
A CONTRIBUTION TO UNDERSTANDING THE EFFECT OF BLUE FLUORESCENCE ON THE APPEARANCE OF DIAMONDS

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Some gem diamonds fluoresce, most commonly blue, to the concentrated long-wave ultraviolet radiation of a UV lamp. There is a perception in the trade that this fluorescence has a negative effect on the overall appearance of such a diamond. Visual observation experiments were conducted to study this relationship. Four sets of very similar round brilliant diamonds, covering the color range from colorless to faint yellow, were selected for the different commonly encountered strengths of blue fluorescence they represented. These diamonds were then observed by trained graders, trade professionals, and average observers in various stone positions and lighting environments. For the average observer, meant to represent the jewelry buying public, no systematic effects of fluorescence were detected. Even the experienced observers did not consistently agree on the effects of fluorescence from one stone to the next. In general, the results revealed that strongly blue fluorescent diamonds were perceived to have a better color appearance when viewed table-up, with no discernible trend table-down. Most observers saw no relationship between fluorescence and transparency.

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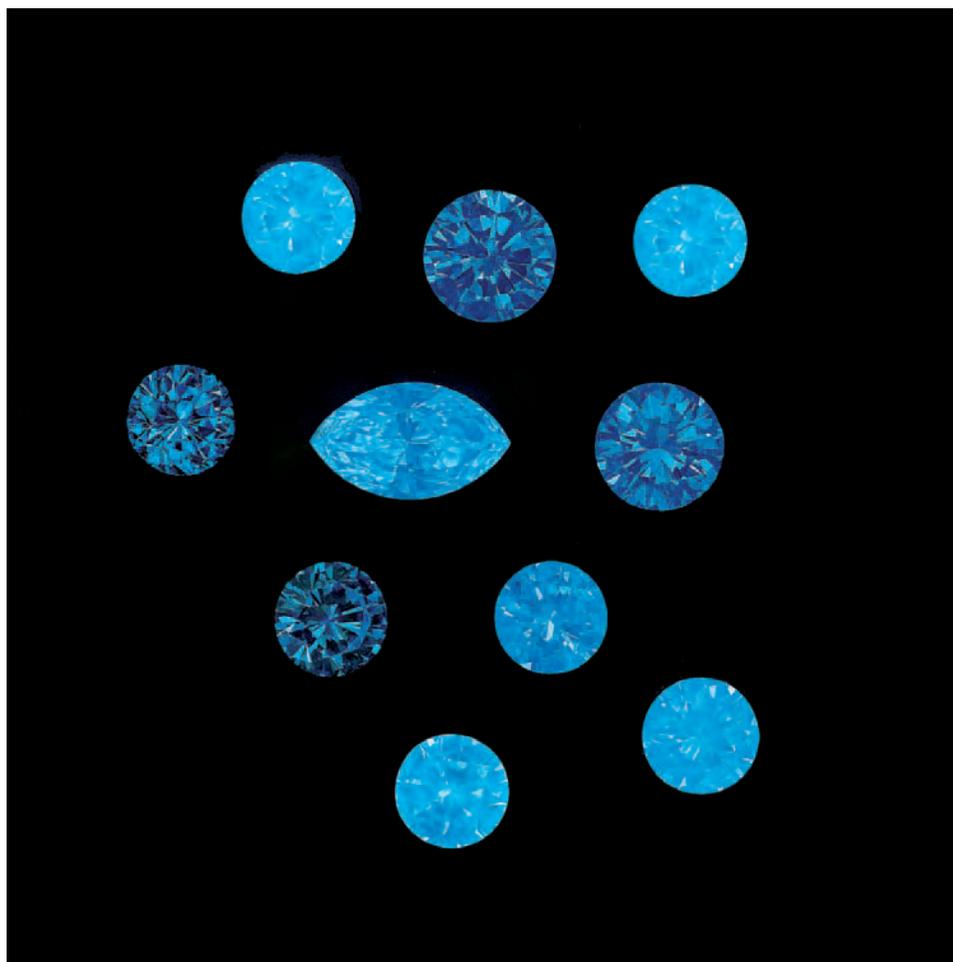
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Many factors influence the color appearance of colorless to faint yellow diamonds. Typically, such diamonds are quality graded for the absence of color according to the D-to-Z scale developed by the Gemological Institute of America in the 1940s (ShIPLEY and LIDDICOAT, 1941). By *color appearance*, however, we mean the overall *look* of a polished diamond's color that results from a combination of factors such as bodycolor, shape, size, cutting proportions, and the position and lighting in which it is viewed. When exposed to invisible ultraviolet (UV) radiation, some diamonds emit visible light, which is termed *fluorescence* (figure 1). This UV fluorescence arises from submicroscopic structures in diamonds. Various colors of fluorescence in diamond are known, but blue is by far the most common.

The response of a diamond to the concentrated radiation of an ultraviolet lamp is mentioned as an *identifying characteristic* (rather than a grading factor) on quality-grading reports issued by most gem-testing laboratories. Other light sources—such as sunlight or fluorescent tubes—also contain varying amounts of UV radiation. Although there have been instances where the color and strength of the fluorescence seen in diamonds observed in these other light sources are also believed to influence color appearance, in recent years the fluorescence noted on grading reports has been singled out by many in the diamond trade and applied across the board as a marker for pricing distinctions. Generally, these distinctions are applied in the direction of lower offering prices for colorless and near-colorless diamonds that exhibit fluorescence to a UV lamp (MANNY GORDON, pers. comm., 1997). Other trade members contend that the overall color appearance of a diamond typically is not adversely affected by this property (WILLIAM GOLDBERG, pers. comm., 1997); many even say that blue fluorescence enhances color appearance.

Figure 1. Blue is by far the most common fluorescence color encountered in gem diamonds when they are exposed to the concentrated long-wave ultraviolet radiation of a UV lamp. In recent years, this property of many diamonds has been the subject of much debate with regard to its effect on appearance and value. Photo by Harold & Erica Van Pelt.



To date, however, there have been no studies that examine the influence of blue fluorescence on the appearance of a diamond under normal viewing conditions. To this end, we identified certain fundamental variables that we needed to investigate as a first step in understanding this complex issue. For example, a grading laboratory such as the GIA Gem Trade Laboratory (GIA GTL) assesses color under carefully controlled lighting and viewing conditions and mainly with the diamond positioned table-down. In a retail jewelry store, when a diamond is examined for its overall color appearance in mounted jewelry, viewing normally occurs with the diamond table-up in any of a variety of lighting conditions, as it does for the wearing of jewelry. Also, because it is within the D through J range that fluorescence has become a greater influence on pricing (Don Palmieri, pers. comm., 1997), we decided to focus our initial investigation on diamonds that represent this end of the color scale. Thus, the purpose of this study was to explore the perceived influence of reported blue fluorescence in colorless to faint

yellow diamonds when viewed in different positions and under different lighting conditions by observers from both within and outside the diamond industry.

BACKGROUND

Industry Perception of Fluorescence in Diamonds.

Historically, the trade has given names to certain types of fluorescent diamonds based on the mines that produced significant numbers of such stones. The term *premier*, for example, has been used to describe light yellow diamonds with strong blue fluorescence, because such diamonds were often recovered from South Africa's Premier mine. The term *jager* has been used to describe colorless stones with strong blue fluorescence; the name originates from the Jagersfontein mine in South Africa, where such diamonds were once common (Bruton, 1978). Historically, some diamond merchants would seek out near-colorless to light yellow diamonds with strong blue fluorescence because they

BOX A: FLUORESCENCE IN DIAMOND

Fluorescence is a form of luminescence. For the purposes of this paper, *luminescence* is defined as the emission of light by a substance that has absorbed UV radiation. A substance is *fluorescent* if the emission of light stops when the energy source causing it is removed. (In contrast, if a substance continues to glow after the energy source is removed, it is *phosphorescent*.)

