The Rediscovery of the 'French Blue' diamond

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Jean-Baptiste Tavernier (1605-1689), a French traveler, returned from India in 1668, with a large (115.16 carats) blue diamond from an unknown mine in India [1,2]. After the King of France, Louis XIV (1638-1715), purchased the gem, it became the largest diamond of the French Crown Jewels. Alas, in September 1792, this very unique and large blue diamond was stolen along with other gems of the French Crown Jewels [2]. Although most were eventually recovered, the 'French Blue' diamond never reappeared [1-3].

However, in 1812 a deep blue diamond of 45.5 carats was held in London by Daniel Eliason, a British diamond merchant [3]. Suspicions arose that this stone was illegally cut from the stolen 'French Blue' [4], losing about 1/3 of its weight as well as its 17^{th} century cut [2-4]. But no proof could be found, for lack of accurate information about the 'French Blue' before its robbery. This gem, called the 'Hope diamond' after its first owner, went through a succession of owners until it was donated in 1958 by Harry Winston to the Smithsonian Institution in Washington, D.C., (USA) [3]. Despite the fact that the 'Hope diamond' was believed to represent the modern avatar of the stolen 'French Blue', no thorough proof was available to verify this hypothesis.

▲ **FIG. 1:** The Paris lead cast (30.5 mm width) and the dismounted 'Hope' diamond (courtesy Smithsonian Institution, Washington, DC, USA).

Historical lead model

A recent inventory of the mineral and gem collection of the *Muséum national d'Histoire naturelle* in Paris revealed the presence of a previously unknown unique lead cast of the 'French Blue' diamond, donated sometimes between 1800 and 1850 [1]. To study this old and fragile cast, the artefact was laser-scanned [1] in order to obtain a 3D mesh of the diamond (Figure 1). The surface scanning was so sensitive that it revealed more than 3000 individual surfaces, while the actual number of 'true facets' was estimated by eye to be around 78. In this study, we present a more reliable 'mesh cleaning', achieved using a quadratic collapse edge decimation method (Meshlab package).

True color of the 'French Blue'

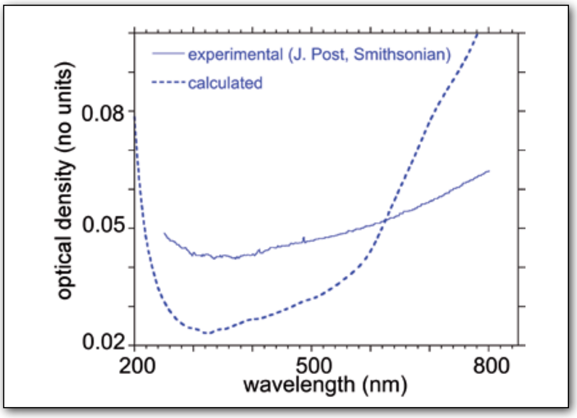
The cleaned mesh was compared in 3D to a series of known blue diamonds that are claimed to be modern avatars of the 'French Blue', namely the 'Hope' (44,5 carats) and the 'Terenschenko' (40,5 carats) diamonds. However, only the 'Hope' diamond could fit into the scanned lead cast (Figure 1). In fact, the asymmetric shape of the 'Hope' diamond seems directly related to the triangular shape of the 'French Blue' [1].

On the other hand, the 'Hope' is described as a dark grayish blue diamond [5]. But was that the case for the 'French Blue' diamond? In fact, lapidarists know very well that a given cut can significantly alter the color of a gem. Actually, when the 'Hope' diamond is held above a white paper, the diamond appears dark grayish blue, except at its center where it absorbs much less light. As a result, one can easily see the background paper through the gem (see Figure 1). This tells us that the 'Hope' diamond is, in fact, cut from a relatively light blue diamond. Its peculiar XIX^{th}-century cut apparently makes it dark blue because the light is trapped inside the diamond by facets cut mostly at an angle greater than the critical angle of diamond (around 24.4° for the diamond/air boundary). This means that the large front facet (called the 'table') and the small facet cut in the back of the diamond (called the 'cutlet', parallel to the table) will behave as transparent boundaries for the viewer. In contrast, all the other facets will reflect light inside the diamond due to total internal reflection, because the angle between the incident light and the facet is usually above the critical angle of diamond. As a consequence, light absorption will be enhanced thanks to those facets, until light is eventually reflected back to the viewer. Hence, the apparent blue color of the diamond is rather intense (that is, dark) while the actual diamond color is light blue. Where does this color come from?

