Cut: It's Relevance and Importance As It Pertains to a Jewel's Optical Physics

Fine Jewelry Application

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Charles & Colvard, Ltd., the sole manufacturer and distributor of created moissanite jewels, developed this booklet to be used as a course of study and reference guide.
It is our intention to provide company personnel, distributors, manufacturers, retailers and others with an in-depth understanding of the unique faceting designs that allow moissanite to exhibit more brilliance, fire and luster than any other jewels used in the creation of jewelry.

Moissanite, also known as silicon carbide, is a naturally occurring mineral found in limited quantities or as small particles in the earth. The rarity of large natural Moissanite crystals prohibits their use in jewelry making.

For years, scientists tried in vain to re-create this extraordinarily brilliant material. Only recently, through the power of advanced technology, Charles & Colvard developed a way to duplicate this unique and near-colorless jewel by producing large, gem-quality crystals. Moissanite is truly a unique and beautiful blend of art and science.

Every Charles & Colvard created Moissanite jewel is precisely calibrated and hand cut by a master technician to create maximum brilliance and to spark the ultimate fire.

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"Moissanite" as used in this document refers to Charles & Colvard created Moissanite.

Cover Photography: Buddy Langston, Charles & Colvard, Ltd.

Cut: *It's Relevance and Importance As It Pertains to a Jewel's Optical Physics*

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Moissanite jewels have more brilliance, fire and luster than any other hard jewel. These essential properties – brilliance, fire and luster – are what determines a jewel's beauty.

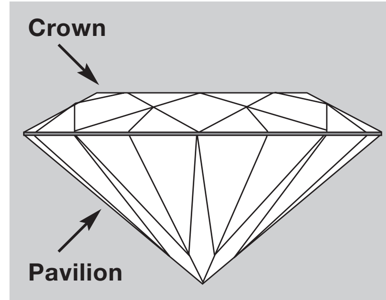
This booklet has been developed to provide you with the scientific background to support Charles & Colvard's marketing claims that moissanite actually has more of these highly valued and prized attributes than any other jewel used today for the creation of fine jewelry – including diamond.

ROBERT S. THOMAS
Chairman, President & CEO
Charles & Colvard, Ltd.

CHARLES & COLVARD®
Created
MOISSANITE

FUNDAMENTALS OF JEWEL PROPORTION

The ***crown*** of a jewel acts as a window, allowing light into the jewel, and light that has entered the jewel to then exit. The ***pavilion*** of a jewel acts as a mirror to reflect light back out of the crown. Light that leaves through the pavilion is potential brilliance lost and is defined as leakage. Light leaving the crown travels upward and is seen by the eye as ***brilliance***.



The crown and pavilion of a jewel.

OPTICAL PHYSICS: THE SCIENCE OF BRILLIANCE

Brilliance is determined by the amount of light that a jewel reflects back to the eye. When light strikes a material other than a vacuum it meets resistance and slows down. In the case of jewels, the slower the light travels, the higher the resulting potential brilliance.

Material	Miles Per Second
Vacuum	186,282 mps*
Sapphire	105,244 mps
Cubic Zirconia	85,844 mps
Diamond	76,976 mps
MOISSANITE	**70,295 mps**

Speed of Light Comparison for Selected Near-Colorless Materials

Note: There are slight variations in the published numbers of different journals. All numbers used here, and throughout this publication, are nominal and widely accepted.

MAXIMIZING BRILLIANCE IN JEWELS

Brilliance is light leaving the crown of a jewel traveling upward which is visible to the eye, and is created in two different ways:

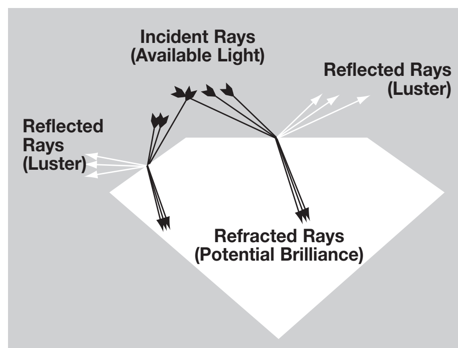
1. LUSTER – Reflection from the Surface

When available light (incident rays) meets a surface, some of it reflects and some enters the material. The reflected light is referred to as "first surface reflection" or **LUSTER** and depends upon the Refractive Index (R.I.) of the material. *See illustration to the right.*

$$\% \text{ Luster} = \frac{(\text{R.I.} - 1)^2}{(\text{R.I.} + 1)^2} \times 100$$

Luster of Diamond 17.2%
Luster of Moissanite 20.4%

Reference: GEMS by R. WEBSTER Fifth Edition, pg. 729, Fresnel's Formula.