In a luminescent substance, the absorption of UV radiation causes an electron to move from its stable low-energy position ("ground state") into a temporary high-energy ("excited") state (figure A-1). This high-energy state is unstable, so the electron relaxes into a lower-energy excited state that is slightly more stable. As the electron falls back to the ground state, the substance emits light. This emitted energy is always less than excitation energy. Since wavelength increases as energy decreases, emission occurs at longer wavelengths than the excitation wavelength (again, see figure A-1). Submicroscopic structures that allow this movement of electrons are called *luminescence centers*. These centers arise from certain defects in the crystal lattice, such as electrically charged ions, or atomic vacancies or substitutions (see Nassau, 1983; Waychunas, 1988).

Gem diamonds typically contain a variety of structural defects, most involving impurity atoms such as nitrogen, hydrogen, and boron. Nitrogen-related defects are the most common of these, and only some of the resulting defects cause luminescence (Clark et al., 1992; Collins, 1992; see also Davies et al., 1978). The nitrogen-related defects, and their association with fluorescence, are described as follows:

- A single nitrogen atom substituting for carbon in a

diamond that is partly type Ib (see, e.g., Fritsch and Scarratt, 1992) produces orangy yellow fluorescence.

- A group of two nitrogen atoms, the A aggregate, tends to quench—that is, extinguish—fluorescence.
- A group of three nitrogen atoms is called the N3 center, and produces blue fluorescence.
- A group of four nitrogen atoms is called the B aggregate, and is not known to cause luminescence.
- A lens-shaped cluster of nitrogen atoms is called a platelet, and is associated with yellow fluorescence.
- A single nitrogen atom trapped near a carbon vacancy causes bright orange fluorescence.
- A vacancy trapped near an A or B aggregate is called the H3 (H4) center, and generates green fluorescence.

A single diamond may contain several different kinds of defects, leading to a range of complex relationships between nitrogen content, nitrogen aggregation state, diamond color, and fluorescence color and strength. A diamond may also display two different fluorescence colors, either clearly zoned or closely mixed together. As described in the Background section of the text, of 5,710 colorless to near-colorless diamonds that fluoresced a noticeable color, 97% showed blue fluorescence, which is caused by the N3 center. Of 16,835 diamonds in the same study that did not fluoresce, many contained N3 centers, but they also contained enough A aggregates to prevent any visible luminescence. The existence of N3 centers in these diamonds is suggested by their yellow bodycolor (most commonly caused by "Cape" absorption bands, which are related to these centers); the existence of A aggregates (or other centers that quench luminescence) is evident from the fact that the stones do not fluoresce. These complexities confound the trade notion that nonfluorescent diamonds are more "pure" than those that fluoresce, since there are nitrogen-related centers that extinguish fluorescence, as well as those that cause blue fluorescence.

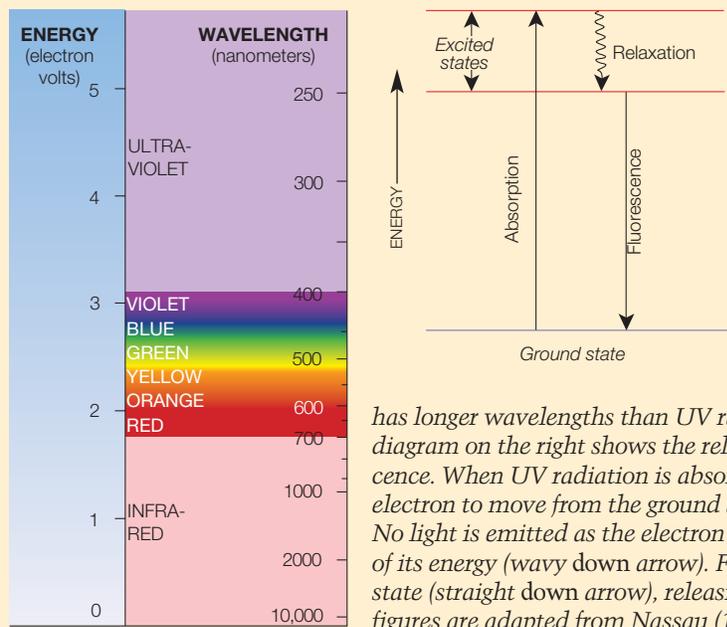


Figure A-1. The diagram on the left shows the relationship of visible light to ultraviolet and infrared radiation. The wavelength of light is related to its energy in an inverse manner: the longer the wavelength, the lower the energy. Visible light

has longer wavelengths than UV radiation, but is lower in energy. The energy diagram on the right shows the relationship between absorption and luminescence. When UV radiation is absorbed at a luminescence center, it causes an electron to move from the ground state to an excited state (straight up arrow). No light is emitted as the electron moves to a slightly lower state, losing some of its energy (wavy down arrow). From this lower state it returns to the ground state (straight down arrow), releasing energy as fluorescence (visible light). Both figures are adapted from Nassau (1983).

believed that such fluorescence gave rise to a diamond that appeared "more colorless" (i.e., "less yellow") under lighting with a high UV content. Firms such as C. D. Peacock were known to actively look for such fluorescent diamonds (Joe Samuel Jr., pers. comm., 1997). Often these diamonds were marketed as "blue-white," a term that was prohibited by U.S. Trade Practice Rules in 1938 (U.S. Federal Trade Commission, 1938). Recognizing that some highly fluorescent diamonds might have a slightly different color appearance when viewed under light sources with differing UV content, Shipley and Liddicoat (1941) emphasized the importance of controlled lighting conditions for consistent color grading of faceted diamonds.

Tradespeople further observed that some gem diamonds with a hazy appearance also fluoresced strong blue to UV radiation. In the dynamic market of the late 1970s, some dealers began offering substantially lower prices for what they called "milky Ds" (diamonds with a color grade of D, very strong blue fluorescence, and reduced transparency). Over the next decade, the perceived negative impact of fluorescence spread down the color grade scale (as far as F) and eventually also included stones with weaker fluorescence (M. Rapaport, pers. comm., 1997). In recent years, fluorescence has had more impact as a value factor because of the influx of large quantities of high-quality diamonds from Russia. Many of these diamonds exhibit moderate to strong blue fluorescence to the UV lamp (Kevo Ayvazian, pers. comm., 1997).

The concerns about fluorescence can be attributed to a number of factors. These include notions that: (1) nonfluorescent diamonds are more "pure" than those that fluoresce, (2) nonfluorescent diamonds (in the colorless range [D-F]) are rarer than fluorescent diamonds in the same color range, and (3) the hazy appearance seen in some strongly fluorescent diamonds must exist in more weakly fluorescent diamonds as well. With the airing of a television "exposé" in South Korea in 1993 (*We Want to Know That*), the negative image of fluorescent diamonds was brought to the attention of consumers as well.

An indication of the extent to which fluorescence influences market value is found in the *Rapaport Diamond Report* weekly price guide. In the November 7, 1997, *Report*, for example, some higher-color (D-H) diamonds with very strong fluorescence were listed for up to 15% less than compa-

rable nonfluorescent stones. From the spring of 1993 until the present time, the *Report* has stated that "the impact of blue fluorescence on price depends on its noticeability." Although the fluorescence description (which is based on observations made under a long-wave UV lamp) can be read from a laboratory grading report, "noticeability" refers to the direct observation of the diamond under the lighting conditions of a normal trading environment. In that same issue of the *Report*, lower-color (I-N) diamonds with very strong fluorescence carried a *premium* of up to 4% over similar nonfluorescing stones. This may be due to the continuing perception of many in the trade that blue fluorescence acts to mask or offset the faint to very light yellow bodycolor of some gem diamonds.

