Module B. Colour from the Cosmos

Lesson 12: Colour, Light and Optics 1

What is Colour?

Colour is what our brain interprets from the incidence of light (electromagnetic radiation within the visible spectrum) on our eye. In other words, the colour of an object is our eye's interpretation of light in the visible range that has interacted with the object we are looking at.

The electromagnetic spectrum is continuous and represents radiation energy ranging from high intensity gamma rays (short wavelength, high frequency) to low intensity radio waves (long wavelength, low frequency). In the middle of this is the visible region which ranges from about 350 to 750 nanometers (nm). This range comprises the visible rainbow with which we are all familiar with: violet at the short end (~400 nm) and red at the long end (~700 nm).

Light in the visible spectrum (collectively called "white light") is composed of colours (or wavelengths) in the visible portion of the electromagnetic spectrum. We can use the acronym "ROY G. BIV" to remember the sequence of colours of the visible portion of the spectrum: Red - Orange - Yellow - Green - Blue - Indigo - Violet. Just outside of the visible region on the shorter wavelength end is the UV (ultraviolet) range and at longer wavelengths is the NIR range (near infrared). White does not appear as a colour in the spectrum because white light is an even mixture of light of wavelengths across the visible range.

The electromagnetic spectrum with the visible portion expanded. Illustration by G. Lascu.

The absorption qualities of a material will usually define how it looks to our eye after light has interacted with it. For example, if 'white' light is shined on a surface that appears red to our eyes, then that means electromagnetic radiation in the 'red region' is most effectively reflected. The figure below illustrates some of these ideas.

Examples of light reflecting off different surfaces. Image from Connexions Website.

The colour of a gemstone in balanced white light is largely the result of absorption and transmission of certain wavelengths of electromagnetic radiation by the gemstone. The colour that we see (wavelengths that are transmitted through the gem and/or reflected from its surface) are complimentary to the colours (wavelengths) that are absorbed in **subtractive**colour theory. In a sense, gemstones are like "colour filters".

An example is if blue-violet light is absorbed, the resulting wavelengths that are transmitted will produce yellow colour, as interpreted by our eyes. If all wavelengths other than blue and red are absorbed (ie, blue and red transmitted, green absorbed), we would see purple/magenta. It is important to remember that when we ‘absorb’ a particular colour we are absorbing swaths of the electromagnetic spectrum in bell-curved shapes, not single-line wavelengths.

Electromagnetic spectrum labeled with representative colours

The next figure shows both additive and subtractive colour theory plots/figures each with three primary colours: Red-Green-Blue in additive and Cyan-Yellow-Magenta in subtractive. We’ll focus on the Subtractive Colour Theory side. If we subtract the yellow portion of the electromagnetic spectrum we look across the diagram and will accordingly see a predominance of blue light. Similarly, if we subtract yellow and cyan (ie, green) we see a predominance of magenta (blue and red) light. Conversely, if we subtract magenta (blue and red) we see green.

It’s also kind of like saying “yellow ink is really good at absorbing blue” or “yellow sapphire is really good at absorbing blue” and really good at letting the wavelength region centered on yellow reflect/transmit. Or, “magenta+yellow ink is really good at absorbing green+blue” or “ruby is really good absorbing green+blue” and really good at letting the wavelength region around red reflect/transmit.

Additive and Subtractive Colour Theory Diagrams

These plots are another way of depicting the same concept of subtractive colour theory.

Subtractive Colour Theory Schematices with incident light coming from the left, interacting with the coloured filter, and 'exiting' to the right. The spectra on the right are examples of what the transmittance profile would look like.

Another (simpler) way of looking at this is via a colour wheel. The one depicted below is based on the Munsell Colour Chart and theory. Note that some of the names of colours are different than the above figures, but in effect if you look across the wheel from the colour you are absorbing that will be roughly your end product (ie, if you subtract/absorb blue you’ll get yellow).

The Munsell Hue Circle

In both cases, if include all colour in subtractive colour theory, we will end up with Black, or the absence of colour. Conversely, in additive colour theory if we include all colours we will end up with “White Light”, or balanced light.

The following figure is a classic "colour wheel" used in complementary colour theory. The core includes three primary colours (yellow, blue, red), which is surrounded by combinations to generate secondary and tertiary colours. In complementary colour theory we often use these wheels to predict what colour will be produced when mixing pigments. Pigments are based on subtractive colour theory whereby their components will absorb certain portions of the electromagnetic spectrum and some classic opaque gemstones, such as lapis lazuli (also known as ultramarine), have been used as pigments through antiquity.

Colour wheel with Primary, Secondary and Tertiary additive colours

OK, so that’s a bit much to take in, but, here are a few absorbance graphs that will hopefully solidify some colour theory as applied to ‘imperfect’ gemstones and their absorbance spectra from [CIGEM](http://www.cigem.ca/). Where the line is high, there is greater absorbance. Where the the line low, little light of that wavelength is absorbed.

ABSORBANCE GRAPH: Strong absorbance in the green-yellow region leads to a purple hue in this synthetic sapphire.

ABSORBANCE GRAPH: Strong absorption in the blue and yellow-red regions lead to the green colouration

From these two graphs it can be seen that subtractive colour theory can help understand the generation and perception of colour in gemstones. However, it also shows that looking at regions in the electromagnetic spectrum where light is transmitted (ie, not absorbed) can be equally or even more intuitive for investigating gemstones. In these two cases, it is pretty easily seen that transmittance of the blue and red will generate the purple colouration for the sapphire and that transmittance of the green (and a tad bit of red) will generate the warm green in the emerald. You also may have noticed some irregularities in these absorbance plots - for the scientist and gemologist these irregularities (such as the bumps at ~620 nm and ~680 nm in the emerald sample) can help identify the origin and identity of a particular gemstone!