Incident, reflected and refracted rays.

"Since this (luster) is determined by the refractive index (along with the flatness of the polished surface), the higher the luster, the higher the refractive index."

Reference: Handbook of Gem Identification published by Gemological Institute America, pg. 216.

The luster is measurable with an instrument. Luster meter by Hanneman or Jemeter. (The surface must be perfectly clean.)

Reference: GEMS by R. WEBSTER Fifth Edition, pg. 730 – 734.

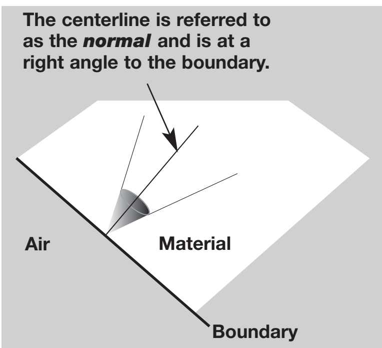
2. REFRACTION AND SNELL'S LAW
Potential Brilliance from Inside the Jewel

REFRACTION – When light meets a surface, some of it reflects and some of it enters the material. The light that enters the material slows down and will also change direction if it enters at an angle other than perpendicular to the surface – this is ***refraction***. The ***Refractive Index (R.I.)*** is the measurement of the slowing of light.

$$\text{R.I.} = \frac{\textbf{Speed of Light in a Vacuum*}}{\textbf{Speed of Light Inside of the Material}}$$

**Note: For all present purposes, air and vacuum are the same.*

SNELL'S LAW defines the direction of the light that enters or leaves the material. When the angle of an approaching light ray and the refractive index of the material and air are applied to Snell's Law, the direction the light ray will take when it crosses a material boundary is determined.



The normal.

Snell's Law Formula

Given:

i =	**angle from the normal of the approaching light ray**
r =	**direction of light ray after passing from air into a different material**
R.I. =	**refractive index of the material the light is entering**

$$\sin(r) = \frac{\sin(i)}{\text{R.I.}}$$

Note: Scintillation is experienced when a jewel moves in the light and its brilliance flashes. Therefore, if the cut of a jewel is designed to take advantage of brilliance, the brilliance will enhance scintillation. Scintillation does not add to brilliance, scintillation takes advantage of brilliance.

THE IMPORTANCE OF THE CONE OF ACCEPTANCE*
"The Cone that Lets Light Out"

Light rays inside a material that encounter a boundary with air will exit if the approaching angle is **less** than the angle described by the ***cone of acceptance***. This represents leakage of light when it exits the pavilion and brilliance when it exits the crown. Angles are measured from the normal (illustrated on page 3).

If a light ray is approaching at an angle ***greater*** than the angle described by the cone of acceptance, the light will be reflected internally and travel on to the next boundary. Reflection will continue to occur internally until the light ray falls within the cone of acceptance of a boundary it encounters.

This is similar to skipping a flat rock across a still, smooth pond. The rock must be thrown at a low angle so when it hits the water, instead of going into the pond, it will skip along on the surface. The critical angle in this discussion describes the angle that the light will either skip along, or pass through the boundary of the material. This factor is the major reason that some jewels are more brilliant than others. If the light cannot escape out of the pavilion (bottom) of the jewel, it continues to skip along inside (similar to the rock that skips several times on the surface of the pond), until it escapes through the crown and travels on towards the eye to be seen as brilliance.

The cone of acceptance of moissanite is approximately 9% smaller than diamond, so on average 9% less of the light that enters the jewel will escape from the pavilion of moissanite compared to diamond.

The light entering into a jewel is the available light less that reflected as luster.
For example:

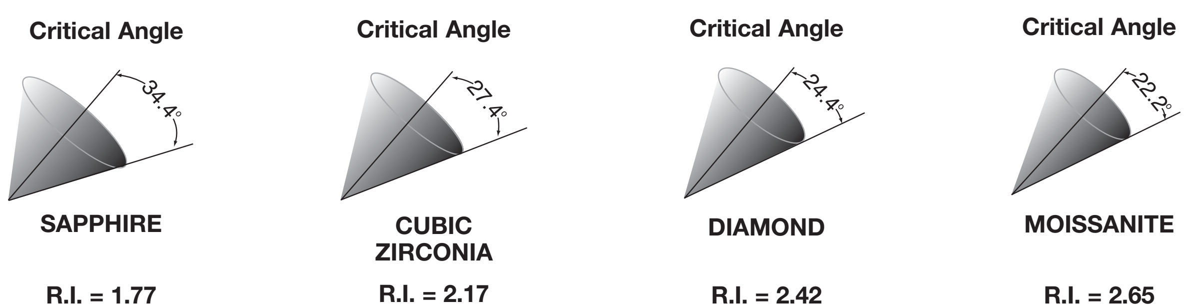
100% minus 20.4% luster of moissanite = 79.6% of light entering moissanite.
100% minus 17.2% luster of diamond = 82.8% of light entering diamond.