Blue diamonds

Only a modest number of blue diamonds are known nowadays, mostly from India ('Wittelsbach', 'Tereschenko', 'Hope') and South Africa ('Copenhagen Blue'). The latter (45,9 carat) is the largest blue diamond presently known, although well below the past 'Tavernier Blue' (115.4 carat) and 'French Blue' (69.0 carat) diamonds, while a nameless diamond weighing 121.9 carat is reported to exist

◄ cubic zirconia replica of the 'French Blue' in the royal gardens of Versailles. Also shown is a lead cast, rediscovered in Paris in 2008, of the original diamond.



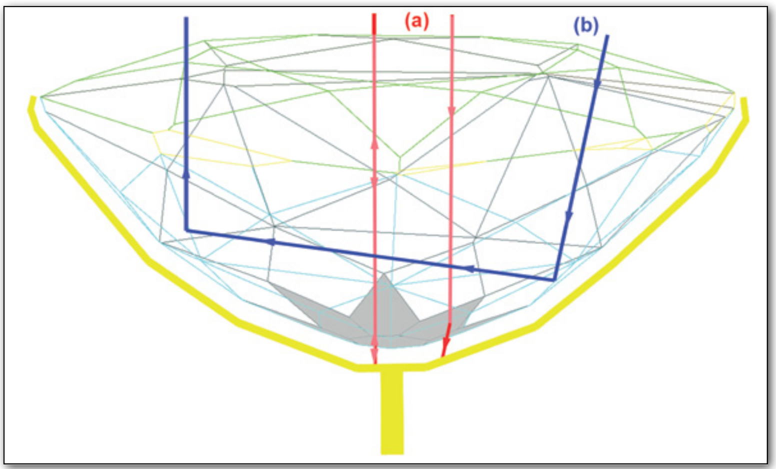
▸ **FIG. 2:** Optical spectroscopy spectrum measured for the 'Hope' diamond (courtesy of Smithsonian Institution, Washington, DC, USA) together with a computer spectrum assuming a boron atom inside a 63-carbon atom cluster.

[6]. Interestingly, type IIb blue diamonds are depleted of N_2 (*i.e.*, below current detection levels [7]) but boron-bearing (a few ppm) [8]. In addition to having high thermal conductivity and dielectric strength, unlike other diamonds they are semiconductors to superconductors [9]. B-bearing diamonds have an acceptor state at 0.385 eV above the valence band. These features also make blue diamonds very much investigated for their impressive electrical properties [7,9], *e.g.*, in high voltage diodes, transistors and electrochemical electrodes.

In diamond, the blue color typically arises from small amounts – on the order of ppm – of B atoms [5,10] (the color of some blue-green to violet diamonds from Argyle, Australia, is not related to B [8]). B and C are trivalent and tetravalent, respectively. So, when C is substituted by B, an electron vacancy is created: B can act as a semiconductor acceptor (p-type). This can be compensated by a single N substitution, which acts as an electron *donor*. Only 'uncompensated' B atoms (B_0) will contribute to the color [7,8,10]. Some blue diamonds exhibit strong chemical and color zoning, for example the 'Hope' diamond [10]. The B atoms strongly enhance optical absorption in the red part of the visible wavelengths up to the IR region (~3.5 µm). This gives a blue color to the transmitted light for those diamonds, but the intensity of the perceived color is not a straightforward function of the B_0 content [10]. Gem faceting strongly alters the perception of its intrinsic color, and the perceived color of a cut gem is typically estimated using empirical color gradings. Finally, some blue diamonds exhibit a grayish hue that is likely due to the presence of a brownish component related to distortion [5].