Observation of Fluorescence. Fluorescence is the "emission of visible light by a material such as diamond when it is stimulated by higher-energy X-rays, ultraviolet radiation, or other forms of radiation. Fluorescence continues only as long as the material is exposed to the radiation" (Liddicoat, 1993, p. 91). In gem testing, the ultraviolet unit that is commonly used provides two types of UV radiation. These two types are normally referred to by their most intense excitation wavelengths: 365 nm, or long-wave UV (also an important component of daylight); and 254 nm, or short-wave UV. Although the latter provides identification data for the laboratory, it is long-wave UV fluorescence that is meant when *fluorescence* is discussed in the diamond trade or described on a diamond grading report. (For more on fluorescence in diamonds, see Box A.)

Depending on the viewing conditions and the observer's visual perception, the reaction of a diamond to long-wave UV radiation may vary in both strength and hue. Both colorless and colored diamonds can fluoresce several hues, most commonly blue, yellow, orange, and white. Some pink (and, on rare occasions, colorless and near-colorless) diamonds fluoresce bright orange. Some blue diamonds, such as the Hope, fluoresce (and phosphoresce) red to short-wave UV. These different colors of UV fluorescence arise either from trace impurities (mainly nitrogen and boron, possibly hydrogen) or from other submicroscopic defects in the diamond crystal structure (again, see Box A). In the experience of GIA GTL, strength of fluorescence does not directly correlate to either color or clarity. For example, a diamond with a clarity grade of

internally flawless and a color grade of D can exhibit the same strength of blue fluorescence as another diamond with a clarity of I₁ and a color grade of J.

A gemological report assigns grades so that the quality of one diamond may be assessed relative to others, but it also provides information that describes the stone and helps separate it from other diamonds. At GIA GTL, the fluorescence entry on a diamond grading report is considered to be a description, not a grade. In fact, the laboratory has used fluorescence to help clients recover diamonds that were lost or stolen.

At GIA GTL, the standard procedure for observing UV fluorescence includes use of a long-wave UV lamp in a darkened viewing environment. Factors such as the distances and viewing angles between the UV lamp, the diamond, and the observer are specified to maintain consistency between observers. A set of reference diamonds is used to establish the intensity of the fluorescence exhibited by a stone within the ranges none, faint, medium, strong, and very strong. In a procedure similar to that employed for color grading with the D-to-Z scale, the diamond being examined is placed table-down and moved between the reference stones until the intensity of the fluorescence is stronger than the

reference stone on the left, and weaker than the reference stone on the right (figure 2). As with color grading, the trained eye adjusts for differences in facet arrangement, size, and shape between the diamond and the reference stones. This procedure follows the standard methodology recommended by the American Society for Testing and Materials (ASTM, 1996) for comparing the colors of objects.

To better understand how common UV fluorescence is among colorless to faint yellow diamonds, we reviewed a random sample of 26,010 GIA GTL grading reports for diamonds in this range. The data revealed that approximately 65% of these diamonds had no reported fluorescence to long-wave UV radiation. (Note that a report description of "none" means that any fluorescence exhibited is weaker than that of the reference stone that marks the none/faint boundary.) Of the 35% (9,175 diamonds) for which fluorescence was reported, 38% (3,465) were described as having faint fluorescence and 62% (5,710) had descriptions that ranged from medium to very strong. Of the 5,710 diamonds with medium to very strong fluorescence, 97% (5,533) fluoresced blue (in varying intensities) and only 3% (162 stones) fluoresced another color (yellow, white, or orange; no color is reported for descriptions of faint fluorescence.). Therefore, only 35% of the 26,010 diamonds fluoresced, and less than 1% fluoresced a color other than blue. Of the 11,901 diamonds in the D-to-F range, a similar proportion fluoresced (4,250 diamonds, 36% of the total).

Although yellow fluorescence is also a concern in the industry (see, e.g., the June 1997 issue of the *Diamond Value Index*), our decision to limit the present study to diamonds with blue fluorescence was based on the preponderance of such diamonds and the difficulty of finding sufficient numbers of yellow-fluorescent stones to conduct a parallel study. Diamonds with extremely strong blue fluorescence and a distinctive oily or hazy appearance, often referred to as "overblues," are also a concern to the industry. In our experience, however, they are even rarer than diamonds with yellow fluorescence.

MATERIALS AND METHODS

Diamond Samples. From an initial population of more than 1,000 diamonds made available for study, we identified approximately 300 stones with varying degrees of blue fluorescence. From these, we assembled four sets of six stones each that were very similar to one another in all respects except their fluorescence (see figure 3 and table 1). Based on

Figure 2. As with diamond color grading, both the control of observation variables (light source, environment, viewing geometry) and the use of known reference stones are required to make consistent fluorescence observations. At GIA GTL, the diamond being examined is placed table-down and moved between the fluorescence reference stones until the intensity of the fluorescence is stronger than the reference stone on the left, and weaker than the reference stone on the right. Photo by Maha DeMaggio.



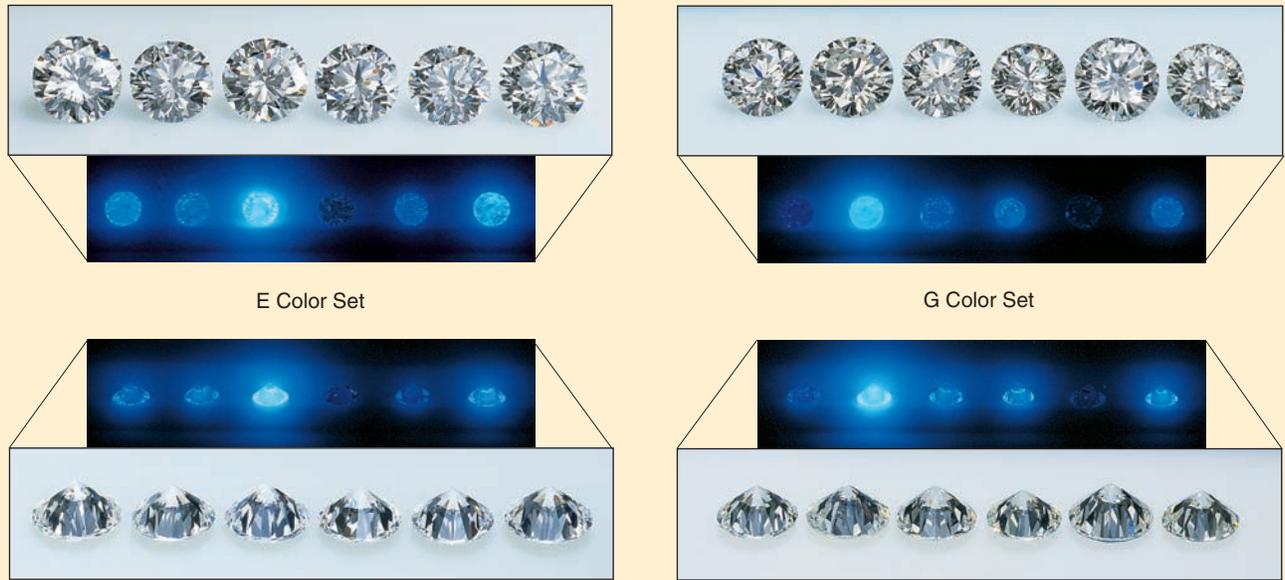


Figure 3. The four color sets of diamonds used for the observation experiments are seen here table-up and table-down under normal lighting conditions, and under the long-wave UV lamp used to make fluorescence determinations in the laboratory. See table 1 for precise descriptions of these stones as they are presented here, which is the same arrangement within each set shown to the observers. From left to right, top to bottom: the six stones in the E set show strong, medium, very strong, none, faint, and strong fluorescence; the G set stones show faint, very strong, medium, medium, none, and strong fluorescence; the I set stones show medium, very strong, faint, strong, none, and strong fluorescence; and the K set stones show very strong, faint, strong, strong, faint, and strong fluorescence. (Because of the inherent difficulties of controlling color in printing, the colors in this illustration may differ from the actual colors of the stones.) Photos of diamonds in normal light are by Harold & Erica Van Pelt; and in UV light, by Maha DeMaggio.