The 82.8% of light entering diamond is then comparatively reduced by 9% to 75.3%. Accordingly, the two components of brilliance, the luster and the light inside the jewel available for exiting the crown, are both larger for moissanite than for diamond.

DETERMINING THE CONE OF ACCEPTANCE

The width of the cone of acceptance is determined by the ***Critical Angle***, which is calculated from the ***R.I.*** of the material.

$$\sin(\text{Critical Angle}) = \frac{1}{\text{R.I.}}$$



Critical angles and refractive indices for sapphire, cubic zirconia, diamond and moissanite.

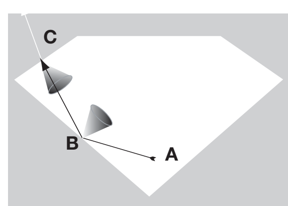
**Reference: "Faceting for Amateurs" by Glenn and Martha Vargas that further references "...'cones of acceptance' are adapted from drawings in literature published by The Gemological Institute America."*

UNDERSTANDING LIGHT RAY TRACING

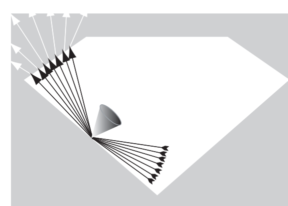
Light rays enter the jewel through the crown and approach the pavilion boundaries inside the jewel from many different directions. To illustrate how light reacts when it encounters material/air boundaries specific starting points have been selected for the light rays in the following pictures and discussion. The light rays that exit the crown add to brilliance. Those that exit the pavilion boundary at the bottom of the jewel represent potential brilliance lost (***leakage***). These are idealized views to illustrate the fundamental concepts. The illustrations on the left show the path of a single light ray, whereas the illustrations on the right show an accumulation of similar light rays.

In the illustration on the right, the approaching light ray (starting point A) is outside the pavilion cone of acceptance (point B) so it reflects to strike the next boundary (point C) on the crown's main facet inside its cone of acceptance, exiting as brilliance. Like the rock on the pond, it skips along when it hits the pavilion boundary, but it hits the crown boundary at too steep an angle to skip, so it exits as brilliance.

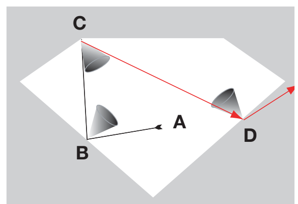
Brilliance



Brilliance

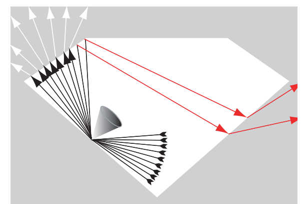


The additional light rays shown here (starting point A), after being reflected from the pavilion (point B) into the crown (point C), again encounter a boundary outside the cone of acceptance for that boundary, shown in red. They are then reflected back to the other side of the pavilion (point D) where they encounter the third boundary and are inside the cone of acceptance for that boundary, exiting as potential brilliance lost (leakage).



Leakage

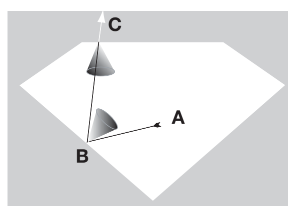
Brilliance



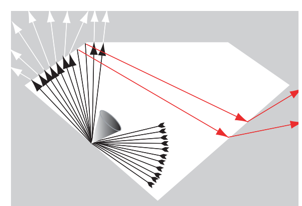
Leakage

The additional light rays shown here (starting point A) after being reflected from the pavilion (point B), strike the table and are inside the table's cone of acceptance (point C), so they exit from the crown, adding to brilliance.

Brilliance

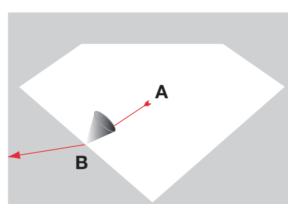


Brilliance



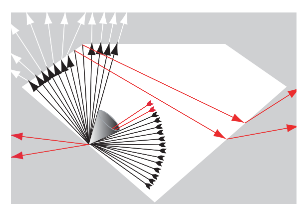
Leakage

The additional light rays shown here (starting point A), strike the pavilion boundary within the pavilion cone of acceptance (point B), exiting out the bottom of the jewel as potential brilliance lost (leakage), shown in red.