Despite the great complexity of our perception of color, the optical absorption spectroscopy of the 'Hope' diamond was measured using a high-resolution charge-coupled device (CCD) spectrometer (Ocean Optics HR2000) with a 5 nm slit width and a light source (Ocean Optics DH-2000) that was used with both the deuterium and halogen light sources, covering a wavelength range of 215–2000 nm (Figure 2). The spectrum was measured between 250 and 900 nanometers, which is enough to get good quantitative information on its intrinsic color, independent of its faceting. To understand and better model this property, theoretical first-principles Bethe-Salpeter Equation calculations [11] of the optical absorption of substitutionally B-doped diamond were carried out. We started from a supercell with 63 C atoms and one B atom in a DFT-relaxed diamond crystal structure using ABINIT [12,13]. Based on this cluster, an UV-VIS-NIR optical spectrum was calculated that is comparable to that measured for the 'Hope' diamond (Figure 2: details will be published later). Briefly, the results show that B-doped diamonds absorb preferentially in the red, and strongly above about 700 nm due to the presence of a B impurity band, consistent with their 'cold blue' color.

▾ **FIG. 3:** Sketch illustrating how light (blue and red paths) is refracted inside the 'French Blue' diamond when it was set into a gold stick (yellow). (a): Red light crosses through the boundary facets (in gray) that were cut with an angle ~ 0 and 20°, *i.e.*, below the critical angle of diamond. (b): Blue light is refracted inside the diamond as the incident angle of that facet (in white) is above the critical angle of diamond.



Virtual recreation

The experimental optical absorption spectrum for the 'Hope' diamond was also used to photorealistically simulate the 'French Blue' diamond, using the mesh described above as input to the DiamCalc software. Special care was given to parameterize the illumination conditions (color temperature etc). In addition, we set the diamond according to the 1691 inventory of the French Crown Jewels that states that the gem was *"violet and set into gold and mounted on a stick"* (probably designed to facilitate the observation of the gem by the king). Therefore, a gold foil was set behind the 3D mesh of the diamond. This detail is relevant because the 'French Blue' has 8 back facets that are cut below the critical angle of diamond. Thus, one expects that those 8 central facets will allow the observation of the back gold foil. On the other hand, the 70 other facets will contribute to darken the intrinsic colour of the natural diamond (see paths (a) and (b) in Figure 3). But the question remains: what was the exact color — blue or violet — and fieriness?

◂ **FIG. 4:** The final photorealistic simulation of the 'French Blue' diamond when set into gold, following the 1691 inventory of the French Crown Jewels.

An unsuspected masterpiece

A photorealistic simulation of the "French Blue" is shown on Figure 4. As predicted, we could observe that the 8 central facets that are 'golden'. The 70 other facets contribute to the dark blue hue of the diamond, but not as dark as the 'Hope'. This superb optical illusion is due to an excellent understanding of the critical angle of diamond that was obviously well known (most likely heuristically) by the King's jeweler, Jean Pittan the Younger (ca.1617-1676) [1]. Also, the 'French Blue' diamond is more indigo than the 'Hope': the adjective 'violet' referred to an intense blue during the 17th century [2]. Therefore, this diamond was cut to the colors of the French monarchy *"of azure and gold"*: it served as a political instrument devoted to the power of the King. Accordingly, the central golden motif acts as a central sun, the favorite icon of King Louis XIV, also known as the "Sun-King".

To summarize, we needed to use modern computers and sophisticated software to recreate and understand the optical properties of a forgotten 17th century masterpiece that served the image and power of the King of France. A spectroscopic understanding of the exact color of the 'Hope' diamond has given us access to that lost *chef d'oeuvre*. ■

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