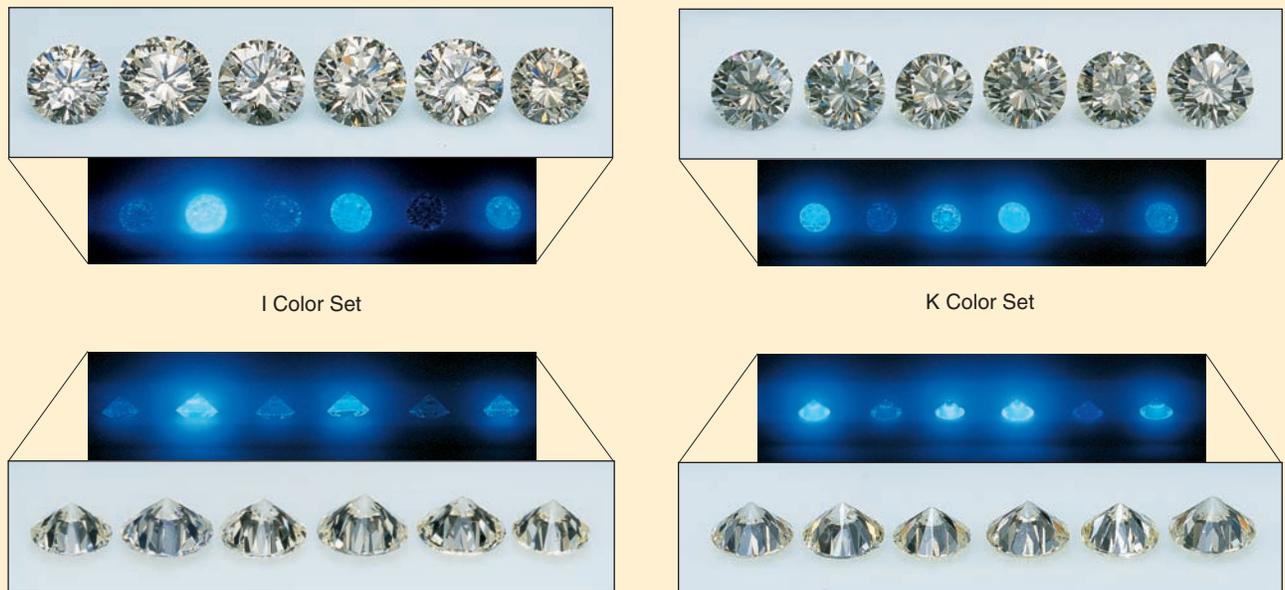


TABLE 1. Description of the 24 faceted diamonds used in this study.^a

Letter	E color (Set 3)			G color (Set 2)			I color (Set 1)			K color (Set 4)		
	Fluor. ^b	Clarity	Wt. (ct)	Fluor.	Clarity	Wt. (ct)	Fluor.	Clarity	Wt. (ct)	Fluor.	Clarity	Wt. (ct)
A	Strong	VS ₁	0.76	Faint	VVS ₁	0.60	Medium	SI ₁	0.79	V. strong	SI ₂	0.56
B	Medium	VVS ₁	0.68	V. strong	VS ₂	0.62	V. strong	VS ₂	1.15	Faint	SI ₁	0.56
C	V. strong ^c	IF	0.70	Medium	IF	0.63	Faint	VS ₁	1.01	Strong	VS ₂	0.47
D	None	VVS ₁	0.69	Medium	VS ₂	0.50	Strong	VS ₁	1.19	Strong	SI ₁	0.59
E	Faint	VS ₁	0.65	None	IF	0.72	None	VS ₁	1.03	Faint	VS ₂	0.48
F	Strong	VVS ₁	0.77	Strong	VS ₁	0.51	Strong	VS ₂	0.80	Strong	VS ₂	0.65

^aThe letters represent how the diamonds were referred to in answering our questionnaire and their order from left to right as they were placed in trays or ring mounts for viewing (i.e., the diamond labeled "A" was on the left, "B" next, etc.). The set numbers refer to the order in which each color set was given to the observer. For all four sets of diamonds, polish and symmetry were good, very good, or excellent.

^bFluor. = strength of fluorescence to a long-wave ultraviolet lamp.

^cV. Strong = very strong.

our experience grading millions of diamonds, the selection was typical of those encountered in the trade. All 24 diamonds were round brilliants; most had clarity grades at or above the VS range, were of good or better symmetry and polish, had similar proportions, and fell within similar size ranges. Each set comprised a different color grade—E, G, I, and K—representing important commercial break-points. Within each of the four sets, the six diamonds represented a wide range of intensity of blue UV fluorescence (from none to very strong). For all observations, the diamonds were arranged in each set so that there was no particular order to the strength of their fluorescence. As noted above, we did not include those diamonds with extremely strong blue fluorescence and a hazy appearance ("overblues"—see, e.g., figure 4), because we could not obtain sufficient numbers of such stones. However, the diminished transparency of these extreme examples prompted us to investigate transparency as well as color in this study. Although we would have preferred a larger sample of diamonds, we felt that this initial study should focus on controlling those other variables that could affect appearance, leaving fluorescence as the variable to be studied. Despite the large number of blue fluorescent diamonds that were available, potentially influential factors such as size, proportions, polish, symmetry, and clarity considerably narrowed our final selection.

Viewing Environments and Methodology. Because faceted diamonds are observed under different lighting and viewing situations in different parts of the trade, we identified five representative viewing environments for this experiment (see table 2 and figure 5). These environments cover the range of

lighting and viewing situations commonly encountered in the industry. (Although incandescent lights are frequently used in retail jewelry stores for display purposes, diamond value judgments made by jewelers are typically made with daylight or fluorescent light.) The viewing environments that we used fall into two general categories: "grading environments" and "appearance environments."

In *grading environments*, an attempt is made to control, as much as possible, all observation variables to achieve consistent, repeatable results during the evaluation of a diamond's color grade. Here, as in standardized GIA color grading, the faceted diamonds were viewed table-down through the pavilion facets, so that the effects of cutting, such as facet reflections, would be minimized. Two such environments were used:

1. A GIA GEM DiamondLite viewing unit, with a nonfluorescent white interior and two overhead Verilux (daylight equivalent) fluorescent tube-type lamps, was placed in an otherwise darkened room. In this configuration, the six diamonds in each set were positioned table-down on the floor of the viewing box, 5–10 cm (2–4 inches) below the lamps, with the observer looking at the diamonds in profile view (again, see figure 5). This is the standard position and environment for color grading diamonds in the D-to-Z range at GIA GTL.
2. An overhead, desk-mounted, Phillips F15T8/D 15-watt (daylight equivalent) fluorescent tube-type lamp was placed in a standard office setting. In such an environment, there may or may not be ambient light sources nearby (in this instance, there were). The diamonds were positioned table-down in a grooved, white, non-fluorescent plastic tray and observed in profile

Figure 4. The 127 ct Portuguese diamond at the Smithsonian Institution in Washington, DC, is a classic example of a blue fluorescent diamond referred to as an “overblue.” These diamonds of extremely strong blue fluorescence may exhibit a noticeable oily or hazy appearance when excited by any of a number of light sources. Although diamonds described on a laboratory report as having very strong blue fluorescence are routinely seen in the trade, a true “overblue” is not commonly encountered and was not part of our study. Photo © Harold & Erica Van Pelt.



view. (Although many diamond dealers regularly use a folded business card for such observations, most white card stock itself fluoresces bluish white and thus adds its own emitted light to the diamond being observed, potentially altering the color appearance.) This is the standard position and environment for diamond color grading used in diamond bourses around the world and in retail jewelry stores.