Leakage

Brilliance

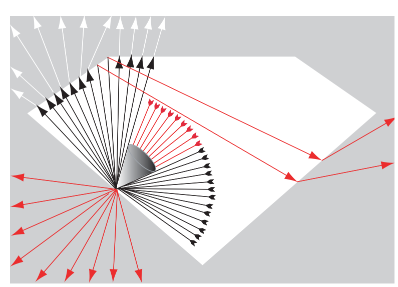


Leakage **Leakage**

This illustration shows light rays at all possible angles that exit the crown (table facet and crown facets) as brilliance. Light rays that exit the pavilion boundaries are potential brilliance lost (leakage). You can see from this illustration that a larger cone of acceptance will allow more light to leak out of the pavilion making it unavailable to exit the crown to become brilliance.

Sapphire, cubic zirconia and diamond all have larger cones of acceptance than moissanite, thus more leakage (brilliance lost).

Brilliance



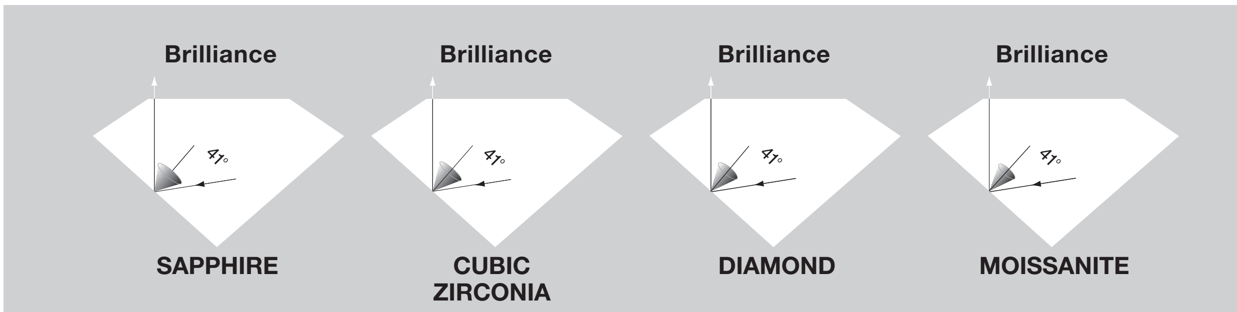
Leakage **Leakage**

LIGHT RAY TRACING FOR SPECIFIC FACETED JEWELS

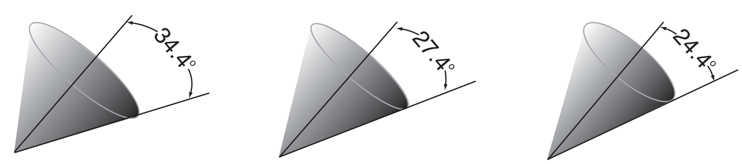
The ***cone of acceptance***, a result of the R.I., for different materials directly affects their ***brilliance***. The following illustrations depict, at various angles, the results of the cone of acceptance affecting brilliance for sapphire, cubic zirconia, diamond and moissanite.

Notes: 1. The Cone of Acceptance and Critical Angle for each material is shown below for reference purposes.
2. Snell's Law defines the direction of entering and exiting light rays.

The **41-degree** light ray approaches the pavilion surface at an angle that is ***greater*** than the critical angle of the sapphire, cubic zirconia, diamond or moissanite, so no leakage occurs in any material and the light ray is reflected towards the table then exits and adds to brilliance.

