Module B. Colour from the Cosmos

Lesson 12: Colour, Light and Optics 1

How is Colour 'Generated' in Gemstones?

Traditional ways of explaining colour often use the terms idiochromatic (or "self-coloured" from an essential constituent), allochromatic (or "other-coloured" from an impurity), and pseudochromatic (or "false-coloured" from physical optics). This straight-forward simplification of more complex interactions between light and the coloured medium works well for describing the main colours observed in gem materials. An element responsible for colouration of a mineral is called a chromophore, and is typically one of the transition elements (e.g., Fe, Ti, Cu, Co, Mn...).

Idiochromatic minerals have inherent colours that are derived from essential elemental constituents of their crystal structure. The gemstone "peridot" (Fe2SiO4) is an example of a transparent idiochromatic gem mineral (forsterite) where Fe is the chromophore. Turquoise (CuAl6(PO4)4(OH)8·4H2O) is an example of an opaque idiochromatic gem mineral where Cu is the chromophore.

Peridot is a common idiochromatic transparent gemstone. Photo courtesy of Rob Lavinsky.

Turquoise is a common idiochromatic opaque gemstone. Photo courtesy of Rob Lavinsky.

Lazurite is a common idiochromatic opaque gemstone. Photo courtesy of the [Gemological Institute of America](http://www.gia.edu/).

Allochromatic minerals do not have inherent colours, or at least not vivid colours, and require "impurities" to generate their colour. Emerald (Be3Al2Si6O18) is an example of an allochromatic gem mineral where Cr is the impurity that acts as the chromophore (recall from Lesson 7 why Cr is not listed in the mineral's chemical formula). The tricky thing with allochromatic minerals, however, is that you can't just "shove" chromophore elements into a crystal, as we learned in the lesson on minerals. There needs to be an atomic site where a chromophore can substitute for a pre-existing element that is similar in ionic size and electric charge (not too big, not too small, but just right - the "Goldilocks Principle"). In the case of emerald, the base formula is Be3Al2Si6O18 showing that it contains Be (normally +2 charge), Al (normally +3 charge), Si (normally +4 charge), and O (normally -2 charge). Chromium, normally with a +3 charge, substitutes for the only +3 cation in the base formula, Al.

The Gachala Emerald from Colombia is an example of the mineral beryl with Cr impurities. Photo courtesy of the Smithsonian Institute's [National Museum of Natural History](http://www.mnh.si.edu/).

Pseudochromatic minerals show colours and optical effects through dispersion and scattering of light. Colour and optical effects generated from scattering includes asterism, chatoyancy, iridescence, opalescence, andlabradorescence.

Colour generated from dispersion, as we learned earlier, is the result of light passing between media with varying refractive indices. Gemstones with higher values of dispersion will show greater spreading, or dispersion, of colour. Diamond is a well-known example of colour, or "fire", generated through dispersion. The minerals calcite, moissanite, sphalerite and zircon are all great examples as well.

Very large calcite gem (~1800 carats) showing fantastic dispersion. Photo courtesy of the Smithsonian Institute's [National Museum of Natural History](http://www.mnh.si.edu/).

Asterism describes a prominent star shape that normally occurs as a six pointed star (although 4, 8 and 12 are possible) and is due to crystallographically oriented mineral inclusions in the host mineral. Gemstones with this characteristic are best cut as "cabochons" (shaped and polished as opposed to faceted) to show off this optical effect and the most famous examples are in sapphires and rubies.

Six-rayed star in ruby. Photo courtesy of the[Gemological Institute of America](http://www.gia.edu/).

Chatoyancy is the result of many fine fibre inclusions oriented in a parallel manner producing the well known "cat's eye" effect. This is similar to asterism, thus stones with chatoyancy are also usually cut as cabochons.

This 58-carat chrysoberyl specimen originated from Sri Lanka and exhibits fantastic chatoyancy. It is cut in a cabochon style. Photo courtesy of the Smithsonian Institute's[National Museum of Natural History](http://www.mnh.si.edu/).

Play of colour from internal scattering of light off of fine particles in a mineral is known as iridescence oropalescence, but is sometimes described as "schiller". It is commonly seen in the gems sunstone and opal.

Sunstone showing strong iridescence from light scattering off abundant hematite inclusions. Photo courtesy of the Smithsonian Institute's [National Museum of Natural History](http://www.mnh.si.edu/).

Labradorescence is similar to iridescence and is most commonly seen in labradorite, a species of the mineral feldspar. It is caused by diffraction of light interacting with very thin intergrown layers of calcium feldspar and sodium feldspar. The width of the thin layers defines the colour generated during diffraction.

Labradorite carving showing excellent range of colours from labradorescence, from deep blue to light orangey pink.

**Optional Readings**

Formally, this simple division into three groups (idiochromatic, allochromatic, andpseudochromatic) is not 100% accurate, but for for now this is as far as we will take it. If you are willing to dive into the chemistry and physics of colour (which I highly recommend!) this article by K. Nassau, "[The Origin of Color in Minerals](https://connect.ubc.ca/bbcswebdav/pid-2559954-dt-content-rid-10494280_1/courses/SIS.UBC.EOSC.118.99C.2014WC.44220/Course_Files/moduleB/lesson12/download/Nassau-1978.pdf)", published in the journal American Mineralogist is a fantastic start. It describes four formalisms of colour generation within which are 12 main causes of colour in minerals.

In addtion to the article by Nassau, these two by [Fritsch and Rossman (1987)](https://connect.ubc.ca/bbcswebdav/pid-2559954-dt-content-rid-10494280_1/courses/SIS.UBC.EOSC.118.99C.2014WC.44220/Course_Files/moduleB/lesson12/download/FritschRossman1987.pdf)[Fritsch and Rossman (1988)](https://connect.ubc.ca/bbcswebdav/pid-2559954-dt-content-rid-10494280_1/courses/SIS.UBC.EOSC.118.99C.2014WC.44220/Course_Files/moduleB/lesson12/download/FritschandRossman1988_Colour2.pdf) have a more gemmological slant.