

OPTICAL PROPERTIES OF GEMS

Properties related to the behavior of light on, or in, a gemstone. Some of these can be seen, and even quantified, with the naked eye alone.

OPTICAL PROPERTIES OF GEMS

Other characteristics are revealed, or measured, only through the use of special instruments. Some of these include: refractive index, optical character, birefringence, pleochroism, dispersion, reaction to ultraviolet light and selective absorption. When these properties of gems are analyzed and measured, one is engaging in *laboratory gemology*.

1. Luster

The luster of a gemstone is comprised of the *quantity and quality* of the light reflected from its surface. There is an inherent, potential luster possible for each species and variety of gemstone. The actual luster, on any individual piece, however; may be less than this, due to the skill level of the lapidary or faceter, the presence of inclusions, or various chemical or physical changes, such as oxidation or abrasion, that can affect the surface.

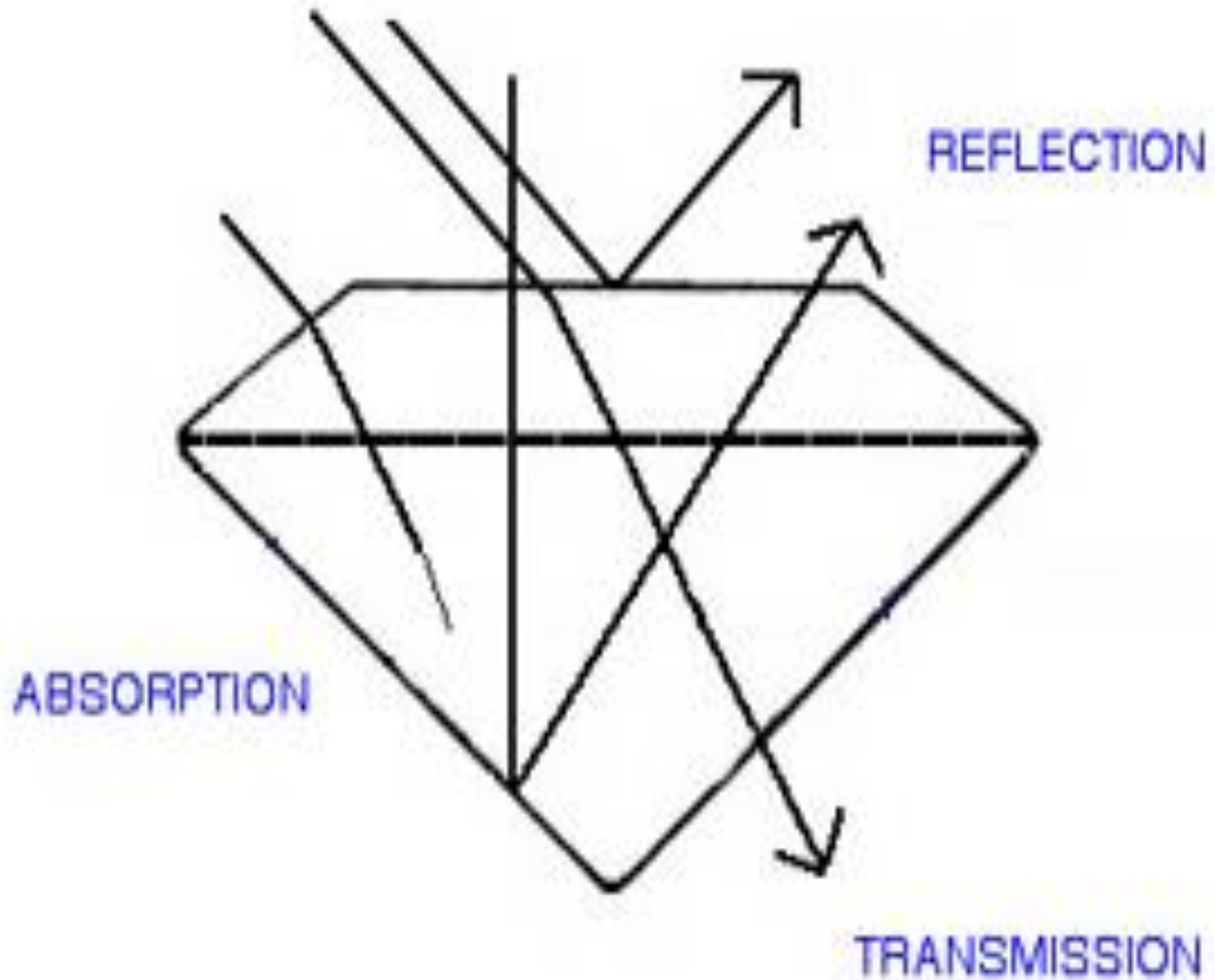
Transparency

Technically known as "diaphaneity", is the degree of transparency of a gemstone.

Transparency (or lack of it) is dependent on how much light gets through the gem, and is affected not only by the chemical and crystalline nature of the gem, but also by its thickness and, as in the case of luster, by inclusions, and its surface condition.

Transparency

When light hits the surface of a gem, there are only three fates for it (with respect to transparency). Various portions of the total amount of light will be reflected, absorbed or transmitted. The proportion in each category will determine the transparency of that gem.



FATE OF LIGHT

Reflection: Light is reflected when it hits an exterior or interior surface of the gem and is bounced back off, or out of, the gem, in the direction of the observer.

Absorption: When light enters a gem and does not exit, we say it has been absorbed. Light is a form of energy, and energy does not just disappear, instead the visible light has been converted to a non-visible form of energy, in most cases, heat.

FATE OF LIGHT

Transmission: Light that travels through the gem and exits in a direction other than that of the observer, is said to have been transmitted.

Transparency

The issue of transparency (with the factors of reflection, absorption and transmission) is intimately linked with the color characteristics of a gem.

For the time being, however; we can be satisfied with the following descriptions:

Opaque: No light is transmitted.

Translucent: Some light is transmitted.

Transparent: A high proportion of the light is transmitted.