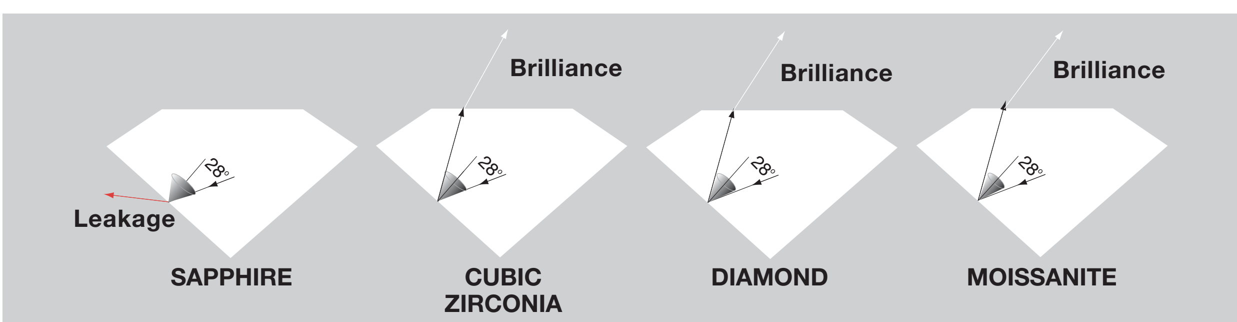


Critical Angle

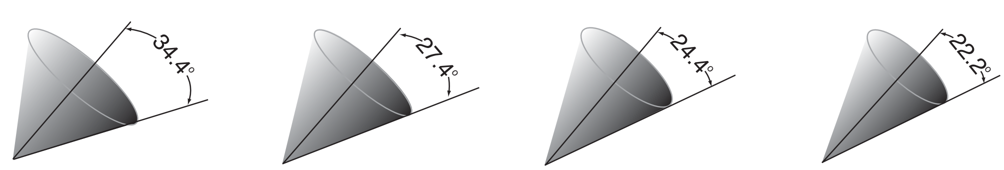


The **28-degree** light ray approaches the pavilion surface at an angle that is ***greater*** than the critical angle of the cubic zirconia, diamond or moissanite, so no leakage occurs and the light ray is reflected towards the table then exits and adds to brilliance.

This angle of the light ray is ***less*** than the critical angle of sapphire so it leaks out the bottom and potential brilliance is lost (***leakage***).

