Colour change effects in gemstones: Causes and perception

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Colour change, also known as "alexandrite effect" has been studied extensively since it first was described 1831 for alexandrite (chromium-bearing variety of chrysoberyl) from Russia (von Pott, 1842). Since then, numerous minerals or gemstones with colour change have been documented (Figure 1), including corundum, spinel, zircon, fluorite, monazite, bastnäsite, garnet, diaspore, kyanite, epidote and kornerupine, to name a few.

Figure 1: Colour changing gemstones in daylight (always left top of the pairs) and incandescent light (always right bottom). This picture has been combined from several pictures. The relative size of the stones is not maintained. The colours in daylight and incandescent light have been corrected (Adobe Photoshop®) to best match the observed colours. © M.S. Krzemnicki, SSEF

Traditionally, we speak of a colour change when the main hue of a mineral in daylight differs from that seen in incandescent light (LMHC 2010, Infosheet No. 9). With the advent of new light sources (fluorescent and LED lamps), and recently with the ban of incandescent tungsten bulbs, this definition may need further specification in the future. The main factors to observe a colour change in a gemstone/mineral are: a) two white light sources of distinctly different emission spectra (e.g. daylight versus incandescent light), b) a material that shows two transmission "windows" in its absorption spectrum separated by an absorption band at approximately 570 nm, c) an observer whose brain interprets the incoming residual light energies accordingly into a colour sensation (White et al., 1967; Schmetzer et al., 1980; Nassau, 1983; De Valois & Jacobs, 1984; Burns, 1993; Liu et al., 1999). Apart from colour change, there are further colour effects, which may considerably contribute to the colour perception of a mineral or gemstone, namely pleochroism (Liu et al. 1995) and the Usambara-effect (Halvorsen, 2006). Pleochroism describes the effect of different colours due to different selective absorption along the two or three vibrational directions within an anisotropic mineral (very distinct in alexandrite), whereas the Usambara effect is a colour change effect related to the path length of light transmitted in a stone (Halvorsen & Jensen 1997).

In our study, we will summarize our findings on a number of colour changing minerals (Figure 1) that owe their colour change either to the presence of a broad absorption band due to a transition metal (commonly Cr or V, e.g. alexandrite, corundum, garnet, Krzemnicki et al. 2001 and references therein) or well-defined narrow absorption bands of rare earth elements (REE) in the 3+ valence state (e.g. zircon, fluorite, Nd-bastnäsite, Nd-monazite; Dieke & Crosswhite, 1963; Herzog & Krzemnicki, 2011)

We will further show how pleochroism may influence the perceived colours in anisotropic minerals, actually "reducing" the colour change especially in faceted alexandrite due to multiple internal reflections of the different plane polarised pleochroic colours (Figure 2) (see also Liu et al. 1995).