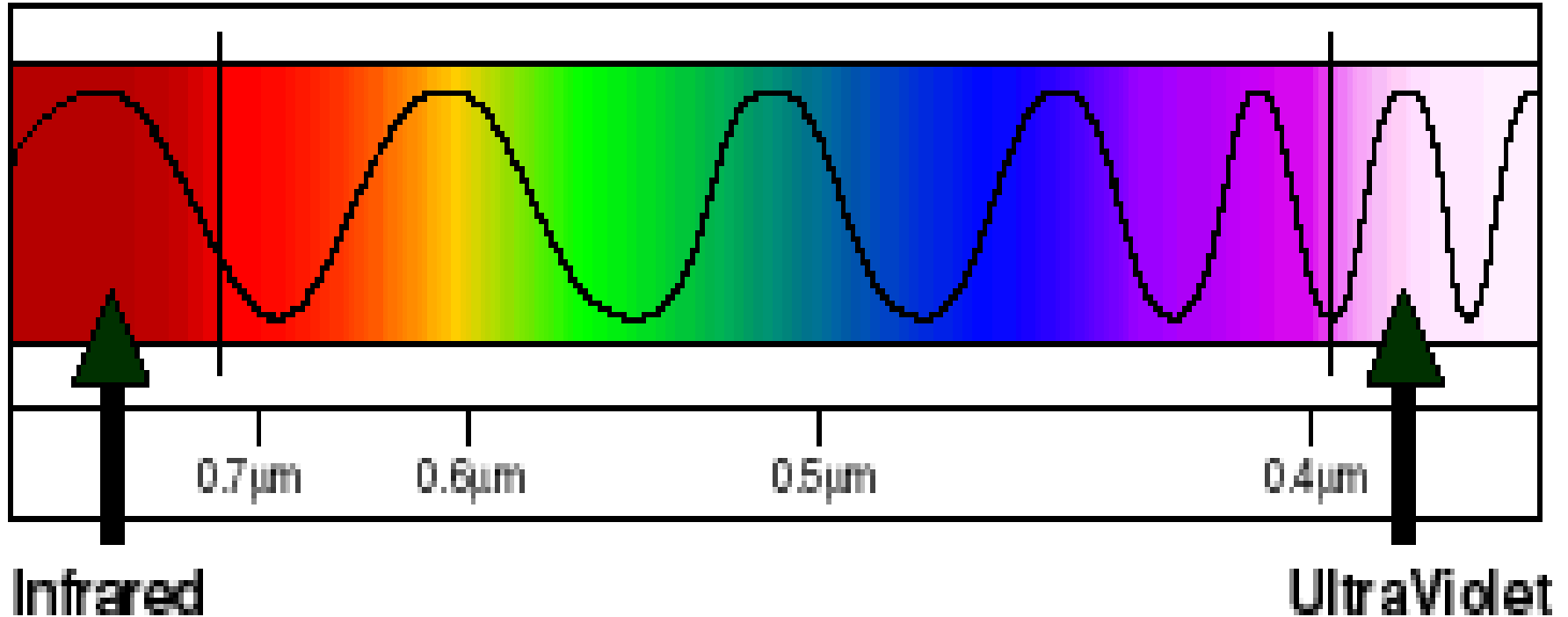
Transparency

Within any particular species of gem, it is often the most transparent pieces which are the most valuable.

Color

The color of a gem is determined by selective absorption of some of the wavelengths of light. We know that what appears to us as white (or colorless) light is actually made up of light of various colors. Issac Newton was the first to demonstrate this back in the 17th century.

Visible Light Region of the Electromagnetic Spectrum



The color of light is a function of its wavelength

Visible Light Spectrum (nm)

infrared, microwaves and radiowaves

- **700 - 630 = red**
- **630 - 590 = orange**
- **590 - 550 = yellow**
- **550 - 490 = green**
- **490 - 440 = blue**
- **440 - 400 = violet**

ultraviolet, xrays and gamma rays

light of shorter wavelength is more energetic than light of longer wavelength.

Selective Absorption

The color of most objects, gems included, is a result of a process called "selective absorption".

With opaque objects it is the color of *reflected* light that we see, with transparent and translucent ones, the color we see consists of a mix of both their reflected and transmitted wavelengths.

Transparency and Color

***Transparency* will depend on the relative proportion of light reflected, transmitted and absorbed by a gem. The *color* of the gem will depend on what is reflected or transmitted after selective absorption has removed some portion of the spectrum.**

- If none of the wavelengths are absorbed: the gem will be colorless if it is transparent, or white if opaque.
- If equal amounts of each wavelength are absorbed: the gem will be grey.