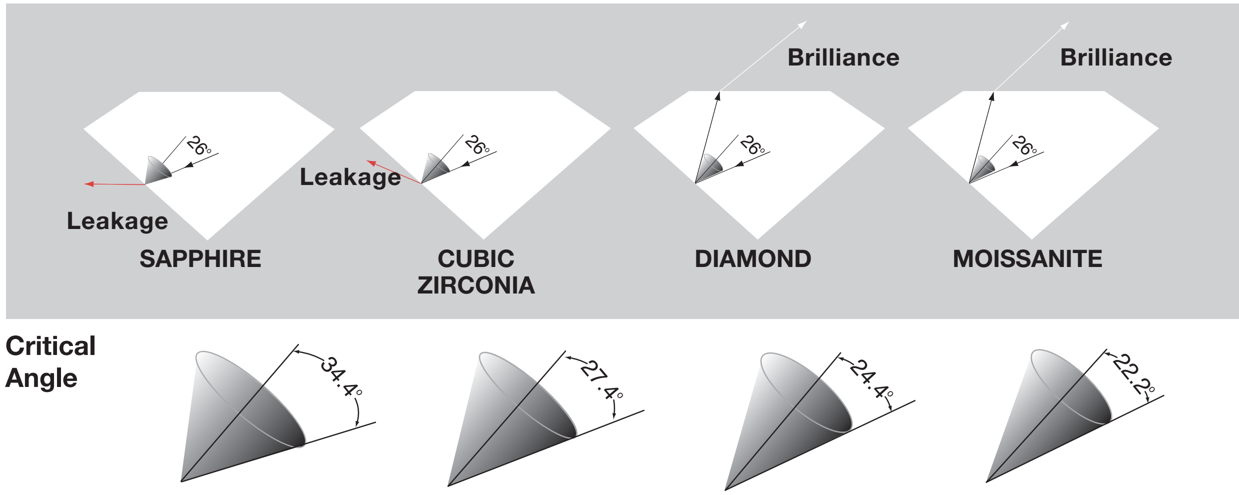


Critical Angle

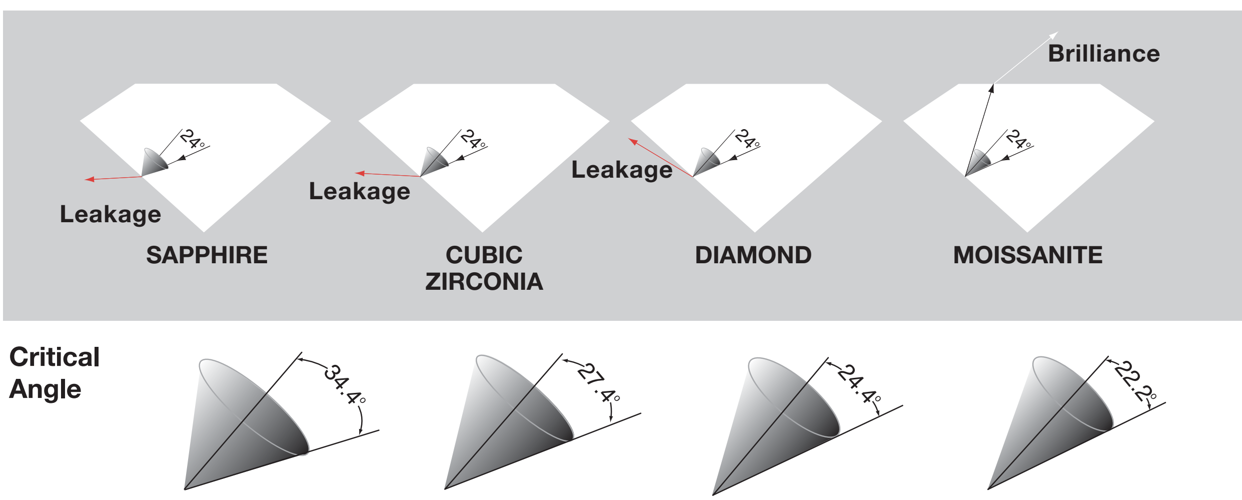


The **26-degree** light ray approaches the pavilion surface at an angle that is greater than the critical angle of the diamond or moissanite, so no leakage occurs and the light ray is reflected towards the table then exits and adds to brilliance.

This angle of the light ray is ***less*** than the critical angle of the sapphire and cubic zirconia, so it leaks out the bottom and potential brilliance is lost (***leakage***).



The **24-degree** light ray approaches the pavilion surface at an angle that is ***greater*** than the *critical angle* of the moissanite, so no leakage occurs and the light ray that is reflected towards the table then exits and adds to brilliance. This angle of the light ray is ***less*** than the *critical angle* of the sapphire, cubic zirconia and diamond, so it leaks out the bottom and potential brilliance is lost (leakage).



SYNOPSIS: Billiance

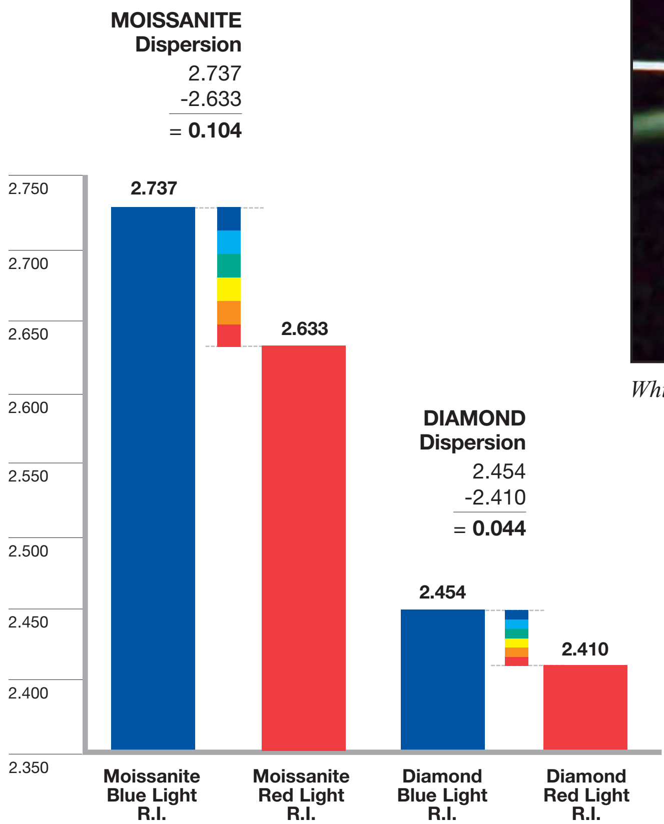
Potential brilliance of a transparent jewel is determined primarily by the refractive index (R.I.) of the material. The higher the R.I., the greater the potential for higher brilliance and more luster.

The proper cut will change potential brilliance into realized brilliance.

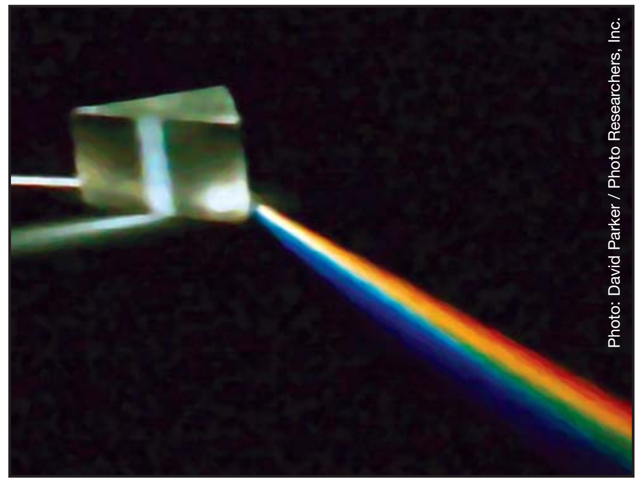
A well-cut moissanite jewel leaks 9% less light through the pavilion (light that has entered the jewel through the crown), than a well-cut diamond.