In *appearance environments*, there is less attempt (or opportunity, or perceived need) to control the observation variables that can affect the diamond’s color appearance. Typical situations include: informal color grading of D-to-Z diamonds; observations of color appearance made at the time a diamond is bought or sold; and, for the jewelry-buying public, how a diamond might appear when worn in jewelry. Here, the diamond is viewed *table-up through the crown facets*, where the cutting style has more influence on the perceived color. Three such environments were used in our experiment:

- Observations were made with an overhead, desk-mounted, Sylvania Cool White F15T8/CW 15-watt (daylight equivalent) fluorescent tube-type lamp in a standard trading environment. (Recognizing that different offices have different overhead fluorescent lighting, we felt that the use of different bulbs for environments 2 and 3 provided a broader representation of trade environments. Again, in such a setting, there may or may not be ambient light sources nearby. In this environment, we did not have ambient light.) For this experiment, the diamonds were observed table-up in a grooved, white, nonfluo-

TABLE 2. The five viewing environments used in this study.

No.	Lighting environment	Light source	Observer type (no.)	Stone orientation	Distances: light-to-object / observer-to-object
1	DiamondLite, in a darkened room	Verilux type fluorescent tubes (2)	Laboratory grader (5) Trade grader (2)	Table-down, floor of viewing box	2–4 in. / 12–18 in. (5–10 cm / 30–45 cm)
2	Overhead desk-mounted light, in a lighted room	18" Phillips F15T8/D 15-watt fluorescent tube	Laboratory grader (6) Trade observer (4)	Table-down, grooved tray	12–18 in. / 6–18 in. (30–45 cm / 15–45 cm)
3	Overhead desk-mounted light, in a darkened room	18" Sylvania F15T8/CW 15-watt fluorescent tube	Laboratory grader (8) Trade grader (2) Trade observer (2)	Table-up, grooved tray	12–18 in. / 6–18 in. (30–45 cm / 15–45 cm)
4	Ceiling-mounted room lighting	Phillips FB40CW/6 40-watt fluorescent tubes	Laboratory grader (6) Trade grader (1) Average observer (5)	Table-up in ring, ring tray	Approx. 6 ft. / 6–18 in. (Approx. 2 m / 15–45 cm)
5	Window (indirect sunlight)	South daylight (1:00–4:00 pm, July, in New York City)	Laboratory grader (3) Average observer (6)	Table-up in ring, ring tray	Not applicable / 6–18 in. (NA / 15–45 cm)

rescent plastic tray. This is a standard environment for evaluating diamonds in the trade.

4. Observations took place in a room with Phillips FB40CW/6 40-watt fluorescent tube-type ceiling lights. Each of the diamonds was placed in a spring-loaded white metal display mounting, and each set was placed in a neutral gray ring tray. This also is a standard condition for buying and selling diamonds in the trade; in addition, it approximates the lighting conditions for typical indoor wearing of diamond jewelry.
5. Observations were made in a room where the only light was external, indirect sunlight coming through a window (July afternoon daylight, on a sunny day, from a southerly direction in New York City). Each of the diamonds was placed in a spring-loaded white metal display mounting, and each set was placed in a neutral gray ring tray. This is a standard position and environment for buying and selling diamonds in the retail jewelry industry. Although partial filtering of UV radiation occurs through a window, this approximates typical outdoor wearing of diamond jewelry.

Because different intensities of ultraviolet radiation in the light sources could affect the diamonds' fluorescence reaction, we used a UVX digital radiometer manufactured by Ultraviolet Products, Inc., to measure the UV content in each of the light sources chosen. The measurements revealed no appreciable differences in long-wave UV content from one fluorescent light source to the next. They also revealed that these light sources emit approximately 5% as much UV radiation as the UV lamp, at the light-to-object distances used in the laboratory. According to our measurements, indirect daylight through our windows has about as much UV radiation as the fluorescent light sources.

Observers. We assembled four groups of observers, a total of 46 individuals, to represent both the diamond industry and the diamond-buying public, as follows:

1. Laboratory Graders (25 total)—trained individuals employed by GIA GTL, who routinely perform diamond color grading using the D-to-Z scale and GIA's standard grading procedure. Because of their experience in diamond grading and the fact that they are constantly monitored for consistency, we felt that the members of this group would best be able to make the dis-

tinctions we were investigating. Consequently, members of this group participated in every viewing environment.

2. Trade Graders (5 total)—trained individuals employed by diamond manufacturers, who routinely perform diamond color grading using the D-to-Z scale and a standard grading procedure.
3. Trade Observers (5 total)—individuals employed by diamond manufacturers or diamond brokers, who have a working knowledge of diamond color-grading practices but either do not carry out color grading on a daily basis or, if they do color grade, they use less stringent guidelines than those used by the Laboratory and Trade Graders.
4. Average Observers (11)—individuals who represent the diamond-buying public. Some of these had limited knowledge of diamond color-grading procedures, while others had none. In either case, none of these individuals had previously made observations of color appearance in diamond in any systematic way.

We asked these four sets of observers to view the four sets of diamonds in one or more of the viewing environments. Because some observers brought their own trade practices to the experiment, and others had no prior experience with some of the environments, we did not ask all observers to make observations in each type of environment. Nor do we have equal numbers of observations for each group of observers and viewing environment. However, we did ask four observers (three Laboratory Graders and one Trade Observer) who had both laboratory and extensive trade experience to look at the diamonds in more than one viewing environment. All told, the final data represent a total of 50 observations for each of the four sets of diamonds (i.e., 46 observers, four of whom viewed the diamonds in two environments).

Observer Questionnaires. We gave each observer a sheet of instructions that briefly stated that the research project concerned diamond fluorescence and then asked questions regarding his or her observations (table 3). The observer was verbally instructed not to alter the geometry of the environment (the arrangement of the light source, diamond, and eye) in which the observation was being made. Terms such as *hue* (color), *depth* (strength) of *color*, and *transparency* (in this instance, the presence or