- If all wavelengths are absorbed equally and completely: the gem will be black.
- In colored gems: we will see a mix of wavelengths which were not absorbed and which (depending on reflectance vs transmittance) will give us a colored transparent, translucent or opaque gem.

Chromophores

The atoms (or ions) which create color in a gem are called "*chromophores*". Some of the most common chromophores in gemstones are: atoms of titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, nitrogen, and boron and their various ions.

Idiochromatic and Allochromatic Gems

With regard to the source of their color, gems fall into two categories: *idiochromatic* and *allochromatic*.

Idiochromatic Gems

Idiochromatic gems derive their color simply from the chemistry of their basic formula. Due to this fact, such gems will always occur in various shades of the same basic color.

Idiochromatic Gems



Cuprite (Cu^{+1})



Rhodocrosite (Mn)



Malachite (Cu^{+2})



Peridot (Fe^{+2})

Cuprite is red, malachite is green, and both contain copper! What gives the color?

Each gem's color is determined by an interplay between its chemical makeup (including the ionic state of its chromophores) and its structure.

Allochromatic

The more common group are the allochromatic gems. The chemistry of their basic formula does *not* cause any selective absorption so in the pure state, they are white or colorless. In gems of this sort it is tiny, trace amounts of impurities that act as the chromophores. Such gems occur in colorless forms as well as in a variety of other colors depending on the nature and amount of the "contaminants" in them.

