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Gemstones and Light
The Science

This 5.42 carat Sri Lankan sapphire can look dramatically different when viewed in different lighting. On the left, the stone is photographed under a 6500K bulb. On the right, it is photographed with an incandescent light source. Photos by Bear Williams.

Gemstones can look dramatically different when viewed in different lighting conditions. The perceived color can make a huge difference when grading and pricing these gems. Understanding what light sources to use first requires a knowledge of the science of lighting.

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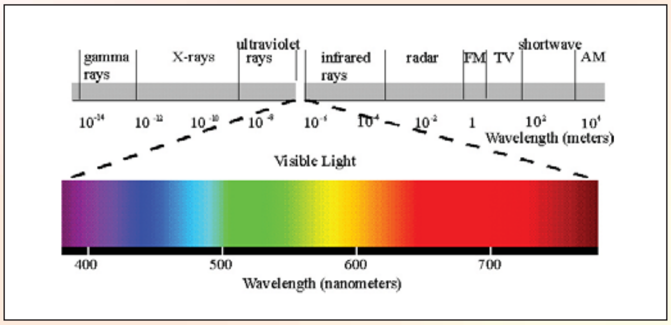
In our article, "Gemstones and Light – The Basics" (published in the January/February *GMN),* it was stated that the most important attribute of a colored gemstone is its color. Without color, a colored gemstone has no value. The color of a gemstone comes from light and the interaction of this light with trace minerals in the gemstone crystal. If a light source does not emit all the colors of the rainbow, then some colors will not be visible in the gemstone.

An overview was also presented about light, terminology, and illuminants. In this installment, a more detailed and useable explanation is provided. After you read and study this issue and the next installment, "The Lamps," you will have the knowledge to discuss intelligently with your partners, store designers and electricians about what your actual lighting needs are and whether their suggestions will properly fulfill your needs. When your lighting salesperson comes into your store, you will be ready!

The Science is divided into two sections:

1. What is light and how does light create color?
2. How can light quality and quantity be measured?



What is Light and How Does it Create Color in Gemstones and Jewelry?

Visible light is electromagnetic energy such as x-rays, radio waves, microwaves and cosmic rays. Visible light or the visible spectrum is a small section of the electromagnetic spectrum that the human eye responds to. This portion of the electromagnetic spectrum, from a violet 380nm (nanometers) to a red 770nm, is visible because the human eye developed "rods" and "cones" that are sensitive to these particular wavelengths. Different wavelengths are interpreted as different colors by our cones. With rods we see shades of gray or black and white, or, if the light is not strong enough to activate the cones, then the rods interpret color as shades of gray.

White light occurs when an even combination of all the colors or visible wavelengths are included in the light source and are scattered randomly. Black is perceived when all the wavelengths have been absorbed, and no light is being reflected from the object being viewed.

Graphic by Schorr.

When the wavelength that we interpret as red strikes the cones and rods in the back of our eye, we see red. We cannot see ultraviolet or infrared light. What we see is the secondary effects of ultraviolet light when it reacts with various minerals and causes them to fluoresce and emit visible light. We feel infrared as heat when the infrared wavelengths hit our skin.

There are two types of illuminants:
Natural daylight and *artificial light.*

Natural daylight comes from the sun. The strengths of all the wavelengths of the visible spectrum ranging from the violet/ultraviolet to the red/infrared are extremely even and close to each other in intensity. When an object we are viewing is being illuminated by sunlight, all the colors are present. The sun is so powerful that the light can also penetrate deeply into the objects we are viewing and the internal color can be reflected back to us.

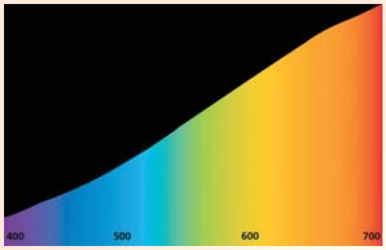
Artificial light is created by various processes that are enhanced by technology. The light in the incandescent bulb is caused by the heating of a wire filament causing it to glow as it resists the flow of electricity. Fluorescent light is a gas-discharge source that uses electricity to excite gases inside a glass tube, producing short-wave ultraviolet light, then phosphors become excited and fluoresce, producing light. High intensity discharge (HID) lamps produce an arc of light between tungsten electrodes inside a small glass tube that is filled with special gas and minerals. Light from an LED (light emitting diode), is caused by the movement of electrons in a semiconductor material. These are a few of the most common ways of creating artificial light.