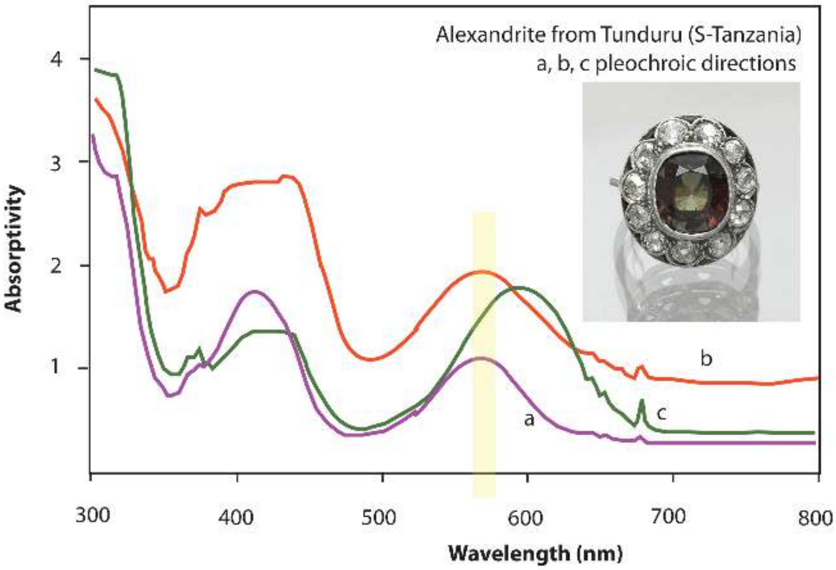

Fig. 2: Absorption spectra of alexandrite from Tunduru (S-Tanzania) for the three crystallographic directions a, b, c (pleochroic colours). The yellow bar indicates the 570 nm maximum criterion for a colour change which is not fulfilled for the c-direction. The photo shows a faceted alexandrite in daylight illustrating the effect of pleochroism. © M.S. Krzemnicki & L. Phan, SSEF

Furthermore we present data of some exceptionally large colour changing garnets (50-100 cts) from southern Tanzania which were recently analysed at SSEF. These chromium- and vanadium-bearing garnets of the pyrope-spessartine series show a distinct colour change (brownish green in daylight and red in incandescent light) combined with a distinct Usambara effect, resulting in reddish facet reflections around the girdle (Figure 3). This effect, first noted by Manson & Stockton (1984) as "colour-shift" on colour-changing garnets was only later fully described by Halvorsen & Jensen (1997) on Cr-bearing tourmaline from the Usumbara mountain range, and thus named the Usambara effect. Normally this effect is best seen when two dark green Cr-tourmalines are superposed. The resulting red transmission colour is due to the near-doubling of the path length (see also Fig. 4). In the studied large faceted garnets, however, this effect is seen even without superposition of a second stone. In daylight these colour-changing garnets display a brownish-green colour in the main part below the table (± simple light transmission through the volume of the stone), and reddish facet reflections around the girdle as a result of increased path lengths of light by internal reflections.

Using colorimetric calculations based on computer generated absorption spectra, we will present spectroscopic criteria which are required to result in a colour change and Usambara effect in a mineral.

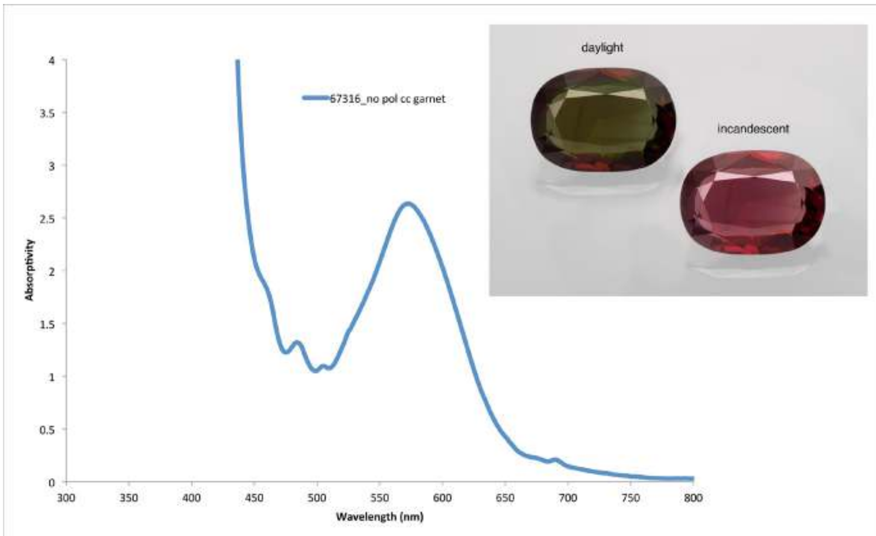

Fig. 3: Absorption spectrum of a large colour changing garnet from Tanzania, showing a marked absorption band due to vanadium and chromium at 570 nm. The inserted photo shows the colour change of this garnet from daylight (brownish green) to incandescent light (red). The reddish brown facet reflections around the girdle in daylight are the result of the Usambara effect. © M.S. Krzemnicki, SSEF

Figure 4. Usambara effect shown with two superposed colour changing garnets of 50+ ct each. © M.S. Krzemnicki, SSEF

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