Allochromatic Gems

Some examples of allochromatic gems are: beryl, corundum, quartz, grossular garnet, tourmaline, topaz, spinel and nephrite jade. In some cases the "pure" material is the most common and therefore the lowest in value (corundum, quartz, beryl and topaz are in this category); but in others, the pure form is so rare as to be a high value collector's item. This is especially true in the case of grossular garnet, tourmaline and nephrite jade. Colorless spinel is so rare that it literally has not been found in Nature; we know it can exist, though, because colorless synthetic spinel is made in labs.

A good example of an allochromatic gem species is corundum. Pure Al_2O_3 is colorless, as in white sapphire, but if we add just a tiny bit of iron to the mix then we get yellow or orange fancy sapphire, pair the iron with a bit of titanium, and the gem is the familiar blue, and if chromium is the chromophore, then the corundum is red and called ruby.

To further pursue this point: some emeralds are green due to chromium content, while some get their green color from vanadium. So, iron (as in peridot), copper, chromium or vanadium can each be responsible for "greenness" in a gem. But on the other hand, chromium in corundum makes red rubies, and iron in chalcedony, makes orangey carnelian, but in sapphires gives us yellow. Furthermore, green zircons and green diamonds get their color not from chromophores, but from crystal defects.

Allochromatic Gems (in their pure state)



"white" sapphire



colorless quartz (rock crystal)



Colorless beryl (Goshenite)



colorless grossular garnet (leucogarnet)]

Allochromatic Gems (in their impure state)



Beryl: emerald (chromium or vanadium)



Corundum: sapphire (titanium and iron)



Quartz: carnelian (iron)



Garnet: Spessartite (manganese)

Other Sources of Color

Some gems get their color (or apparent color) from visible to microscopic inclusions of other minerals within them.

One of the most beautiful of all the chalcedonies, often called "gem silica" but more properly termed "chrysocolla chalcedony" has a vivid blue-green color. The minute quartz crystals are actually colorless, but in amongst them are tiny crystals of the blue green (very soft) mineral, chrysocolla.

Patterns in color

Banding/zoning

One of the most common features of some of the aggregate gems is the presence of patterning. Since these gems are formed from very tiny single crystals, we can easily envision conditions where differently colored pools or batches of tiny crystals mix and intermesh creating bands, dots or other patterns. Agates and jaspers are the most commonly seen gems with strong patterns.

Patterns in color

It frequently happens that single crystal gems subjected to changing conditions during their growth can also show bands or zones of different colors or shades of the same color. When these are dramatic and attractive, they are desirable, but far more commonly, gems of this type have nondescript, patchy, or zoned coloration, and are considered inferior to more evenly colored pieces.

Aggregates With Patterns



Zebra agate



Picture jasper



Mookaite jasper



Carnelian



lavendar agate,



Dalmation jasper



Rain forest jasper

Single Crystal Gems with Attractive Color Zoning



multi-color tourmaline,



Ametrine



watermelon tourmaline

Color Descriptions in Colored Gemstones

There are three aspects to a formal colored stone color description:

- *Hue***
- *Tone, and***
- *Saturation.***

Using these three descriptors, very detailed and nuanced color discriminations can be made, and communicated, between gemologists, jewelers and gem buyers

Refraction and Birefringence

When a ray of light passes from air into a denser medium, such as a gemstone, part is reflected from the surface and part enters the gem material. Light entering the gem is slowed and bent, with the amount of bending dependent upon the angle with which it hit the surface and velocity of light in the two media. Higher angles and greater velocity difference between air and the gem will result in greater refraction. This refraction or bending of light can be measured and this number is termed the refractive index. ***This index is a constant in different types of gems and is used in identification..***

Refraction and Birefringence

The refractive index is defined as a ratio of the speed of light in air to the speed of light in the stone. That is, if the speed of light in air is 300,000 km/sec and speed of light in diamond, 125,000 km/sec, then dividing 300,000 by 125,000 is 2.4 or the refractive index of diamond is 2.4. Light in air is 2.4 times faster than the speed of light in diamond