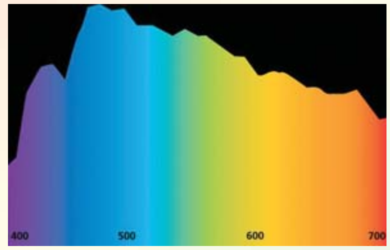
The biggest difference for the gemstone and jewelry trade between natural daylight and artificial light is not how they are produced but their spectral output. Every artificial light source has some color bias. Lamps available to the trade at an economic price do not evenly emit all the colors visible to the human eye. Even commercially available so-called "daylight fluorescents" do not match the output from the sun.

Understanding the spectral output of various light sources is the focal point for understanding how light affects colored gemstones. Without full spectral output we cannot accomplish daily activities like matching pairs, evaluating the worth or enjoying the beauty of our gemstones.

Here is an example we are all familiar with. You wake up in the morning and put on a pair of dark socks you believe are black only to discover, when you go outdoors, that one sock is blue and the other is black. What happened? When you got dressed under the incandescent 70 watt bulb which is very strong in the red but very weak in the blue, you could not see the blue in one of the socks. Outdoors, in the full spectrum sunlight where there is a strong blue emission, you could see your sock's true colors. The same problem happens with gemstones. If you have the wrong light, the colors will not be represented accurately.

What happens when different lights are used to illuminate gemstones? If daylight has all the colors then why is a ruby red and a sapphire blue? They are both corundum, which in the pure state is colorless and the same light source—the sun—is illuminating





From left to right: Incandescent bulb; Incandescent SPD; Daylight SPD; Daylight

the gemstone.

In gemstones, a "base" crystal structure and chemistry exists such as in corundum, beryl or tourmaline. In these gemstones, the base crystal chemistry would produce a clear or colorless crystal, but due to trace minerals that have entered the crystal during its formation such as iron, vanadium, chromium etc., color is created. When you look at a corundum crystal and see red, what occurred is that the trace minerals in the crystal absorbed all of the wavelengths of light except for the red. The red, since it was not absorbed, is reflected back to you and we have a ruby. If a different trace element absorbs all the colors except blue, then we see a blue sapphire.

Photos by Schorr.

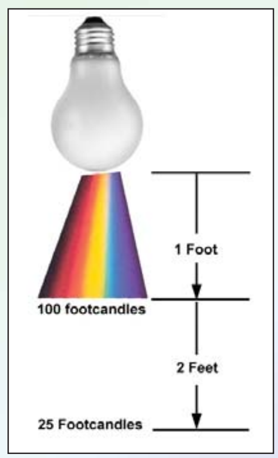
Another example is the beryl aquamarine, originally a greenish blue gemstone. If it is a strong green then we call this stone an emerald, but if we change the "chemistry" by heating the gemstone, we can eliminate the yellow and end up with pure blue. Blue and yellow make green. Two different trace minerals are in the stone. One absorbs all the colors but yellow, the other absorbs all the colors but blue. Combine the blue and green wavelengths and we perceive green. Take out the yellow, and we see only blue.

How can we grade lamps and know what each lamp is good for?

There are several standard methods in the lighting trade to measure the quality and quantity of light being emitted by various light sources. The methods you will most likely encounter are: Lumens, Footcandles, Kelvin, CRI and SPD. We will discuss each of these methods and their pros and cons.

Lumens: Lumens are used to compare the light output of various light sources. Lumens are a unit of measurement of the quantity of light emitted from a light source. This measurement is printed on light bulb packaging in stores and technical data from manufacturers.

