipley R.M., Liddicoat R.T. (1941) A solution to diamond grading problems. *Gems & Gemology*, Vol. 3, No. 11, pp. 162–167.

Shipley R.M. Jr. (1941) Letter to Robert Shipley Sr., April 2. Richard T. Liddicoat Library and Information Center, Carlsbad, CA.

——— (1958) Electronic colorimeter of diamonds. *Gems & Gemology*, Vol. 9, No. 1, pp. 136–143, 158.

Shuster W. (2003) *Legacy of Leadership*. Gemological Institute of America, Carlsbad, CA.

Sloan G. (1956) Letter to the Colorimeter Committee (Baumgardt, Broer, Donovan, Kaplan, Shipley Jr., Woodill, Muller, and GIA), October 13. Richard T. Liddicoat Library and Information Center, Carlsbad, CA.

The standardization of colour (1933) *The Gemmologist*, Vol. 2, No. 23, pp. 380–381.

Tashey T. (2000) True colors: Professional Gem Services takes a stand on the effect of fluorescence in color grading and appearance of white and off-white diamonds. *Cornerstone*, Fall, pp. 1, 3, 7.

Tashey T. (2001) The effect of fluorescence on the colour grading of white and off-white diamonds. *The NCJV Valuer*, Vol. 19, No. 2, pp. 8–12.

Tavernier J. (1676) *Les six voyages de Jean Baptiste Tavernier, Ecuyer Baron d'Aubonne qu'il a fait en Turquie, en Perse, et aux Indes* [*The Six Voyages of Jean Baptiste Tavernier, Baron d' Aubonne, Made to Turkey, Persia, and the Indies*]. Gervais Clouzier et Claude Barbin, Paris.

Wade F. (1915) Color and its affect [sic] on the value of diamonds. *The Jewelers' Circular*, August 4, pp. 49–53.

Wade F. (1916) *Diamonds: A Study of the Factors that Govern Their Value*. G. P. Putnam & Sons, New York.

Warner D. (2006) The Duboscq Colorimeter. *Bulletin of the Scientific Instrument Society*, No. 88, pp. 68–70.

Wodiska J. (1886) *A Book of Precious Stones*. G. P. Putnam's Sons, New York.