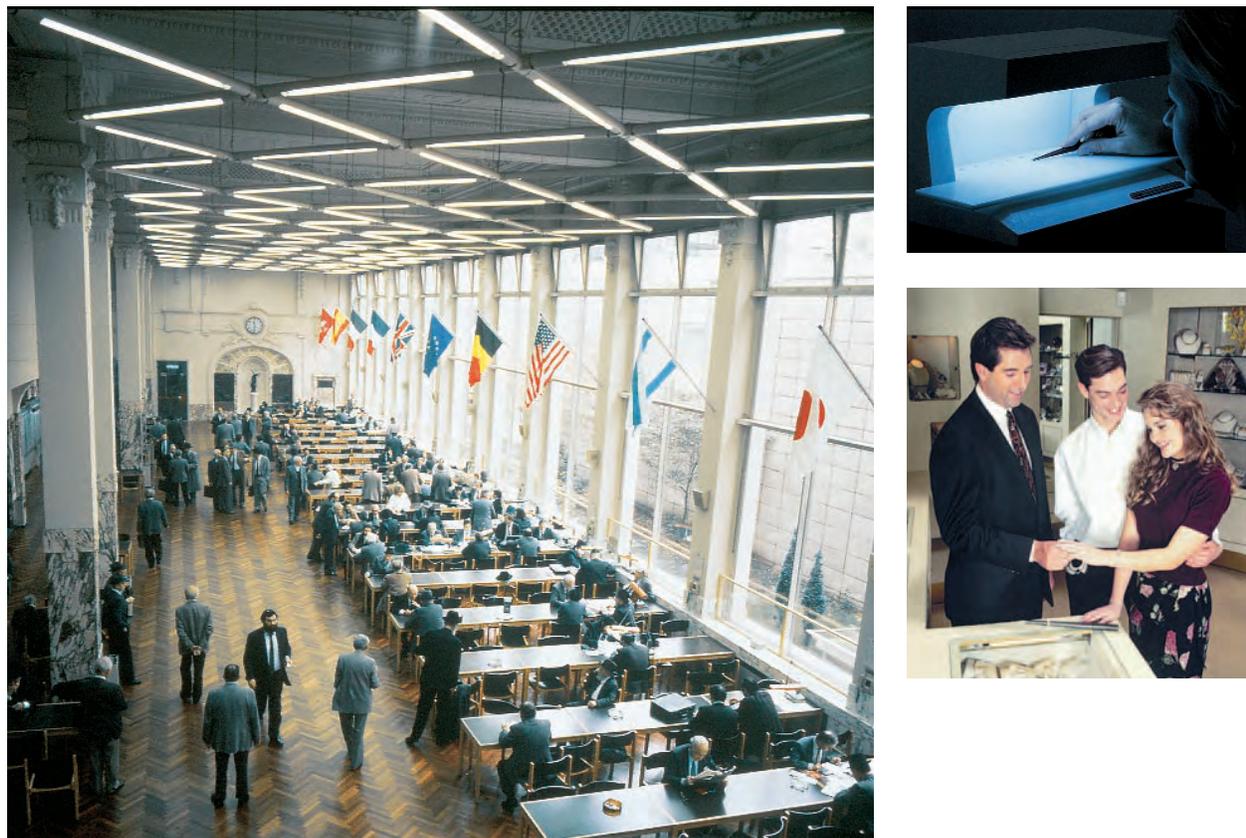


Figure 5. Gem diamonds are viewed in various environments and positions. These range from a highly controlled grading environment (DiamondLite, upper right) through more variable environments such as the diamond bourse (at Antwerp, above left) to the more generalized environment of the retail jewelry store (lower right). DiamondLite photo by Maha DeMaggio, jewelry store photo by James Aronovsky, and bourse photo courtesy of the Diamond Bourse, Antwerp.

absence of haziness or oiliness) were defined so that all observers were responding to the same characteristics. Our concern was to determine whether these observers could perceive any effect from fluorescence on the appearance of the diamonds (that is, more or less colored or more or less transparent) under normal lighting conditions.

We presented the diamonds to each observer one set at a time, and then asked the individual to answer the same group of questions for each set. Observers were allowed to select more than one stone as “most colored,” “least colored,” etc. No time limit was given to view the sets of diamonds.

RESULTS

Analysis of the Data. Questions 1, 2, and 6 were designed to focus the observer’s attention on the properties we wanted to test: color and transparency. Questions 3 and 4 provided us with quantifiable data on color that could be statistically analyzed.

The answers to question 5 were not statistically meaningful. Questions 7 and 8 provided quantifiable data for transparency.

We analyzed the combined results for all observers and all viewing environments to see whether there was an overall trend in (A) perceived strength or weakness of color in relation to fluorescence; and (B) perceived transparency in relation to fluorescence. Next, for questions 3, 4, 7, and 8 (again, see table 3), we tallied the number of observers who chose a particular diamond in response to each question. Since we had different numbers of stones in each fluorescence category (e.g., two diamonds with “strong fluorescence” in the E color set), we used a statistical normalizing technique to correct for the number of observations, so that each fluorescence category had the same chance of being considered as most colored, least colored, most transparent, or least transparent. This normalization was important because certain fluo-

rescent stones were picked more often than others of equal fluorescence strength in the same color set. We also adjusted the totals where needed to account for a single observer "splitting his or her ballot"—that is, choosing more than one stone as most colored, least colored, most transparent, or least transparent. We used this corrected data set to build distributions of the number of observations versus fluorescence strength, for each question and a variety of groupings (across observer types and viewing environments).

With this analytical technique, key trends in the data can be readily discerned. These trends are best seen as bar graphs of the (normalized) number of observations for each fluorescence category. The answers to the two questions "most colored" and "least colored" (or "most transparent" and "least transparent") actually constitute *one set* of observations; that is, if a fluorescent effect exists, it should be evident in the choice of both "most color" and

"least color." To see this, the data are plotted on the same graph, with more desirable attributes (least color and most transparency) plotted above the axis, and less desirable attributes (most color and least transparency) plotted below the axis (see, e.g., figure 6). A trend is indicated when the averages for each category (above and below the axis) form a sloped line. For instance, figure 7A does not show a trend, whereas the trend in figure 8A is pronounced.

We first compared the Laboratory Grader responses to questions 3, 4, 7, and 8 to those of each of the other groups (Trade Graders, Trade Observers, and Average Observers). We found that the observations by the Trade Graders and Trade Observers showed trends similar to the observations by Laboratory Graders. However, observations by Average Observers were randomly distributed (that is, even in a color set and viewing environment where trained Laboratory Graders detected a trend in stone color or transparency, average observers did not). Therefore, the results for Average Observers were excluded from the remainder of the analysis. It is apparent that the Average Observers were not able to consistently discriminate any fluorescence-related effects in the viewing environments most similar to those in which jewelry is purchased and worn.

Assessing the Fluorescence Effect. Questions 1 and 6 provided a general measure of the strength of the effect fluorescence *might* have on color and transparency. Seventy-one percent of all observers (excluding Average Observers), across all environments and sets, said that stones in a given set appeared to have different depths of color. Twenty-nine percent reported that all the stones in a set had the same color appearance. However, when the answers for each color set were examined separately, it became evident that these results were related to color grade: 46% of the observations indicate no difference for the E-color diamonds, 41% for the G-color diamonds, 15% for the set with an I color grade, and 10% for K color. No difference in transparency was reported by 62% of the observers in response to question 6. This result also varied by color set, from 72% for the E set to 56% for the I set.

The data revealed a weak "fluorescence effect" in color appearance over all five viewing environments considered together (figure 6). Although responses to strongly fluorescent stones were mixed, in general, observers were more likely to

TABLE 3. The observer questionnaire.

Name: _____
 Viewing Method: _____
 Diamond Series: _____

1. Do all the diamonds in this group appear to have the same depth of color? (Yes No)
 If yes, please proceed to question 6.
 If not, circle the corresponding letter for the one or ones which appear different.
 A B C D E F
2. Do any of the diamonds have a different hue (color)? (Yes No)
 If yes, which one or ones?
 A B C D E F
3. Which diamond (or diamonds) has the most color?
 A B C D E F
4. Which diamond (or diamonds) has the least color?
 A B C D E F
5. Of the diamonds that remain, are any more colored than the rest? (Yes No)
 If yes, which one or ones?
 A B C D E F
6. Is there a difference in the transparency of any of these diamonds? (Yes No)
 If yes, please answer the next two questions.
7. Which diamond (or diamonds) appears the most transparent?
 A B C D E F
8. Which diamonds appear the least transparent?
 A B C D E F

choose inert and faintly fluorescent stones as “most colored” and very strongly fluorescent stones as “least colored” within each color set. For transparency, the “fluorescence effect” appears even weaker, since most observers detected no effect at all.

Because all the viewing environments were included in the above analyses, further evaluation was needed to determine whether any particular factor—viewing position, light source, and/or stone color—influenced the perceived effects of fluorescence on color and transparency.

Viewing Position. Observations made with similar lighting conditions, but with the stones observed table-down in environment 2 and table-up in environment 3, showed noticeably different results. Table-down yielded no trend in color with respect to increasing strength of blue fluorescence. However, table-up showed a trend of better color appearance with greater strengths of fluorescence. We then grouped the color observations for all light sources for each of the two positions, with the results shown in figures 7a and 8a. Viewed table-down, neither the most colored nor the least colored choices show a trend with fluorescence. In the table-up position, there is a clear trend for strongly fluorescent diamonds to look less colored, and for diamonds with no to weak fluorescence to look more colored.

Across both viewing positions, most observers saw no effect of fluorescence on transparency. Half the observers saw no difference in transparency in the table-down position; the other half observed a clear trend toward lower transparency with stronger fluorescence (figure 7b). As seen in figure 8b, 71% of the observers saw no difference in transparency table-up in similar lighting, and there was no discernible trend in the observations of those who did perceive a difference.

Light Source. We saw no difference in the relationship between apparent color and strength of fluorescence in diamonds observed table-down in a DiamondLite unit (environment 1) as compared to fluorescent overhead illumination (environment 2). Nor did we see different relationships between color and fluorescence in stones viewed table-up with fluorescent overhead illumination as compared to external window light (environments 3, 4, and 5). In other words, there did not appear to be any difference among the light sources we used in their effect on perceived color relative to fluorescence.

