7.15: Double Refraction

Some gemstones have more than one refractive index (RI) because these stones belong to crystal systems (anisotropic) that have atomic structures that cause an incident ray of light to be resolved into two rays traveling at different velocities. This difference related to velocities is named "birefringence". When the two rays change their direction of travel (i.e. are refracted) and move in different directions this phenomenon is called "double refraction. The numerical difference between one RI value and the other RI value measured in any one case is called the "birefringence" for that test, and the difference between the highest possible RI and the lowest possible RI considering all possible directions is called the birefringence of the gemstone.

Refraction is when light changes direction as it passes through a surface. Refringence is when light changes velocity as it passes through a surface. Light passing through a surface at the normal may be slowed down without being refracted. Light passing through a surface at an inclination allows the slowing of that light to change the direction of travel, yielding refraction. Birefringent materials slow light to two different velocities (according to each of two mutually perpendicular vibration directions). When light travels into a zircon through the prism face of a crystal, the vibrations are sorted in two and each vibration travels at a different velocity. If the light enters at an oblique angle, each vibration changes direction and travels along paths that differ from the original path AND differ from each other. This is double refraction caused by the birefringence. If the light enters normal to the prism face, each vibration travels at a different velocity, but no refraction occurs. Both vibrations were incident at a perpendicular to the wavefront so the velocity change does not cause a direction change. In this direction, the light experiences zero refraction and maximum birefringence.
When a ray of light enters the gemstone, the atomic structure allows only those rays vibrating in two specific directions to continue. These two rays vibrate in planes that are mutually perpendicular and are therefore polarized. Both these rays travel at different velocities inside the gemstone and thus will refract at different angles when incident other than parallel to the normal.

The strength of birefringence (BI) varies with direction and we measure the maximum BI (Δ). These maximum values differ from one gemstone to another. For instance:

- **Strong BI** - zircon (0.059)
- **Medium BI** - tourmaline (0.020)
- **Low BI** - quartz (0.009)

In uniaxial gemstones, one ray will vibrate in the direction perpendicular to the optic axis and will obey Snell's Law (one can calculate its angle of refraction). This ray is named the ordinary ray (usually indicated with ω). The other ray vibrates perpendicular to the vibration of the first ray and in a direction between perpendicular to and parallel to the optic axis (usually at some inclination) and so does not obey Snell's Law (i.e. the angle of refraction will vary according to the angle of vibration). That ray is named the extra-ordinary ray (indicated by ε).

The maximum RI difference between these two rays is named "birefringence", often indicated by the symbol "Δ" (Greek letter delta). This difference is largest when light enters the gemstone at an angle perpendicular to the optic axis. When light enters the gem at an angle parallel to the optic axis, the birefringence will be 0 (zero).

Although in gemology the term "birefringence" usually indicates the maximum difference between the ordinary and extra-ordinary rays (or the α and γ readings in biaxial stones), the term is also applied to any variation in refractive indices. Not just the maximum.
In faceted stones, a strong birefringence may result in visual doubling of facets, which is observed in a large number of zircons. Although the BI is at its maximum when viewed in the direction perpendicular to the optic axis, no doubling of facets will be seen in that direction due to superimposition.

When an anisotropic stone is examined in the direction parallel to an optic axis, the stone will behave as an isotropic gemstone. Therefore no doubling of facets will be seen in that direction either.

Gemstones belonging to the cubic crystal system and amorphous gems have only one RI and therefore do not show birefringence; all other gemstones do. Uniaxial stones (those crystallizing in the trigonal, hexagonal and tetragonal systems) will show two readings and have one optic axis. Biaxial gemstones (orthorhombic, monoclinic and triclinic systems) have two directions in which the incident light will react as if it were isotropic and therefore will have two optic axes.

- Refraction
- Refractometer
- Pleochroism

- Gemmology 3rd edition (2005) - Peter Read