DISPERSION (Fire)

In physics, "dispersion" (***fire***) is the property by which light is spread out according to its wavelengths (***colors***) as it passes through an object. For example, when white light is directed into a prism, the different colors of light bend in different degrees so they spread out to make a rainbow, as pictured below. This occurs because different colors of light have different refractive indices in a given material. Each color interacts with the molecular structure of the prism differently, depending on its wavelength and the material. Different wavelengths of light bend in different degrees by the dispersion. This is also known as "dispersive refraction". A graphical representation of dispersion (***fire***) for moissanite and diamond is shown below.



This graph shows the refractive index for both blue and red light for moissanite and diamond. The difference between the red and blue R.I. represents dispersion.



White light enters a prism, exiting into spectral colors.

SYNOPSIS: Dispersion (Fire)

Highly refractive, near-colorless jewels rely on fire and brilliance for beauty.

Diamond's ideal cut has proportions that maximize the FIRE – therefore reducing the potential brilliance. This is desirable because of diamond's relatively low dispersion and provides the balance that results in the most beauty in diamond.

Moissanite that is well cut has proportions that maximize BRILLIANCE – therefore reducing potential fire. However, moissanite's greater dispersion allows it to maintain dramatic fire effects that are greater than can be achieved in other materials, including diamond.

JEWEL DISPERSION COMPARISON USING A J-FIRE UNIT

Moissanite has dispersion of 0.104, which is greater than both cubic zirconia (0.060) and diamond (0.044).

The J-Fire Unit developed by Charles & Colvard is used to illustrate a jewel's dispersion.

Note: The diameter of a jewel's dispersed light is determined by a combination of its dispersion and refractive index.

MAXIMIZING OPTICAL PROPERTIES THROUGH CUT AND FINISH

Every type of jewel must have different facet and proportion designs to achieve the best optical performance in order to create the greatest beauty. For example, colored jewels need to be designed to maximize certain qualities (see below).

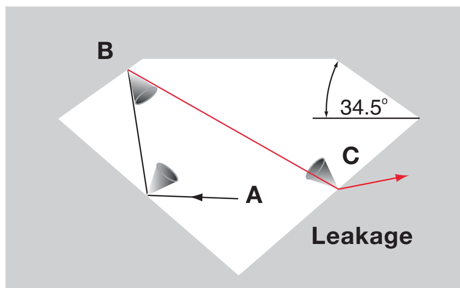
COLORED JEWELS	Emerald	Cut is designed to optimize the color with a large step cut pavilion.
	Tourmaline	Cut very steep on the ends to reduce darkness.
	Dark Jewels	Have shallow pavilions to lighten the color seen.
	Light Jewels	Have deep pavilions to intensify the color seen.

Near-colorless jewels with a high refractive index such as diamond and moissanite depend upon brilliance, fire and luster for their beauty.

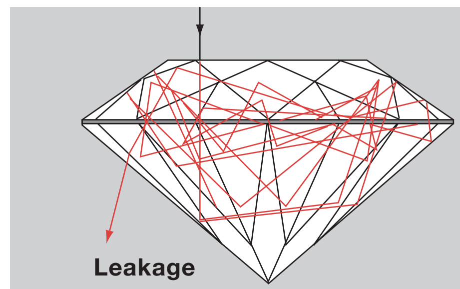
THE IMPORTANCE OF CUT FOR MOISSANITE

MOISSANITE when cut using proportions designed for an "ideal cut" diamond:

Due to a greater crown angle, the light ray is reflected back internally to then leak from the right side of the pavilion (C).

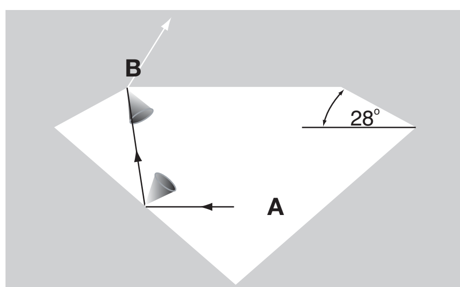


When the "ideal cut" for diamond is used for moissanite, the light ray reflects internally until it escapes from the pavilion where potential brilliance is lost (leakage).

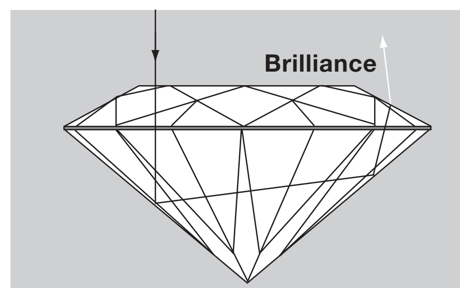


MOISSANITE when cut using proportions designed by Charles & Colvard specifically for moissanite:

The moissanite crown angle is lowered to allow more light to exit from the crown (B). The pavilion design has additional specifications.