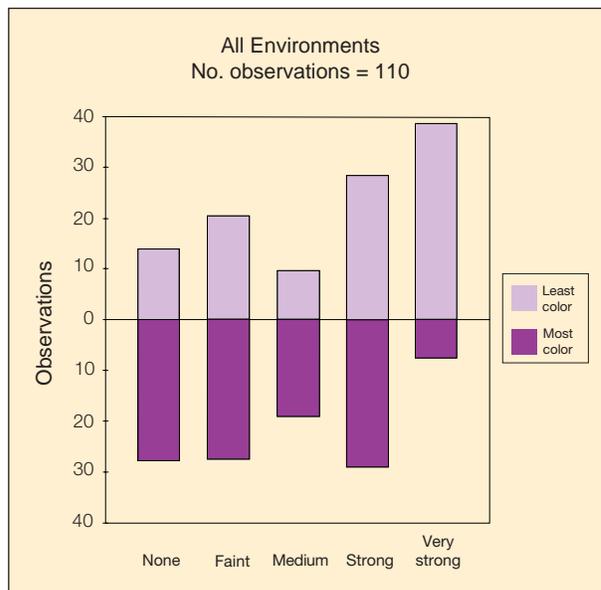


Figure 6. This bar graph illustrates the observations of color appearance in which color differences were noticed, for the various fluorescence categories across all color sets and all experienced observers. Strongly fluorescent diamonds are more likely to be considered “least colored”—that is, to have a better color appearance—in contrast to weakly fluorescent stones, which were somewhat likelier to be considered “most colored.”

By contrast, the results for transparency suggested a difference between daylight (environment 5) and artificial light (environments 1–4). Non-fluorescent and weakly fluorescent stones were reported by some observers to be more transparent table-down in artificial light (environments 1 and 2; figure 7b), but less transparent table-up in indirect sunlight (environment 5; figure 8c). Although we were not able to make any definitive conclusions because of the limited number of usable observers for the indirect sunlight environment, the preliminary correlation of greater transparency with stronger fluorescence in the table-up position merits further investigation.

Diamond Color. For each of the four color sets (E, G, I, and K) taken separately, we also saw no relationship between strength of fluorescence and color appearance with the diamonds viewed table-down, but we again saw a trend toward better color appearance with stronger fluorescence when the diamonds were viewed table-up, regardless of light source. It

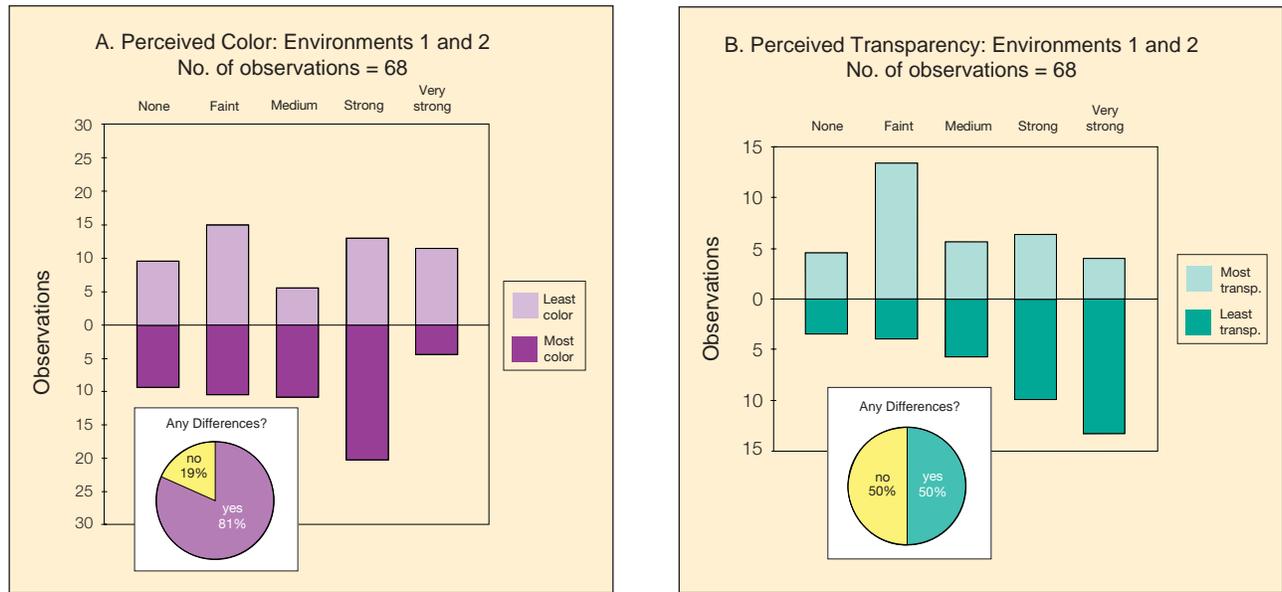


Figure 7. These graphs show the results of the observations on the diamonds positioned table-down. (A) Although color differences were seen in most cases (across all experienced observers and color sets), as indicated by the pie chart, there is no clear trend in color appearance with strength of the fluorescence. (B) In half the cases, no differences in transparency were seen in the diamonds positioned table-down; however, the remaining observations showed a clear trend for weakly fluorescent diamonds to be considered more transparent than strongly fluorescent stones.

appears that fluorescence had a weaker effect on table-up color appearance for the diamonds in the E and G color sets than for those in I and K. However, as there were far fewer observations for a single color set than for all sets taken together, these results are less definitive.

DISCUSSION

For the observers in this study, the effect of blue fluorescence on color appearance and transparency in colorless to faint yellow diamonds was subtle. In fact, our results indicate that Average Observers could not make the fine distinctions sought in this study. Of the experienced observers, most saw an effect on color appearance, but far fewer saw any difference in transparency. Even among the experienced observers, responses varied from stone to stone. Because some highly fluorescent diamonds in a set were singled out and others were not, it is possible that other factors are affecting color appearance more strongly than fluorescence strength.

The results of this study indicate that there is a perceptible relationship between blue fluorescence and color appearance, which depends on viewing position. On average, strongly fluorescent diamonds have a better color appearance table-up, and this

effect is most noticeable at lower color grades. Most observers did not detect any differences in transparency among diamonds in a given color set. Of those who did see a difference under fluorescent lighting, it was only apparent in the table-down position. These results challenge the notion that strongly fluorescent diamonds typically have a hazy appearance.

Classic examples of fluorescent and nonfluorescent diamonds that have similar color appearance and transparency can be seen in many pieces of fine jewelry. Figure 9 shows two complete views of the diamond necklace and earrings from the cover of this issue: one view under normal lighting conditions and the other under the long-wave UV lamp. Clearly, there is a range of fluorescence strengths to the diamonds brought together in these pieces; however, there is a generally uniform overall appearance to the diamonds under normal lighting conditions.