Refraction and Birefringence

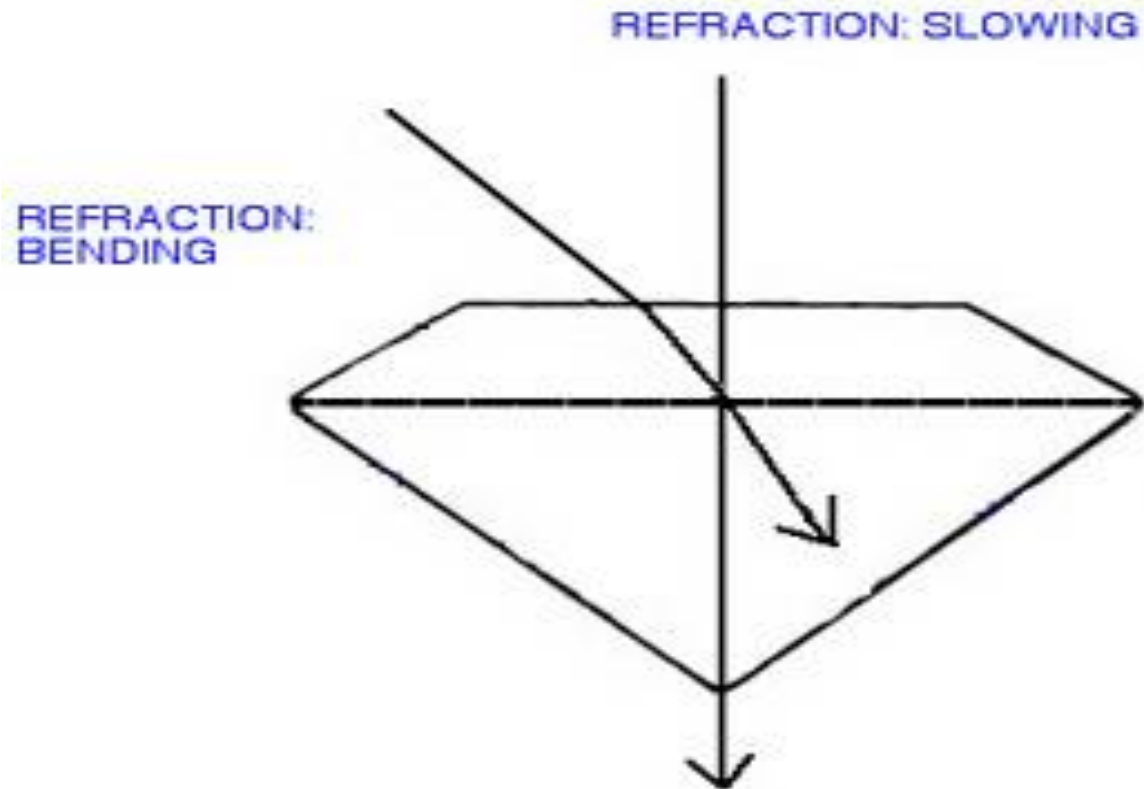
Higher angles and greater velocity difference between air and the gem will result in greater refraction.

birefringence

- When light hitting a gemstone splits into two rays traveling through the stone at different speeds and in different directions, ***the reaction is called birefringence or double refraction***. This is seen uncommonly and in a variety of calcite called Iceland Spar as well as zircon, rutile, and sphene.

Behavior of Light - Refraction

The ratio of the speed of light in air, to the speed of light in a gem, is called the gem's *refractive index* or RI. It differs, sometimes dramatically, between gem species, and is one of the most useful gem identification criteria. In natural gems it ranges from about 1.2 to 2.6. and can, in most cases, be measured by an instrument called a refractometer.