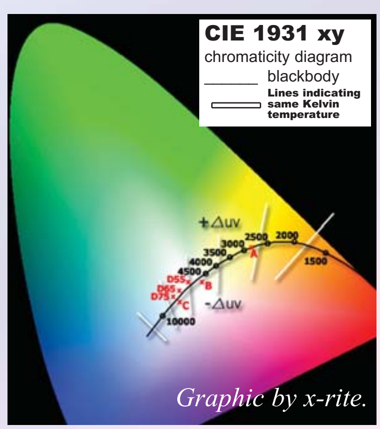
Footcandles (fc): A unit of measurement used to calculate adequate lighting levels. One footcandle equals the quantity of light falling on a surface one foot from an international standard candle. Sunlight has an intensity of approximately 10,000 fc, and on an overcast day around 1,000 fc. The intensity of light near a window can range from 100 to 5,000 fc, depending on the orientation of the window, time of year, and latitude. A typical jewelry store has lighting levels between 10 and 100 footcandles.



Graphic by Schorr.

Inverse Square Law: A mathematical formula used to calculate the decrease of light between the light source and your product. Light intensity diminishes over distance. The brightness declines by the square of the distance, so an object (of the same size) twice as far away, receives only ¼ the light energy.

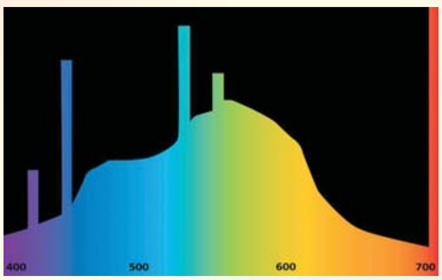
Kelvin (K) Temperature: A means of specifying the hue or color of a light source as a color temperature measured in degrees Kelvin. The Kelvin scale was developed by observing a metal rod being heated. As this rod is heated the color of the metal will transition from black to red, orange, yellow and finally blue-white. A higher temperature, for example 6500K would indicate a whiter/bluer and "cooler" light source while a lower 3500K would indicate a redder or "warmer" lamp.



Graphic by x-rite.

The Kelvin system is only a vague gauge of the color bias of a light and has two major drawbacks. Color needs to be described as a specific point in three dimensional "color space." Kelvin does not specify a specific point, but a huge range of different points in color space. It also does not quantify the relationship between red, blue and green, the primary colors that make up white light. Therefore, two different lamps with the same Kelvin temperature, which means they should be emitting the same colors, will actually be emitting different colors. They will look different to the eye and your gemstones will look different under each light.

The second problem is how Kelvin temperature is determined in fluorescent lighting. Most fluorescent lamps use three phosphors (some up to seven); each phosphor emits its own color. When measuring the color output of a three phosphor lamp there will be 4 valleys (areas in the visible spectrum where very little light is emitted), and three peaks (areas where the light emitted is very intense). Not all colors are emitted equally. The output of these peaks and valleys are added together and then an average is calculated as its Kelvin temperature. It is possible for two lamps to have very different color emissions, very different peaks and valleys, illuminate your product differently and still have the same Kelvin temperature.



Cool white fluorescent with three phosphor spikes and one gas spike. Graphic by x-rite.

Kelvin will give you a general idea if the light you are using is strong in the red, or strong in the blue or closer to white, but it does not tell you the real quality of white light being produced.

CRI: Color Rendering Index is used to describe how well a lamp renders the colors of an object. In determining CRI, a lab illuminates 17 different standard color swatches with the lamp being tested. Each lamp is graded as to how well each color is rendered compared to a standard light. A scale of 1-100 is used with 100 being the best. The highest CRI would come from natural daylight, at noon, on a clear day, with no pollution. A high CRI of 98 would mean that all of the test colors would look natural and you could easily tell the difference between two different but very similar colors. In this environment it would be easy to match gemstones for color. A low CRI of 75 would mean that many colors would not look natural and it will be difficult to tell the difference between two very similar colors.