CONCLUSION

Documenting the effects of blue fluorescence on the appearance of gem diamonds is a difficult and complex process. In this study, we screened more than 1,000 polished diamonds to find 24 that fit the chosen color grades, clarity, cutting style and quality,

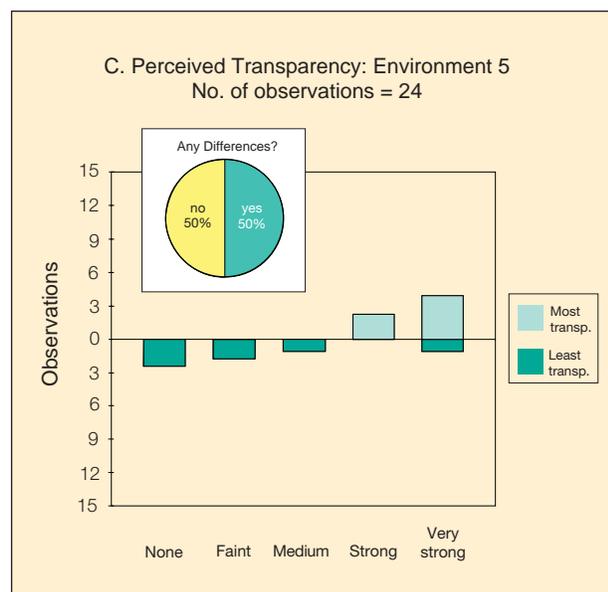
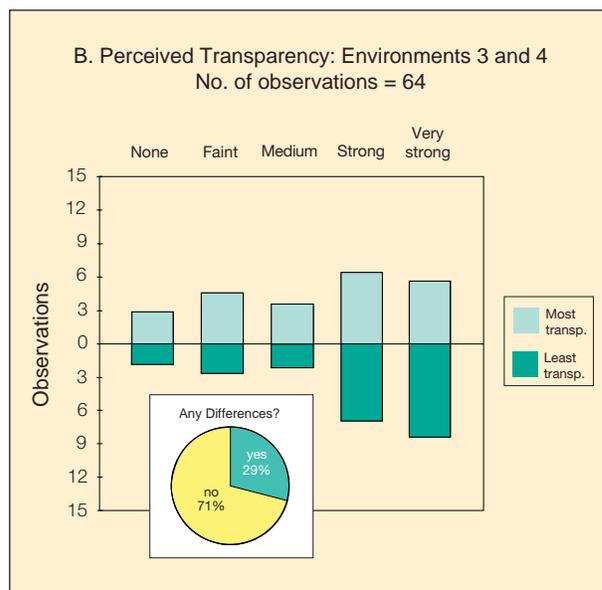
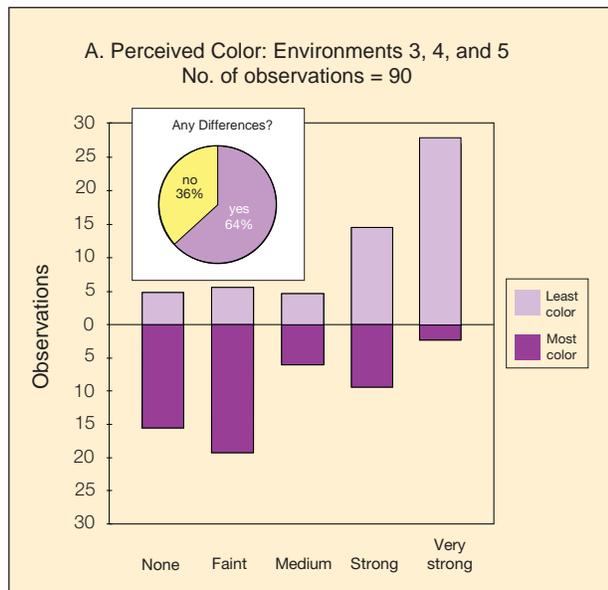


Figure 8. The results were also graphed for observations on diamonds positioned table-up with the different types of fluorescent light and indirect sunlight. (A) Differences in color appearance were noted in all three environments; they showed a clear trend for strongly fluorescent diamonds to be considered less colored than weakly fluorescent stones. (B) In most cases, no differences in transparency were seen for diamonds positioned table-up in fluorescent light environments; for observations in which differences were noted, no trend was seen. (C) In half the observations, no differences in transparency were seen; for diamonds positioned table-up in indirect sunlight, the few observations in which differences were seen suggest that strongly fluorescent diamonds were likelier to be considered most transparent.

and size range while representing the various strengths of fluorescence. Although yellow fluorescent diamonds and “overblues” are also of concern in the trade, such stones are so rare that we could not assemble appropriate examples to perform a comparable study. We obtained the cooperation of 46 observers from a wide variety of trade and non-trade backgrounds. One interesting aspect of this study was that the nontrade observers could not make meaningful distinctions. For this group, which would be considered most representative of the jewelry-buying public, fluorescence had no overall effect on color appearance or transparency.

For the experienced observers, we found that, in general, the strength of fluorescence had no widely perceptible effect on the color appearance of diamonds viewed table-down (as is typical in laboratory and trade grading). In the table-up position (as is commonly encountered in jewelry), diamonds described as strongly or very strongly fluorescent were, on average, reported as having a better color appearance than less fluorescent stones. In this study, blue fluorescence was found to have even less effect on transparency. These observations confirm GIA GTL’s experience grading millions of diamonds over the decades.



Figure 9. The necklace and earrings reproduced on the cover of this issue of *Gems & Gemology* are seen here in their entirety under normal lighting conditions (left) and under the long-wave UV lamp (right). Quite often, diamonds in a range of fluorescent strengths and colors are placed next to inert diamonds, yet the piece maintains a uniform overall appearance under normal lighting conditions. The diamonds in the necklace weigh a total of 132 ct; the diamonds in the earrings weigh 23 ct, with the two large pear shapes 3.04 and 3.20 ct. Jewelry courtesy of Harry Winston, Inc.; photos by Harold © Erica Van Pelt.

Although we identified general tendencies across all diamonds and experienced observers, we also identified apparent variations in fluorescence effect for different color sets. For instance, the effect of fluorescence on color was most noticeable in the lower (I and K) colors, although in the marketplace the influence on price is greater in the higher (D through H) colors.

Unlike the notion held by many in the trade,

fluorescent diamonds are not as prevalent as nonfluorescent stones, as the GIA Gem Trade Laboratory sample data for more than 26,000 diamonds showed. The present study also challenges the trade perception that fluorescence usually has a negative effect on better-color diamonds. Our results show that the diamond industry would be better served by considering each individual diamond on its own visual merits.

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REFERENCES

- American Society for Testing and Materials (1996) *ASTM Standards on Color and Appearance Measurement*, 5th ed., ASTM, Philadelphia, PA, D1729-89: Standard practice for visual evaluation of color difference of opaque materials, pp. 82–84.
- Bruton E. (1978) *Diamonds*, 2nd ed. N.A.G. Press, London, 532 pp.
- Clark C.D., Collins A.T., Woods S.G. (1992) Absorption and luminescence spectroscopy. In J. Field, Ed., *Properties of Natural and Synthetic Diamond*, Academic Press, London, pp. 35–80.
- Collins A.T. (1992) The characterisation of point defects in diamond by luminescence spectroscopy. *Diamond and Related Materials*, Vol. 1, Nos. 5-6, pp. 457–469.
- Davies G., Welbourne C.M., Loubser J.H.N. (1978) Optical and electron paramagnetic effects in yellow type Ia diamonds. *Diamond Research 1978*, pp. 23–30.
- Fritsch E., Scarratt K. (1992) Natural-color nonconductive gray-to-blue diamonds. *Gems & Gemology*, Vol. 28, No. 1, pp. 35–42.
- Liddicoat R.T., Ed. (1993) *GIA Diamond Dictionary*, 3rd ed. Gemological Institute of America, Santa Monica, CA, 275 pp.
- Nassau K. (1983) *Physics and Chemistry of Color*, John Wiley & Sons, New York, 454 pp.
- Shipley R.M., Liddicoat R.T. Jr. (1941) A solution to diamond color grading problems. *Gems & Gemology*, Vol. 3, No. 11, pp. 162–167.
- U.S. Federal Trade Commission (1938) *Trade Practice Rules for the Wholesale Jewelry Industry*. Rule No. 6, p. 4, as promulgated March 18, 1938.
- Waychunas G.A. (1988) Luminescence, X-ray Emission and new spectroscopies. In F.C. Hawthorne, Ed., *Reviews in Mineralogy*, Vol. 18, Spectroscopic Methods in Mineralogy and Geology, Mineralogical Society of America, Washington, DC, pp. 639–698.
- We Want to Know That* (1993) SBA-TV, South Korea, broadcast May 9.