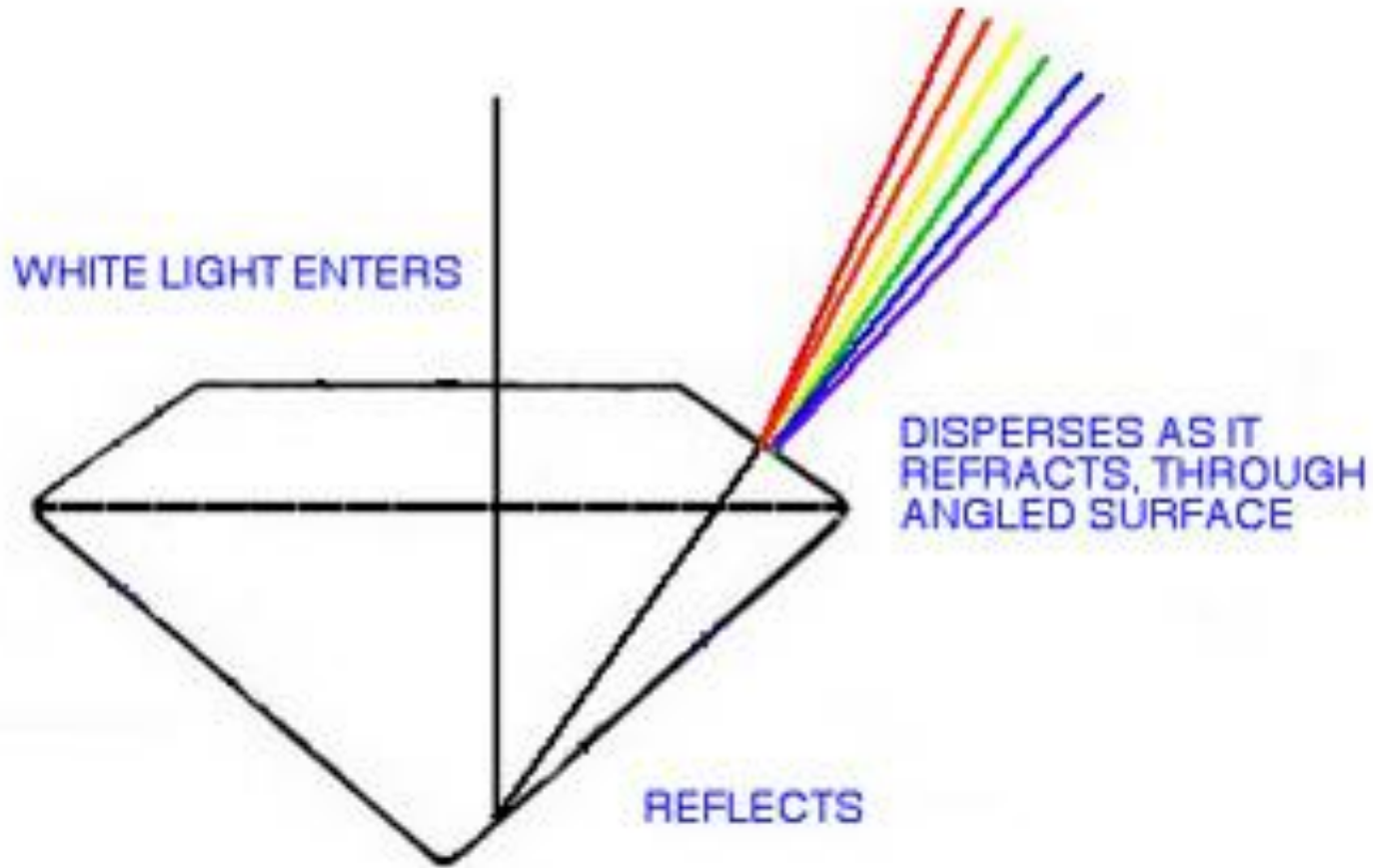
Refraction includes the slowing and the (usually) consequent bending of light as it enters a gem

Behavior of Light - Dispersion

- Light is slowed and refracted or bent upon entering a denser medium. A characteristic refraction or bending is associated with each different wavelength of light and this separation of white light into component colors is called dispersion. In other words, dispersion is the separation of light into its separate spectral colors.

