Module B. Colour from the Cosmos

Lesson 12: Colour, Light and Optics 1

Reflection and Refraction

When light passing through one medium strikes another medium, part of that light is reflected (like a mirror) and the other part is refracted (like what you see through a fish tank).

Reflection obeys a simple geometrical law where the **angle of incidence is equal to the angle of reflection**(<*i* = <*r*).

Refraction is different from reflection. When light passes from one medium into another, its speed changes causing light to "bend" or change in direction. The degree to which light is slowed and bent relate to the differences in the refractive indices between the two media as well as the angle at which the light path makes with the medium.

The refractive index, *n* of a medium (such as a gemstone) is a measure of how much it will refract light of a specific wavelength passing from a vacuum into the medium in question. In other words, the refractive index measures how much the incident light is slowed when it enters a new medium compared to when it travels in a vacuum (where the refractive index is, by definition, equal to 1). Note that the refractive index of a medium is also dependant on wavelength - this is important for dispersion (L12.8).

Refractive indices of minerals and gemstones are used as diagnostic features in identification. Diamond's refractive index of 2.419 quickly sets it apart from regular glass with a refractive index of 1.5.

The refraction of light between two media: air and water. The refractive index of air is 1.0003 and the refractive index of water is 1.333. For reference, glass has a refractive index of ~1.46.

When cracks or fissures are present in a rough gemstone, gem dealers will often attempt to fill them with an epoxy to strengthen the stone. This allows the material to be faceted into a larger gemstone. If the refractive index of the epoxy is not matched with the host mineral's refractive index, the epoxy's different refractive index will cause the light traveling within the stone to refract (or bend). Because gemstones are normally homogenous, the refraction of light *inside* an 'epoxied' stone will be atypical and distracting, taking away from its value.

If the epoxy's refractive index matches that of its host, no refraction will occur and the filler material will be optically undetectable. Consequently, a great deal of effort is invested in order to ensure that the refractive index of an epoxy matches that of the mineral that it is strengthening.

Total internal reflection is an important property to consider for faceted gemstones. When light travels from a medium with high refractive index (gemstone) to one with low refractive index (air), total internal reflection can occur if the angle of incidence is greater than the critical angle. The value of the critical angle is dependent on the refractive index of the gemstone and surrounding material. The critical angle defines the angle of incidence above which total internal reflection occurs.

This phenomenon is particularly significant in diamonds. Diamonds, which have a high refractive index of 2.419, are faceted with specific angles and proportions to maximize the amount of light that undergoes total internal reflection. Maximum brilliance of a stone is achieved when much of the light that enters the crown facets reflects from the lower pavilion facets and then re-emerges from the crown to our eyes!

Incident light can refract and reflect (red rays) if the angle of incidence is less than the critical angle, or undergo total internal reflection (blue ray) if the angle of incidence is greater than the critical angle. Similarly, the lower diagram shows light undergoing reflection (I1), refraction at the critical angle (I2) and refraction (I3) out of the gemstone. If light is incident along "Normal" it would simply pass through.

Faceted quartz and diamond are good minerals for investigating this phenomenon (see figure below) because they are common 'colourless' gem materials with significantly different optical characteristics. The probability that light rays will undergo total internal reflection in faceted quartz and diamond of roughly equivalent dimensions and angles, varies because the refractive index of these two minerals is different and as a result their critical angles are different.  So the ability of these two minerals to accept and return light back up through their crowns’ is also different.  Diamond has a lower critical angle than quartz.  As a result for diamond, there is a greater range of incident angles of light that can be redirected back through the gemstone’s crown rather than go through the pavilion. The end result for the human eye is diamond’s superior brilliance.  When the angle of incidence is less than the critical angle, it will be refracted out of the stone.  So when the critical angle of a gemstone is large, there is a greater chance that light will be refracted out of the stone rather than internally reflected.  One way to increase the amount of total internal reflection in a gemstone with a large critical angle is to deepen its pavilion and thus modifying the incident angles.

The example of critical angles using quartz and diamond of roughly equivalent dimensions and angles.