Noble gas in corundum: interests in gemology

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Noble gas in geology

Noble gases —elements of the last column of the periodic table—are chemically defined by their full outer electron shells, making them highly inert and very volatile under ambient conditions. In geology, they are used to trace a wide range of processes, including mantle circulation and degassing, hydrocarbon reservoir formation, climate change, and ocean circulation (Burnard, 2013). Among the noble gasesthe lightest (helium, neon and argon) are the most commonly used and possibility present in gems. Their lack of chemical interaction makes them useful in gemology for two main purposes: detecting heat treatment and determining geographic origin.

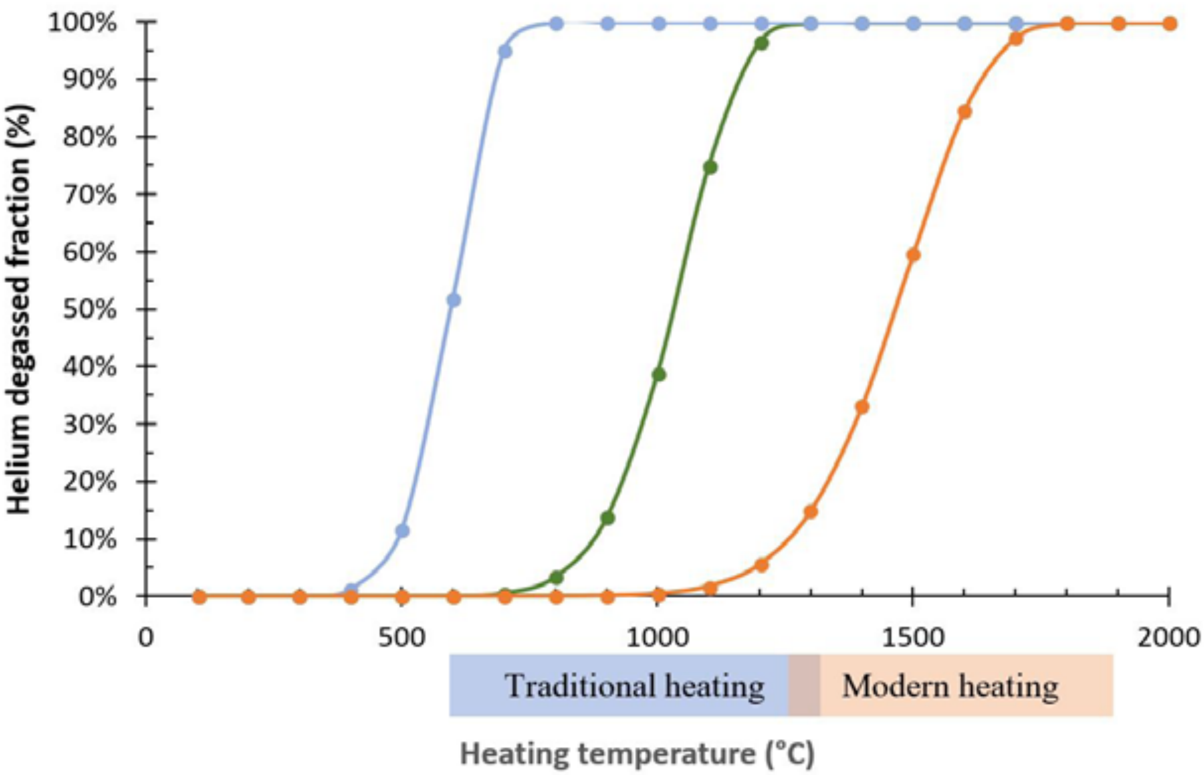

Figure 1 : Fraction of helium degassed during heating according to theoretical data from Zhang *et al.* 2016, with activation energy of 100 (blue), 150 (green) and 200 (orange) kJ/mol, calculated from the equation from Fechtig and Kalbitzer (1966).

Heat-treatment

Traditional heat treatment (~600°C–1200°C) is one of the oldest known gemstone enhancements, used over 4,000 years ago for improving corundum color (Notari *et al*., 2019). Modern treatments reaching up to ~1850°C leave detectable traces, while low-heat methods remain to date an important challenge to identify and spur further research (Saeseaw *et al*., 2021; Hughes & Vertriest, 2023; Karampelas *et al*., 2023).

Due to their volatility, noble gases—especially helium—could serve as scientific indicators of heat treatment. Quantifying diffusion of noble gases in crystals is then necessary to use these volatiles as tracers. Theoretical models and experiments on synthetic materials suggest that helium diffuses out of the crystal between 500 °C and 1700 °C, depending on the nature of the defects in which it is trapped and the duration for which the temperature is maintained (*e.g.*: Campbell, 1960; Fechtig & Kalbitzer, 1966; Zhang *et al*., 2016). The diffusion of noble gases is highly dependent on the local environment of diffusion, as demonstrated in high-density SiO_2 polymorphs (Figowy *et al*., 2024). As noble gases easily may easily diffuse as low as 500°C, the absence of helium in natural corundum may indicate human-induced heating, potentially calling for a reassessment of current heat treatment detection methods. Ongoing experiments on six samples treated at various temperatures aim at better constraining the conditions required for helium degassing. In parallel, new *ab initio* molecular dynamics calculations are performed and compared with experimental results to provide a quantification of diffusion processes and investigate the role of defects.

Origin

Noble gases are commonly used as tracers of geological processes, and their analysis may represent a novel approach for determining the origin of corundum. To date, no data on noble gases in natural corundum have been reported in the literature. To explore this potential, we measured the helium concentration from 116 crystals from 14 different sources. Our results show that sapphires from Kenya, Greenland, and Madagascar have significantly higher concentrations (>100 pmol/g) compared to those from other localities (<30 pmol/g), including Colombia, Vietnam, Mozambique, Kashmir, France, Sri Lanka, Cambodia, Australia, Myanmar, Tanzania, and Thailand. While most conventional provenance methods discriminate between deposit types (magmatic and metamorphic type), it seems that helium content does not directly correlate with the deposit type. While not immediately applicable to the gem trade yet, noble gas analysis could serve as a complementary scientific tool in the study of gem geology and origin determination.

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