White light is in fact a combination of red, blue, and green wavelengths of light. Recognition of this was credited to Sir Isaac Newton in 1666 when he observed a dispersed spectrum through a glass prism.

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Dispersion of white light as it leaves a gem

Behavior of Light - Dispersion

The cause of this phenomenon is the differential refraction (bending) of the various wavelengths of light as they travel through a gem. Red (long wavelength) bends less, violet (shorter wavelength) bends more. *This causes the colors to become separated.* Although dispersion, theoretically, occurs in all gems, the degree depends on the RI of the gem material, and only those gems with sufficiently high RIs, have dispersion which is pronounced enough to be actually visible.

Isotropic or Anisotropic

All transparent substances can be classified as either isotropic or anisotropic. Isotropic includes amorphous mineraloids and minerals in the isometric crystal system. Light entering isotropic gems moves in all directions with equal velocity, *creating only one index of refraction*. That is, a single refractive index results when light is considered moving in a wave motion with vibrations in all directions at right angles to the direction of propagation.

Isotropic or Anisotropic

- In contrast, when light enters anisotropic gem materials the light is split into two polarizing rays, vibrating in mutually perpendicular planes. *Thus in a given orientation, two refractive indices, one associated with each polarized ray, is detected and the specimen is termed doubly refractive.* Double refraction occurs in specimens from five of the six crystal systems, including tetragonal, orthorhombic, hexagonal, monoclinic, and triclinic. These anisotropic minerals possess the power to polarize light or confine the light wave to vibrate in only one direction, blocking all other waves and splitting light into two rays that travel at different speeds at right angles to one another.

Light Refraction

There are two groups of gems with regard to light refraction, each is said to have a different "optic character": SR or DR.

SR = Singly refractive

DR = Doubly refractive

Singly Refractive Gems

In such gems, each beam of light entering the gem stays as a single beam which has a single refractive index (travels at the same speed), regardless of the direction from which it enters. In this group we find all *amorphous* gem materials, such as opal, glass, amber, etc. as well as all crystalline gems belonging to the *cubic* (isometric) system. The most commonly encountered gems of the cubic system are: diamond, garnet and spinel.

Doubly Refractive Gems

In such gems, single beams of light upon entering the gem, are split into two separate beams, which then travel perpendicularly to each other. Each of the resultant beams takes a different path through the crystal and, consequently, has its own speed. Such gems, then, have two RIs, one for each half of the original beam. In this group are all the gems of the non-cubic crystal systems

Optic Axis

Each DR gem, based on details of its crystal structure, has either one or two directions in which the light entering it behaves as if the gem is SR. These directions are known as "optic axes". Those species with a single optic axis are known as "uniaxial" and those with two are, logically, called "biaxial

Birefringence

Birefringence, a property of DR gems only, is measured as the difference between the high and low RIs of the split beams. It ranges from a low of .003 to a high of .287.

Birefringence

When a transparent gem with high BR is faceted, and the view through the table direction of that gem is not in an optic axis direction, the slightly "out of sync" light beams can create an appearance of interior "fuzziness" or in larger stones, can show up as two distinct images of each facet edge. This is known as "facet doubling" and it can be a pain in the neck to a faceter who, in trying to prevent it, must find an optic axis direction for the table of the stone. But it can also be a valuable identifying characteristic that can often be seen with the naked eye or a simple 10x loupe.

Behavior of Light - Pleochroism

DR gems split light into two perpendicular rays, each taking different paths through the crystal: one ramification of this is birefringence, another is pleochroism. Pleochroism is the property of DR gems which results in their showing different colors, or different shades of the same color, when viewed in different crystal axis directions.

Dichroic and Trichroic Gems

Dichroic gems (like corundum) show two different colors while trichroic gems (like iolite) show three.

Pleochroism will *not* be observed in SR gems, nor in DR gems when looking through an *optic axis* direction

In most cases, pleochroism can best be observed using an instrument called a dichroscope

Testing Refractive Index

The refractive index (RI) of a gem is one of the most important characteristics determining its appearance, and is also a very useful piece of data for purposes of determining the species of an unidentified gem.