For example, the incandescent lamp in your bedroom has a very low CRI and that is why you did not notice that one sock was blue and the other black. When you went outdoors, the sun has a very high CRI, and you could easily see the difference between these two very similar colors.

It is important to note that the major drawback for CRI is that not all lamps are measured by the same standards. If you are grading a lamp with a Kelvin temperature of 5000 or more, then the scale being used is based on daylight. However, if the lamp being graded is less than 5000K, let's say 4800K then this lamp will be graded on how it reproduces color against an incandescent standard which is not as good as daylight.

This can be used to mislead. A lighting manufacture may have a filtered daylight halogen of 5000K. This lamp would be tested against a daylight standard and might only get a CRI of 82. By lowering the temperature to 4800K, it will now be tested against a poorer incandescent standard, and get a CRI rating of 92. Yet, a 4800K halogen lamp with a CRI of 92 will not be as good at rendering color for grading as a daylight lamp of 6000K but a CRI of 88.

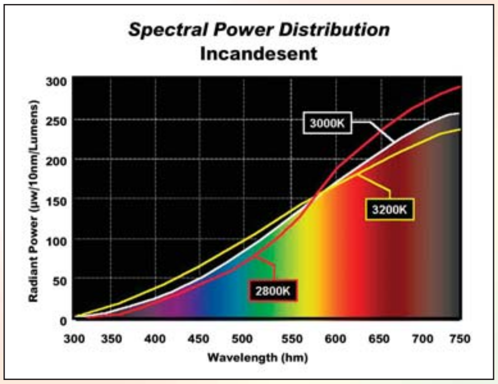
	Color Temp	CRI
Cool White Fluorescent	3400	65
Xenon	5920	94
Mercury Vapor	5900	17
100-watt Incandescent	2856	100
Viewing Booth	5000	94
Typical Summer Sky	6500	100

Notice different Color Temp (K) but same CRI.
(chart by x-rite)

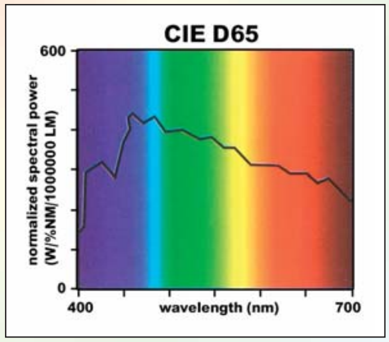
SPD: The Spectral Power Distribution Curve is the most accurate method of determining the quality and quantity of light from a lamp. A light source is measured using a sensitive instrument called a spectrophotometer. This instrument measures two qualities of a light source: the colors that are emitted and the relative intensity of each of these colors. The sensitivity of the instrument is calibrated to determine how fine the increments of measurement in nanometers will be. A lab will then measure the color output of a light source across the full visible spectrum and display a comparative graphic representation of the intensity of every color.

With SPD curves you can compare the actual color output of different lamps by the colors emitted and the intensity of each color and understand the difference in the light produced. For example, look at the SPD curves of incandescent daylight and cool white fluorescent lamps.

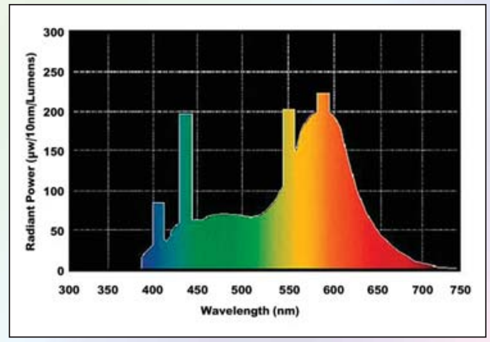
If every lamp had SPD data provided and if the



Incandescent SPD curves. Graphic by GE.



Noon daylight SPD curve. Graphic by x-rite.



Cool white fluorescent SPD curve. Graphic by GE.

trade had standards for calibrating the spectrophotometer that measures and produces the SPD data, then this system would be the best as it actually represents the true mixtures of colors emitted by a lamp.

This concludes the basic science and terminology. The next article in this series will discuss lamps and the information needed to make an informed decision on which to use. ◆

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