When the Charles & Colvard cut is used for moissanite, it properly reflects the light ray and directs it out through the crown as brilliance.



COMPUTER LIGHTING MODELS HELP DETERMINE CUT

Computer programs simulate the light travel throughout jewels with different refractive indices and facet designs. These models are useful to compare different cutting plans to determine which one will produce the most brilliance.

There are two different ways to measure light. One lighting model, cosine (COS), provides light of variable brightness to the crown of the jewel. The other, isometric (ISO), provides light of equal brightness to the crown of the jewel. The computer then calculates the path of each light ray to determine where it will exit the jewel. Light rays that exit the crown contribute to brilliance, and those that exit the pavilion contribute to leakage.

Note: GIA has published studies of light ray tracings in great detail for diamond only.

Cutting Proportions Comparison

The cutting proportion is a significant factor for determining brilliance, and in order to achieve the best brilliance obtainable from moissanite, angles different than those for diamond must be used.

Reference: Proportion and facet modeling created with GemCad Software by Robert W. Strickland, Gemsoft Enterprises.

Diamond cut according to "ideal cut" diamond proportions:

COMPUTER MODEL

Brightness ISO: 89.2% COS: 70.1%

The computer model illustration *(left)* shows white areas that predict the refractive brilliance of an "ideal" cut diamond.

Photo 1
(below) is taken when the jewel is illuminated with a red light source. The red color emanating from the jewel demonstrates the actual refractive brilliance of the jewel. The red areas correspond very closely to areas of brilliance in the computer model.

Photo 2
(below) is taken with the jewel illuminated with a white light source. The white light emanating from the jewel demonstrates the actual refractive brilliance of the jewel. The white areas correspond very closely to areas of brilliance in the computer model.

MOISSANITE
when cut using proportions designed for an "ideal cut" diamond:

Illustrated: *The "ideal cut" for diamond* ***IS NOT*** *the best cut for moissanite.*

COMPUTER MODEL

Brightness ISO: 84.1% COS: 60.7%

PHOTO 1

PHOTO 2

MOISSANITE
when cut using proportions designed by Charles & Colvard specifically for moissanite:

Illustrated: *The Charles & Colvard cut* ***IS*** *the best cut for moissanite.*

COMPUTER MODEL

Brightness ISO: 91.0% COS: 76.5%

PHOTO 1

PHOTO 2

These photos validate the usefulness of the computer modeling technique when used for proportion design.

SYNOPSIS: Cut

The ***Cut and Finish*** are the final significant factors that bring out the potential optical performance in all materials.

The proportions selected for cutting moissanite create high brilliance, fire and luster while maintaining an overall attractive jewel appearance.

HARDNESS AND TOUGHNESS

Hardness and toughness are important characteristics for a jewel's long life and durability. The chart below compares some of the hardest materials on the market.

	MOHS Scratch HARDNESS	KNOOP Indentation HARDNESS Kg/mm2 *	Pressure Tolerance TOUGHNESS Million PSI **
Diamond	10	5700 – 10400	14.6
MOISSANITE	**9 1/4**	**3000**	**7.6**
Sapphire	9	2000	3.7
Cubic Zirconia	8 1/2	1370	2.4

* – *Kilograms per millimeter squared*

** – *Pressure is in millions of pounds per square inch (PSI)*
Converted from Gpa in the reference (1 Gpa per 145,038 PSI)

HARDNESS: Measuring Resistance to Scratching

MOHS is a common jewel reference to measure the relative scratch hardness of different jewels.
Reference: Handbook of Gem Identification by GIA, page 11.

KNOOP is a measurement of specific hardness based on an indentation test.
Reference: Science Volume 290, pp. 783-785, Oct. 27, 2000.

TOUGHNESS: Measuring Resistance to Breakage

PRESSURE TOLERANCE is a measurement of the maximum pressure the material can withstand.
Reference: Science Volume 290, pp. 783-785, Oct. 27, 2000.

IN SUMMARY

On the American Museum of Natural History's website, "The Nature of Diamonds", they describe a jewel's most valued and prized attributes as Refractive Index, Luster and Dispersion. As we have illustrated here, moissanite ranks superior in all three categories.

	BRILLIANCE		FIRE
	Refractive Index	Luster	Dispersion
MOISSANITE	**2.65**	**20.4%**	**0.104**
Diamond	2.42	17.2%	0.044

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